Esters For Engine Oils

Teknor Apex Esters
for Next Generation Engine Oils

Vanderbilt Chemicals, LLC
A Wholly Owned Subsidiary of R.T. Vanderbilt Holding Company, Inc.

Esters in Engine Oil Background

- Esters have been widely used in the past
  - Changes in technology and performance
- Governments around the world want OEMs to develop vehicles with improved fuel economy and reduced greenhouse emissions
  - Engine technology improvements
  - Engine oil technology improvement
    - Thinner oils driving interest in esters
- Other applications for esters too

Esters in Engine Oils

- Recent interest for use in thin engine oil formulation
  - Viscosity index
  - Volatility
  - Low temperature properties
- Currently used in high end and specialty applications
  - High end performance – full synthetics and racing oils
  - High mileage oil
    - Used as a seal swell agent
  - Improves additive solubility in Group II & III base oils
- Biodegradability makes them environmentally friendly
  - Suitable for marine engine oils

Four Esters Used in Project

- TruVis™ A130 Adipate Diester
- TruVis™ D2020 Other Diester
- TruVis™ P3020 Polyol Ester
- TruVis™ P3121 Polyol Ester

Ester Biodegradability

- Environmental concerns are a growing problem for engine oils
  - Some engine oils and/or their additives tend to persist in the ground and waterways
- Three of the four esters are classified as inherently biodegradable
- Classification Requirements
  - Ready Biodegradability
    - 60% CO_2 released in first 10 days
  - Inherent biodegradability
    - 60% CO_2 released by end of 28 day test
  - Ultimate biodegradability
    - 60% CO_2 released before plateau is reached
  - Test used to determine classification was OECD 301B

<u>Biodegradability Classification</u>

	%CO2 @ 28 Days	Days to 60% CO2	Classification
A-130	---	*	Failed
D-2020	62	26	Inherent
P-3020	74	18	Inherent
P-3121	73	20	Inherent

*= 40 days to 38% CO_2

Physical Property Scorecard

	P-3020	P-3121	A-130	D-2020	PAO 4	PAO 5	Group III
Vis. @ 40°C, mm^2/s	19.8	20.6	27.3	14.1	16.8	24.1	21.1
Vis. @ 100°C, mm^2/s	4.3	4.4	5.3	3.7	3.9	5.1	4.5
Viscosity Index	137	129	153	160	124	145	126
Pour Point,°C	$\leq$-45	-36	$\leq$-54	$\leq$-50	-68	-46	-24
CCS @ -30°C, mPa·s	1235	1352	900	N/A	910	N/A	1528
CCS @ -35°C, mPa·s	1924	3364	4788	685	1424	2420	3565
Volatility, Noack, D-5800, %	2.67	2.64	6.81	8.83	13.4	5.6	12.8
Acid Number	$\leq$0.05	$\leq$0.05	$\leq$0.05	$\leq$0.05	<0.03	<0.03	TBD

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Performance Scorecard

Parameter	Test Method	Rating	Comments
Additive Solubility	In-house	Positive	MoDTC solubility in Group II oils
Biodegradability	OECD 301B	Mixed	Varies by ester
Friction	SRV	Directional Improvement	Varies by type and treat rate in a prototype 5W-30 GF-5 oil
Corrosion	HTCBT	Neutral/No Harm	HDDEO application
Bulk Oxidation	ROBO	Mixed	Varies by type. Group II with ester is still not as good as Group III.
Deposit Control	TEOST MHT-4	Mixed	Varies by type
Wear	4 Ball Wear	No Harm or Positive	Varies by type
Elastomer Compatibility	Seal Swell	Positive	All esters swell all seals
LSPI	Engine	Mixed	Effect can be minimized through proper ester selection

Solubility Testing

- Esters can solubilize difficult EO additives such as MoDTC
- 0.7 wt% MoDTC was blended into Gp III basestock, and in Gp III/TruVis ester blends.
  - 350 ppm Mo
- Room temperature solubility data shows similar performance for all 4 esters

Room Temperature Solubility Study

Base Oils + 0.7% MoDTC	Results
Group III	not soluble
Group III + 2% A-130	Soluble
Group III + 2% D-2020	Soluble
Group III + 2% P-3020	Soluble
Group III + 2% P-3121	Soluble

