

2016 DOE Vehicle Technologies Office Review

Integrated Friction Reduction Technology to Improve Fuel Economy without Sacrificing Durability

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Project ID: **FT033**

Overview

Timeline

- Project start date: 10/1/2014
- Project end date: 9/30/2017
- Percent complete: 50%

Budget

- Total project funding
 - DOE \$1M
 - Cost share \$1M
- Funding received in FY 2015
 $\$334\text{K} + \$340 = \$674\text{K}$
- Funding for FY 2016
 $\$334\text{K} + \$417 = \$751\text{K}$

Barriers

- Inadequate data on lubricant fuel economy potential
- Lack of additive components and stable low viscosity base oils
- Lack of GF-6 engine test procedure
- High cost of engine tests

Partners

- GWU (lead)
- Valvoline
- GMC
- R. T. Vanderbilt
- Afton

Component suppliers

- Chemtura
- BASF
- Croda
- Cytec
- Evonik
- Hatco
- Emery & others

Relevance and Objectives

Project objective

- Develop 0W-20 GF-6A formulation to demonstrate 2% fuel economy improvement for legacy vehicles
- Develop 0W-16 GF-6B formulation to further improve fuel economy for new (future) model vehicles
- Demonstrate the use of these fuel economy oils will not reduce engine durability

2015 objective: 0W-20 GF-6A lubricant demonstration

Relevance

- Fuel economy improvement of 2% or higher for both legacy vehicles and future models will reduce oil dependence and cut carbon emissions
- 1.3B vehicles in the world today and 250M light duty cars in the US
- 2% increase in fuel economy will cut 20M tons of CO₂/yr

Milestones

- FY 2015
 - Develop 0W-20 formulations ✓
 - Engine test 0W-20 oil for fuel economy ✓
 - Develop microcapsulated additives (go/no-go) ✓
- FY 2016
 - Develop 0W-16 formulations ✓
 - Engine test 0W-16 oil for fuel economy (go/no-go) scheduled in August 2016 on track
 - Prepare textured engine parts for 3rd testing ongoing on track

Approach/Strategy

- Approach various additive component suppliers to establish partnerships to obtain new and existing additive components
- Set up test equipment or leverage industrial partners to conduct tests on our formulation
- Develop test methods and equipment when needed
- Develop formulations in consultations to additive suppliers/additive formulation experts
- Develop microencapsulated additives for enhanced friction modifiers performance and antiwear booster
- Develop surface materials technologies such as textures, DLC thin films, and novel bonded films for wear protection
- Establish liaison with other projects in the VT program and offer to test their samples

