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HOUSTON SECTION

Welcoming Gavin Duckworth
Vice President of National Accounts for Functional Products
Presenting

"Using Unique Polymer Chemistry to Enhance Automotive and Industrial Formulations".

November 6, 2020

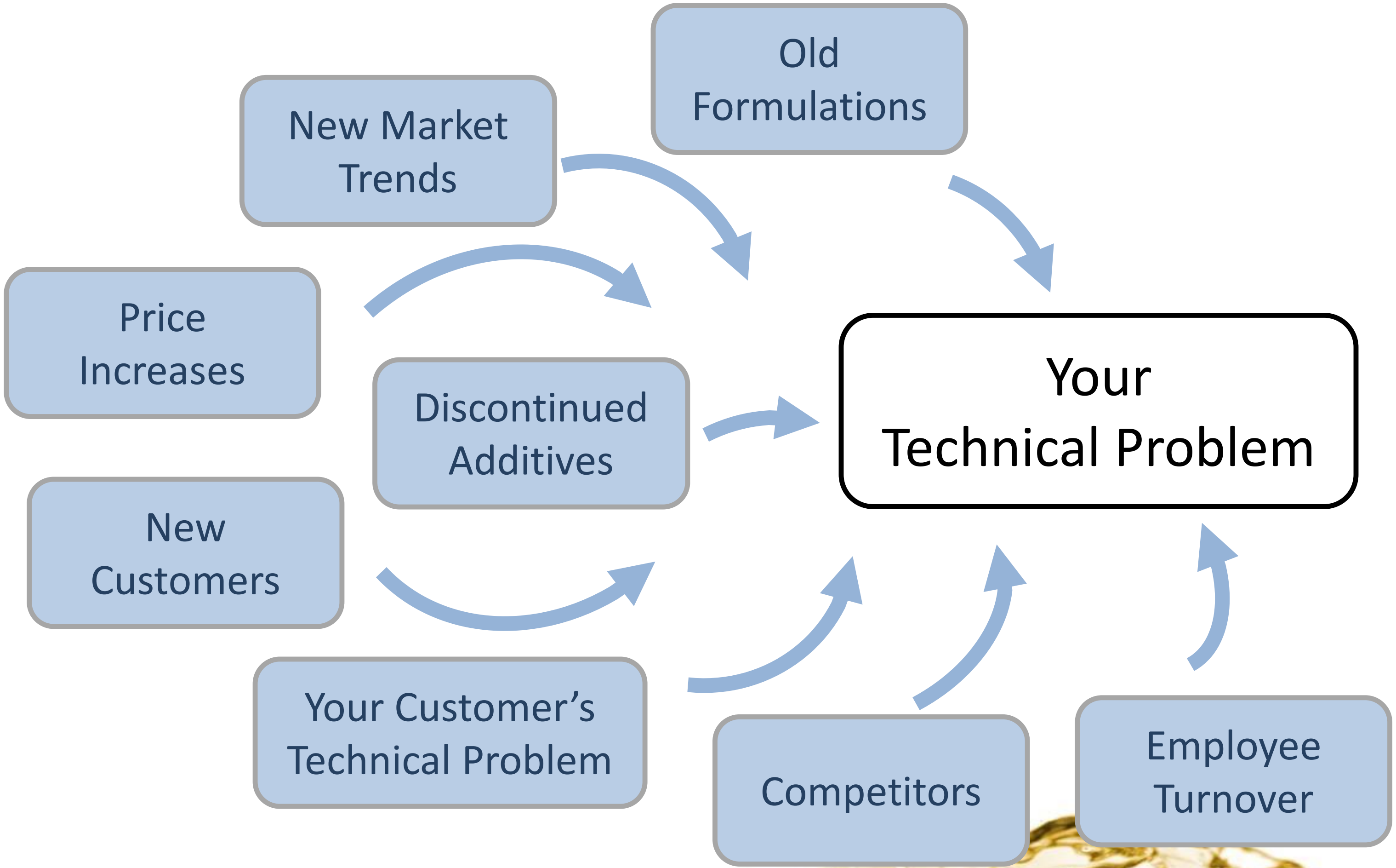
FUNCTIONAL PRODUCTS INC.
Innovative Chemistry for Lubricants

Functional Products Inc.

- Founded in 1985
- Focus on customer driven solutions
- Full service technical support lab
- ISO 9001 with Design
- **Let us do the search and you do the research**

- Full Service Additive supplier
- Tackifier Industry leader
- Bio-Based experts
- Provides polymer chemistry
- Baseoil Chemistry

Formulator's Dilemma



Motivation

- New high performance additives and fluids coming out every year
  - Typically become available to most formulators
    - But if everyone offers the same formulas at the same prices it's hard to differentiate!