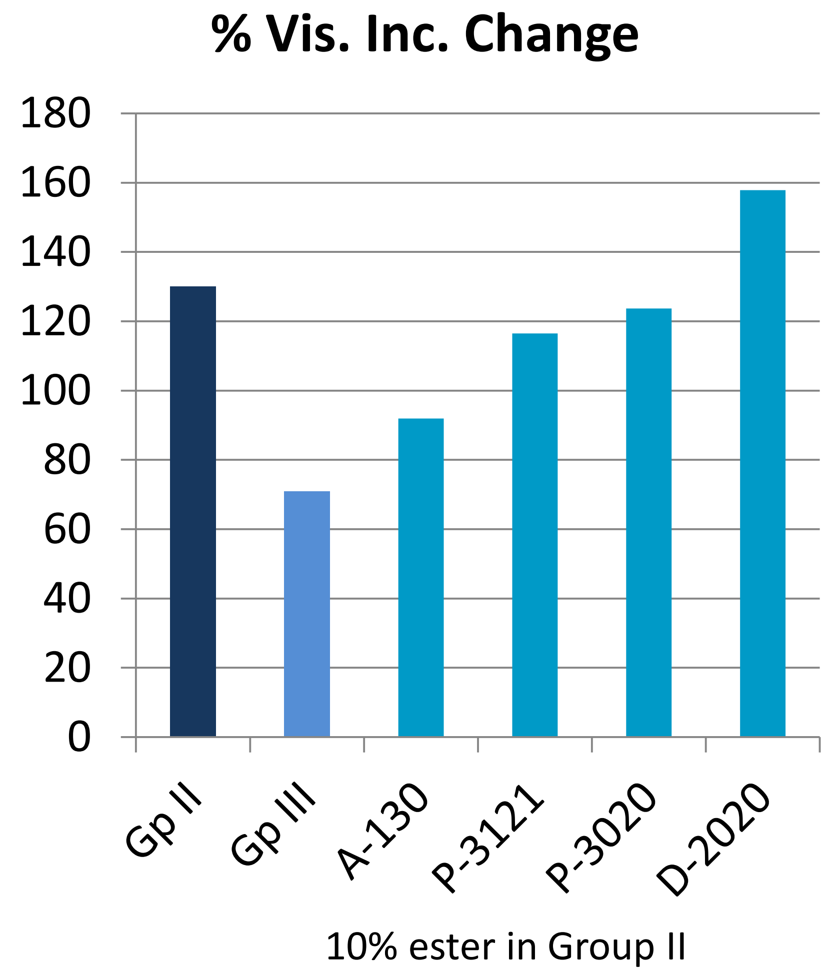
Gp III + MoDTC with Ester

0% 1% 2% 3%

Test data shows all four esters solubilizing MoDTC in Group III at low ester treat rates

