ESTER STRUCTURE PROPERTY RELATIONSHIPS IMPACTING FRICTION AND WEAR CHARACTERISTICS

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EAL/Synthetic Lubrication Technical Track 2I
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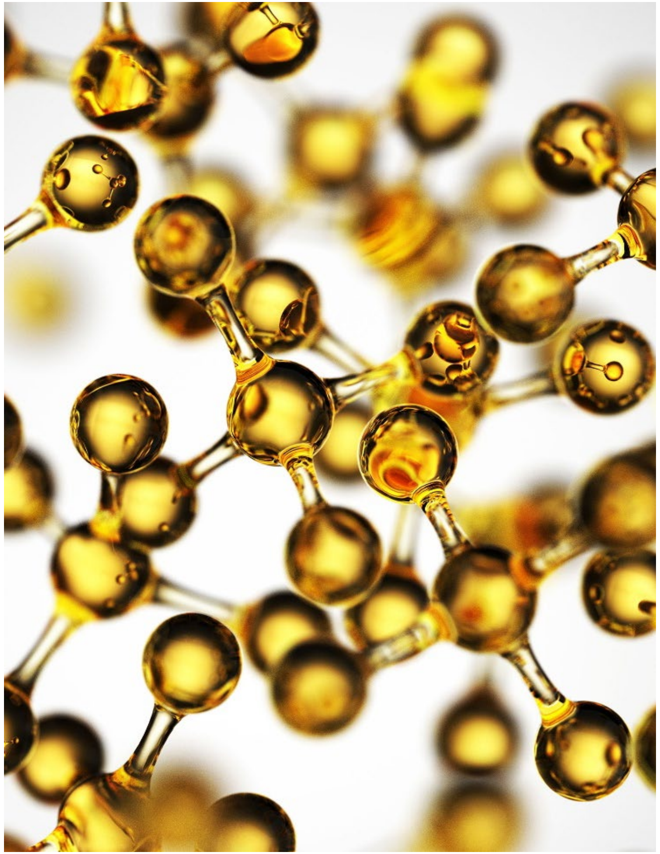
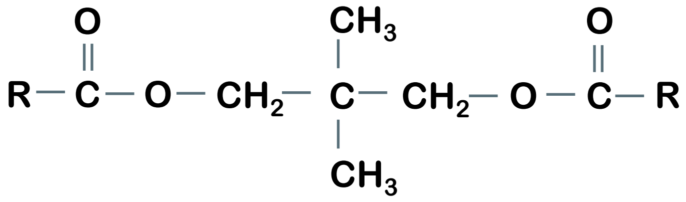
Agenda

- Review molecular structure of VSP and standard synthetic esters
- Comparison of synthetic ester lubricity performance
  - With and without standard AW/CI/MD additives
- Conclusions

