Development of Modified PAG (polyalkylene glycol) High VI High Fuel Efficient Lubricant for LDV Applications

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Project ID # FT020

Overview

Timeline

- Project start date – October 1, 2011
- Project end date – December 31, 2014
- Percent complete – 75%

Barriers

- Barriers addressed
  - Inadequate data on long-term impact of fuel and lubricants on engines and emission control systems.

Budget

- Total project funding - $1,500,000
  - DOE share: $1,200,000
  - Contractor share: $300,000
- Expenditure of Govt. Funds
  - FY12: $108,074
  - FY13: $327,916

Partners

- Collaborations
  - ✓ Dow Chemical
  - ✓ Argonne National Laboratory
- Project lead
  - ✓ Ford Motor Company

Relevance

- **Project Objective**
  - The main objective of this project is to develop lubricant formulations capable of at least 10% engine friction reduction compared to current GF-5 engine oil technology at the same viscosity grade level most commonly used in the North American market.
- **Objectives for this presentation**
  - Polyalkylene glycol based engine oil formulations
  - Friction and wear data on Laboratory bench tests
  - Motored engine component friction data
  - Motored engine friction data
- **Relevance to Vehicle Technology Office Objectives**
  - Reduce petroleum consumption by improving fuel economy
- **Impact**
  - New lubricant technology has no negative impact on emissions
  - Save 3 billion gallons of petroleum fuel per year

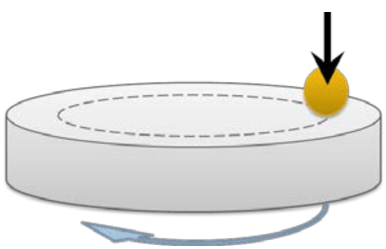
Milestones

Month /Year	Milestone/Go-No-Go Decisions	Milestone Description	Status
Q1'2012	Milestone	Define initial lubricant formulations	Completed
Q2'2012	Milestone	Complete initial assessment of physical and tribological properties of lubricant formulations	Completed
Q4'2012	Milestone	Define final lubricant formulations based on bench test results	Completed
Q4'2013	Milestone	Complete engine component level friction and wear evaluation	In-progress *
Q2'2014	Milestone	Complete full engine (motored and fired) friction and wear evaluation	On Track
Q4'2014	Milestone	Complete vehicle chassis dynamometer test	On-Track

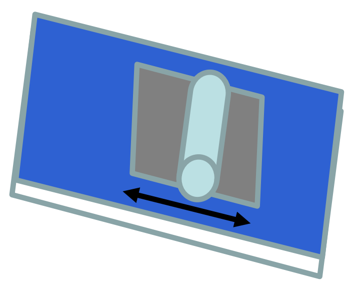
* Completed friction evaluation, wear evaluation delayed because of receiving NRC license

Approach / Strategy

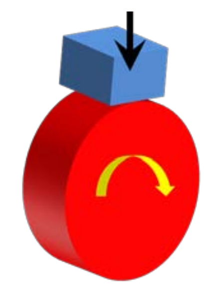
- **Fundamental understanding through laboratory bench tests**
  - New modified PAG base engine oil formulations
  - Measure intrinsic lubricant properties
    - Kinematic viscosities
    - High temperature high shear viscosities
  - Evaluate friction and wear performance



Pin-on-disk
(Pure Sliding)



Roller-on-disk
(Pure Sliding)

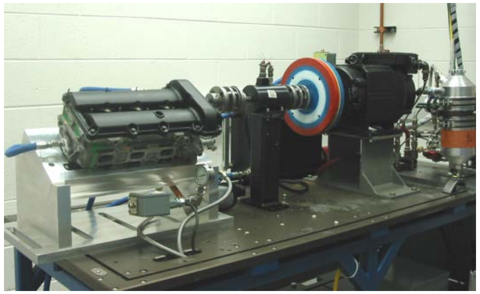


Block-on-Ring
(Pure Sliding)

  - Understand the interaction of surfaces with additive system for the formation of anti-wear, anti-friction surface layers

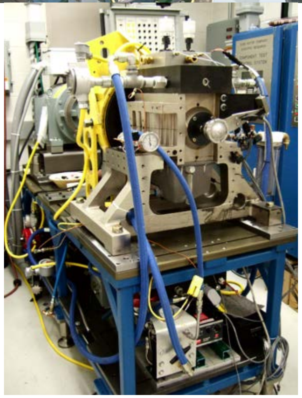
Approach / Strategy

- **Understanding friction contributions from engine component systems**



  - **Motored valvetrain friction tests**
    - Bucket tappet type valvetrain
    - Used extensively in the past to capture friction benefits related to change in lubricant formulations and hardware surface modifications

  - **Motored valvetrain wear tests**
    - Single bucket tappet type valvetrain
    - Used extensively for measuring wear on tappet and cam lobe



  - **Motored single cylinder piston ring friction tests**
    - Measures friction at cylinder bore/ piston and ring interfaces

Approach / Strategy

- **Engine and Vehicle Evaluations**
  - **Motored engine friction tests**
    - Measure friction as a function engine speed (600 – 3000 RPM)
    - Measure friction as a function of oil temperature (40C-100C)
    - Estimate fuel economy from friction data using proprietary analytical tool
  - **Fired engine dyno tests**
    - ASTM Sequence IIIG tests (measures high temp. valvetrain wear, oil oxidation)
    - ASTM Sequence IVA tests (measures low temperature valvetrain wear)
  - **Vehicle fuel economy tests**
    - FTP metro/highway cycles
    - Put at least 500/4000 miles prior to evaluation
    - Record emissions data