ROBO Oxidation Testing

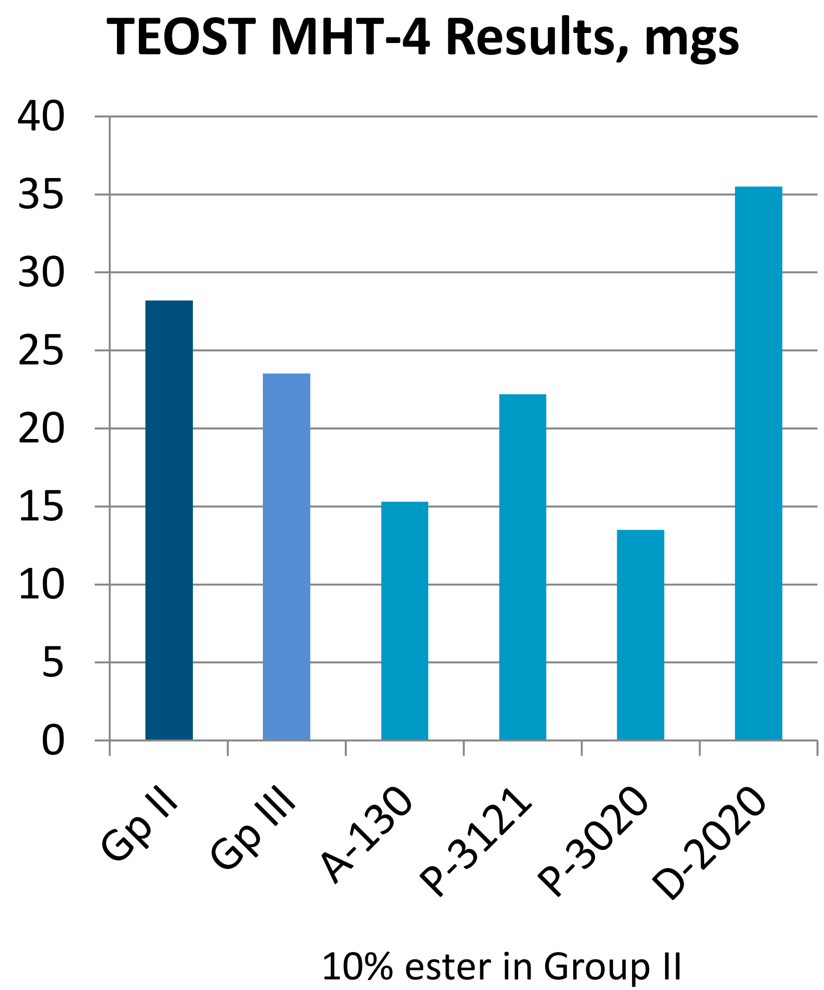
- ROBO testing on a fully formulated oil showed A-130 delivering better oxidative control than the Control oil formulated with Group II base oil.
  - Group III base oils are known to be more oxidatively stable than Group II base oils.
- The other three esters experienced different levels of oxidative thickening compared to the Group II control oil.
- Experimental 0W-20 finished oil with 750 ppm Phosphorous, 2200 ppm Calcium.
  - 0 ppm Molybdenum
  - Same DI pkg and VII
  - 10% ester replaced 10% Gp. II



Select esters can have a positive improvement to the oxidation properties of Group II base oil

