BASF
We create chemistry

IRGALUBE® FE1

Gain the Power to Save on Fuel

IRGALUBE® FE1
Opening Comments

BASF
We create chemistry

- Fuel economy, horsepower, and acceleration are all important aspects of passenger cars intended to maximize the consumer's driving experience
- OEMs spend significant money on R&D to improve these 'aspects' because consumers will consider them heavily as they consider their new vehicles
- The frictional forces inside the engine are a major issue for OEMs, because friction can negatively impact the overall fuel economy, horsepower, and acceleration aspects of a engine
- Engine oil formulators traditionally use conventional organic friction modifiers which work on internal metal surfaces to reduce frictional forces
- BASF's IRGALUBE® FE1 does not perform like a conventional organic friction modifier and works with the ZDDP in engine oils to gain power and save fuel

IRGALUBE® FE1
Opening Comments

BASF
We create chemistry

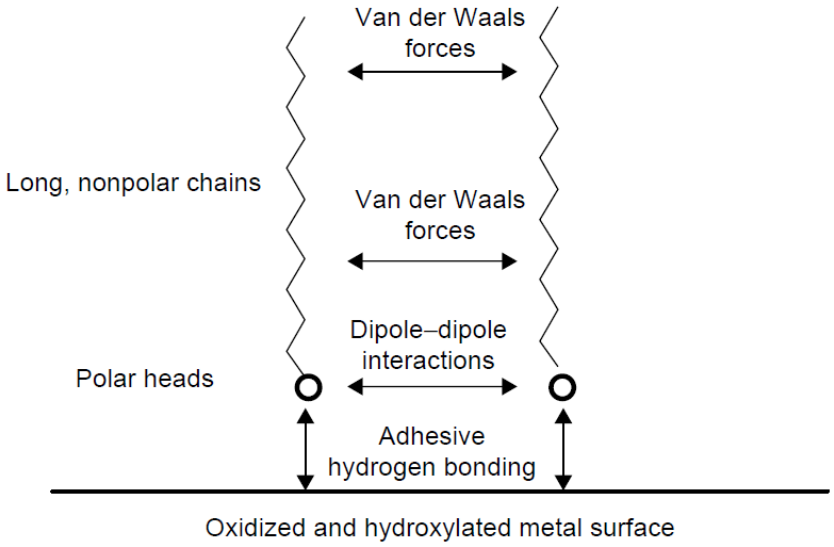
- BASF maintains one of the most extensive vehicle test capabilities of any major lubricant additive supplier in the industry.
- BASF leveraged our Fuel-to-Lubricant knowledge synergy to develop and to prove the performance of IRGALUBE® FE1 in engine oil formulations.
- Our vehicle tests demonstrate that IRGALUBE® FE1 improves fuel economy in a range of vehicles types. We also performed extensive engine tests to show that IRGALUBE® FE1 interacts with ZDDP
- Integrating IRGALUBE® FE1 into the engine oil formulation will help to maximizes the fuel economy benefit of engine oils, and increases vehicle's horsepower and acceleration – tested in actual vehicles, with proven No-Harms performance in fleet trials and extensive bench tests as well.