Technical Accomplishments and Progress

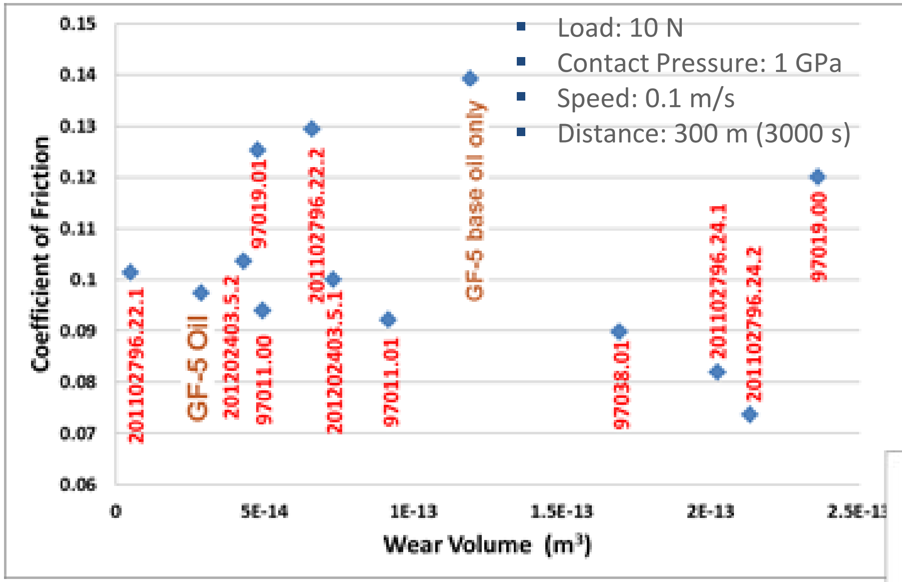
Fluid	Also known as	Formulated (Y/N)	Base oil in Formulation	HTHS @150 C cP[1]	KV 100 C cSt	KV 40 C cSt	VI	Flash Point[2] ˚C	Noack[3] wt%	Base fluid description
XZ97011.00		N	XZ97011.00	2.66	5.55	20.26	239	212		Alcohol initiated capped random copolymer of ethylene oxide and propylene oxide
XZ97011.01 – Fully Formulated E-72		Y		2.83	5.6	22.49	233	212	10.1	
XZ97011.01 – Fully Formulated E-72	15-1	Y		2.68	5.5	20.34	232	>200		E72 adjusted HTHS to 2.6
XZ97011.01 – Fully Formulated E-72	14-2	Y		2.4	5.06	18.36	229	>200		E72 adjusted HTHS to 2.4
XZ97019.00		N	XZ97019.00	2.3	5.21	19.4	223	250		Alcohol initiated capped propylene oxide homopolymer
XZ97019.01 – Fully Formulated E-65	13-3	Y		2.37	5.1	20.01	202	250	7.4	
201102796-24-1		N		2.63	5.99	23.3	223	212		Higher MW version of XZ97019.00
201202403-5-1	15-4	Y		2.66	6.06	25.08	204	>200		
XZ97038.01		Y	XZ97038.00	2.28	5.19	19.8	214	224		Alcohol initiated capped propylene oxide homopolymer
201102796-24-2		N		2.61	6.02	23.4	224	224		Higher MW version of XZ97038.01
201202403-5-2		Y		2.6	6.06	24.87	207	>200		
201102796-22-2		N	201102796-22-2	3.57	8.54	42.15	186	262		Alcohol initiated propylene oxide homopolymer
201102796-22-1– Fully Formulated	14-1	Y		3.58	8.79	46.57	171	262	3.9	
201202403-9-1	22-1	Y		2.56	5.95	29.14	155	>150		
17-1		Y		2.6	6.27	31.29	156	>200		22-1 w/antiwear and antioxidant boost
201202403-8-1		Y	Oil soluble PAG	2.6	6.62	35.55	144	>200		Fully formulated with OSP base stocks
GF-5 SAE 5W-20			Mineral oil	2.6	8.6	48	164			

PAG Base Oil Types

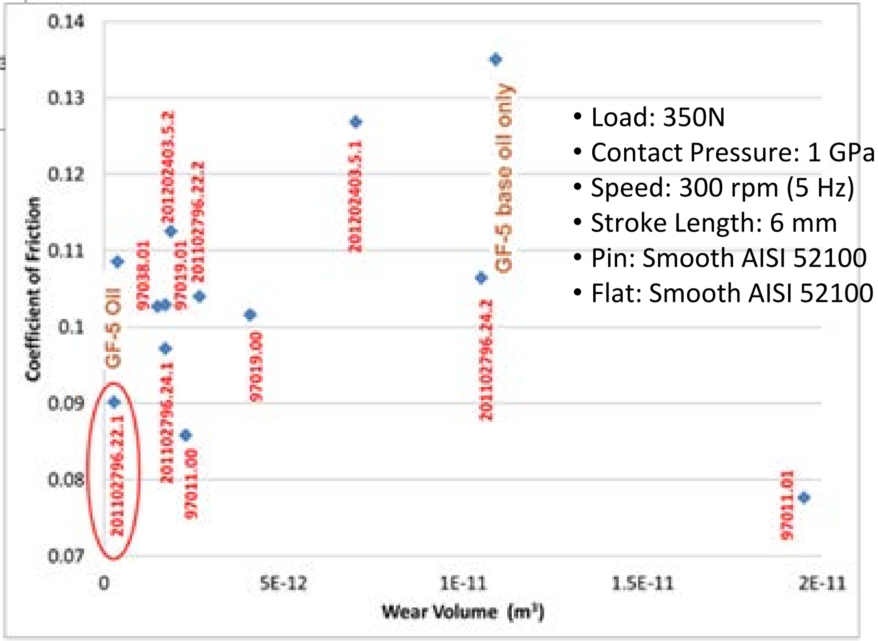
- Capped copolymer of EO and PO
- Capped PO
- PO
- BO

