# Efficiency Does Not Care What You Call The Fluid : Common Properties of Lubricants That Affect Efficiency

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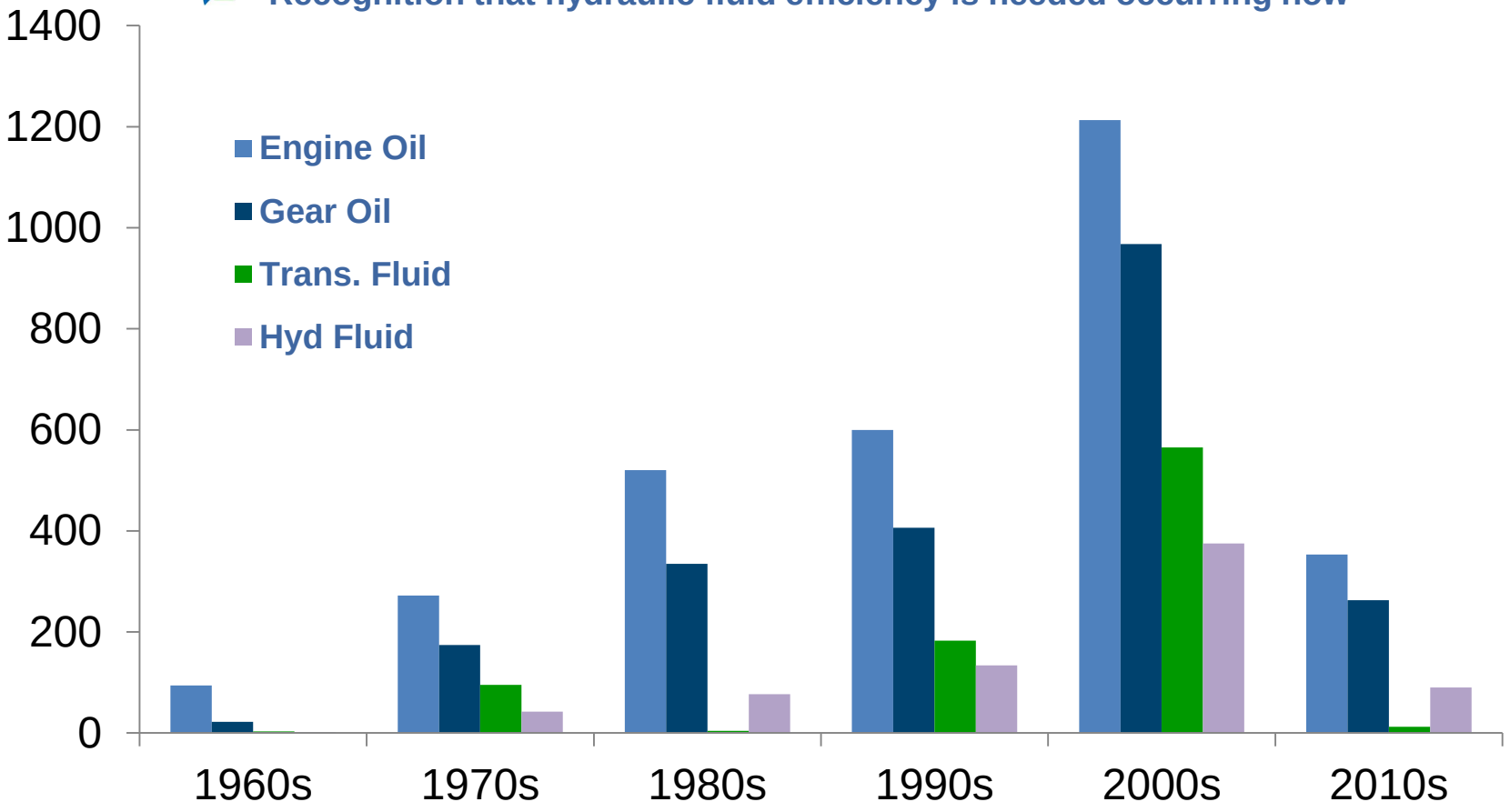
# SAE Papers Related to Fuel Economy and Lubricants

- Engine oil work started fast and furious (still going)
- Gear oil work is a fast-closing second
- Transmission fluid work lags behind but is catching up
- Recognition that hydraulic fluid efficiency is needed occurring now