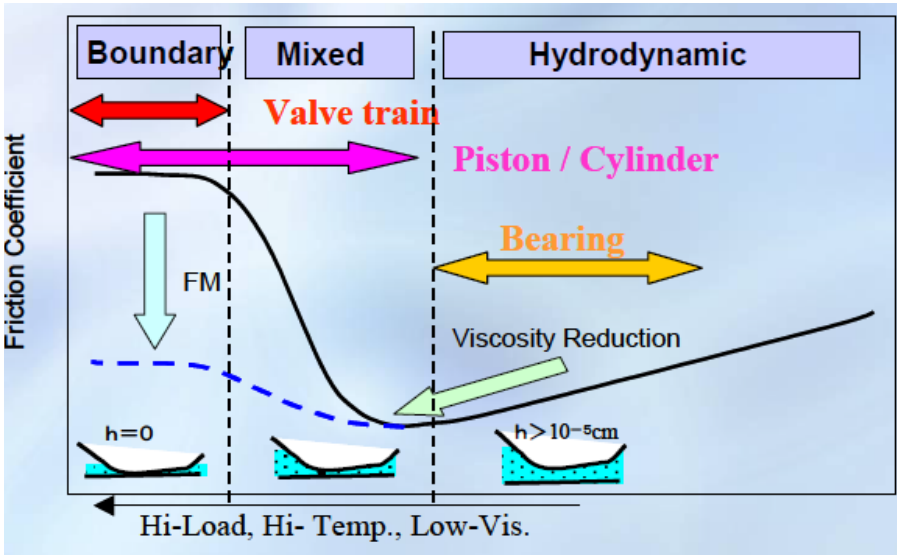
IRGALUBE® FE1
Presentation Overview

IRGALUBE® FE1:

- An ashless, organic engine oil additive that interacts with ZDDP to improve fuel economy, horsepower and acceleration
- A liquid product (100% active) that provides supply chain flexibility and manufacturing ease
- Provides fuel economy improvement that is more than twice as effective as Glycerol Mono Oleate (GMO), even at half the treat rates
- Provides horsepower and acceleration benefits that are appreciated by high performance and racing engine oils
- Provides 0W-20 fuel economy performance from a 5W-30 engine oil

Mechanism of Conventional Organic Friction Modifiers





[1]Kenbeck, D. and Buneman, T.F., "Organic Friction Modifiers," *Lubricant Additives: Chemistry and Applications*, CRC Press, Boca Raton, (2009) Second Edition, Edited by L. Rudnick.

[2]Yamashita, M. (Toyota Motor Corporation), "Automotive Technology Trends and Lubricants Trends," ICIS, The 6th Asian Base Oils and Lubricants Conference, Singapore, June 2012.

Organic FM chemistry binds to metal and works in Boundary regime

Possible Interactions Between Fuel Economy Improver and ZDDP

- Research suggests that ZDDP coats the metal surface to form a phosphate glass with antiwear benefits[1]
  - The phosphate glass film in MTM experiments was measured as 100nm thick → questioned if such a thick film on metal walls inside an engine could decrease fuel economy
- Research also indicates that Fuel Economy Improvers in engine oils should interact with the glass phosphate antiwear film[2]
  - Fuel Economy Improver mechanism is not a simple adsorption onto metal
  - Some level of temperature, pressure and shear could be required to drive the necessary interaction between a Fuel Economy Improver and ZDDP

[1]Fujita, H., Glovnea, R.P., and Spikes, H.A., "Study of Zinc Dialkyldithiophosphate Antiwear Film Formation and Removal Processes, Part I: Experimental" Tribology Transactions, 48, 4, 2005, 558-566.

[2]Miklozic, K.T., Forbus, T.R., and Spikes, H.A., "Performance of Friction Modifiers on ZDDP-Generated Surfaces," Tribology Transactions, 50, 2007, 328-335.