Technical Accomplishments and Progress

Pin-on-Disk Data at 80C



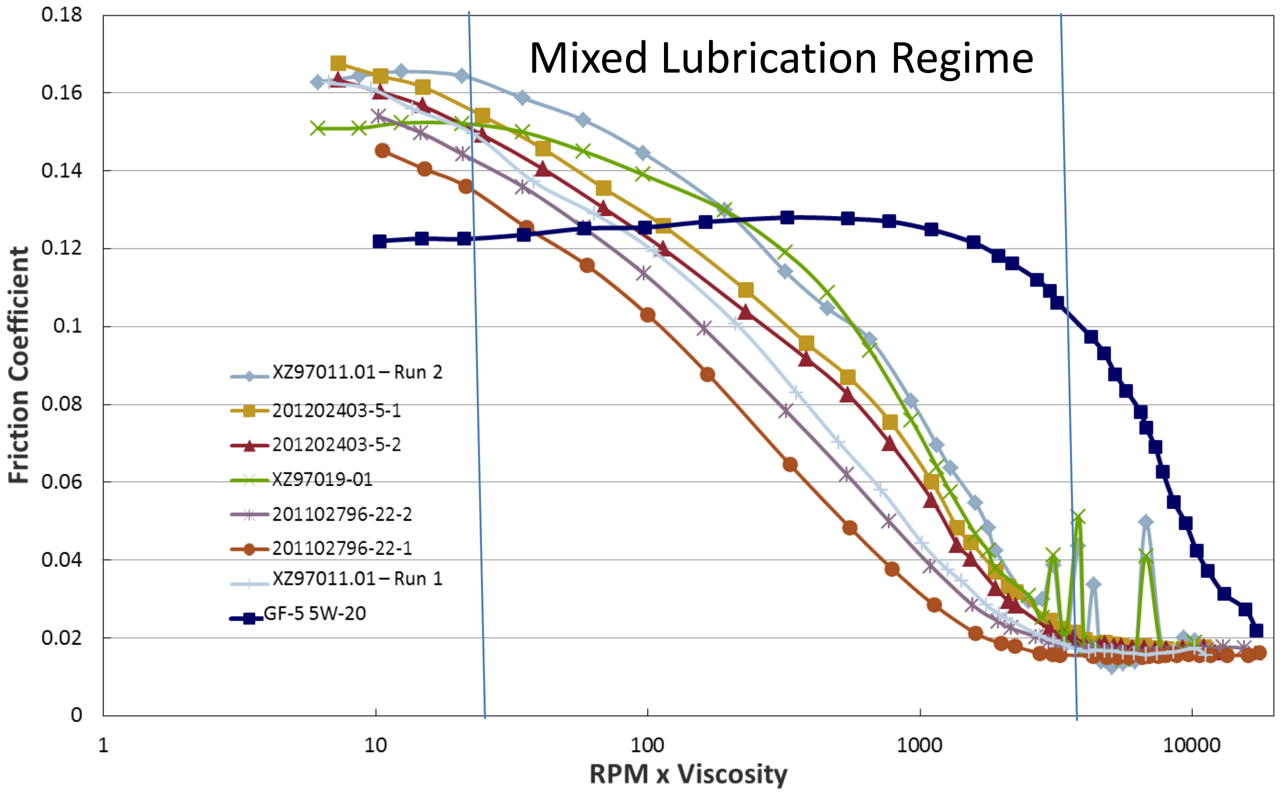
High Frequency Reciprocating Data at 80C



Some of the PAG formulations showed lower friction coefficient and wear than GF-5 SAE 5W-20 oil