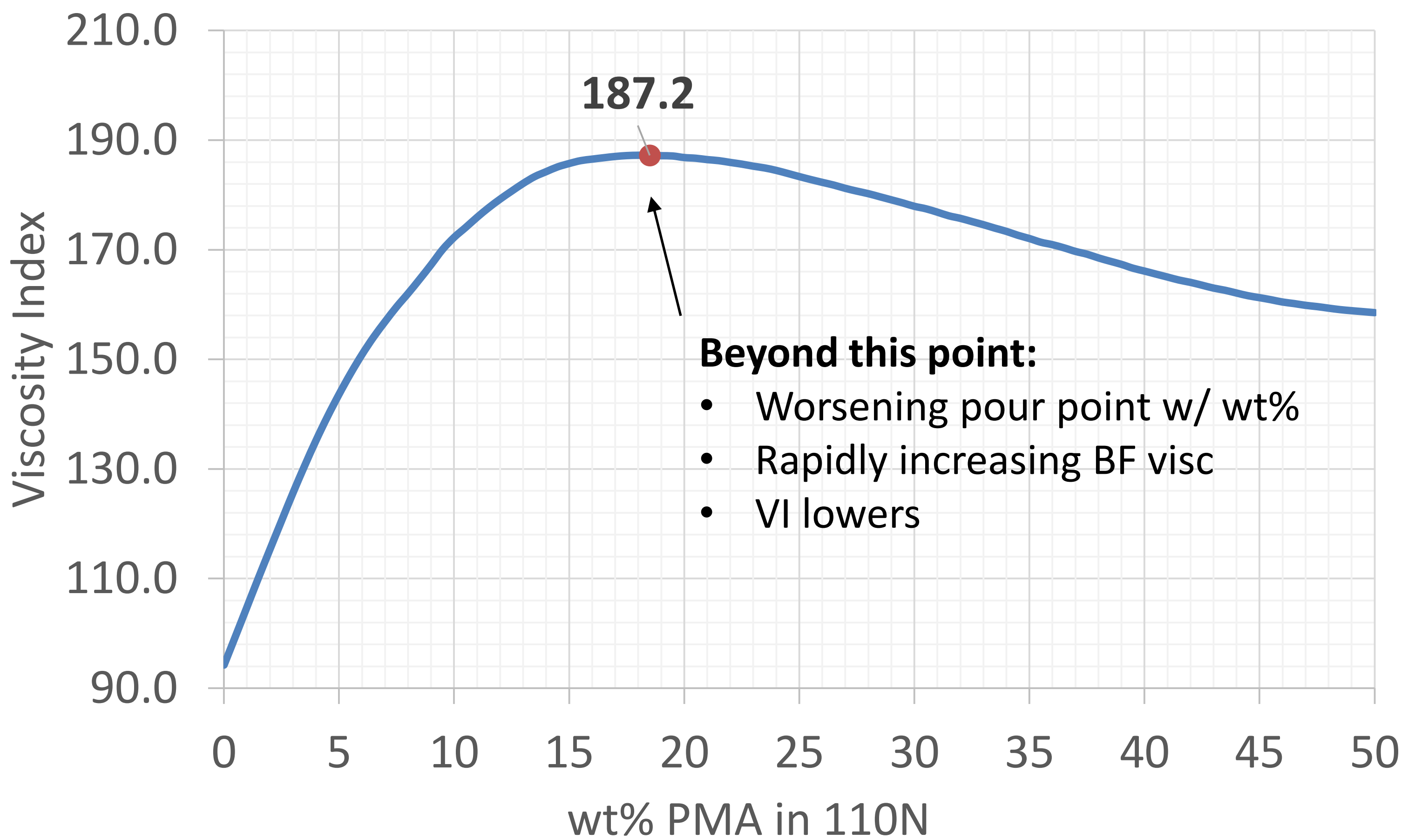
- We typically find the easiest, most direct path to formulating leaves <u>10-20%</u> cost that can be optimized out