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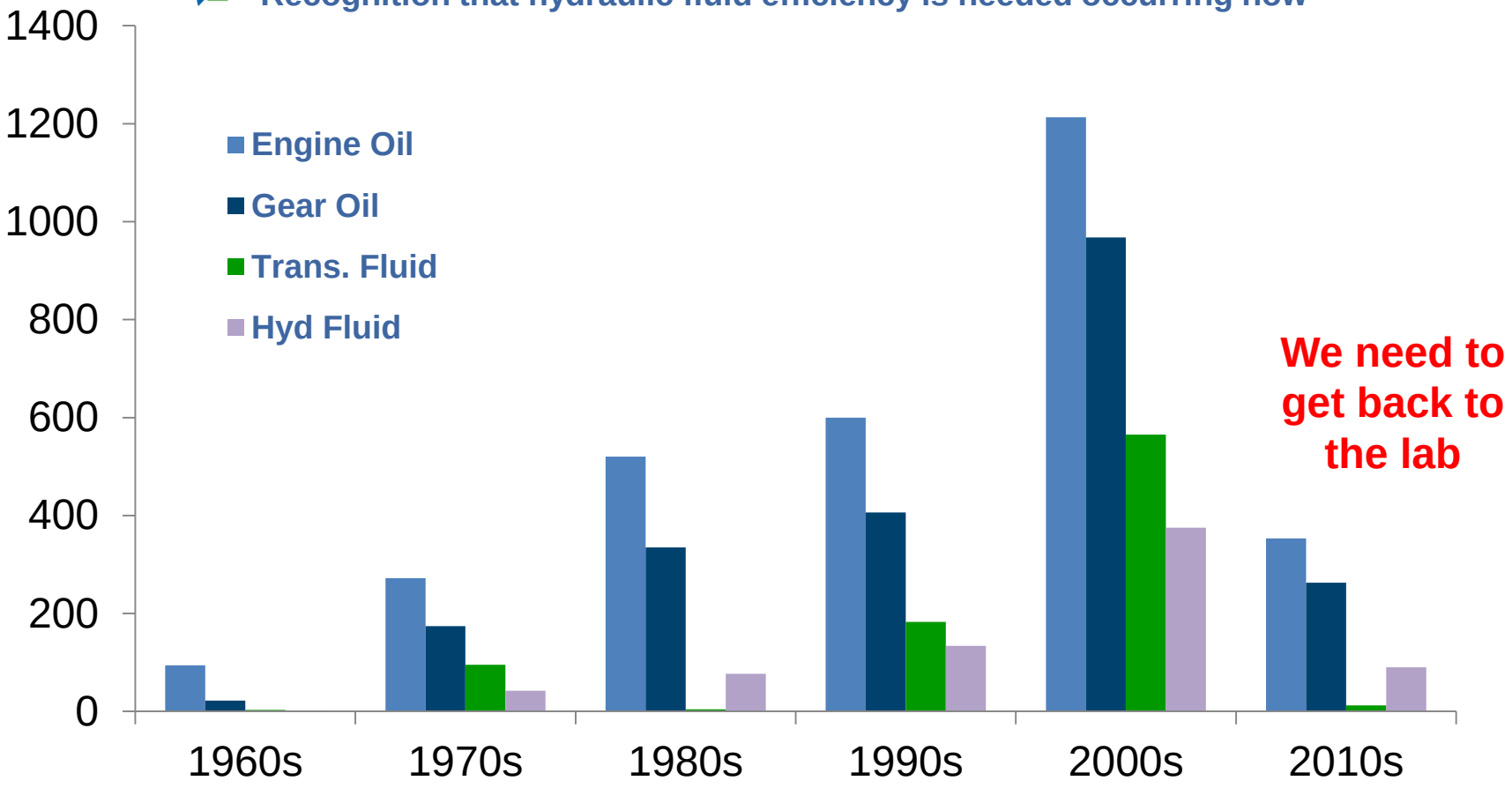


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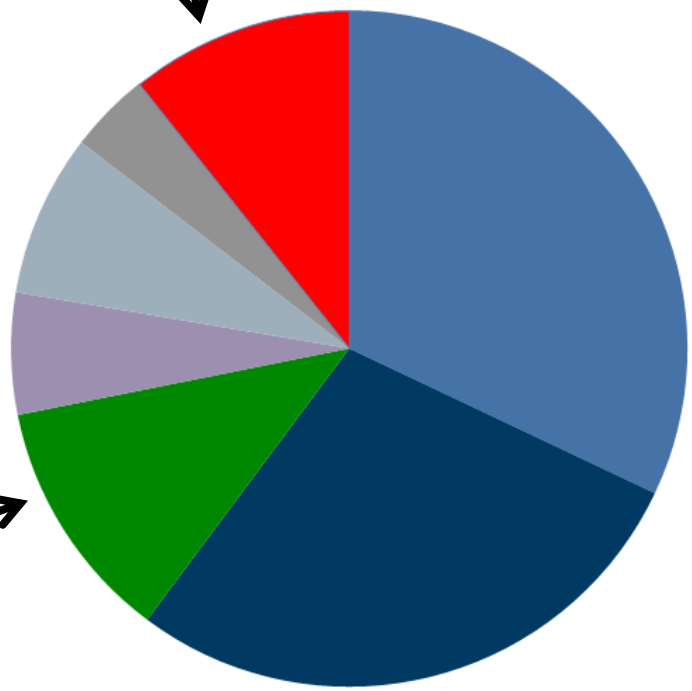
# Putting Lubricant Fuel Economy Benefits in Perspective

**We concentrate on Frictional Energy Losses**




**Potential Signal is Low**
**(~10% of Energy Lost as Friction)**
**Potential Noise is High**
**(Rest of Pie)**

**We measure useful work**

**Tribology International 37 (2004) pp 517-536**

# Fuel Efficiency Determination Must Be a Multi-Platform Investigation

1. Bench Friction Tests
2. Motored Engines / Rigs
3. Systems (Fired Engines)
4. Vehicle Tests

# Fuel Efficiency Research Tools - Comparison

- **Each test has benefits and inherent limitations**
  - There is no perfect fuel economy test
  - A combination of tests is preferred