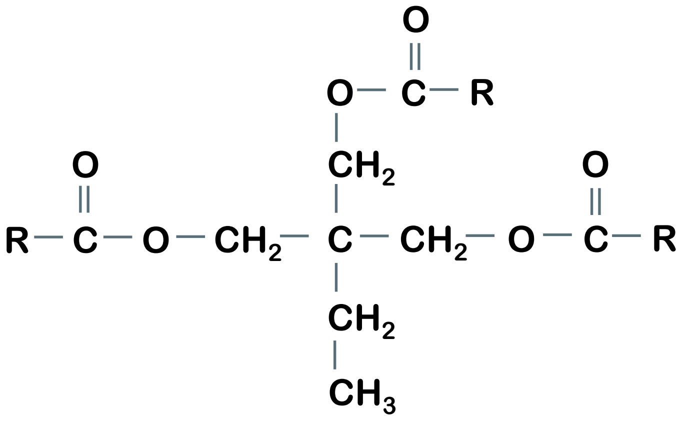


EsterTec®
synthetic esters

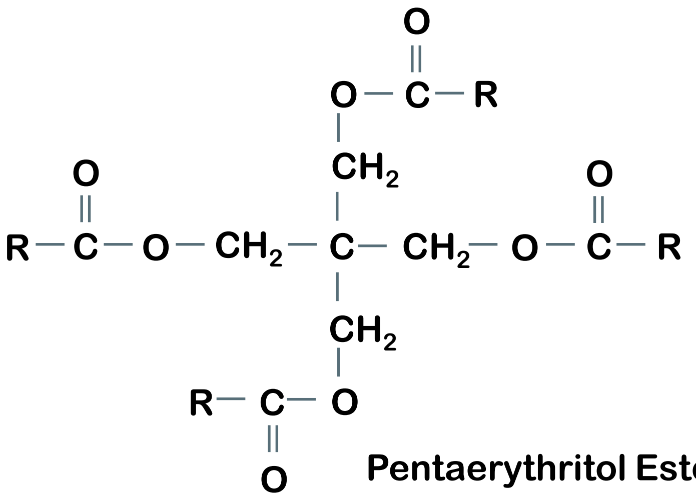
Standard Synthetic Ester Structures



Neopentyl glycol Ester



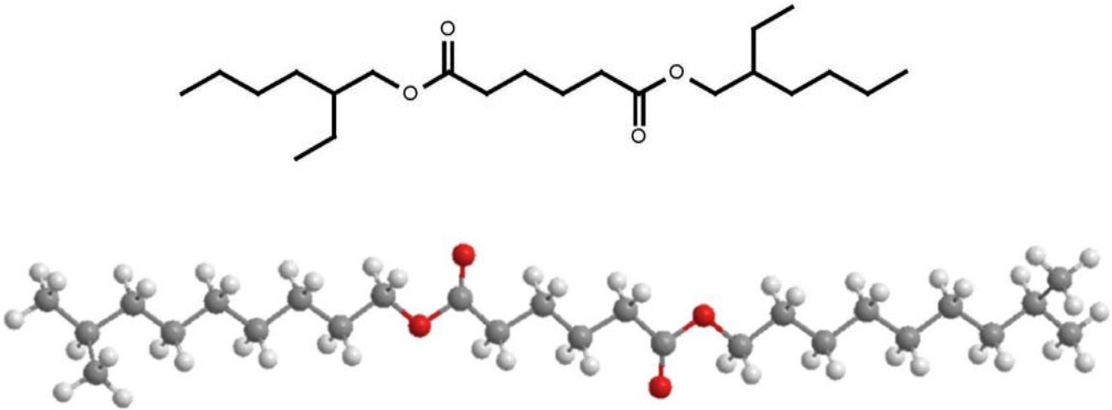
Trimethylolpropane Ester



Pentaerythritol Ester

Standard Synthetic Ester Molecular Structures

Dibasic Acid Ester



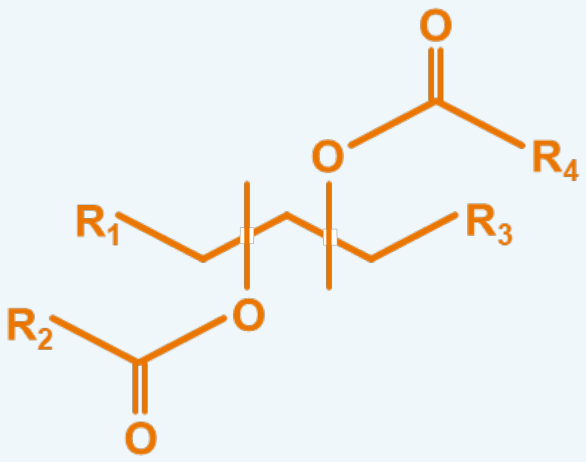
DIDA

Adipate Esters

Vicinal Secondary Polyols Are Now Available

- Novel structure, unique production process
- Based on standard raw materials that are globally and readily available commodities
- High stability vicinal ester molecular positioning
- Steric hindrance that improves oxidative stability
- Secondary alcohols on adjacent carbons improve hydrolytic stability

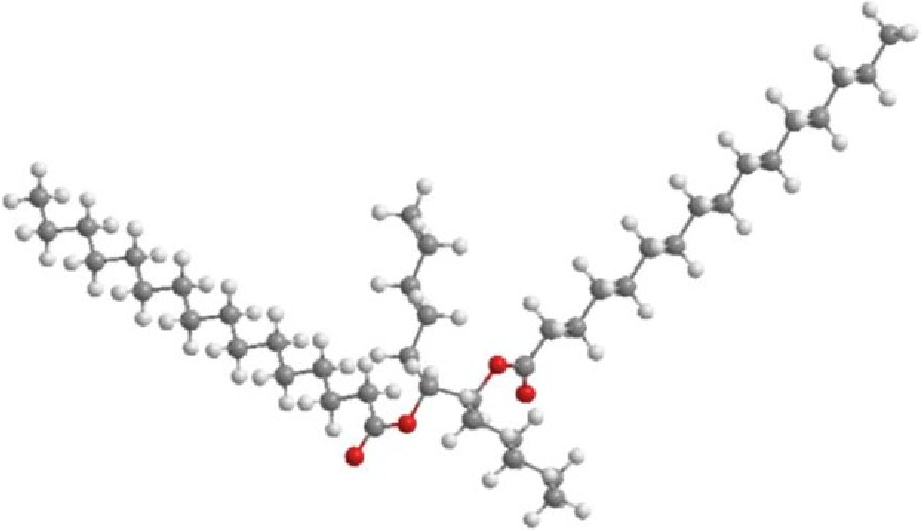
"VSP" Synthetic Esters with Improved Performance



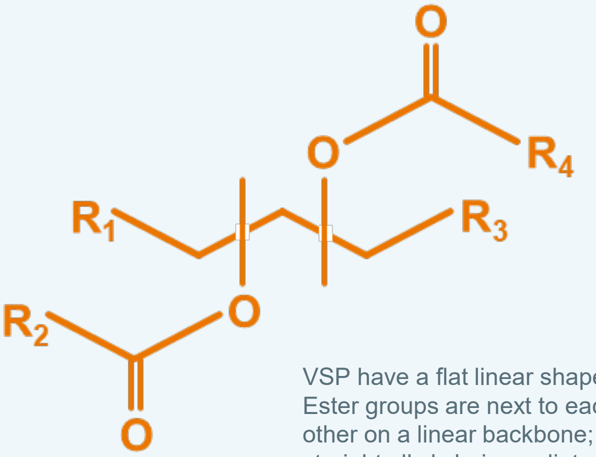
VSP Molecular Structure

EsterTec
synthetic esters

Vicinal Secondary Polyols Are Now Available



"VSP" Synthetic Esters with Improved Performance



VSP have a flat linear shape. Ester groups are next to each other on a linear backbone; straight alkyl chains radiate outward.