VI Blending Study

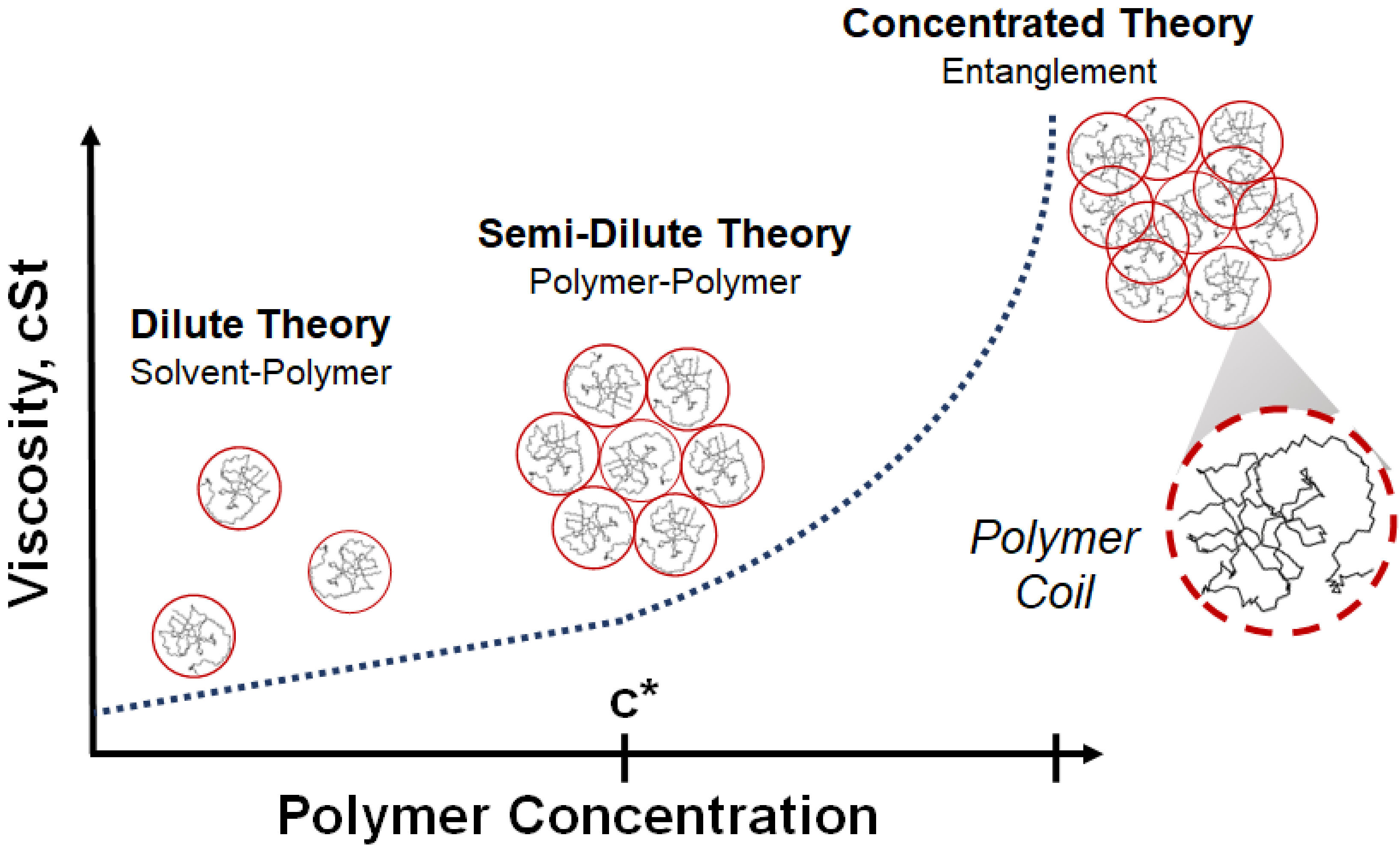
- Many options for VI improver chemistry
- Often diminishing returns on using increasing amounts of one VI improver
  - VI can plateau beyond a certain wt%
  - Pour point can improve and then worsen
- What if we could use the high VI improvement from a PMA with the thickening efficiency of OCP?
- *NLGI 2018 Development Author Award*
- "“Viscometric and Low Temperature Behavior of Lubricants with Blended VI Improvers”

Key Observation

- Inflection point in VI when adding high amounts of VM to oil
  - Why?



Key Theory Realized



Economics Followup

- Initial paper focused on performance like ISO VG vs. VI vs. p.p.

- What about the cost of achieving those different parameters?
  - Are different VM combos better for economics too?

Blending Setup

- Project Setup:

- Two different viscosity modifiers combined at varying wt% in three different oils to evaluate for synergies