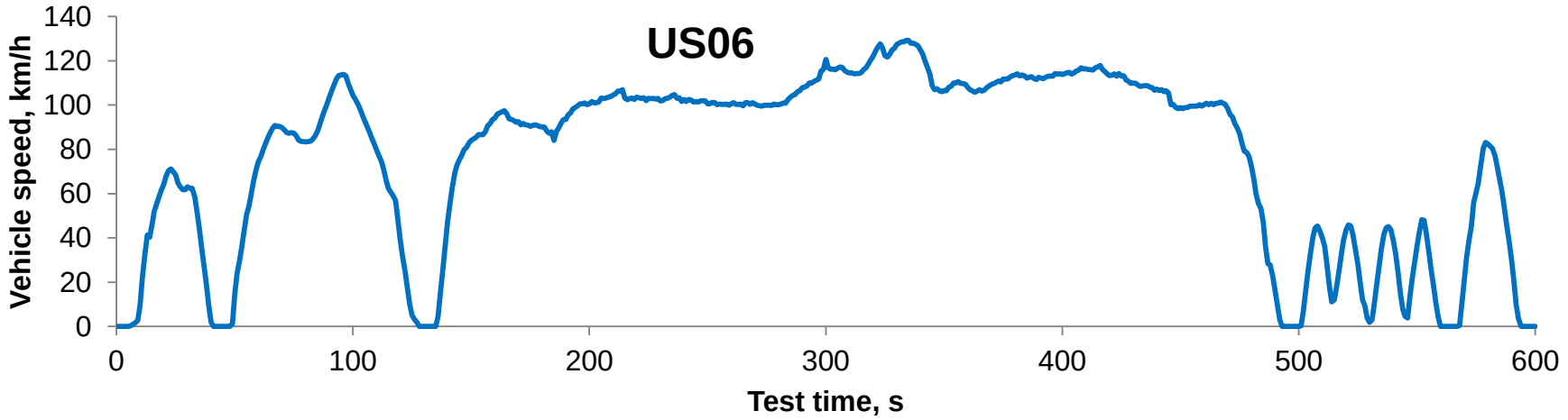
| | Bench Tests | Motored System | Combined Systems | Vehicle Tests |
|---|---|---|---|---|
| **Speed** | 5 | 3 | 2 | 1 |
| **Repeatability** | 5 | 4 | 3 | 3 |
| **Transient Operation** | 0 | 3 | 4 | 5 |
| **Flexibility** | 4 | 5 | 5 | 4 |
| **Response** | 4 | 4 | 3 | 4 |
| **Aged Oil** | 3 | 0 | 4 | 5 |
| **Real-world** | 1 | 2 | 2 | 5 |
| **Cost** | 5 | 3 | 2 | 1 |

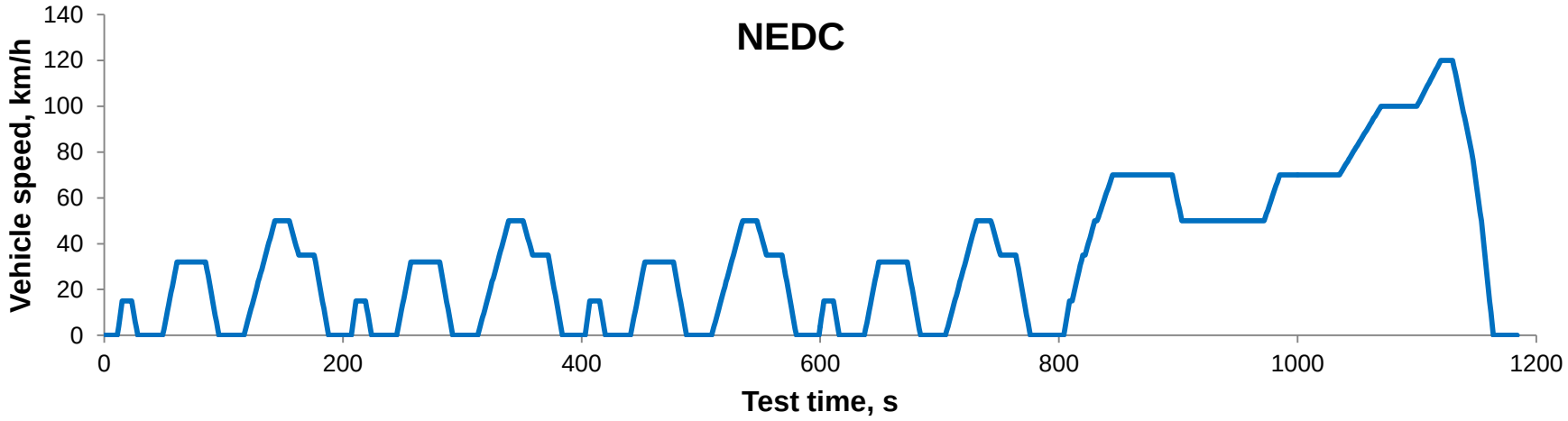
# Why Is It Difficult to See Lubricant Property Effects on Vehicle Fuel Efficiency