VSP Molecular Structure

VSP Synthetic Esters:
A Novel Molecular Technology Platform

EsterTec synthetic esters

VSP Product KV100 Viscosity Grade	VSP-3.6	VSP-4.1	VSP-5	VSP-7	VSP-9	VSP-11	VSP-18
EsterTec Product Name	EsterTec® 2N-1416	EsterTec® 2LN-1418	EsterTec® 2L-1425	EsterTec® 2G-1432	EsterTec® 7GX-1446	EsterTec® 7GX-1468	EsterTec® 8LX-14150
KV100, cSt	3.6	4.1	5	7	9	11	18
KV40, cSt	16	18	25	32	46	68	150
Viscosity Index	110	125	140	180	165	155	130
Pour Point, °C	-60	-40	-25	-42	-40	-40	-35
Density	0.895	0.893	0.890	0.890	0. 900	0.915	0.935
Noack volatility, %	9	7	3	1	1	1	1
Biogenic Content, %	60	65	70	74	60	50	30

ISO 15-32 Transport / MW / EV Fluids

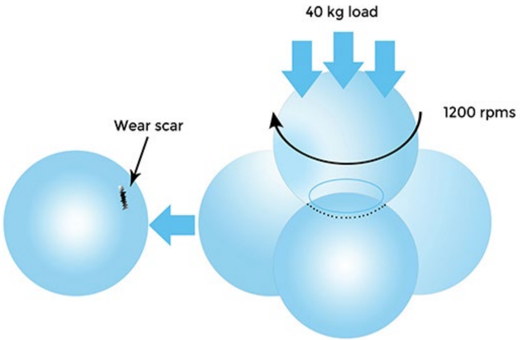
ISO 68+ OCL / Gear / MW

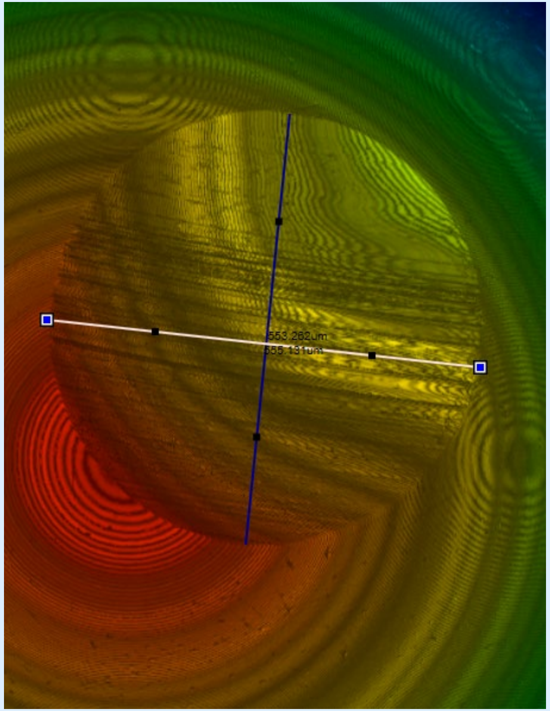
ISO 32-100 Industrial Lubricants

Measuring Friction and Wear

ASTM D4172: 4-Ball Wear test

- 40kg, 75°C, 1200 rpm, 60 min, 52100 steel





Measurements:

- Average Wear Scar, mm
- Average Coefficient of Friction

Comparison of 2 - 4 cSt Synthetic Esters (S) Friction and Wear

Ester Class		VSP	Diester				Polyol Ester		Glyceryl Ester
	Test Method	EsterTec 2N-1416	DIDA	DINA	DIOA	DOA	TMP C7/8/10	TMP-C7	C8/10
KV100, cSt	ASTM D7042	3.6	3.6	3.1	2.7	2.3	4.0	3.4	4.0
KV40, cSt	ASTM D7042	16	14	11	9	8	18	14	15
Pour Point, °C	ASTM D5950	-60	-60	-60	-60	-50	-65	-65	-15

4-Ball Wear, mm*	ASTM D4172	0.52	0.84	0.79	0.89	1.00	0.74	0.65	0.69
Wear Protection Improvement**	Δ	---	78%	75%	80%	84%	71%	59%	65%

Coefficient of Friction*	ASTM D4172	0.167	0.208	0.221	0.247	0.223	0.183	0.217	0.196
CoF Decrease, %	Δ	---	25%	32%	48%	34%	10%	30%	17%

*40kg load, 1200 rpm, 75C, 52100 steel, 1 hour

**Considering the Hertzian contact diameter of 0.43mm

Comparison of 5 – 9 cSt Synthetic Esters (S + U) Friction and Wear

Ester Class	VSP	Diester	Polyol Ester				
	EsterTec 2G-1432	DTDA/1	TMP-TO	PE C810	NGDO	PE C7/9	TMP C8/10
KV100, cSt	7.0	5.4	9.4	6.1	5.8	5.0	4.4
KV40, cSt	32	27	46	32	24	25	20
Pour Point, °C	-42	-60	-40	-5	-30	-55	-40

4-Ball Wear, mm*	0.63	0.75	0.77	0.58	0.72	0.81	0.65
Wear Protection Improvement**	---	38%	41%	-33%	31%	47%	9%

Coefficient of Friction*	0.182	0.210	0.246	0.168	0.201	0.204	0.173
CoF Decrease, %	---	15%	35%	-8%	10%	12%	-5%

*40kg load, 1200 rpm, 75C, 52100 steel, 1 hour

**Considering the Hertzian contact diameter of 0.43mm

Comparison of 6 – 12 cSt Unsaturated Synthetic Esters (U) Friction and Wear

Ester Class	VSP	Polyol Ester		
	EsterTec 2G-1432	NPG-DO	TMP-TO	PE-TO
KV100, cSt	7.0	5.8	9.4	12
KV40, cSt	32	24	46	67
Pour Point, °C	-42	-30	-40	-20