→ Additive interactions have been evaluated in fired engine tests

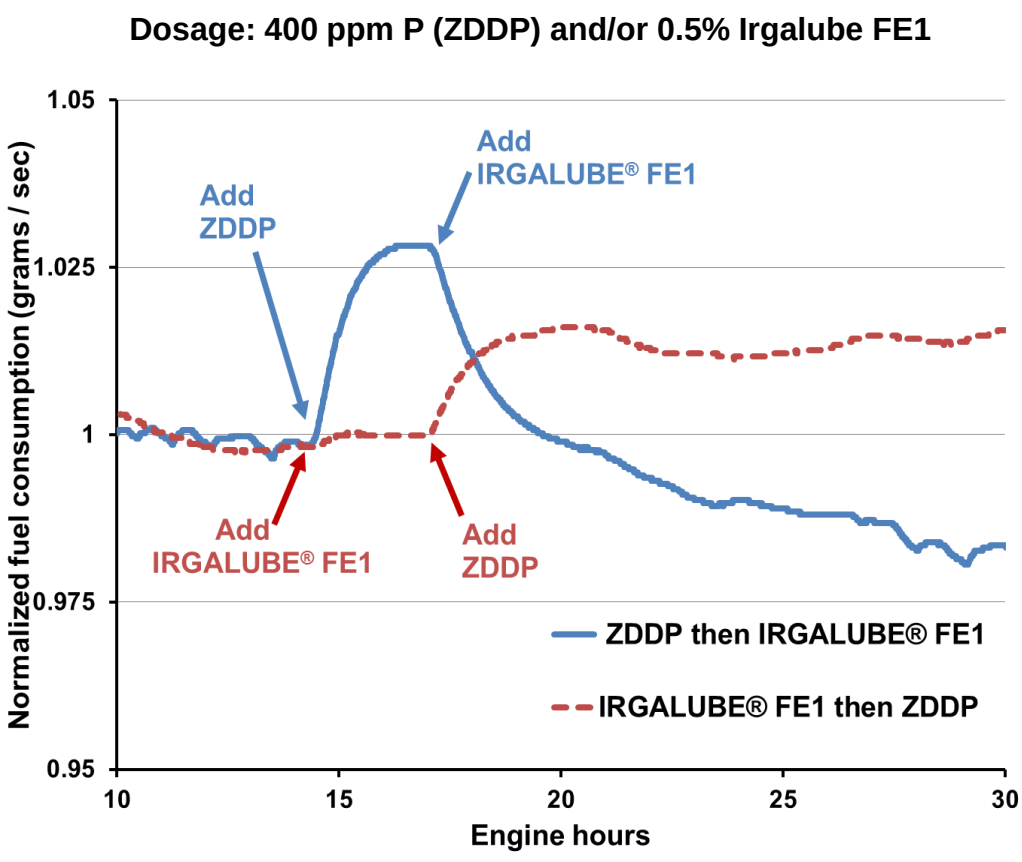
Phase I: Engine Screening Test for Additive Effects in Engine Oil

- Utilized a Chevrolet 5.7L engine (350 cubic inch) rated at 290 HP (216kW)
  - An inexpensive, readily available engine and easy to set up on a dynamometer
- Can be adapted to test additive effects on fuel consumption via injection into the crankcase → same approach used in vehicle testing
- The objective of this study was to evaluate the effects of ZDDP and its interaction with IRGALUBE® FE1 on fuel consumption in fired engines
  - Oil used in the study was a special formulation containing only antioxidants → it is possible to run the engine for a period of time without antiwear additives in the engine oil including ZDDP
  - Significant flushing with high detergent charges between runs to ensure cleanliness of metal surfaces

IRGALUBE® FE1
Additive Effects on Fuel Consumption

BASF
We create chemistry

- Performed additive order of addition studies with the Chevy 5.7L (290 HP) engine on stand
- Test conditions equivalent to highway load and speed (2500 rpm, 25 Nm, oil 120 °C)
- Initial formulation: 5W-20 base oil + antioxidants, no other additives
- IRGALUBE® FE1 or ZDDP independently injected into the rocker cover to test effect on fuel consumption
- Even a small amount of ZDDP (400 ppm P) hurts fuel consumption up to 3%; IRGALUBE FE1 interacts with ZDDP to regain performance and more



IRGALUBE® FE1 is synergistic with ZDDP in engine oil

Phase II: Fuel Economy Test using Fired Engine Vehicles

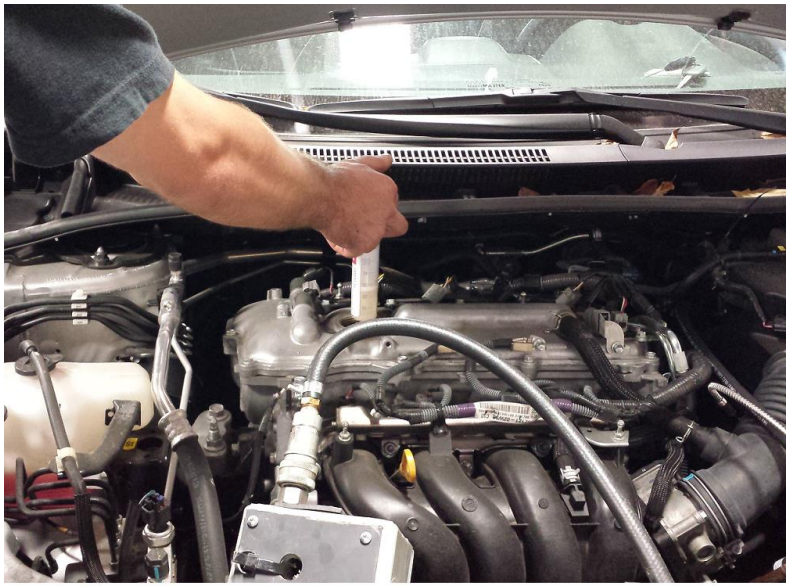
- Experience has shown a high percentage of vehicles respond to Fuel Economy Additives, although at different levels
  - Additive effectiveness was evaluated in multiple vehicles & then averaged
- The fleet of vehicles used to evaluate IRGALUBE® FE1 against GMO:

2012 Buick Regal	2.0L GDI
2004 Mazda 3	2.0L
2012 Honda Civic	1.8L
2012 Ford Explorer	2.0L Eco-Boost

BASF could test any combination of vehicles based upon interest

BASF Fuel Economy Test: Additive Addition with Fired Engine Vehicles

- First half of the experiment was completed with 5W-20 reference fluid
- Pre-measured additive samples that were sized for vehicle / oil charge
- Injected into engine oil fill point while vehicle is operating (hot!)
- Vehicle was not shut off
- Second half of experiment was duplicate of first half

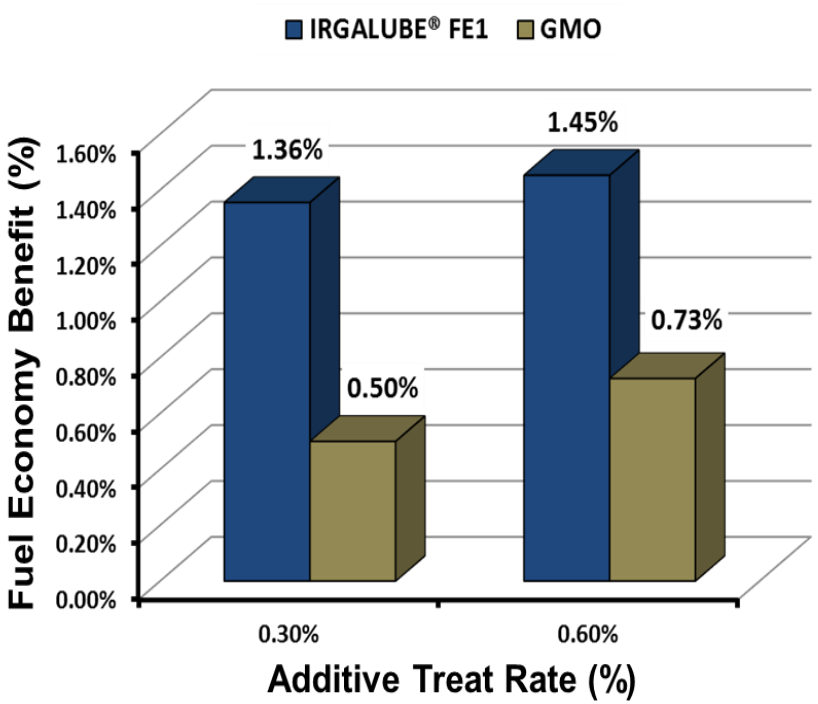


IRGALUBE® FE1
Vehicle Testing FE1 vs GMO

BASF
We create chemistry

- Summary of fuel economy benefit with an unadditized 5W-20 reference engine oil
- Results averaged over the 4 vehicles

	IRGALUBE® FE1		GMO	
Concentration	0.3%	0.6%	0.3%	0.6%
Buick Regal 2.0L GDI	1.17%	1.00%	0.11%	0.66%
Mazda 3 2.0L	1.30%	1.96%	1.53%	1.19%
Honda Civic 1.8L	1.68%	1.62%	0.07%	0.07%
2012 Ford Explorer 2.0L Ecoboost	1.27%	1.23%	0.30%	0.98%
Fuel Economy Averaged All Vehicles	1.36%	1.45%	0.50%	0.73%