- **Noise May Not Be Random**
  - Driver / Lab Effect
  - Environmental Effects
  - Age of Vehicle
- **Signal from Lubricant Properties not Large Enough**
  - More Than One Property Varies at Same Time
  - Effect of Properties Varies with Test Conditions
- **Averaging Multiple Test Results May Not Overcome These Issues**

# Fuel Economy Testing

- **How Well "Driver" Tracks Driving Cycle is a Systematic Error If You Know Which Driver**

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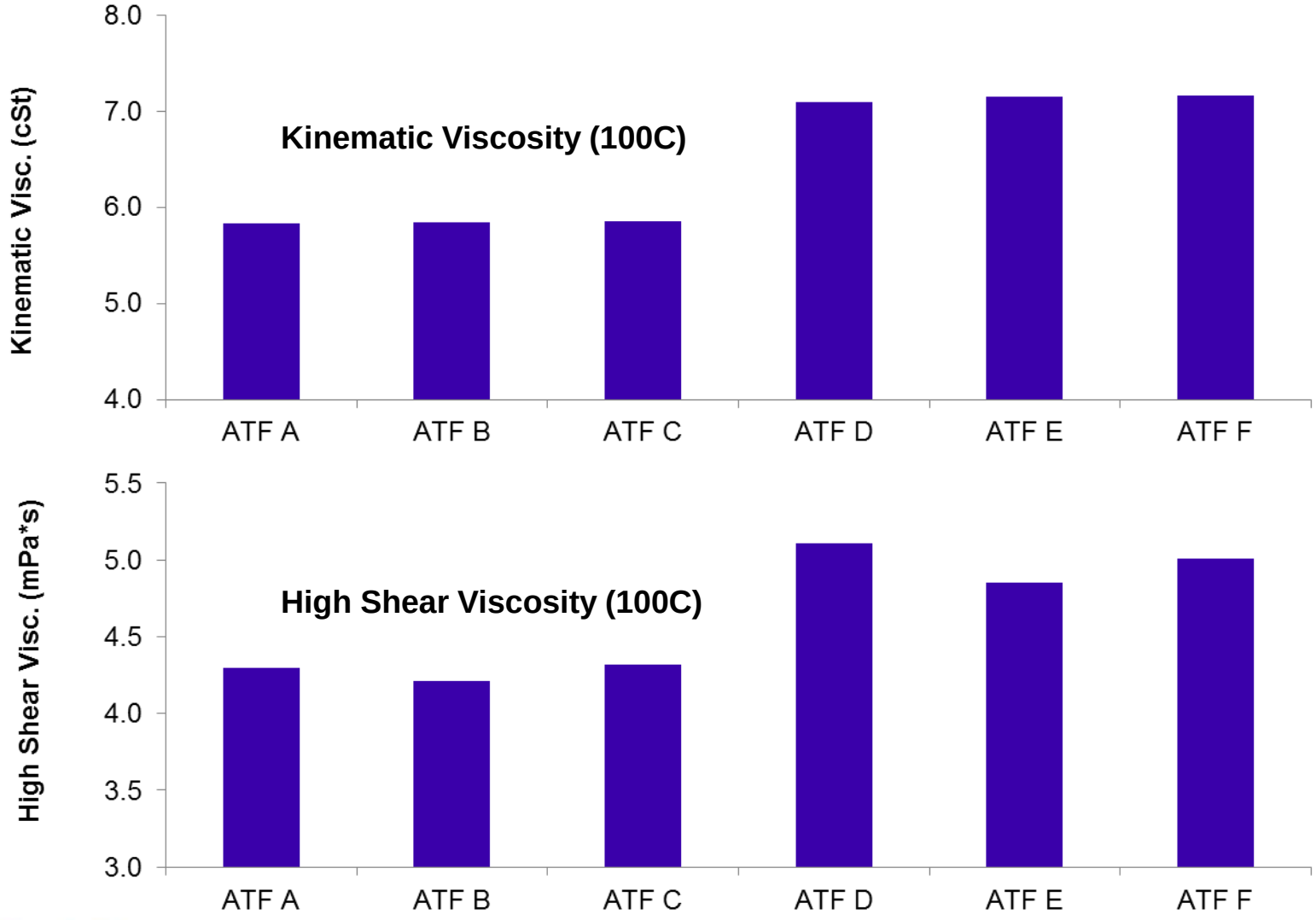
# We All Know Viscosity Affects Fuel Efficiency