4-Ball Wear, mm*	0.63	0.72	0.77	0.69
Wear Protection Improvement**	---	31%	41%	23%

Coefficient of Friction*	0.182	0.201	0.246	0.184
CoF Decrease, %	---	10%	35%	1%

*40kg load, 1200 rpm, 75C, 52100 steel, 1 hour

**Considering the Hertzian contact diameter of 0.43mm

Comparison of 5 – 9 cSt Synthetic Esters Friction and Wear (Mixed S & U fatty acids)

Ester Class	VSP	Polyol Ester			Aromatic
	EsterTec 7GX-1446	TMP-TO	PE + C5/9	PE+2EH	Trimellitate
KV100, cSt	9	9	7	6	8
KV40, cSt	46	46	46	46	50
Pour Point, °C	-40	-40	-40	-15	-50

4-Ball Wear, mm*	0.61	0.77	0.89	0.95	0.99
Wear Protection Improvement**	---	47%	61%	65%	68%

Coefficient of Friction*	0.178	0.246	0.227	0.235	0.257
CoF Decrease, %	---	38%	28%	32%	44%

*40kg load, 1200 rpm, 75C, 52100 steel, 1 hour

**Considering the Hertzian contact diameter of 0.43mm

Comparison of VSP to Standard Synthetic Esters

Friction and Wear – With and Without Additives

	Test Method	VSP 3.6 EsterTec 2N-1416	DIDA	TMP-C7	VSP 7 EsterTec 2G-1432	NPG-DO	VSP 9 EsterTec 7GX-1446	TMP-TO
KV100, cSt	ASTM D7042	3.6	3.6	3.4	7	5.8	9	9
KV40, cSt	ASTM D7042	16	14	14	32	24	46	46
Pour Point, °C	ASTM D5950	-60	-60	-65	-42	-30	-40	-40
4-Ball Wear, mm*	ASTM D4172	0.52	0.84	0.65	0.63	0.72	0.61	0.77
Wear Protection Improvement**	Δ	---	78%	59%	---	31%	---	47%
Coefficient of Friction*	ASTM D4172	0.167	0.208	0.217	0.182	0.201	0.178	0.246
CoF Decrease, %	Δ	---	25%	30%	---	10%	---	38%