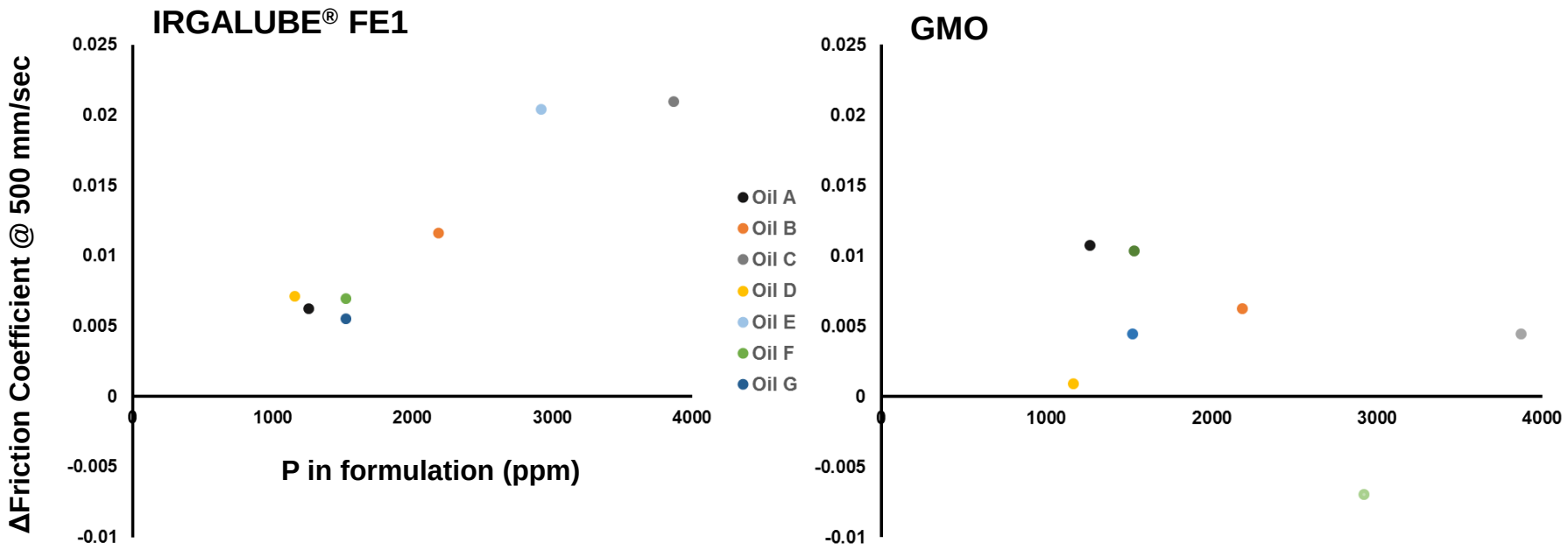


IRGALUBE® FE1: Twice the benefit at half the treat rate

Phase III: IRGALUBE® FE1
Not a Conventional Organic Friction Modifier

We create chemistry

- Tested coefficient of friction for several commercially available racing engine oils using MTM
- Compared change in oils with and without IRGALUBE FE1 or GMO at 500 mm/sec
- Test conditions: 125°C, 50% slide roll ratio, 50N load, equilibrated 4 hours before testing