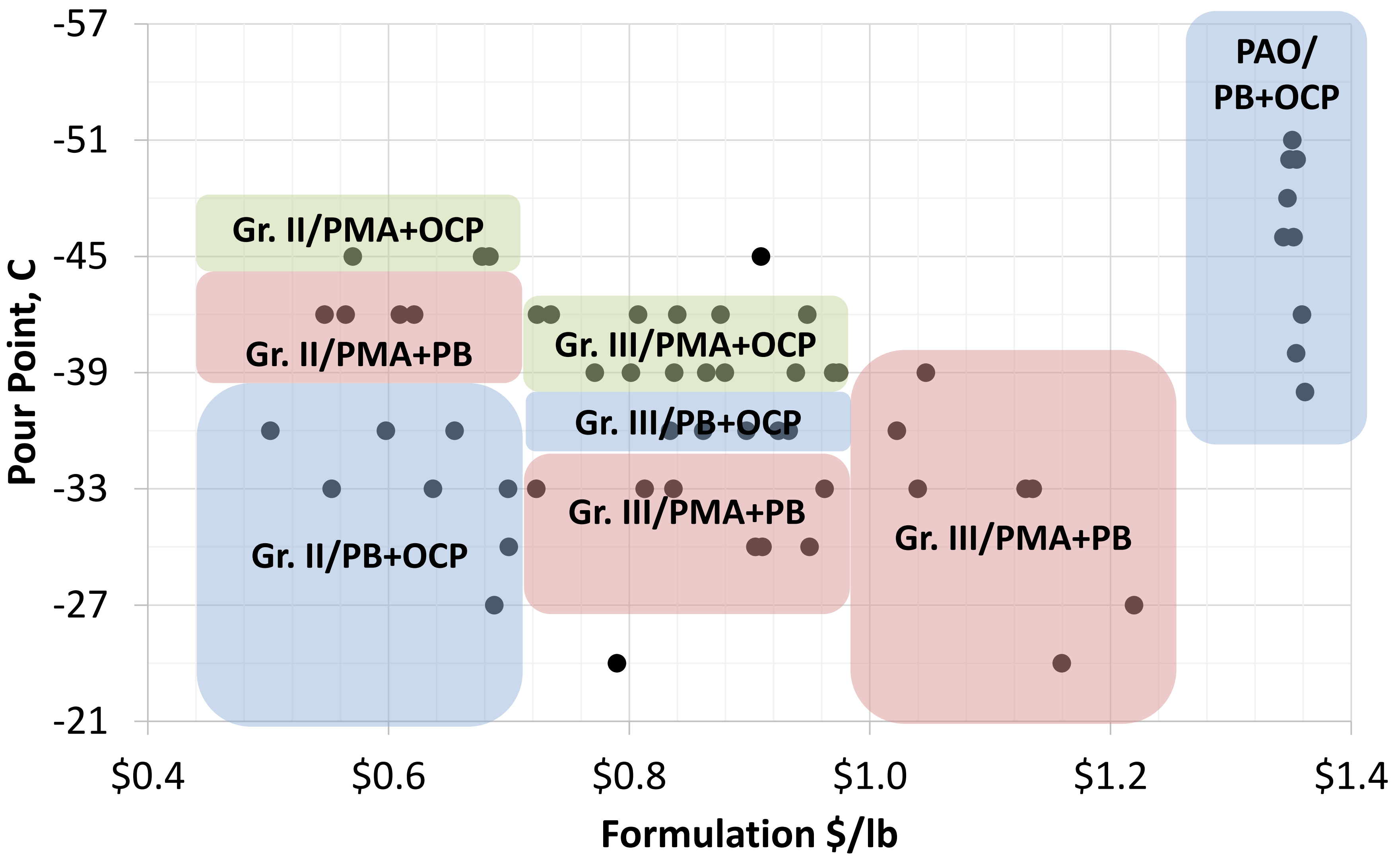
Viscosity Modifier B \ Viscosity Modifier A	5wt%	10wt%	20wt%
5wt%	#1	#2	#3
10wt%	#4	#5	#6
20wt%	#7	#8	#9

x every permutation of two viscosity modifiers b/w PB, OCP, PMA

x 6 cSt Group II, 4 cSt Gr. III, or PAO6

- 9 x 3 x 3 = 81 formulations
  - Measured viscosity, VI, and pour point
    - Determined trends in VI and pour point behavior with VII