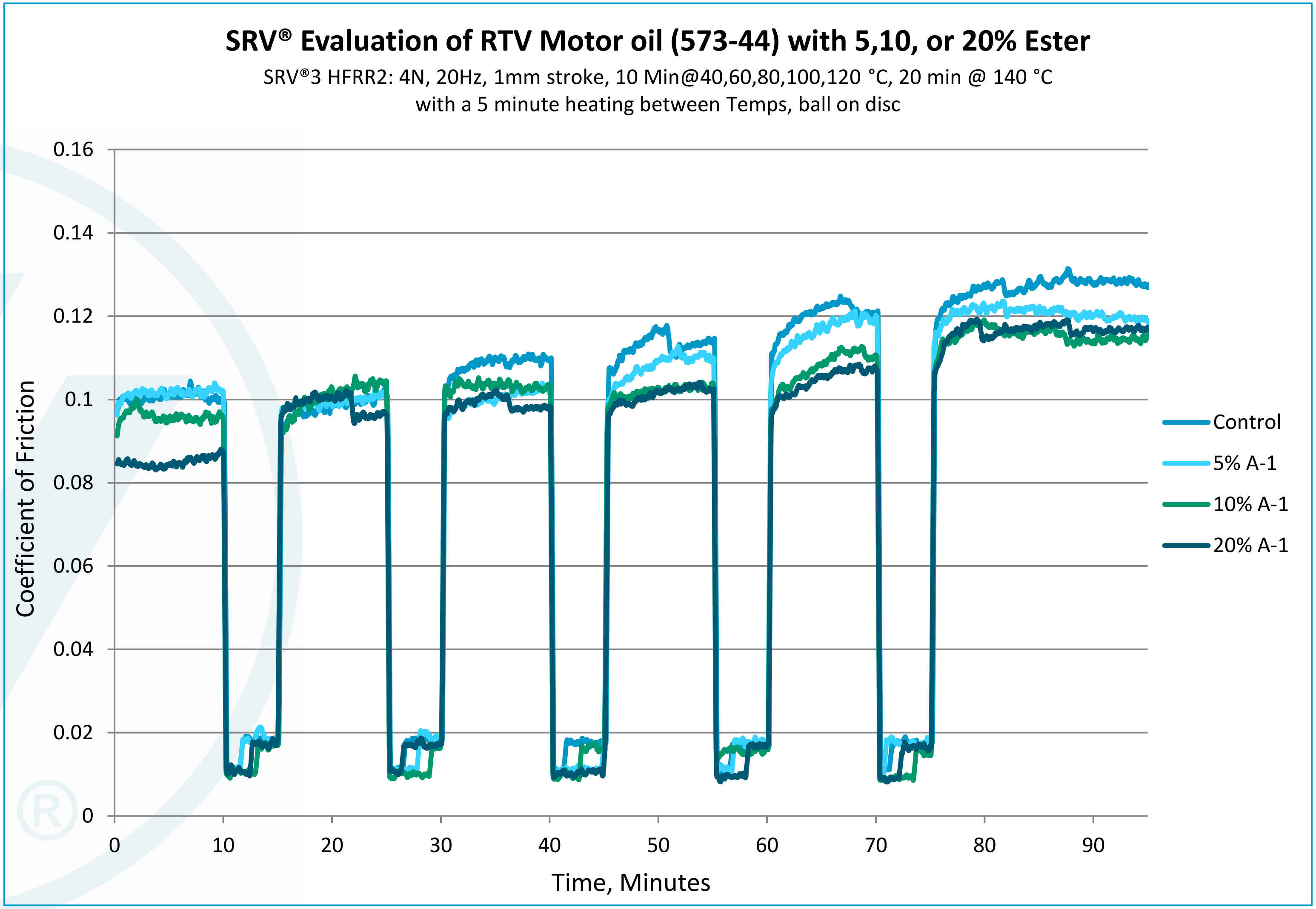
TEOST MHT-4 Deposit Testing

- TEOST MHT-4 deposit testing on a fully formulated oils showed both A-130 and P-3020 delivering improved deposit control versus the control oils formulated with Group II and III base oils.
- D-1 delivered directionally higher deposits than either control
- Experimental 0W-20 finished oil with 750 ppm Phosphorous, 2200 ppm Calcium.
  - 10% ester replaced 10% Gp II
  - 0 ppm Molybdenum
  - Same DI pkg and VII



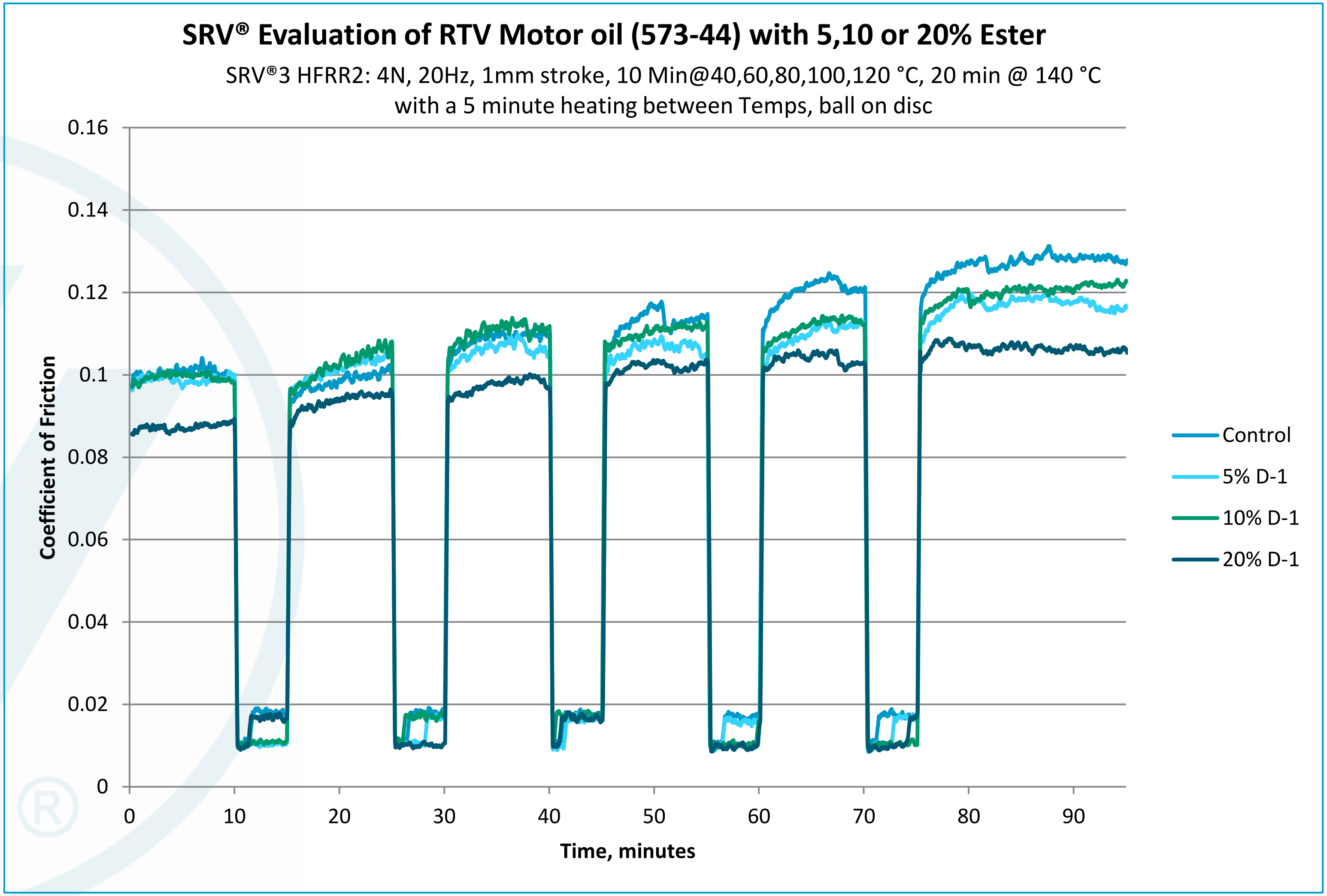
Select esters can have a positive impact on deposits