Technical Accomplishments and Progress

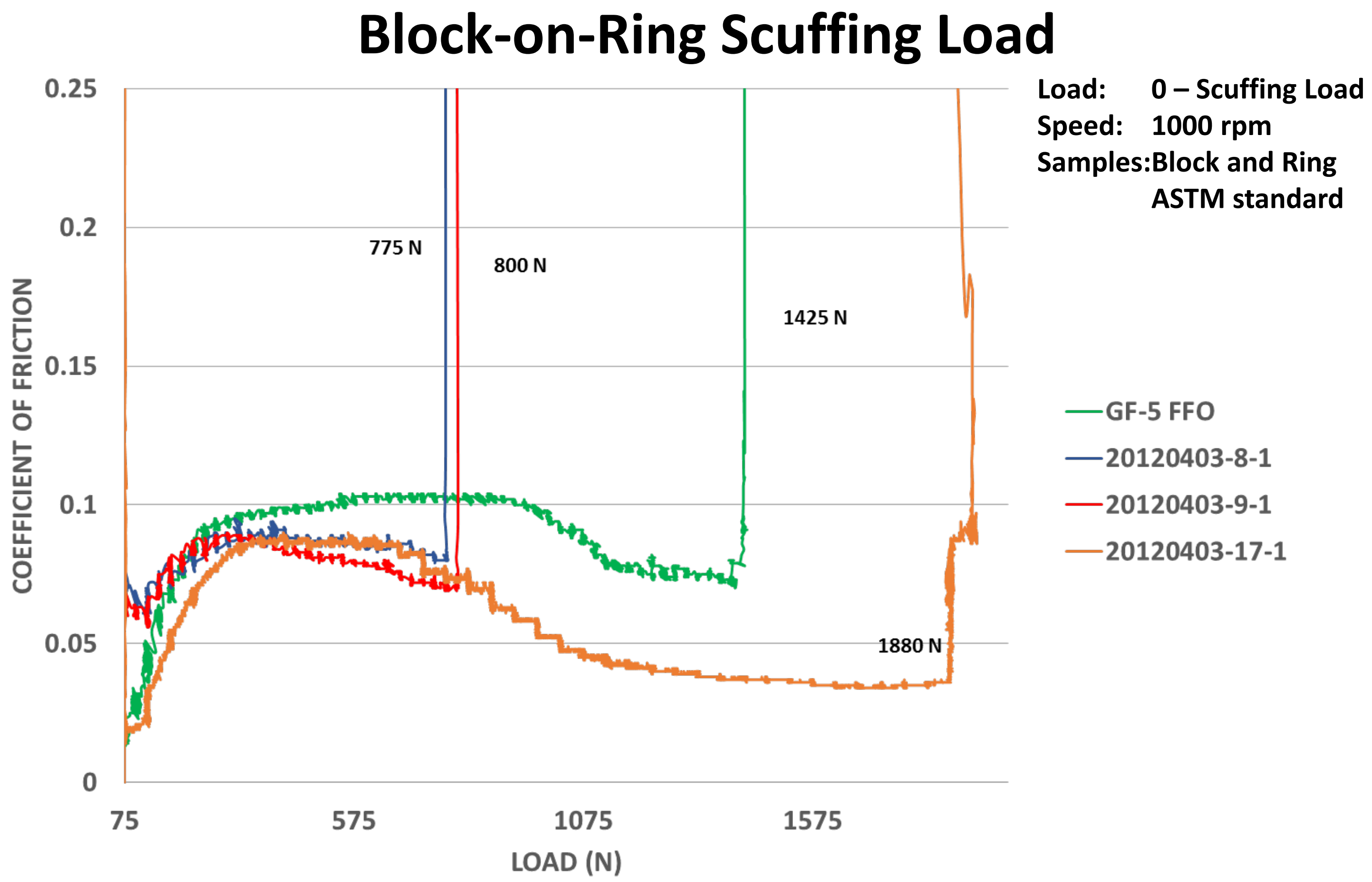
Stribeck Curves



Temperature:	**100°C**
Load:	**Variable**
Speed:	**Variable from 0.02 Hz to 33 Hz**
Stroke Length:	**Variable**
Pin/ball:	**Variable**
Flat:	**Smooth AISI 52100**

All PAG formulations showed lower friction coefficients in the mixed lubrication regime than GF-5 SAE 5W-20 oil