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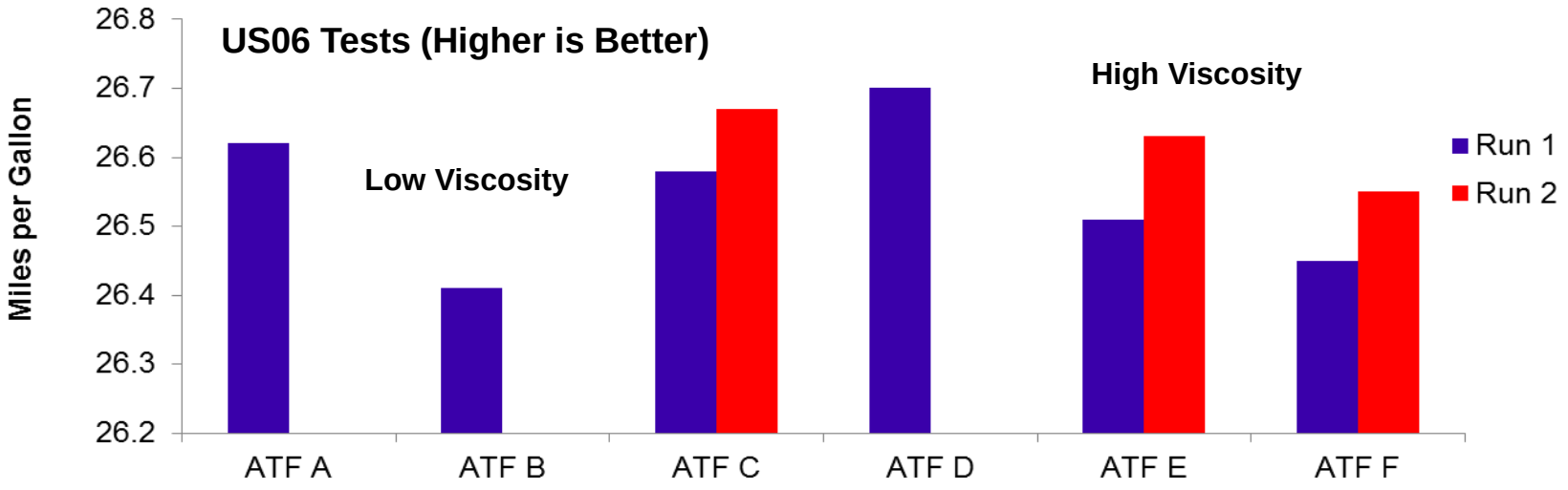
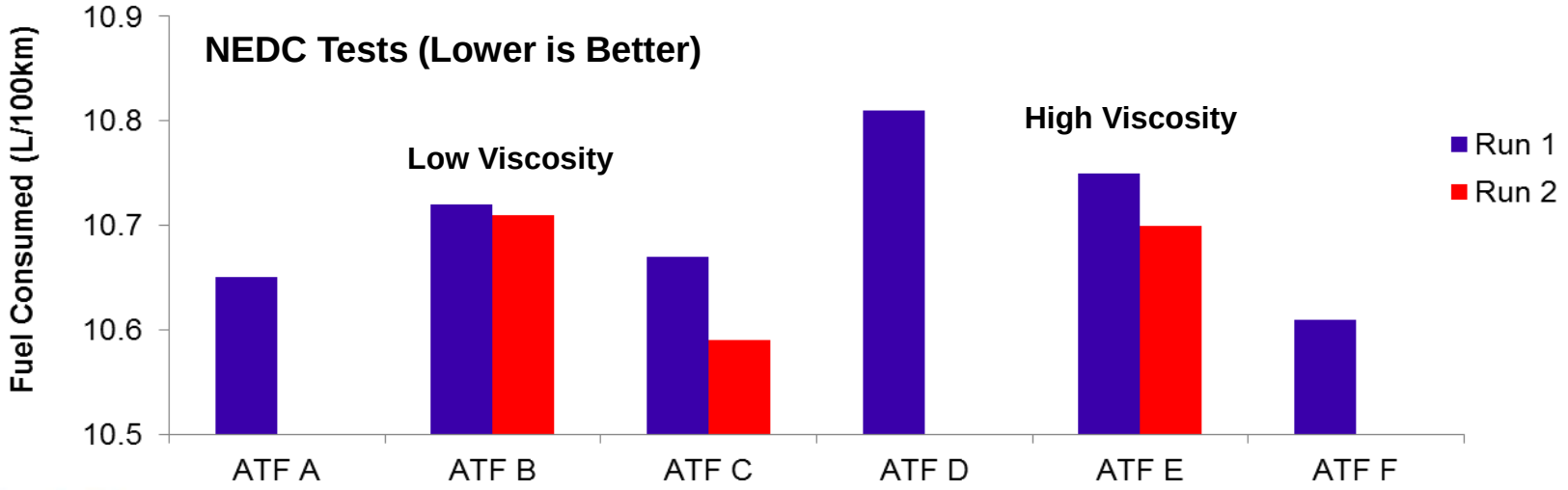
# Why Don't We See  Clear Effect of Viscosity?