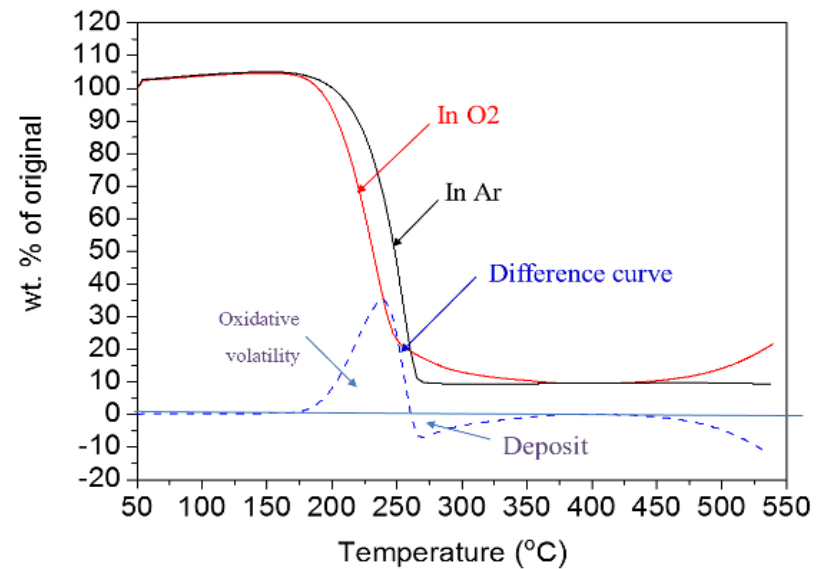
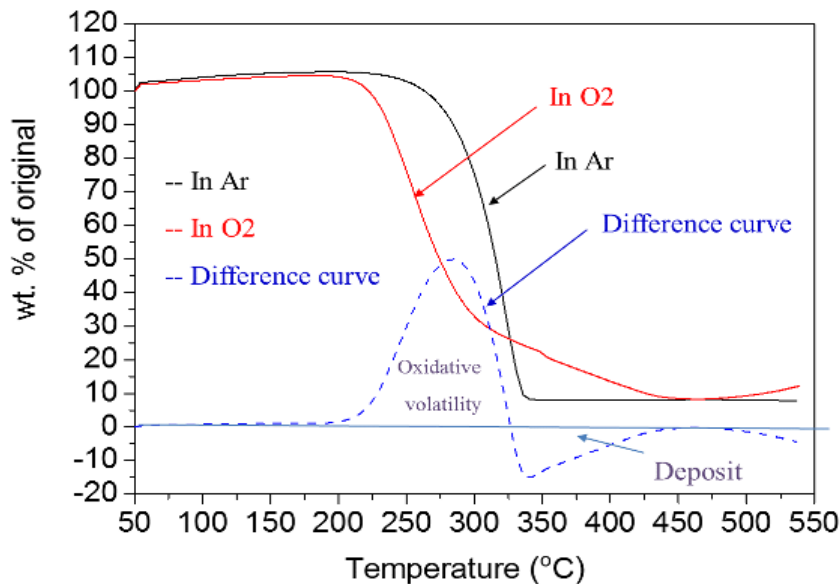
Technical Accomplishments

- Obtained over 120 individual additive components and base oils samples from companies in three continents
- Acquired testing capability in Mini Traction Machine (MTM), High Frequency Reciprocating Rig (HFRR) and High temperature high shear (HTHS) from partners
- Set up ball-on-3 flats, Falex, Plint tests at GWU
- Set up oil blending, oil thickening tests
- Formulated 0W-20 and 0W-16 oils for testing and screened over 40 base oils and additive components
- Develop formulations for screening friction modifiers and antiwear additives and alternative friction and wear approaches

Resolved the lack of additive components to formulate

Base oil selection

- Low viscosity lubricants requires proper oxidative stable base oils and Viscosity Index
- We used a novel Thermogravimetric TGA test in Argon and oxygen to screen base oils