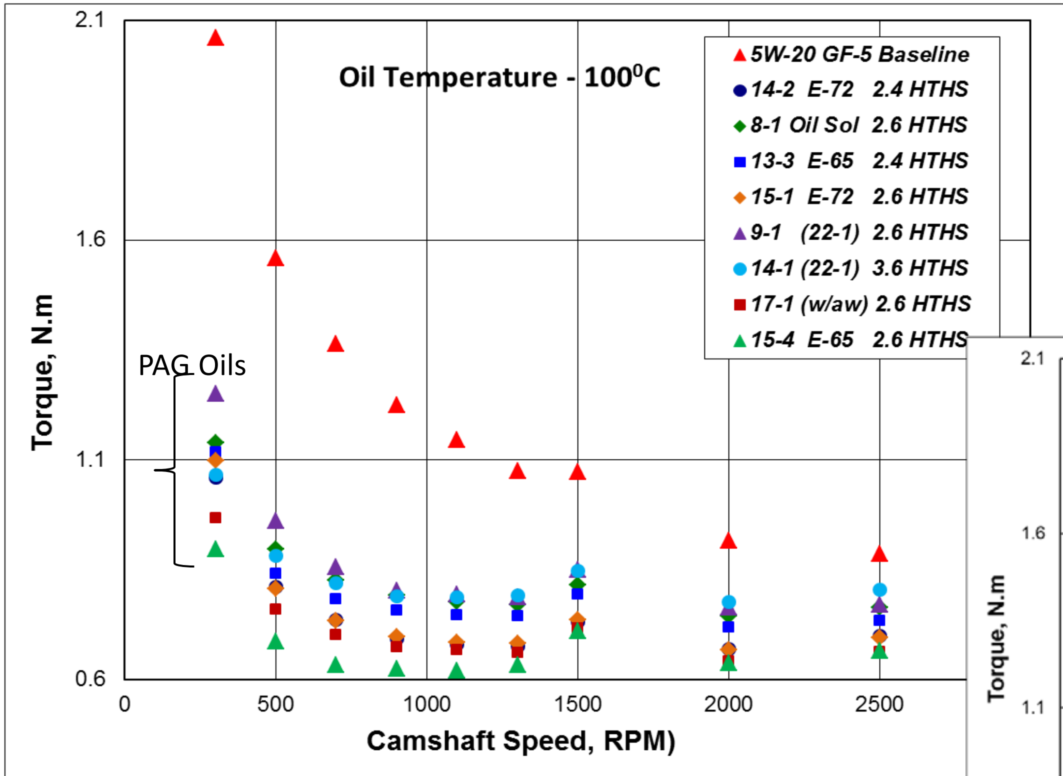
Technical Accomplishments and Progress

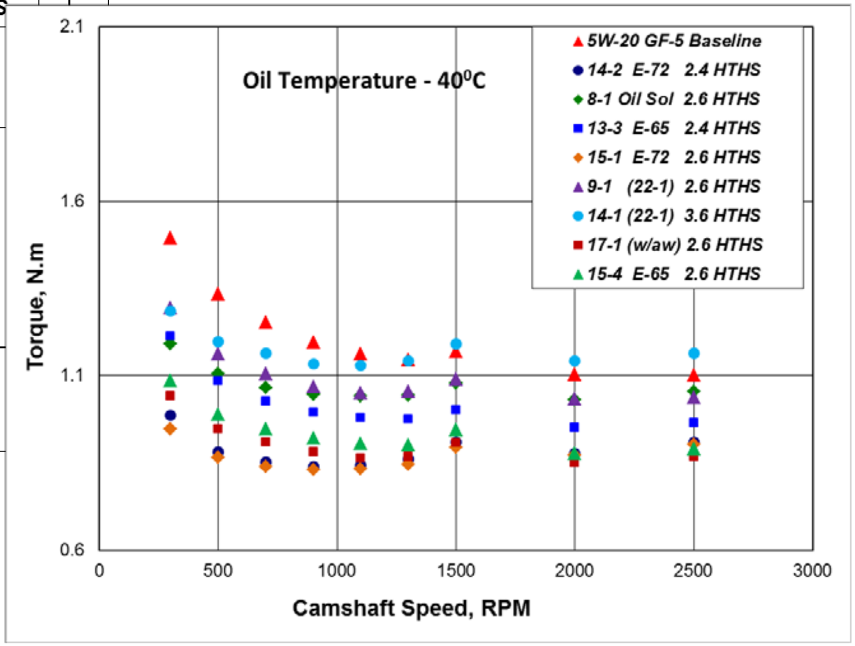


PAG formulation 20120403-17-1 showed lower friction coefficient and higher scuffing load than GF-5 SAE 5W-20 oil

Technical Accomplishments and Progress

Motored Valvetrain Friction Test Data

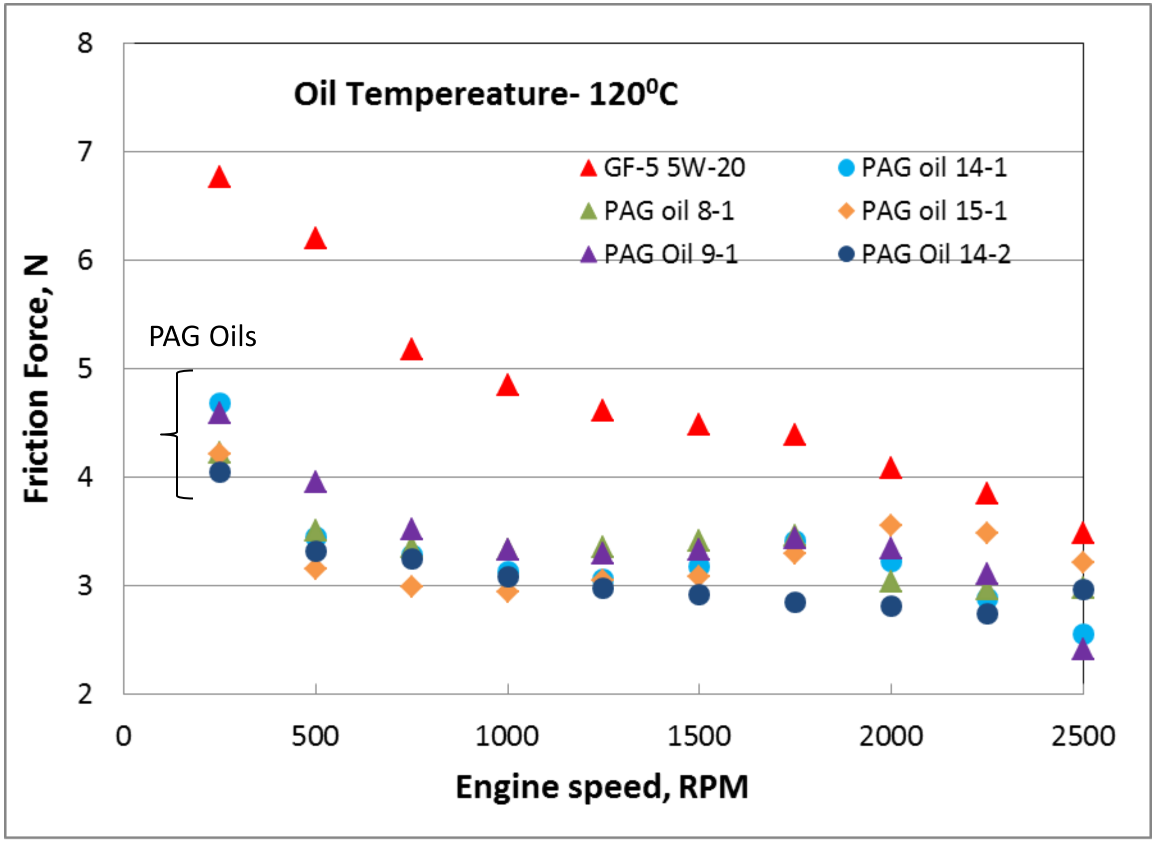




PAG formulations showed up to 48% lower valvetrain friction torque than GF-5 SAE 5W-20 oil