A130 HFRR2 Friction Testing



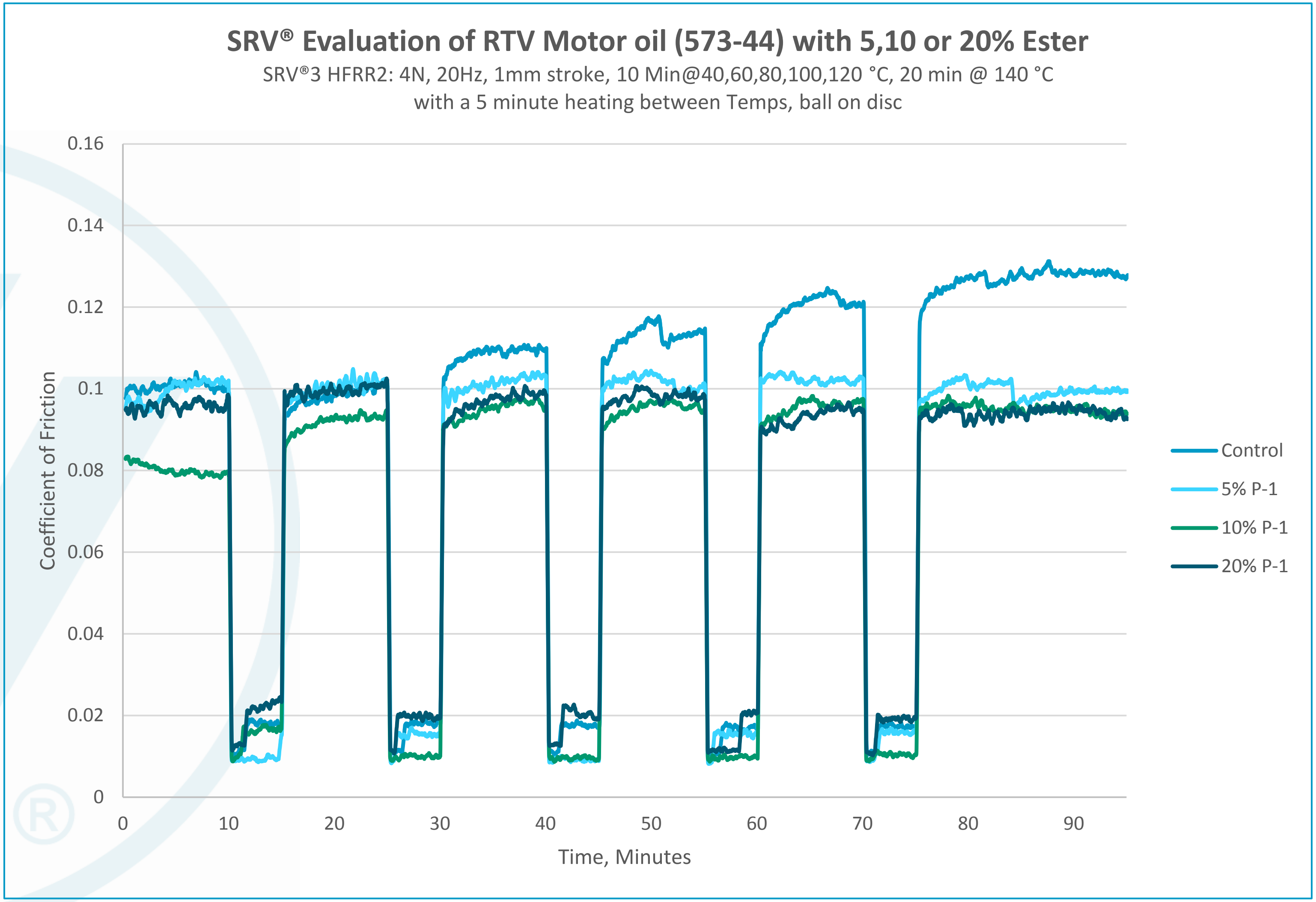
Ester friction performance directionally improved over the control