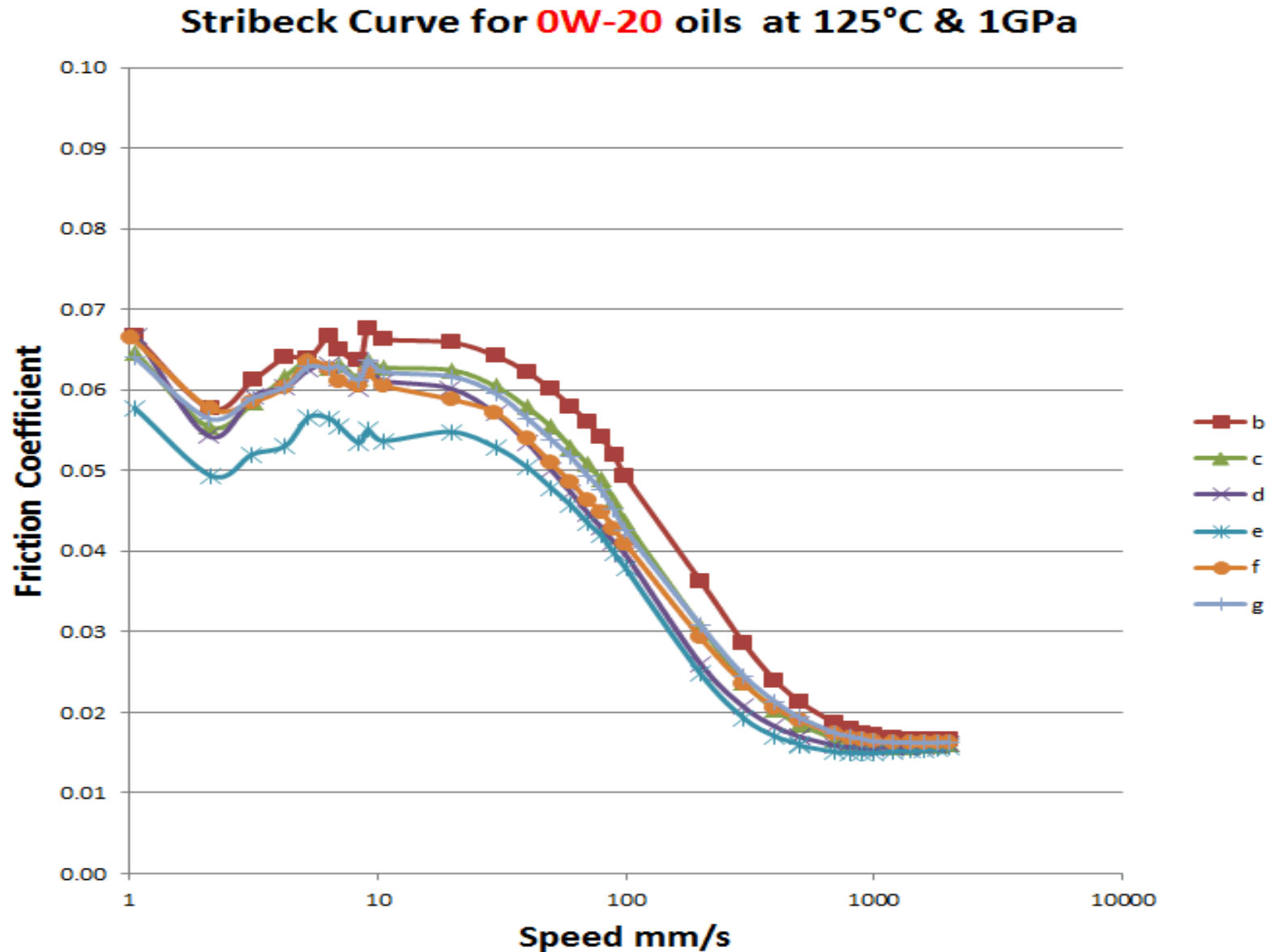


Foundation of a good fuel efficient lubricant

Additive testing in a standard formulation

- **Viscosity modifiers:** olefin copolymer VII, OCP VII, polymethacrylate VII, star molecules, high MW base oils
- **Friction modifiers:** organic and inorganic friction modifiers, various combinations of them
- **Antiwear additives:** Zinc dithiodiphosphate, supplemental antiwear additives, P-free antiwear additives, etc.