Technical Accomplishments and Progress

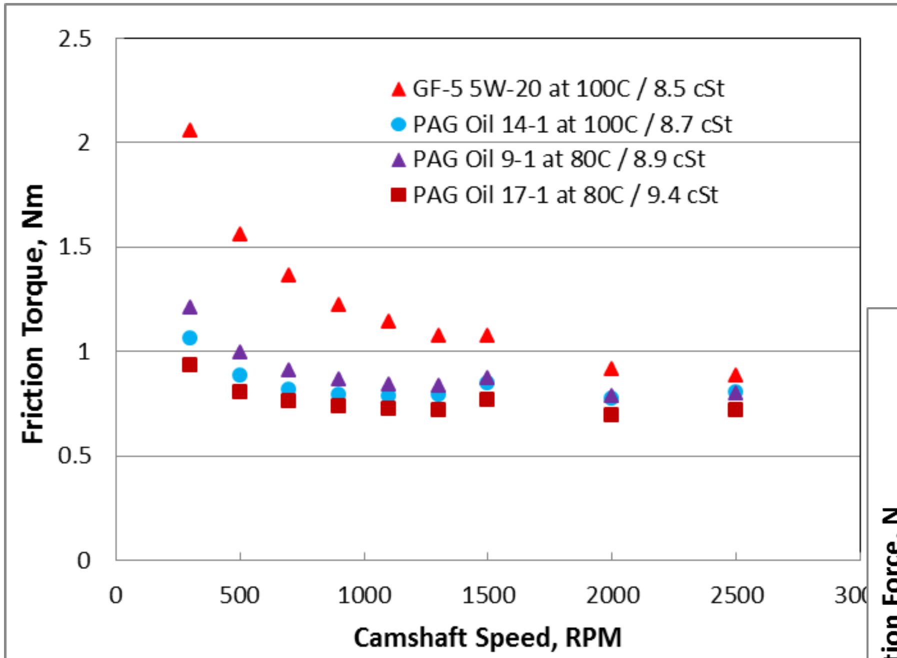
Motored Single Cylinder Piston Ring Friction Data



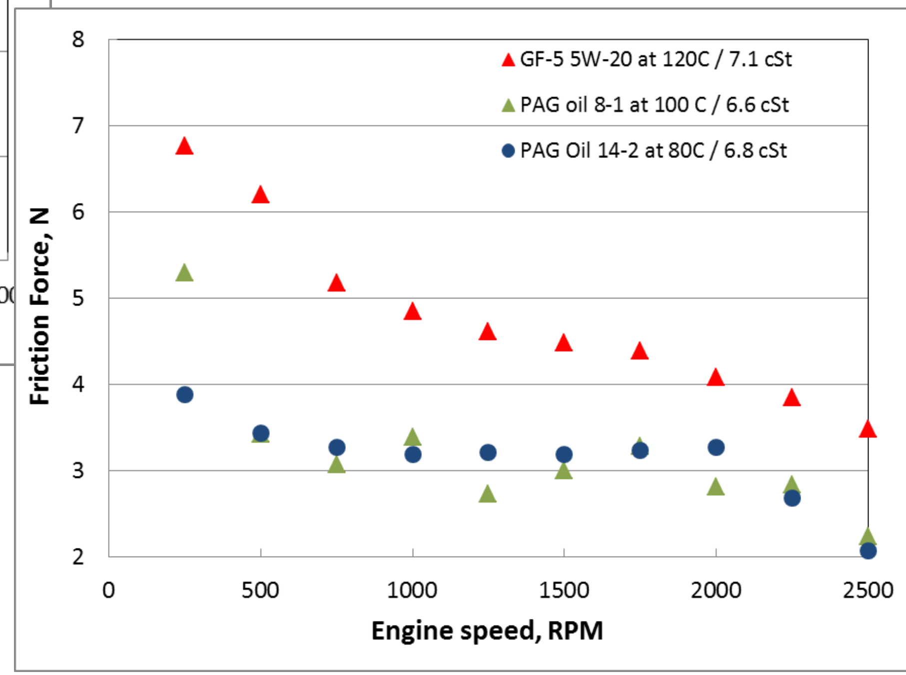
PAG formulations showed 8-49% lower piston ring friction than GF-5 SAE 5W-20 oil