D2020 HFRR2 Friction Testing



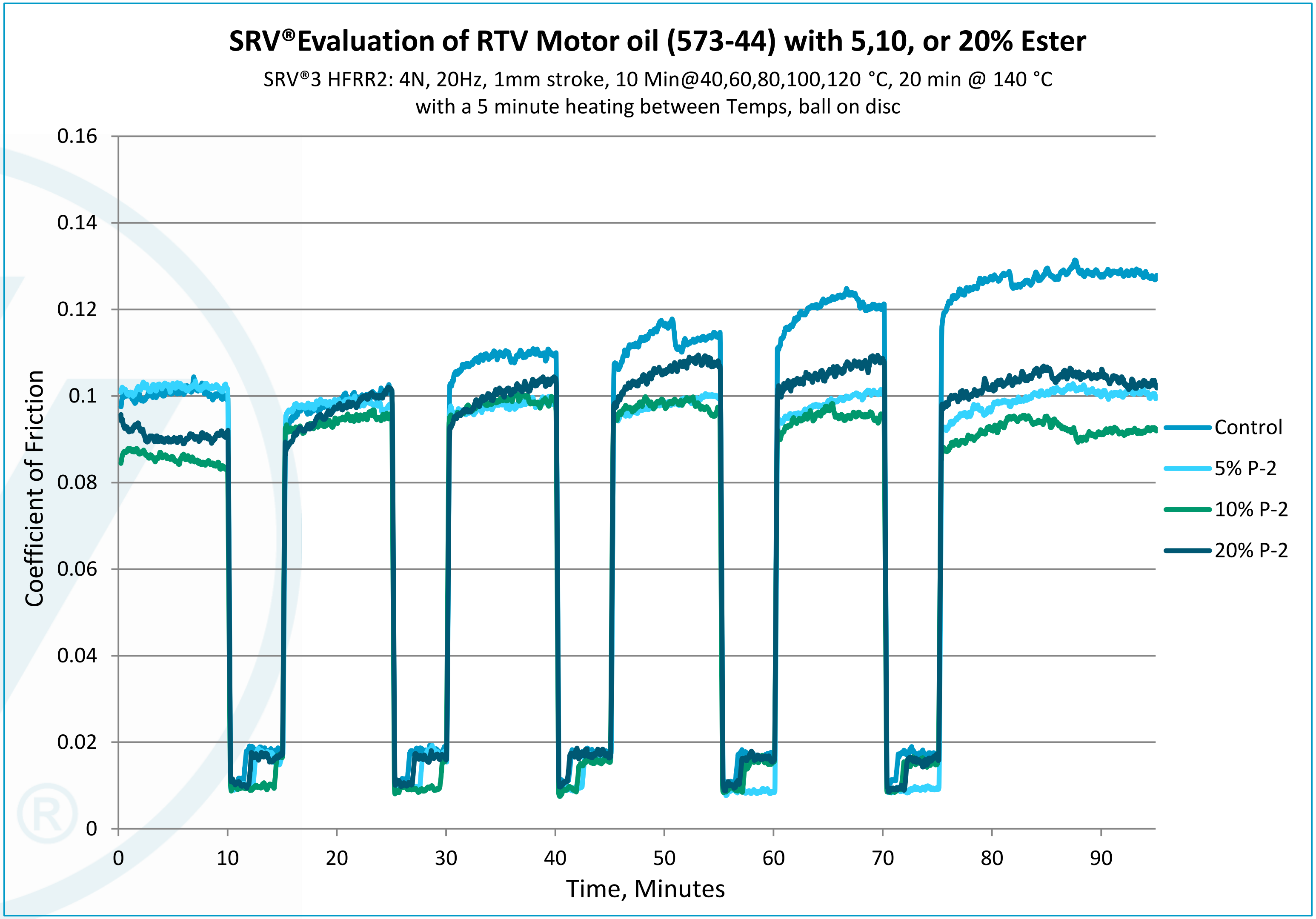
Ester friction performance directionally improved over the control