Friction modifiers testing



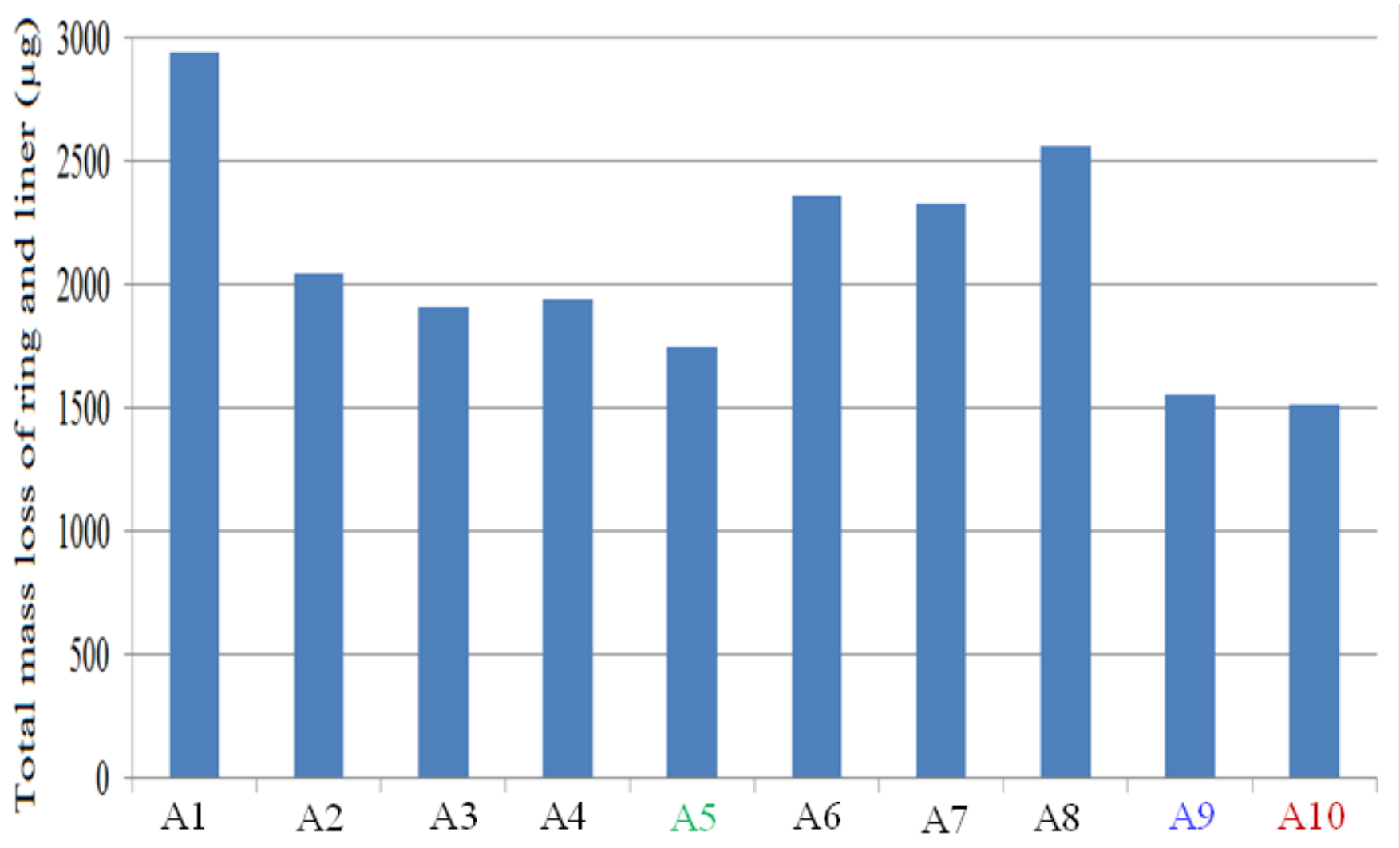
Friction test data in HFRR at higher temperatures

Table 2 HFRR Friction data

Coefficients of Friction, 4N, 20Hz, 1mm on steel

Lube Code	70°C	100°C	130°C
Oil 1	0.122	0.122	0.111
Oil 2	0.114	0.099	0.088
Oil 3	0.123	0.106	0.089
Oil 4	0.115	0.102	0.094
Oil 5	0.124	0.123	0.109
Oil 6	0.114	0.104	0.096