Technical Accomplishments and Progress

Valvetrain Friction



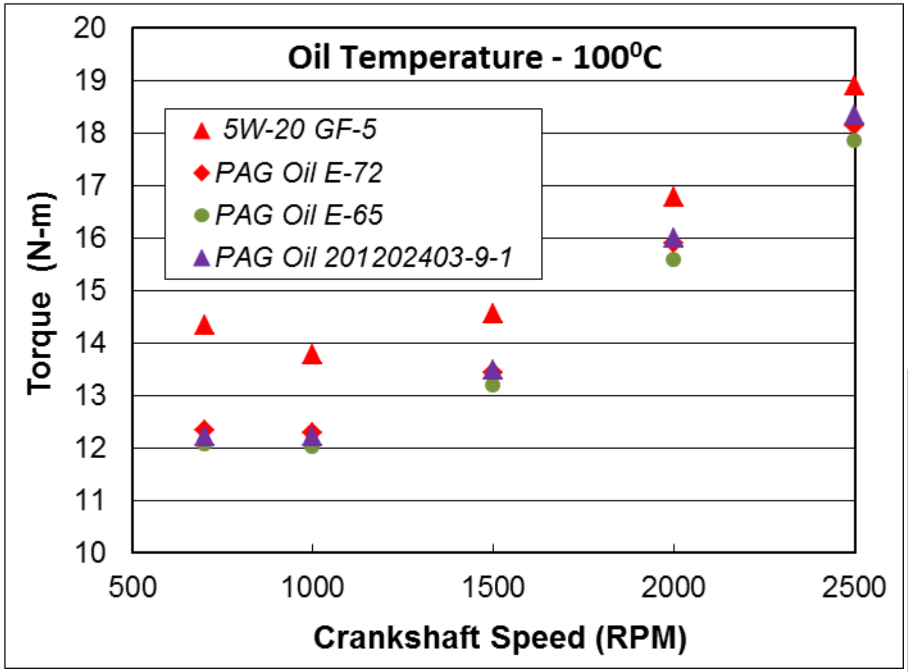
Piston Ring Friction



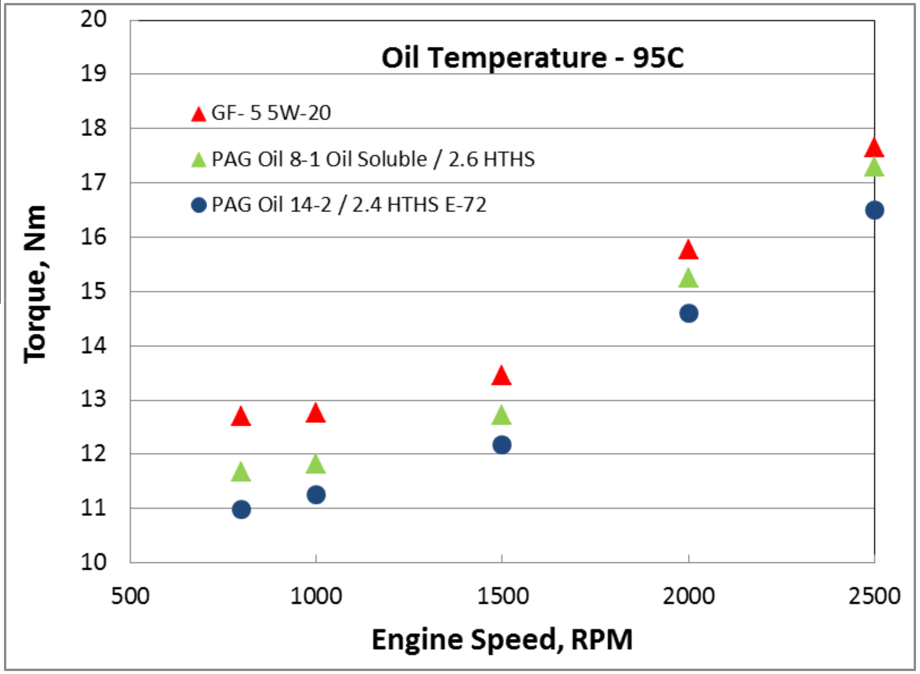
Lower friction of PAG formulations is not due to lower viscosity but chemistry of base oil (different from GF-5 SAE 5W-20 oil)

Technical Accomplishments and Progress

Motored Engine Friction Data



% Friction Reduction Over GF-5 Oil at 100C						
PAG Oils	700 RPM	800 RPM	1000 RPM	1500 RPM	2000 RPM	2500 RPM
14-2		**13.6**	**11.9**	9.5	7.5	6.5
E-65	**11**		**9.6**	6.8	5.4	4.4
E-72	8.9		7.5	5	3.4	2.7



PAG formulations showed 3-14 % friction reduction

Technical Accomplishments and Progress

Sequence VID Fuel Economy Data

Fluids	Vis @ 100C, cSt	HTHS, mPa.s	FEI-2	FEI (SUM)
E-65	5.3	2.4	1.8%	3.2%
E-72	5.9	2.85	1.4%	2.5%
1010 (Ref. Oil)			1.4%	2.7%
1010 (Ref. Oil)			1.2%	2.7%

Oils	Vis @ 100C, cSt	HTHS, mPas	GF-5 Limits	
			FEI 2	FEI SUM
XW-20	6.9 - < 9.3	2.6	1.2	2.6
XW-30	9.3 - < 12.5	2.9	0.9	1.9

PAG Oils E-72 and E-65 do not conform to SAE J300 classification, hence comparison to GF-5 oils is difficult

Collaboration and Coordination with Other Institutions

- **Dow Chemical – Subcontractor**
  - Responsible for
    - PAG oil formulations
    - Viscometric characterizations
    - ASTM Sequence tests (VID, IIIG, and IVA)
- **Argonne National Laboratory – Subcontractor**
  - Responsible for
    - Laboratory bench tests for friction and wear evaluation
      - Pin-on-disk tests
      - Block-on-ring tests
      - Reciprocating roller-on-disk tests
    - Understand friction reduction mechanism through analysis of wear surfaces using x-ray photoelectron spectroscopy, Raman spectroscopy etc.