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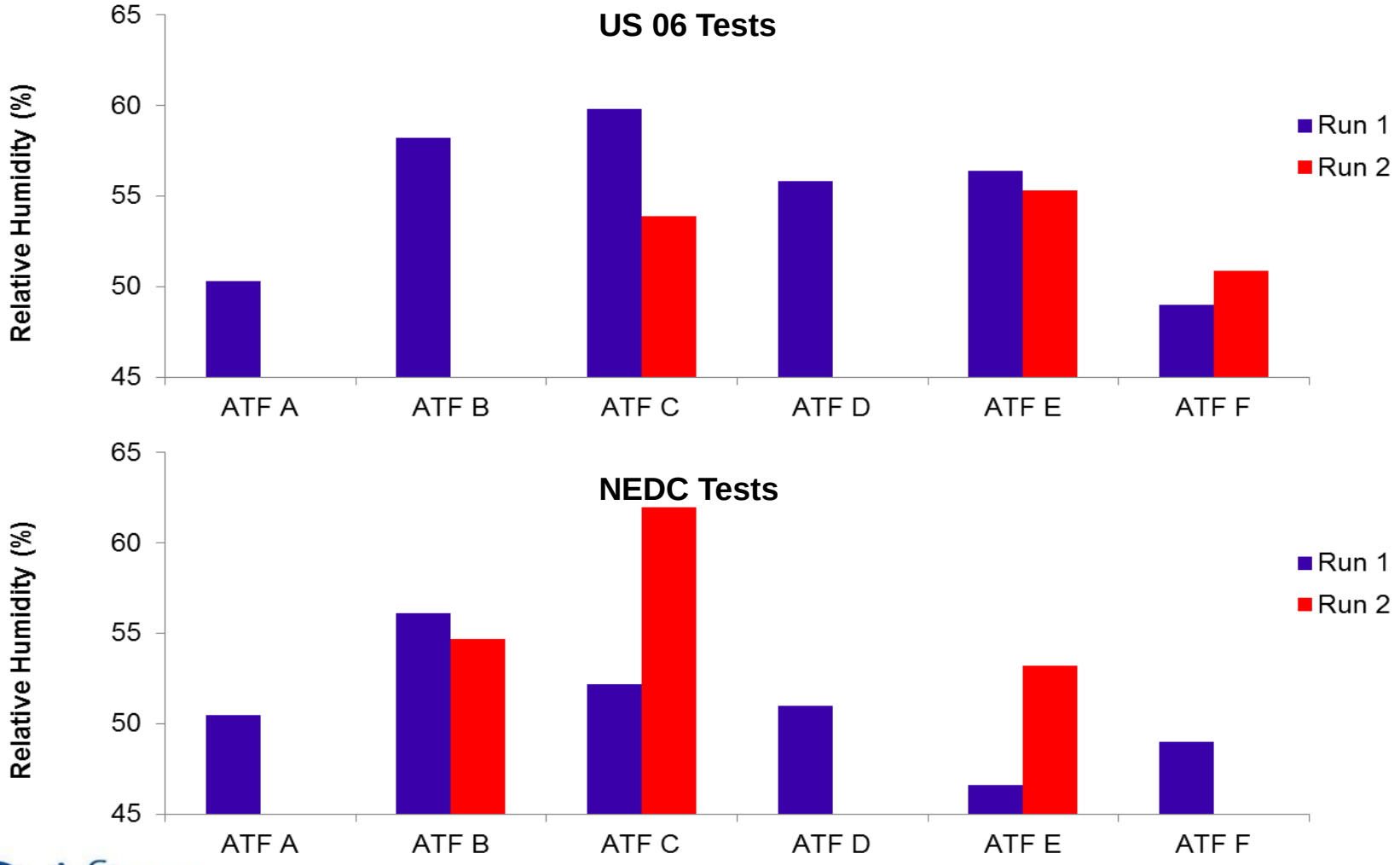
# Environmental Effects

- Fuel Economy = $\frac{\rho_{fuel} * Q_{fuel} * \text{Vehicle Velocity} * \eta_{engine} * \eta_{driveline}}{\text{Vehicle Power Requirement}}$
  - SAE 972658 : The Stretch for Better Passenger-Car Fuel Economy
- Fuel Density ($\rho_{fuel}$) and Fuel Heating Value ($Q_{fuel}$) are Affected by Environmental Condition
- Fuel Efficiency is Measured by Emissions and Emission Detection Systems are Influenced by Environmental Conditions
- Environmental Conditions May Change Randomly But They Have a Known Effect on Fuel Efficiency