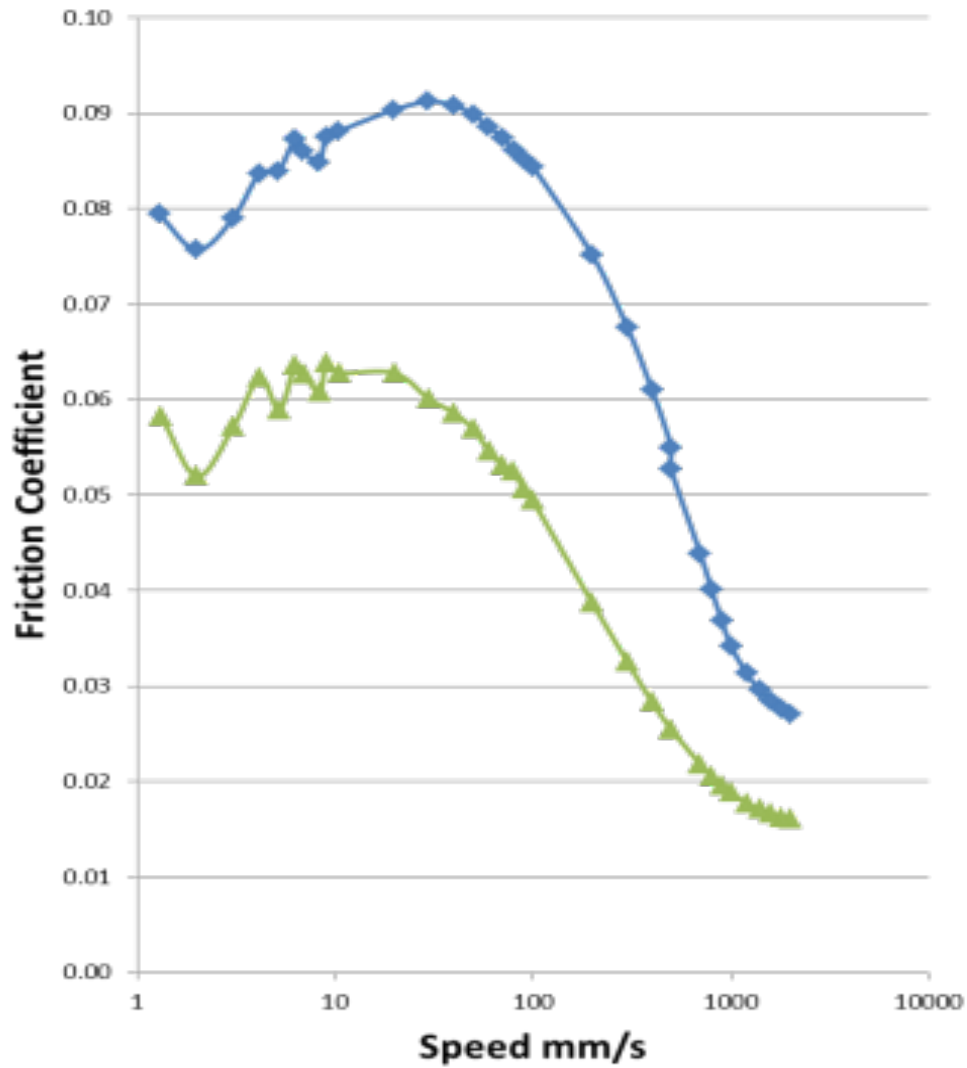
Antiwear chemistry screening (organic + Inorganic) using Plint tester ring on liner (production parts)



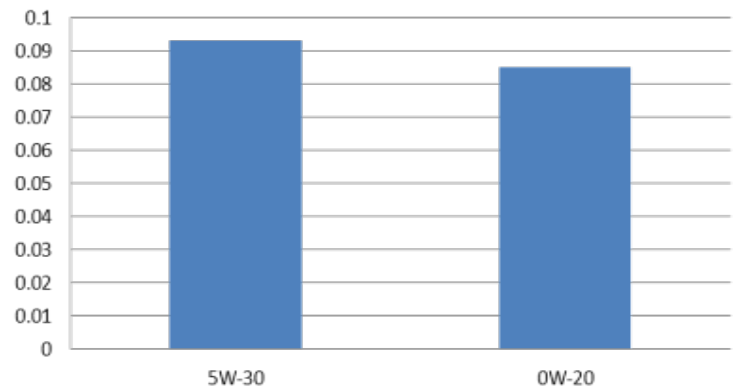
Final formulated 0W-20 candidate to be compared to 2014 GF-5 5W-30 commercial oil