Remaining Challenges and Barriers

- Demonstrate vehicle fuel economy benefits
- Assess wear protection and oil oxidation capabilities in engine dyno tests

Proposed Future Work

Remaining FY 14

- Identified PAG oils for chassis roll fuel economy tests
  - Identified a vehicle for the tests
  - Test will evaluate fresh oil and aged oil fuel economy
    - 500 miles (fresh)
    - 5000 miles (aged)
    - 10,000 miles (aged)
- Durability Tests
  - Sequence IIIG (for high temperature wear and oil oxidation)
  - Sequence IVA (for low temperature wear)
- Understanding friction reduction mechanism (continuation)
  - Through analysis of wear surfaces

Summary Slide

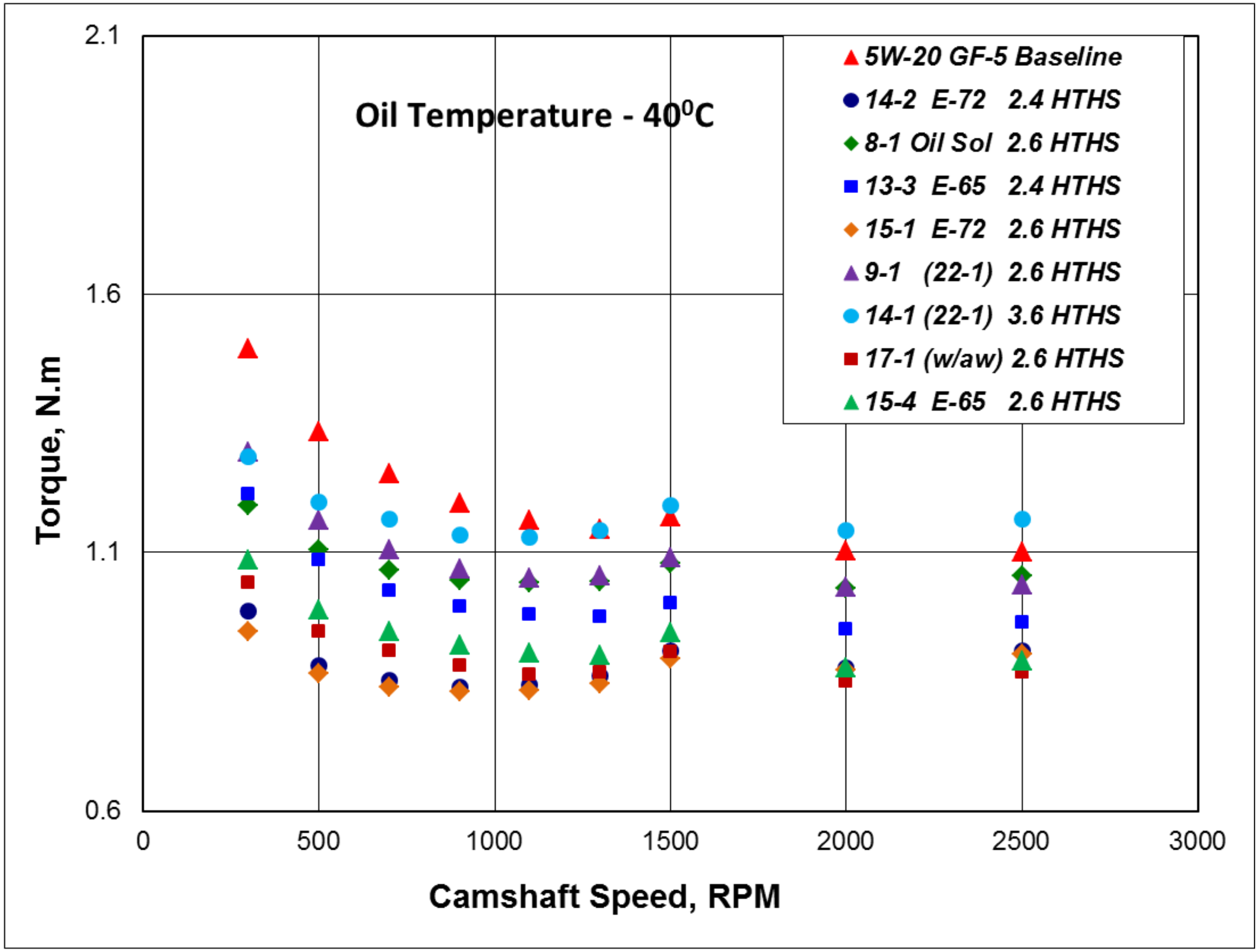
The benefits of PAG oils over GF-5 SAE 5W-20 oil

- Up to 48% friction reduction in motored valvetrain tests
- 8-49% friction reduction in motored single cylinder piston ring tests
- 3-14% friction reduction in motored engine tests
- Selected formulation (17-1) showed significant enhancement (32%) in load carrying capability

THANK YOU

Technical Accomplishments and Progress

Motored Valvetrain Friction Test Data



Oils	Vis. at 40C, cSt
5W-20	47
8-1	33.2
14-2	
13-3	20
15-1	20.2
9-1	28.2
14-1	46.6
15-4	25.1

All PAG formulations showed up to 37% lower valvetrain friction torque than GF-5 SAE 5W-20 oil