*40kg load, 1200 rpm, 75C, 52100 steel, 1 hour

**Considering the Hertzian contact diameter of 0.43mm

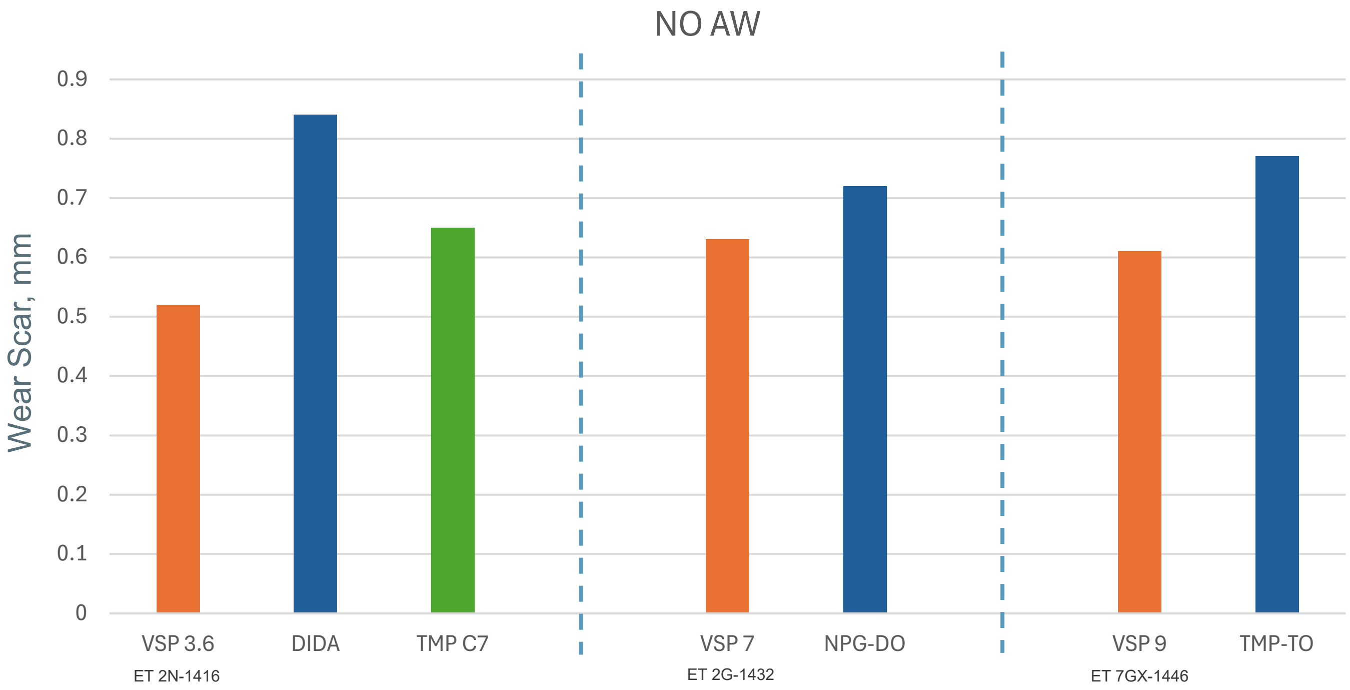
ISO 15-32 Transport / MW / EV Fluids

ISO 32-68 Industrial Lubes

ISO 68+ OCL / Gear / MW

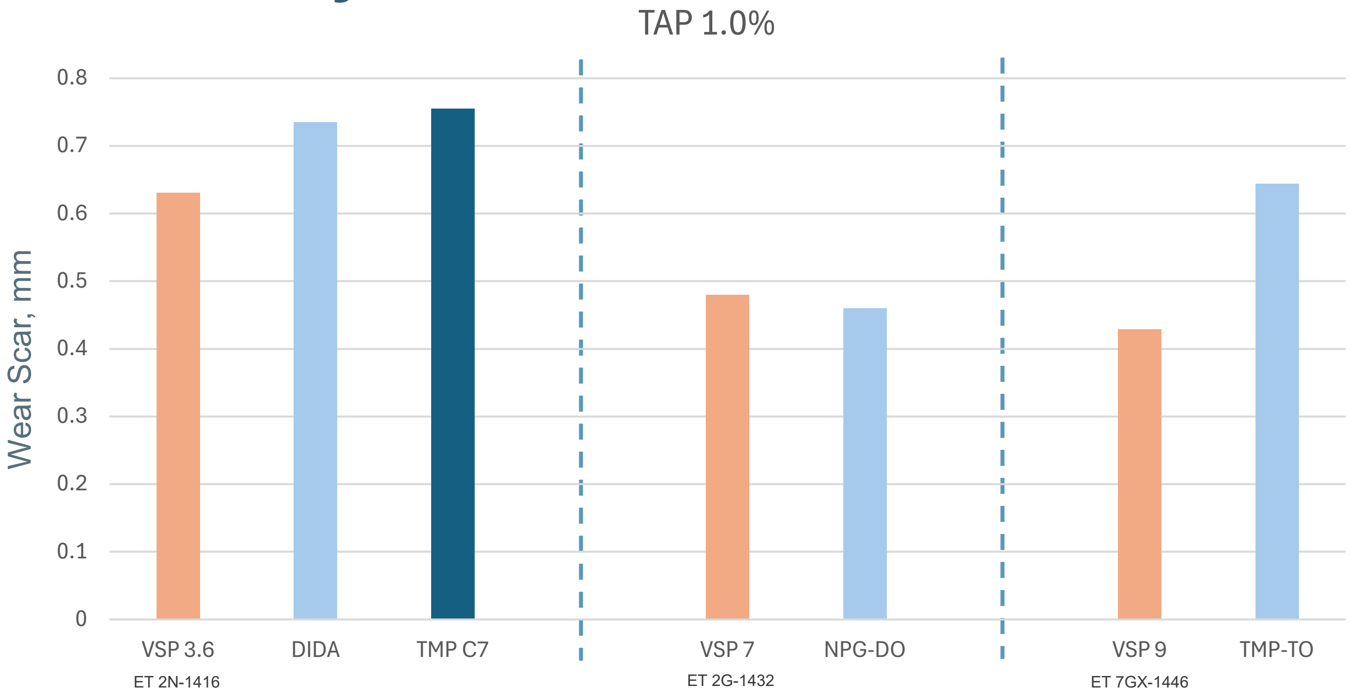
ESTERTEC VSP Compared to Standard Esters

No additives



ASTM D4172: 40kg load, 1200 rpm, 75C, 52100 steel, 1 hour

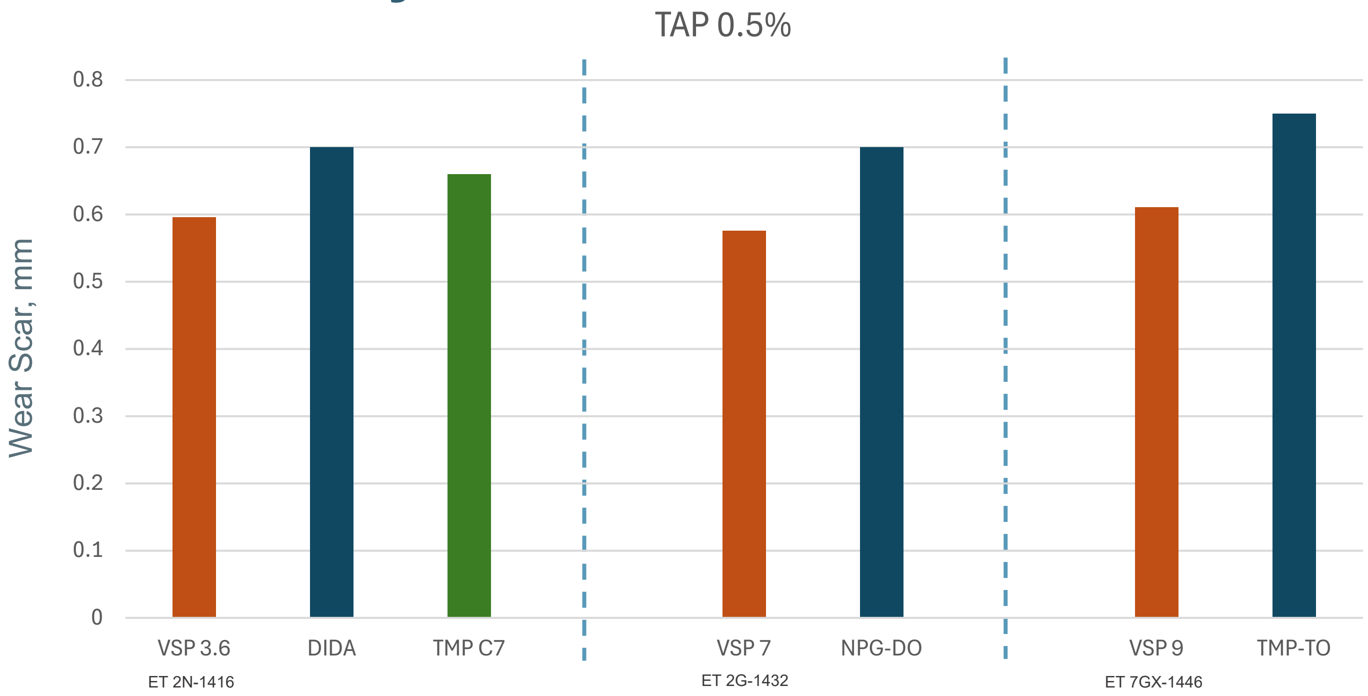
ESTERTEC VSP Compared to Standard Esters
1% TAP AW only