	Baseline	New formulation
	5W-30	0W-20
KV100C	10.67	8.675
KV40C	62.02	36.038
CCS(cP)	6013(-30C)	2336(-35C)
MRV(cP)	32723(-35C)	6546(-40C)
HTHS 150C	3.13	2.64
Pour Point (C)	-42	-60
NOACK(%)	14	11.5
PDSC(minutes)	40.68	45.13

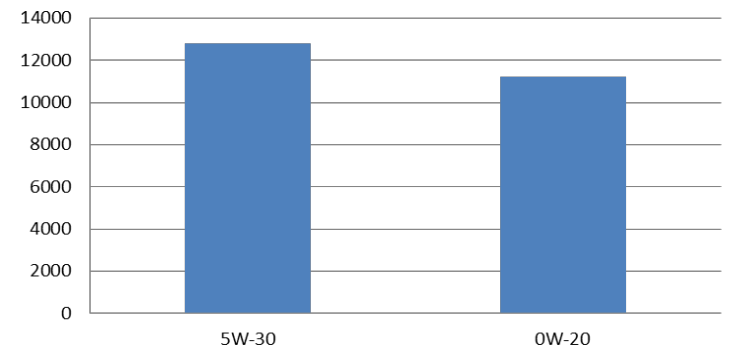
Stribeck Curve at 125C & 1GPa



HFRR friction



HFRR Wear (μm^2)



ASTM Engine Seq. VIE tests for GF-6A oils

The Seq. VIE test procedure is based on issued test protocol on July 14, 2014 (non-official GF-6 specification test yet, it will be official when test statistics are completed)

For this reason, same engine same test stand back to back testing was used to ensure test precision