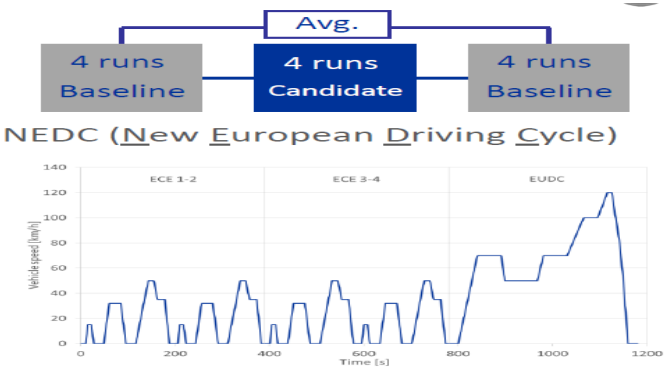


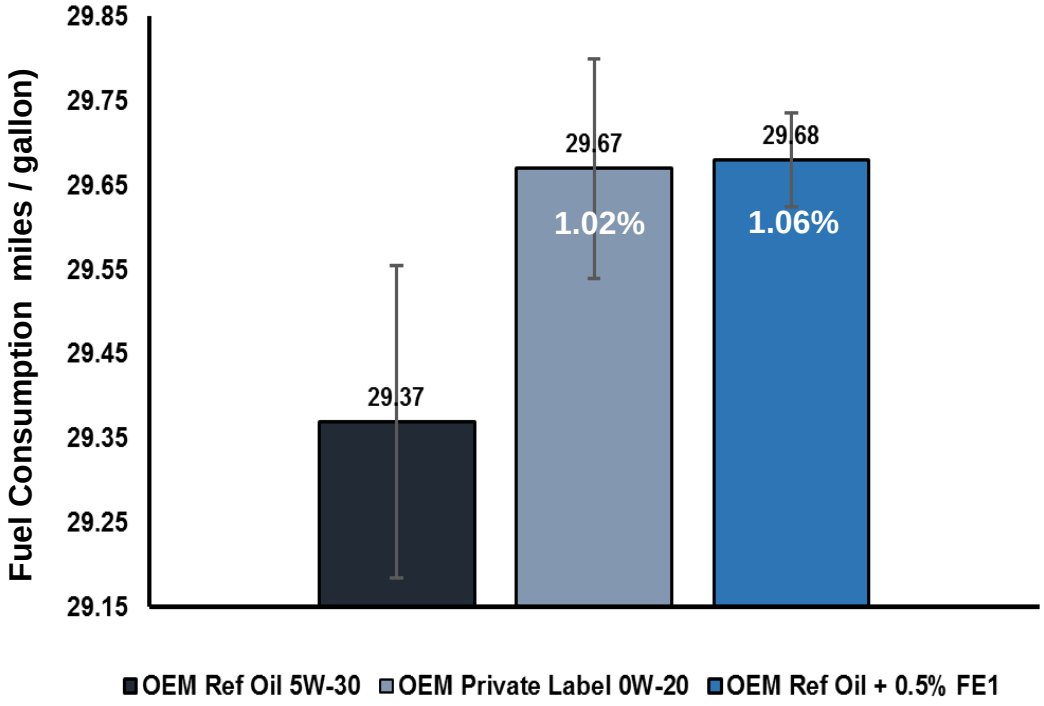
IRGALUBE® FE1 works with ZDDP to become a Fuel Economy Improver

Phase IV: IRGALUBE® FE1 OEM Fuel Economy Study

BASF
We create chemistry

- Test Engine: 1.4L Turbo with MPFI
- Testing FE effect of 0.5% IRGALUBE™ FE1 in OEM reference oil (5W-30)
- Also compared to a commercially available 0W-20 with unknown FM system
- **Summary: 0.5% IRGALUBE™ FE1 in 5W-30 reference oil gave same FE response as commercial 0W-20 oil + unknown FM system**





Percentage change in FE performance compared to OEM 5W-30 reference oil tested in same vehicle

IRGALUBE® FE1 unlocked 0W-20 FE performance in a 5W-30 oil

IRGALUBE® FE1
Presentation Summary

BASF
We create chemistry

IRGALUBE® FE1

- An ashless, organic engine oil additive that interacts with ZDDP to improve fuel economy, horsepower and acceleration
- Provides fuel economy improvements that are more than twice as effective as Glycerol Mono Oleate (GMO), even at half the treat rates
- BASF has extensive No-Harms test results, including vehicle field trials and data from GF-5 bench tests that are available for review
- Additional testing demonstrated improved horsepower and increase acceleration in vehicle tests
- Provides 0W-20 fuel economy performance from a 5W-30 engine oil
- Adding IRGALUBE® FE1 will help to maximizes the fuel economy benefit of engine oils and increases vehicle horsepower and acceleration.

We create chemistry