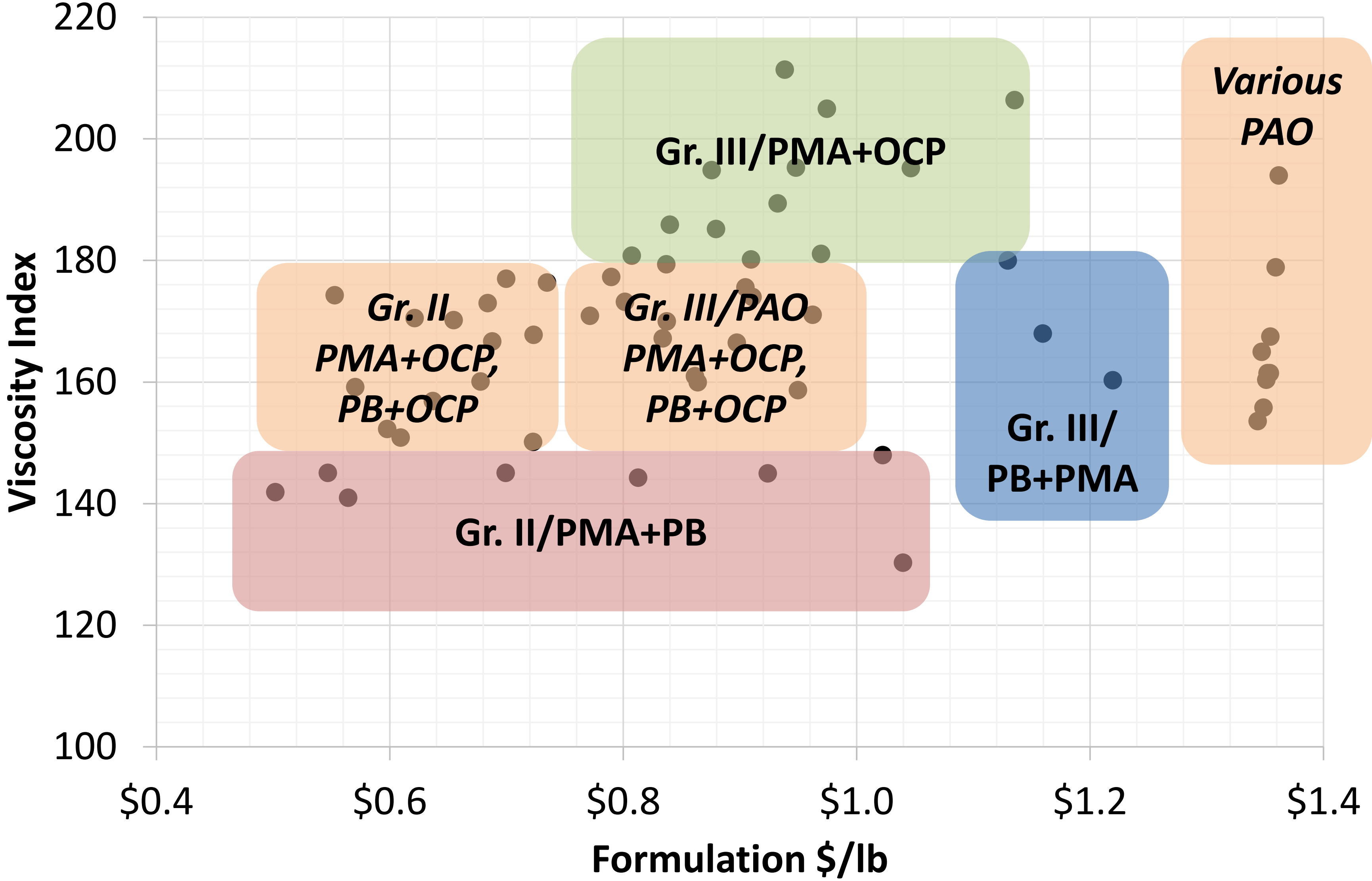
VM Blending vs. PP and Cost



Summary - PP and Cost

- Key findings:
  - PMA + OCP combination offers best pour point versus cost trend
    - Gr. II data shows better performance than Gr. III
      - Likely due to optimization of the PPD – both used a flat 0.2wt%
  - PAO offers lowest pour point but 130% and 50% more expensive than Gr. II and III
  - Worst cost vs. pour point was Group III with PMA + PB

VM Blending vs. VI and Cost



Summary – VI and Cost

- Key findings:
  - Stand-out performance with Group III using PMA+OCP combo
    - VI 180 – 220 are feasible
  - VI from PB+OCP or PB+PMA fall in Gr. II / III / PAO are mostly similar
  - Worst performer is Group III with PB + PMA
    - Lower solvency Group III with high amounts of added PB will begin to affect clarity

OCP as mPAO Alternatives

- mPAO – excellent shear and oxidative stabilities
  - mPAO priced ~$1/lb higher than low visc PAO
    - Not every application requires such shear stability
      - Save the mPAO for industrial gear / HF

- 22 and 50 SSI olefin viscosity modifiers in low visc PAO
    - **10% lower formulated cost** vs. mPAO at ISO >68 in PAO6
    - High SSI VM provides extra VI, tack, stay-in-place
    - Removal of mPAO improves solvency for additives and polymers
    - Benefit to light duty HF, way oils, chain oils, spindle, grease

OCP/PAO vs. mPAO

- Liquid “PAO VM” using 50 SSI metallocene OCP in light PAO

Economics in PAO6 for PAO 100 vs. OCP/PAO VM

	PAO100 in PAO6		OCP/PAO VM in PAO6		
ISO VG	wt% PAO100	Viscosity Index	wt% VM	Viscosity Index	Cost Reduction
ISO 46	13%	154	5%	176	4.4%
ISO 68	25%	158	11%	189	6.5%
ISO 100	40%	162	16%	193	10.7%
ISO 150	50%	167	22%	202	11.0%
ISO 220	60%	171	27%	209	11.6%
ISO 320	70%	175	32%	216	12.5%
ISO 460	80%	180	37%	224	13.3%

- Light duty HF, chain oils, textile, way oils, greases

PMA vs. mPAO

- Some applications require high shear stability, PMA can help
- Higher cost per pound versus mPAO but…
  - Above 20-30% viscosity rapidly increases to outmatch mPAO $/treat
  - Very low SSI will still shear in grade or <15% by KRL
- PMA (15 SSI by KRL) as a high viscosity 'base fluid'

High Viscosity Economics in PAO4

ISO VG	wt% mPAO150	wt% PMA	Cost Reduction
100	42%	31%	0%
150	51%	36%	4%
220	60%	40%	8%
320	68%	44%	11%
460	75%	47%	13%
680	83%	50%	15%
1000	90%	53%	17%

High VI and Cost

- High VI 140+ market moving more towards 180+ and later to 220+
  - How to achieve these VIs?
  - New base oils? Special VI improvers?