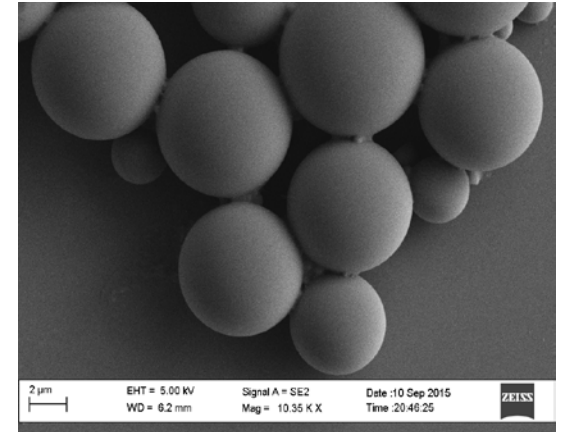
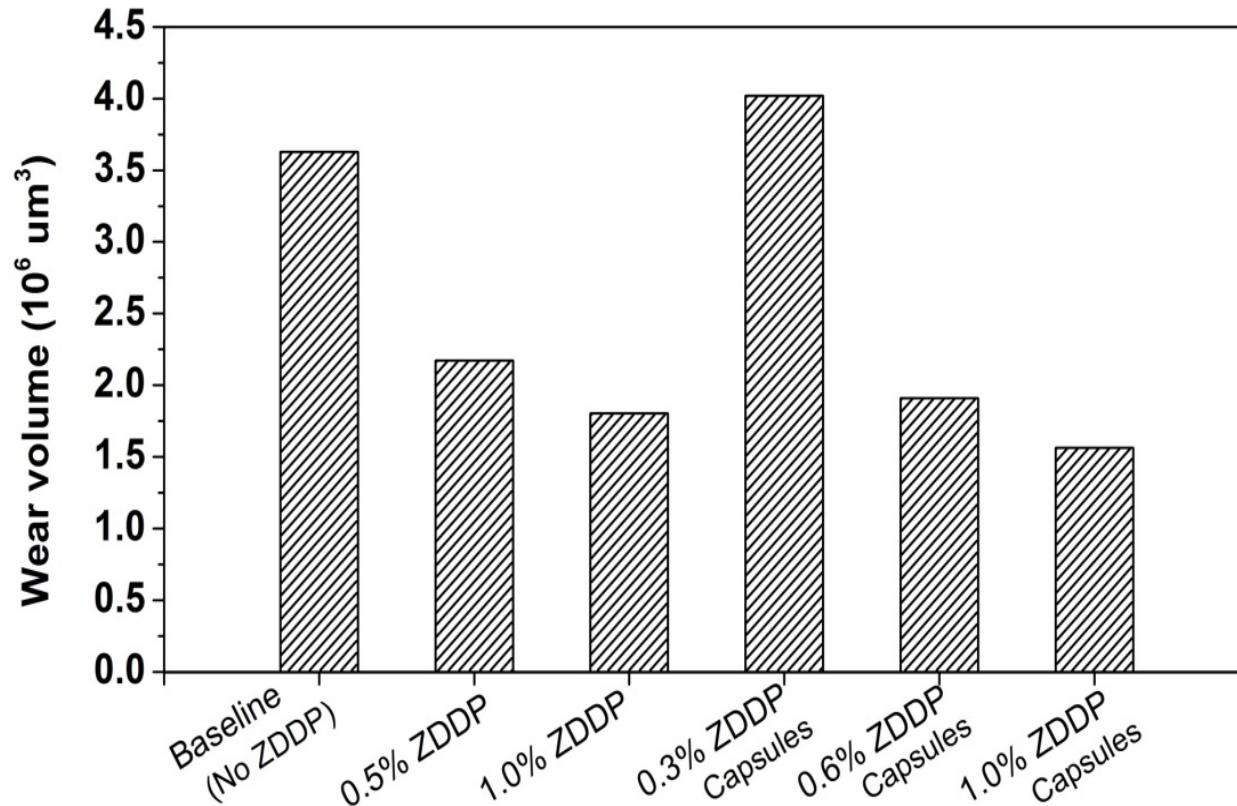
ASTM Engine Seq. VIE test results

	New Candidate	New Candidate repeat	2014 commercial baseline oil	2014 commercial baseline oil repeat	Improvement for Candidate (0W-20) Over Benchmark (5W-30)
EOT Date:	8/28/2015	10/28/2015	9/18/2015	10/13/2015	
Test stand	Number 6	Number 6	Number 6	Number 6	
Engine number	34	34	34	34	
Oil Vis- grade	0W-20	0W-20	5W-30	5W-30	
FEI-1 (new broken- in)	1.84%	2.13%	1.19 %	1.01%	0.89 %
FEI-2 (aged)	2.37%	2.28%	0.72 %	0.92%	1.51 %
FEI- SUM	4.21%	4.41%	1.91 %	1.93%	2.39 %