ASTM D4172: 40kg load, 1200 rpm, 75C, 52100 steel, 1 hour

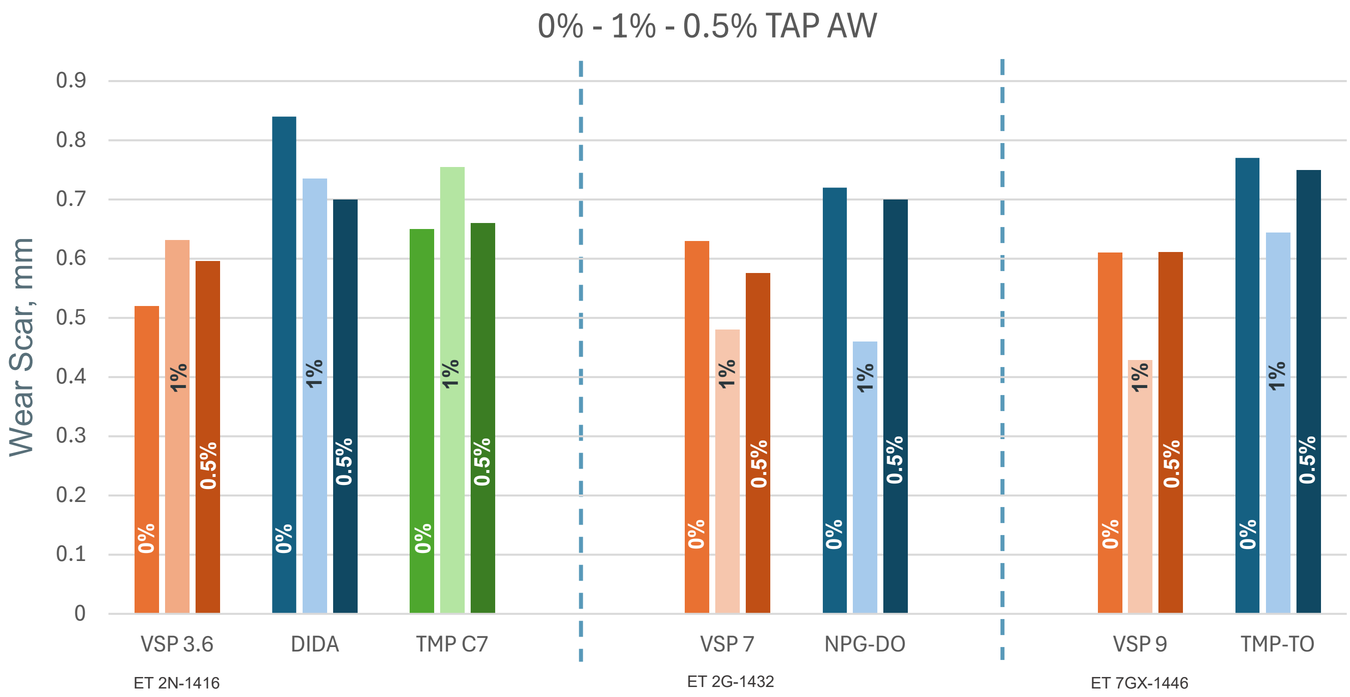
ESTERTEC VSP Compared to Standard Esters