# Environmental Effects

- **Humidity Varies Throughout Test Sequences**

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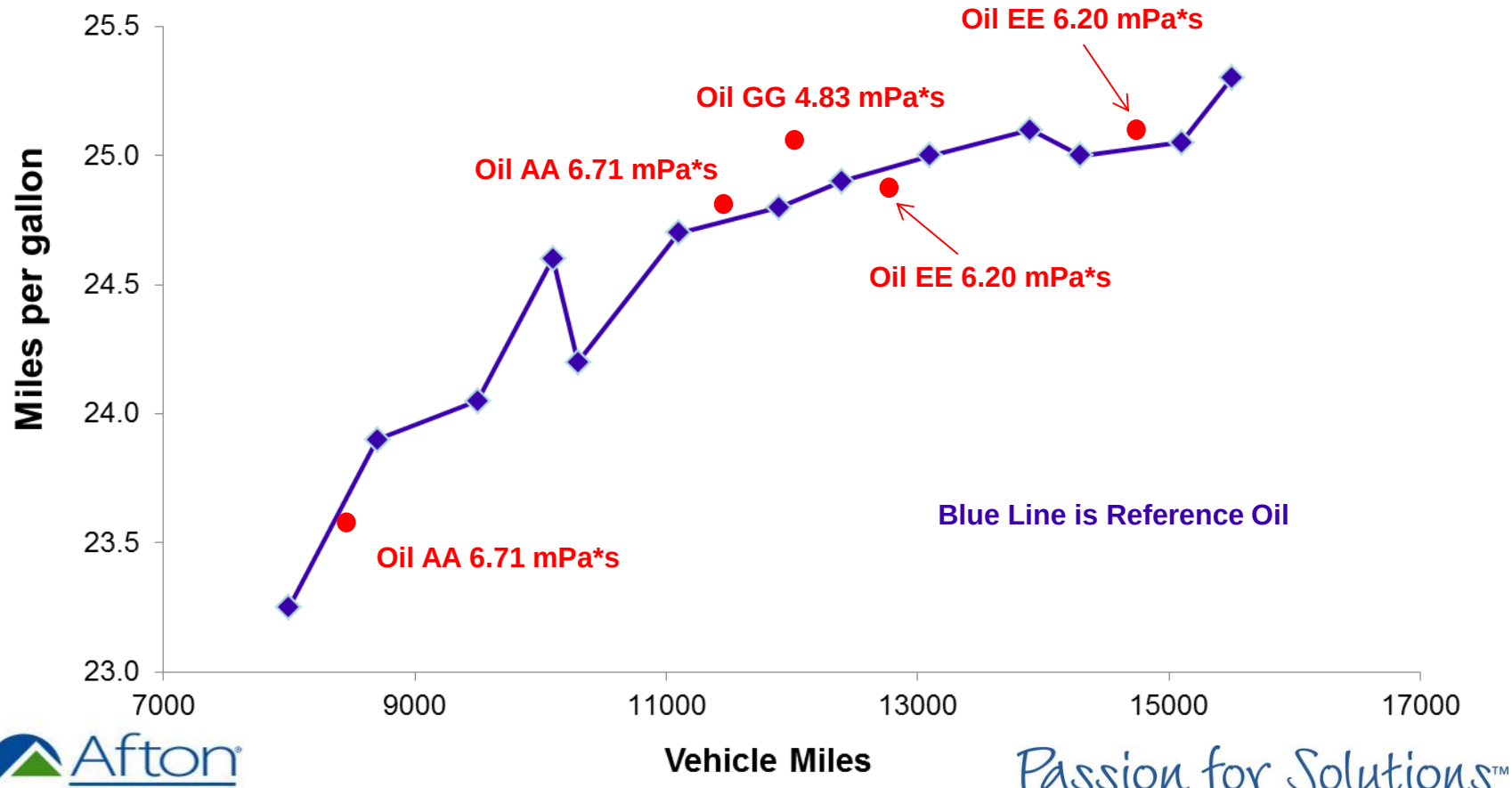
# Age of Vehicle

- **Fuel Economy Improves With Vehicle Miles**
  - SAE 982502 : Engine Oil Effects on Fuel Economy in GM Vehicles
- **Finding Effect of Viscosity Requires Correcting for Vehicle Age**
  - Averaging Results for Oil AA and Oil EE Could Be Misleading

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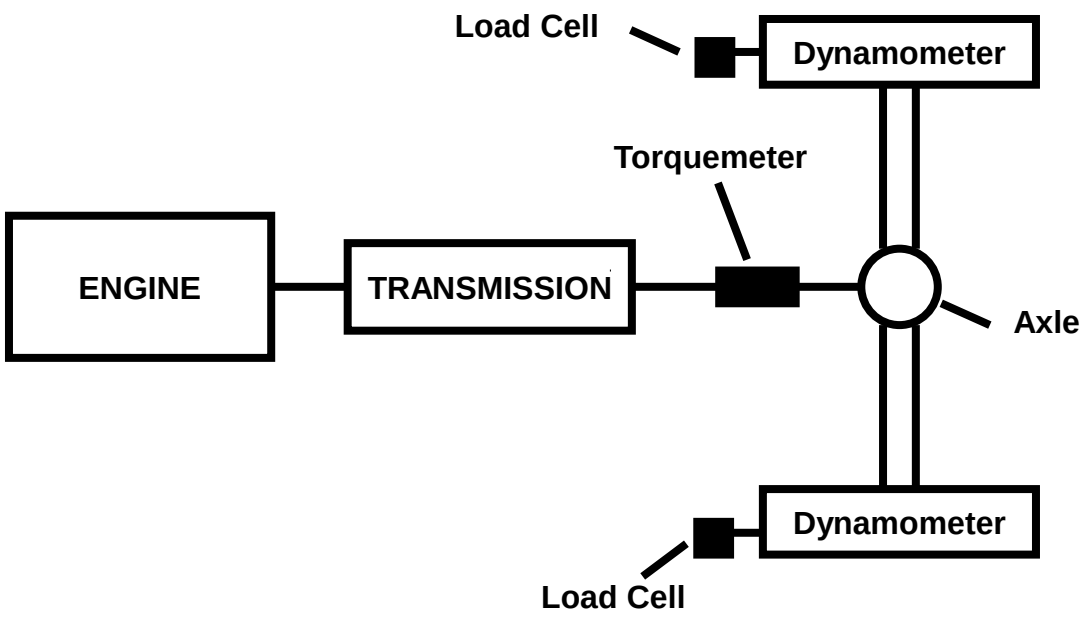
# Even Under Well Controlled Conditions Physical Properties Are Not What You Think They Are