P3020 HFRR2 Friction Testing



Ester friction performance directionally improved over the control

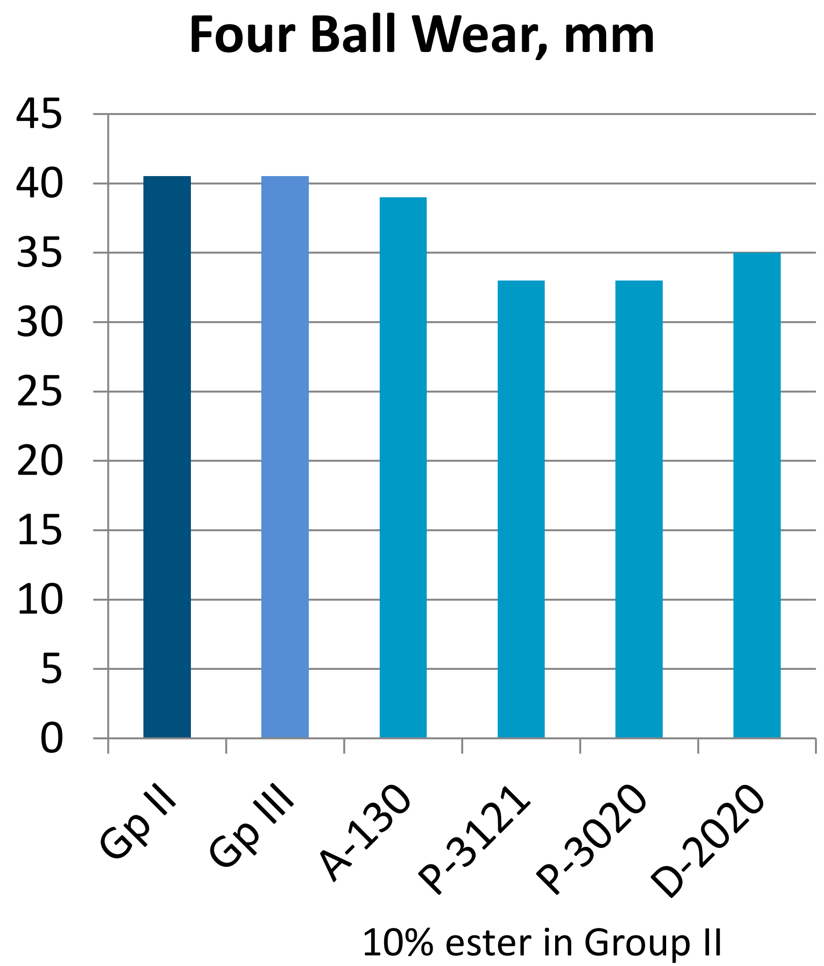
P3121 HFRR Friction Testing



Ester friction performance directionally improved over the control

4 Ball Wear Testing

- 4 Ball wear testing on a fully formulated oil showed both D-1, P-1 and P-2 delivering directionally improved wear control versus the two control oils formulated with either Group II and III base oils.
  - No difference in wear performance between a Group II or Group III.
  - A-1 delivered equivalent wear to the two control oils.
- Experimental 0W-20 finished oil with 750 ppm Phosphorous, 2200 ppm Calcium.
  - 0 ppm Molybdenum
  - Same DI pkg. and VII
  - 10% ester replaced 10% Group II