0.5% TAP AW only



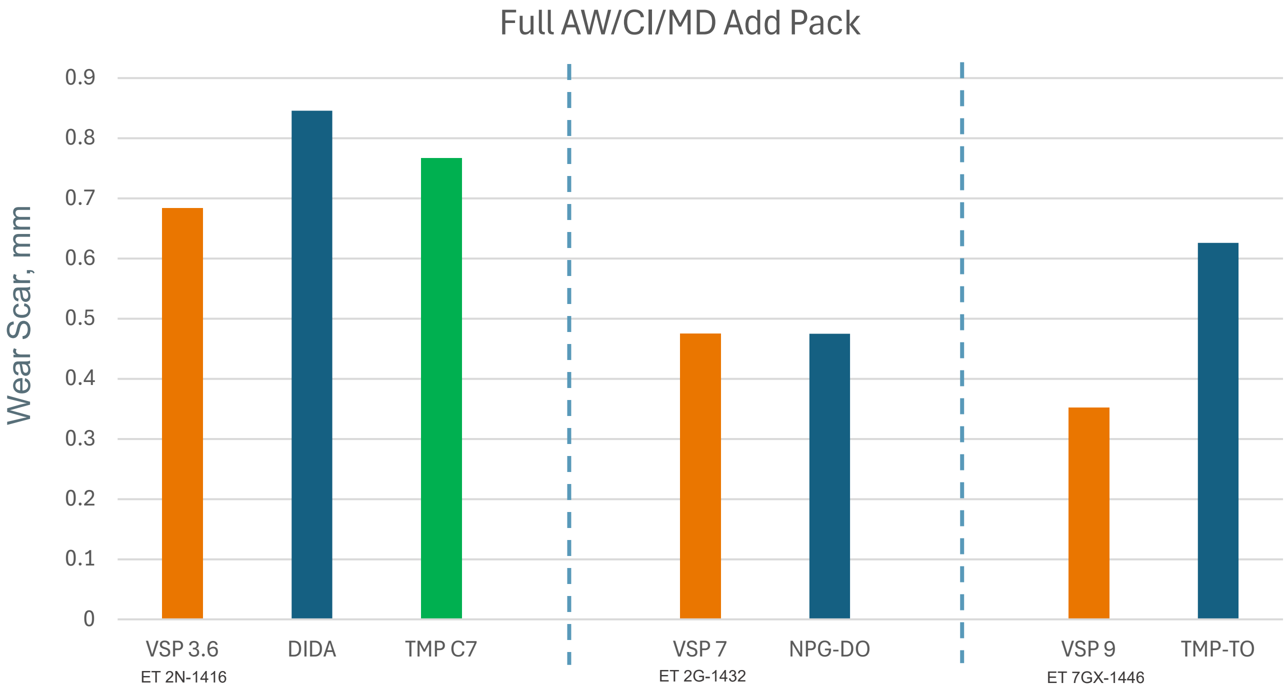
ASTM D4172: 40kg load, 1200 rpm, 75C, 52100 steel, 1 hour

ESTERTEC VSP Compared to Standard Esters
Various AW levels



ASTM D4172: 40kg load, 1200 rpm, 75C, 52100 steel, 1 hour

ESTERTEC VSP Compared to Standard Esters
Full Industrial Additive Package: AW + CI + MD



ASTM D4172: 40kg load, 1200 rpm, 75C, 52100 steel, 1 hour

Standard Industrial Additive Combination:

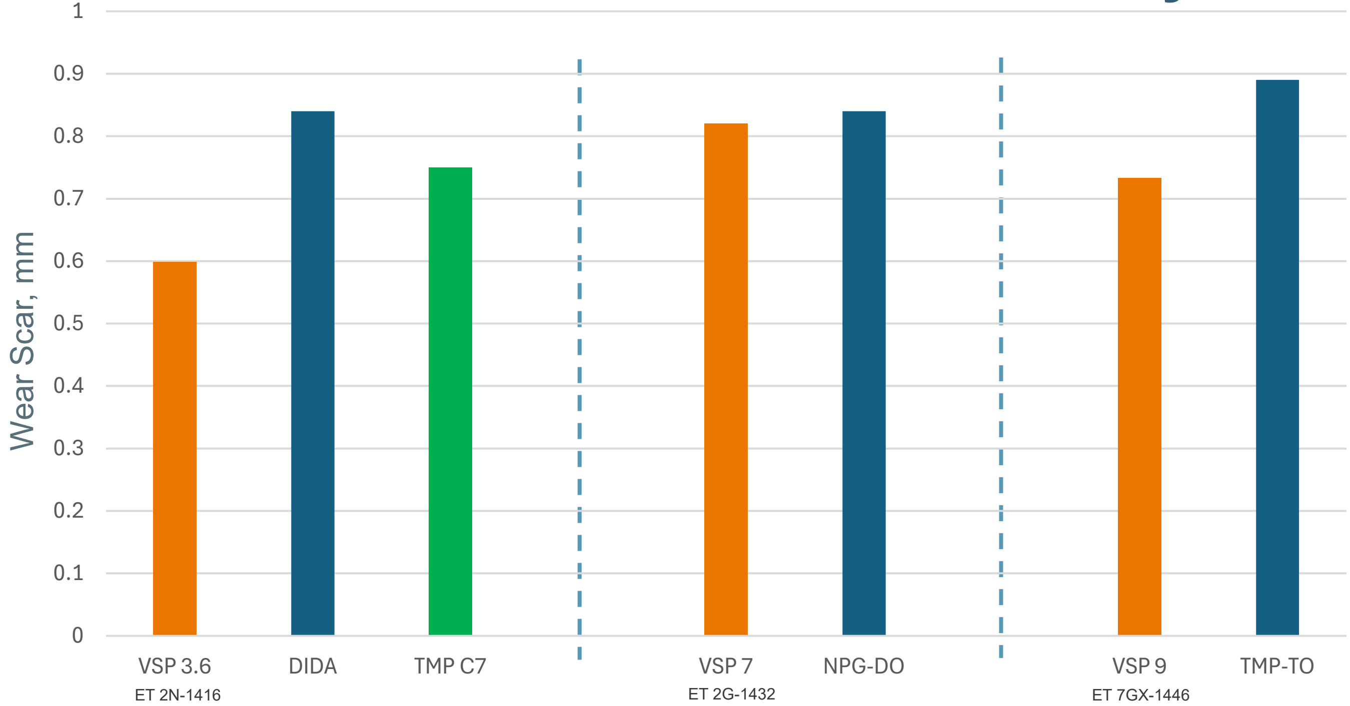
1.0% Triaryl Phosphate (AW)
0.5% Oleyl Sarcosine (CI)
0.1% Benzotriazole (MD)

All CoF are low (0.12-0.20)

The VSP base stocks respond with an equal or better AW result, compared to standard synthetic esters.