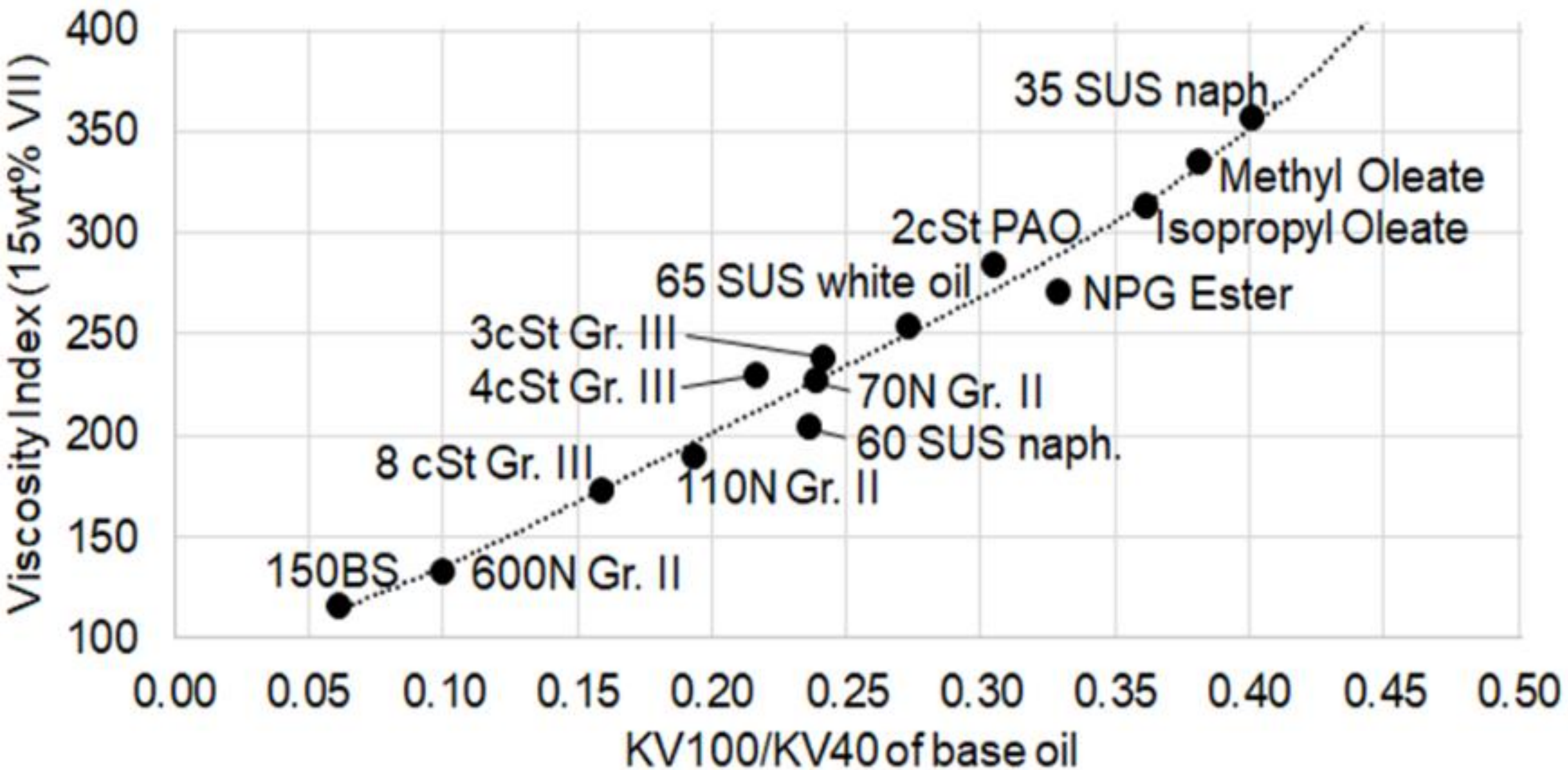
Very High VI

- 15wt% of low SSI PMA viscosity modifier in various fluids
  - We get various viscosity indexes
    - Why do some give very high or very low VI? KV? VI? Synthetic?