Select esters can have a directionally positive impact on wear

HTCBT Results in a HDDEO

	Teknor Ester @ 5.0 % in Base								
	D-2020		A-130		P-3020		Base 5W-40 HDDEO		
Tube position	2	7	4	9	5	10	1	6	
	1	1'	3	3'	4	4'	5	5'	Requirement
Copper (Cu)	8	8	8	8	8	8	8	9	20 ppm max
SwRI Copper	8		8		8		8		
Cu rating	1b	1b	1b	1b	1b	1b	1b	1b	3 max
SwRI Rating	1b		1b		1b		1b		
Lead (Pb)	6	8	6	6	8	8	6	12	120 ppm max
SwRI Lead	18		20		18		20		
SwRI Tin	<1		<1		<1		<1		

Calcium (ppm)	Magnesium (ppm)	Phosphorous (ppm)	Molybdenum (ppm)	Zinc (ppm)	Boron (ppm)
800	1145	1000	42	1220	60

Test data shows no harm to copper, lead and tin corrosion in a commercial full synthetic heavy duty engine oil

Seal Swell Data (ASTM D471)

100% P-3020

Polymer	% Mass Change	% Volume Change
CR	+40.5	+61.9
NBR	+28.0	+36.1
FKM	+0.92	+2.11
ACM	+10.5	+15.6

100% P-3121

Polymer	% Mass Change	% Volume Change
CR	40.47	+62.04
NBR	+27.03	+35.67
FKM	*	*
ACM	+8.7	+13.22

100% A-130

Polymer	% Mass Change	% Volume Change
CR	+43.8	+69.4
NBR	+22.3	+30.6
FKM	+0.93	+2.25
ACM	+7.49	+11.6

100% D-2020

Polymer	% Mass Change	% Volume Change
CR	+55.4	+87.8
NBR	+34.5	+46.6
FKM	+1.15	+2.70
ACM	+10.3	+16.3

Esters have a positive impact on seal swell!

CR = Chloroprene Rubber, NBR = Nitrile Butadiene Rubber, FKM = Viton (Fluoroelastomer), ACM = Acrylic Rubber

Seal Swell Data (ASTM D471) II

5% P-3020 in Group III

Polymer	% Mass Change	% Volume Change
CR	5.57	9.79
NBR	2.1	3.79
FKM	NR	NR
ACM	-0.16	0.38

5% D- 2020 in Group III

Polymer	% Mass Change	% Volume Change
CR	6.1	10.79
NBR	2.11	4.08
FKM	NR	NR
ACM	-0.09	0.39

5% A-130 in Group III

Polymer	% Mass Change	% Volume Change
CR	5.11	9.19
NBR	1.56	3.06
FKM	NR	NR
ACM	-0.15	0.42

5% P-3121 in Group III

Polymer	% Mass Change	% Volume Change
CR	5.64	10.22
NBR	2.28	4.15
FKM	NR	NR
ACM	-0.19	0.44

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LSPI Testing

Ester (5% treat level)	Control	A-130	P-3020	P-3121	"Typical" GF-5
Ester type	**None**	**Diester**	**TMP**	**TMP**	**None**
LSPI Events	**4**	**8**	**6**	**5**	**22**

- Control formulation contained Group III base oil, 750 ppm P, and no Moly
  - Detergent system consisted of Ca/Mg detergents (60/40)
- Formulation not completely optimized
- Each fluid was run once in a Ford LSPI screener engine test
- Maximum allowable number of LSPI events for API SN Plus is 5
- "Typical" GF-5 oil formulated in Group II base oil with 100% Ca detergent

Esters may affect LSPI when used at 5% treat rate.
Effect can be minimized through proper ester selection.

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Thank You!