ESTERTEC VSP Compared to Standard Esters

Partial Add Pack: No AW, CI + MD only

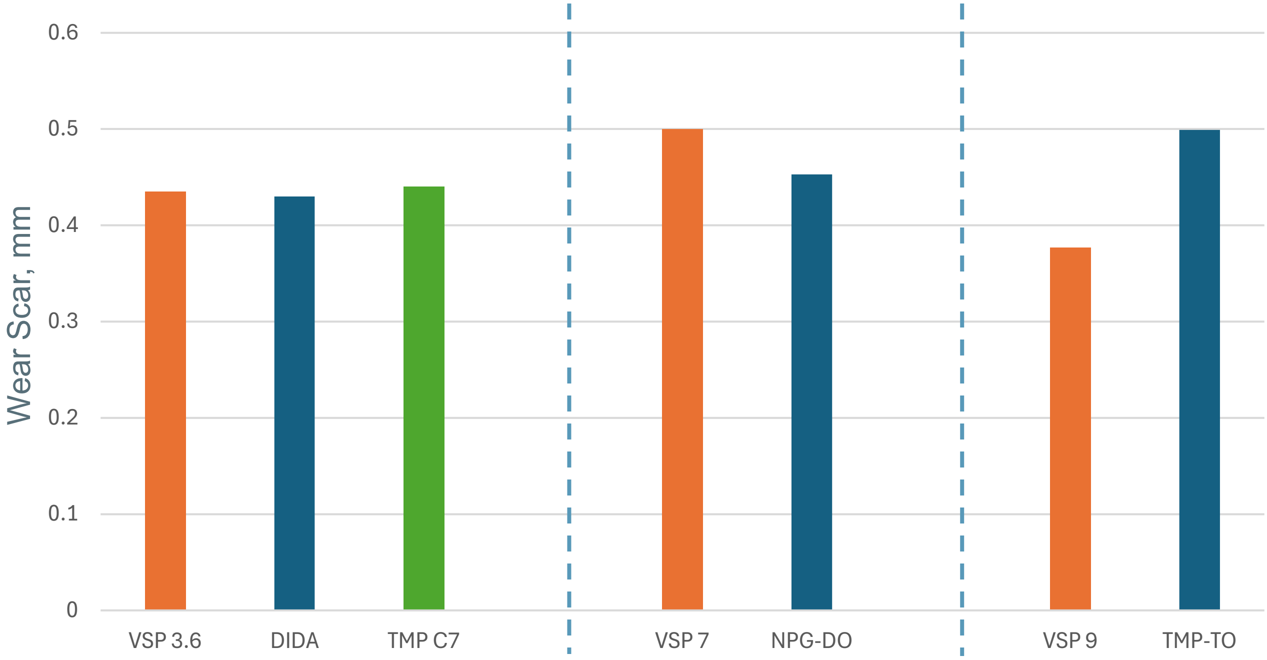


ASTM D4172: 40kg load, 1200 rpm, 75C, 52100 steel, 1 hour

Additive Combination:

0% Triaryl Phosphate (AW)
0.5% Oleyl Sarcosine (CI)
0.1% Benzotriazole (MD)

ESTERTEC VSP Compared to Standard Esters
Full Industrial Additive Package 2: AW + CI + MD



Standard Industrial Additive Combination:

0.1% Amine Phosphate (AW)
0.5% Oleyl Sarcosine (CI)
0.1% Benzotriazole (MD)

All Wear Scars are small
All CoF are low (0.12-0.18)

The more active AW shows a similar response in all ester base stocks

ASTM D4172: 40kg load, 1200 rpm, 75C, 52100 steel, 1 hour

Z&S AT Lab Testing Capabilities:

Ready to Support your Formulation Development Program

- High and low temperature viscosity, pour point.
- Flash and fire point
- Foam tendency, Air release, Demulsibility
- Oxidative stability with DSC, RPVOT
- Deposit formation with Pan test and Panel Coker test
- Volatility by TGA (NOACK) and VOC methods
- Hydrolytic stability
- Copper corrosion
- Friction, Wear and Extreme Pressure measurements
- Material compatibility, seal swell testing
- Dielectric properties
- Thermal Conductivity






CONCLUSIONS

- Antiwear and CoF as measured by ASTM D4172 are not a function of viscosity
- Longer acid chains preform better on wear scar
- Surface competition with additives and esters exists
- ESTERTEC VSPs perform well:
  - Achieve friction reduction and mild AW without additives
  - Provide equal or better AW protection with AW additives
  - Provide equal or better AW protection with “Full” additive packages

VSP synthetic esters are a new class of base oils and additives demonstrating oxidative stability and deposit forming tendency that is equal or better than standard adipate or polyol esters

Special Thanks to the Z&S Global Technical Team for Data Development and Review!

- Michael Creamer
  - Applications Specialist
- Doug Placek
  - Applications Technology Director

ZSCHIMMER & SCHWARZ

QUESTIONS?

VISIT Z&S AT EXHIBIT BOOTH #501
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