Base Fluid	Viscosity Index w/ 15% PMA (35 SSI)
D-Limonene	572
35 SUS naph. oil	357
Methyl oleate	335
Isopropyl oleate	313
PAO2	284
C9 NPG Ester	271
65 SUS white oil	254
3 cSt Gr. III	238
4 cSt Gr. III	230
70N Gr. II	227
60 SUS naph. oil	204
110N Gr. II	190
8 cSt. Gr. III	173
600N Gr. II	133
150BS	116

KV Ratio vs. VI

- VI with VI improver can be predicted based on KV100 / KV40



Some Applications

- Shock absorber (VI 200-400)
- 5605-spec fluids (VI 350+)
- Very high VI hydraulics and gear (VI 220)

- All possible with conventional base oils and VMs chosen carefully
  - Low KV white oils, naphthenic produce higher VIs than Gr. III and PAO
- Lower base oil KV typically improves VI
  - Blending in higher KV base oils quickly drops formulated VI
    - PB as 'base fluid' increases KV of light oils with less effect to VI

Economy HFs

- 25 SSI pellet with just 150SN provides lower cost but higher VI than 50 SSI liquid
  - Using more VI improver actually saved $/lb

		Group I HL/HLP HF				Group I HL/HLP HF			
		ISO 32	**ISO 46**	**ISO 68**	**ISO 100**	**ISO 32**	**ISO 46**	**ISO 68**	**ISO 100**
150SN	Base Oil	97.3	65	29.5	0	97.5	97.15	96.6	95.8
500SN	Base Oil		32	68.2	97.1				
	25 SSI pellet VII					0.1	0.45	1	1.6
	50 SSI liquid VII	0.3	0.5		0.3				
	Ad Package	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
	Gr. I PPD	0.2	0.3	0.4	0.5	0.2	0.2	0.2	0.2
	VI	101	100	100	102	106	114	126	160
	$/lb typical	$0.603	$0.637	$0.668	$0.699	$0.602	$0.608	$0.617	$0.626
					Cost Savings	Same	4.5%	7.6%	10.4%

Group III Automotive Gear

- New Baseoil Technologies on the Market (ie. polyolefin)
- Ability to use GIII in 75W140

	75W-90 Gr. III	75W-140 Gr. III
4 cSt Group III	86.5	81.25
Polyolefin Basestock	9.0	14.25
Pour Point Depressant	0.5	0.5
GL-5 LS Package	4.0	4.0
KV40, cSt	64.0	117.0
KV100, cSt	14.6	26.0
Viscosity Index	240	258
BF @ -40C (D2983)	20,250 cP	30,500 cP
KV100 after KRL	13.7, In Grade	24.05, In Grade
RPVOT (D2722) *	94 minutes	86 minutes

What is the Haze?

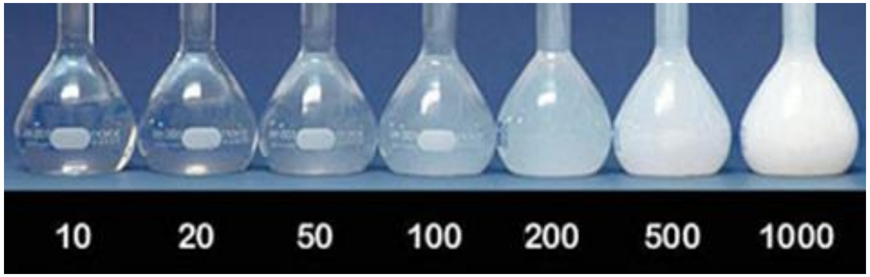
- Haze occurs after blending in additive package
  - The “package” isn’t hazing – likely only a few components

- To identify ‘bad actors’, different components added in isolation to a low solvency 75W140 trial formula (PB/PMA/PAO)
  - Freeze/thaw again, -54C