Achieved the project goal for the first year

Microencapsulated additives

Tested in a four ball wear test, 40Kg, 600rpm, 60min, RT

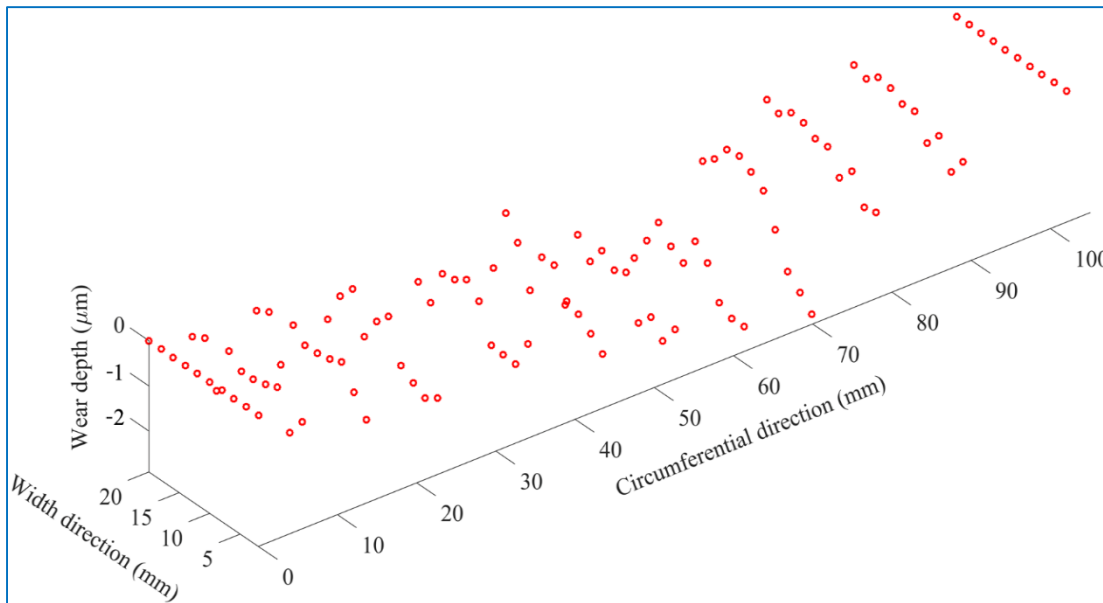


ZDDP capsules

Capsules work!

Surface texture preparation

- Identified the preliminary engine to be textured and tested
- Measure worn engine parts to identify wear spots and wear mechanisms



Responses to Previous Year Reviewers' Comments

This is a new start

Collaboration and Coordination

- Work closely with GMC on engine selection, worn part analysis, and identify potential wear mechanisms
- Work closely with Valvoline on formulation development and additive screening
- Work closely with RT Vanderbilt and Afton to obtain additive samples and research samples
- Work with base oil suppliers to obtain more than 12 base oil samples for blending study and stability testing
- Discussed with ORNL lab and ANL lab on lubrication mechanisms
- Work with many additive companies and obtain many research samples for testing

Remaining Challenges and Barriers

- 0W-16 or lower viscosity oils will have much higher oxidative stability challenges and will be more difficult to maintain sufficient film thickness to prevent wear
- The extent of surface texturing, protective thin films to protect wear of engine components will need to be tested in engine under appropriate operating conditions
- The use of microcapsulated additive has no precedent and testing them to prove effectiveness will take extensive effort to develop test methodology and characterization tools.
- These challenges will be addressed in the remainder of the project duration

Proposed Future Work

- **FY 2015**
 - Finalize 0W-16 formulation
 - Conduct Seq. VI “F” tests to verify fuel economy improvement
 - Fabricate surface textures on engine components for engine testing in FY 2016 as scheduled
 - Develop methods on how to use encapsulated additive in an engine environment
- **FY 2016**
 - Conduct durability engine testing of 0W-16 oils
 - Evaluate the effect of surface textures on wear control
 - Evaluate the viability of microcapsulated friction modifiers to prolong the friction reduction through oil change intervals

Summary

- A 0W-20 GF-6A formulation has been developed
- The oil was evaluated in back to back same test stand Seq. VIE engine dynamometer tests and achieved a 2.4% fuel economy improvement over the 5W-30 2014 GF-5 commercial lubricant
- This oil is backward compatible and can be used for the legacy vehicles in the US, saving imported oil and cutting carbon emission
- A 0W-16 oil has been formulated and undergoing testing and will be tested in Seq. VIF in August, 2016
- Textured engine components are being fabricated to be used in FY2017 durability tests
- Encapsulated additives are developed and will be tested this year for retention of friction reduction