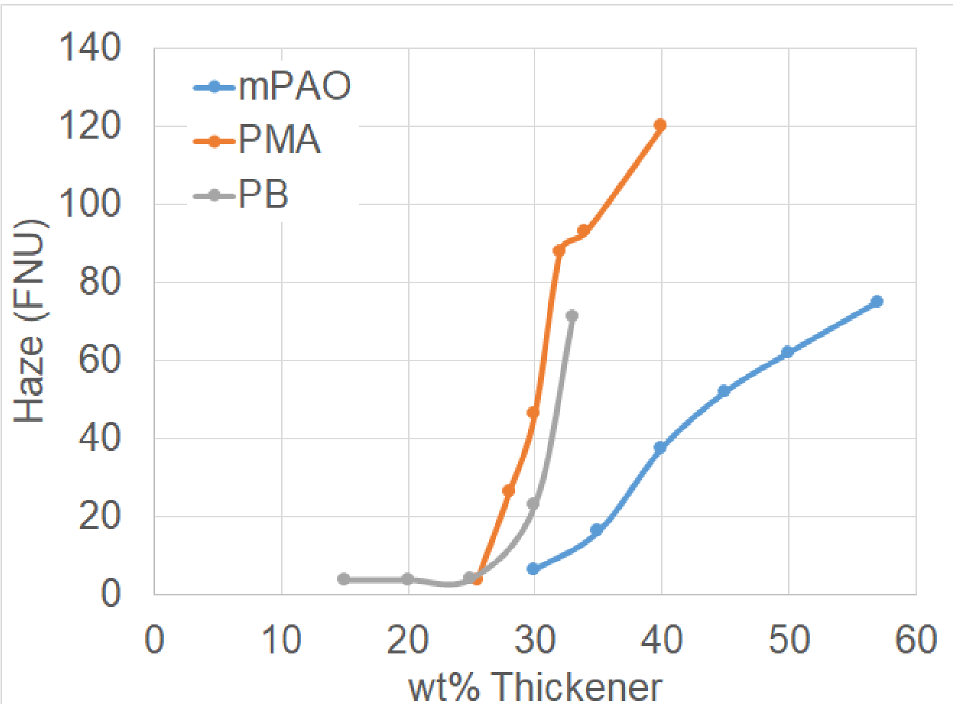
Testing Haze

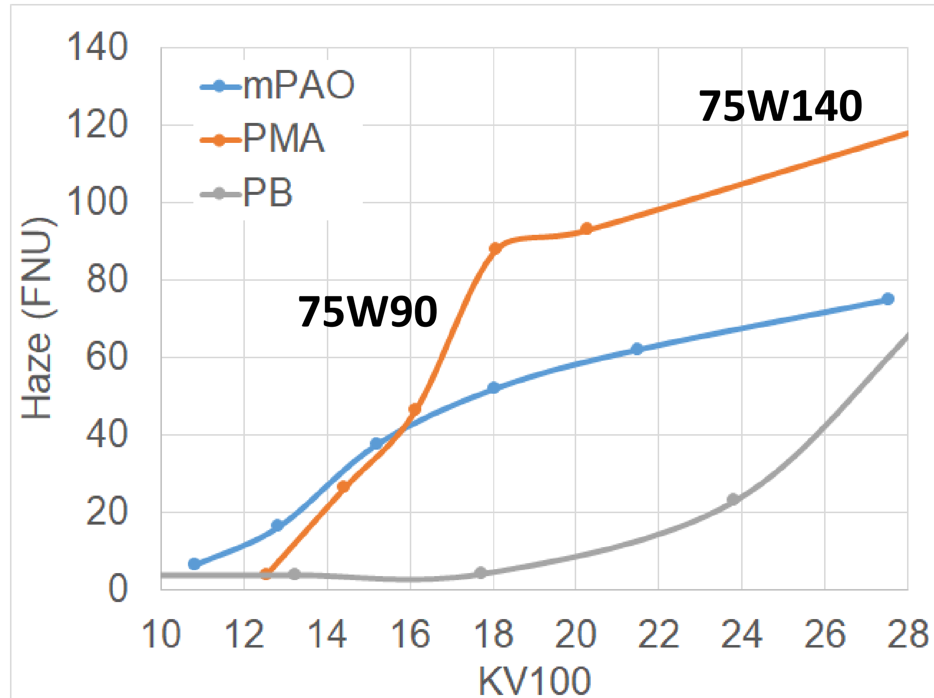
- Formulate polymers in PAO4 with GL-5 ad pak (10% treat)
  - Freeze/thaw at -20C

- Milwaukee Mi 415 turbidity meter (FNU units)



Low Haze 75W's Without Ester





Haze ≥20 FNU is readily apparent and noticeable

Freeze/Thaw on Ad Pak Components

Trial	Chemistry	Treat	Role	FNU Haze	Visual
A	-control-	N/A	<control>	0	Clear
B	Alkyl triazole	0.1%	Corrosion inhibitor	10.6	Clear
C	Mb dithiocarbamate	3.0%	Friction modifier	2.92	Clear
D	Aromatic amine	1.0%	Antioxidant	1.43	**Haze**
E	Ashless dithiocarbamate	1.5%	Ashless friction modifier	1.62	Clear
F	Amine phosphate	1.0%	Corrosion inhibitor	4.55	Clear
G	Overbased calcium sulfonate	1.0%	Detergent	15.7	**Haze**
H	PIBSI	1.0%	Dispersant	0.8	**Haze**
I	Dialkyl pentasulfide	1.0%	Active sulfur	0	Clear
J	Sulfurized ester	1.0%	Inactive sulfur	1.15	Clear*
K	PAG defoamer	0.2%	PEG Defoam	2.7	**Haze**
L	Acrylate defoamer	0.2%	Acryl Defoam	1.3	Clear

- Discrepancy between measured haze vs. visual inspection
- Worst haze: from D > G, H > K; delayed separation with J after one month

Summary on Haze

- Haze in full synthetic automotive gear oils
  - Inherently low solubility base fluids
  - Extra high treat of shear stable polymer
    - Less of an already poor solvent available

- Bad actors
  - Aromatic amine anti-oxidant
  - Calcium sulfonate and PIBSI
  - PAG defoamer

Summary

- 2018 study
  - Group II/III blends with OCP and PMA offer cost competitive VI and pour points against PAO
  - Don't overtreat VM (avoid 'critical concentration') to keep good VI and low temperature fluidity
- mPAO alternatives for thickening low viscosity PAO with OCP where the shear stability doesn't matter
- Fundamentals of high VI formulating allow greater flexibility and cheaper oil selection rather than Group III or other high VI oils

Questions:

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Thank You!

Please join us next month on December 11, 2020.