- **Measure Torque Transfer Efficiency and Operating Temperature under Medium Torque High Speed Conditions (MT-HS)**




| Oil | KV100 (cSt) |
|---|---|
| GO13 | 15.8 |
| GO14 | 15.4 |
| GO15 | 16.4 |
| GO16 | 16.2 |
| **GO17** | **14.9** |
| GO18 | 16.8 |
| **GO19** | **17.1** |
| GO20 | 17.7 |

**V-8 350 HP Gasoline-Fired Engine**
**4L60 Automatic Transmission**
**See SAE 2000-01-2051 or Tribotest 7(4) 2001**

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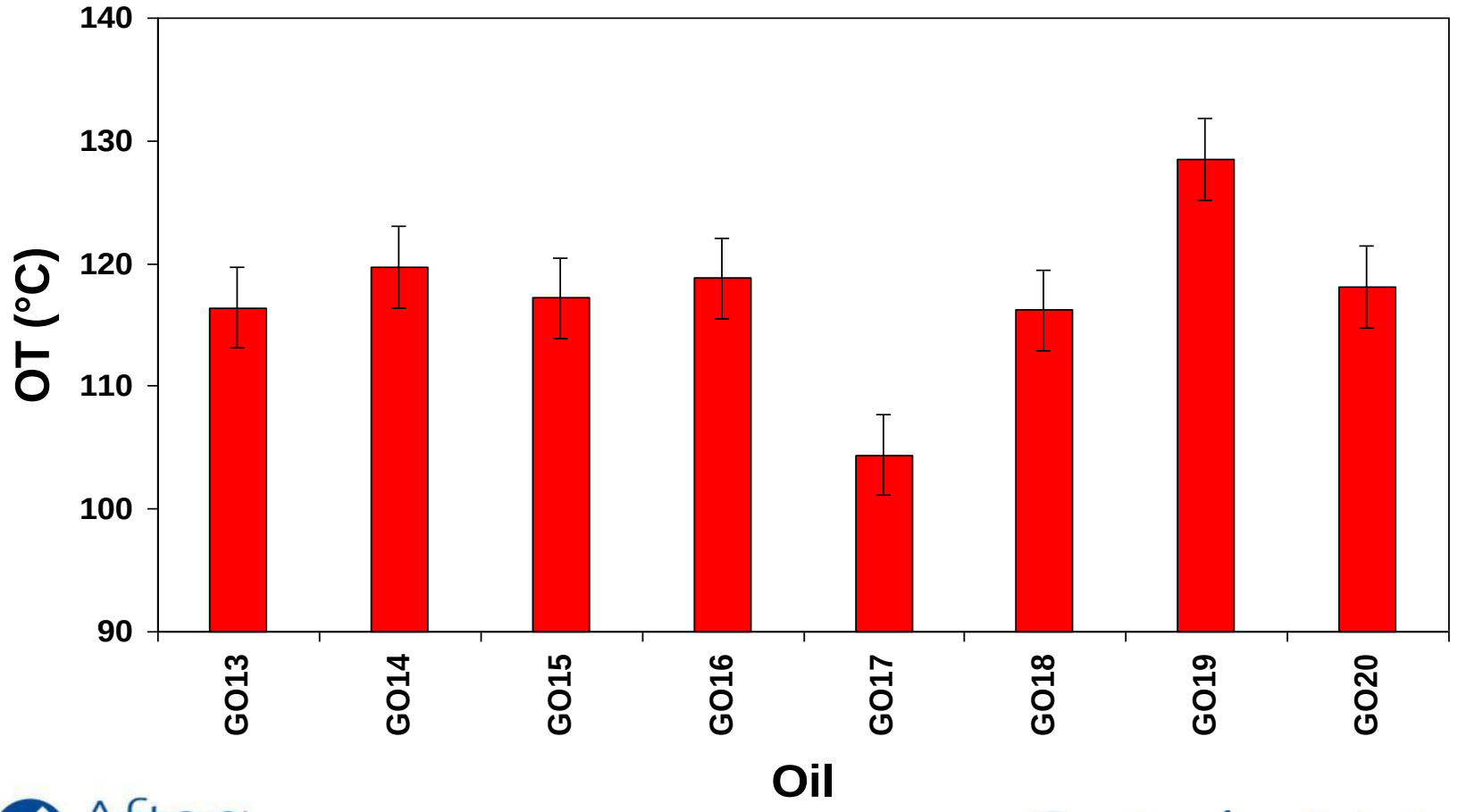
# Operating Temperatures Measured Under Medium Torque and Low Speed Conditions

- **"Operating Conditions" Will Affect Fluid Properties**

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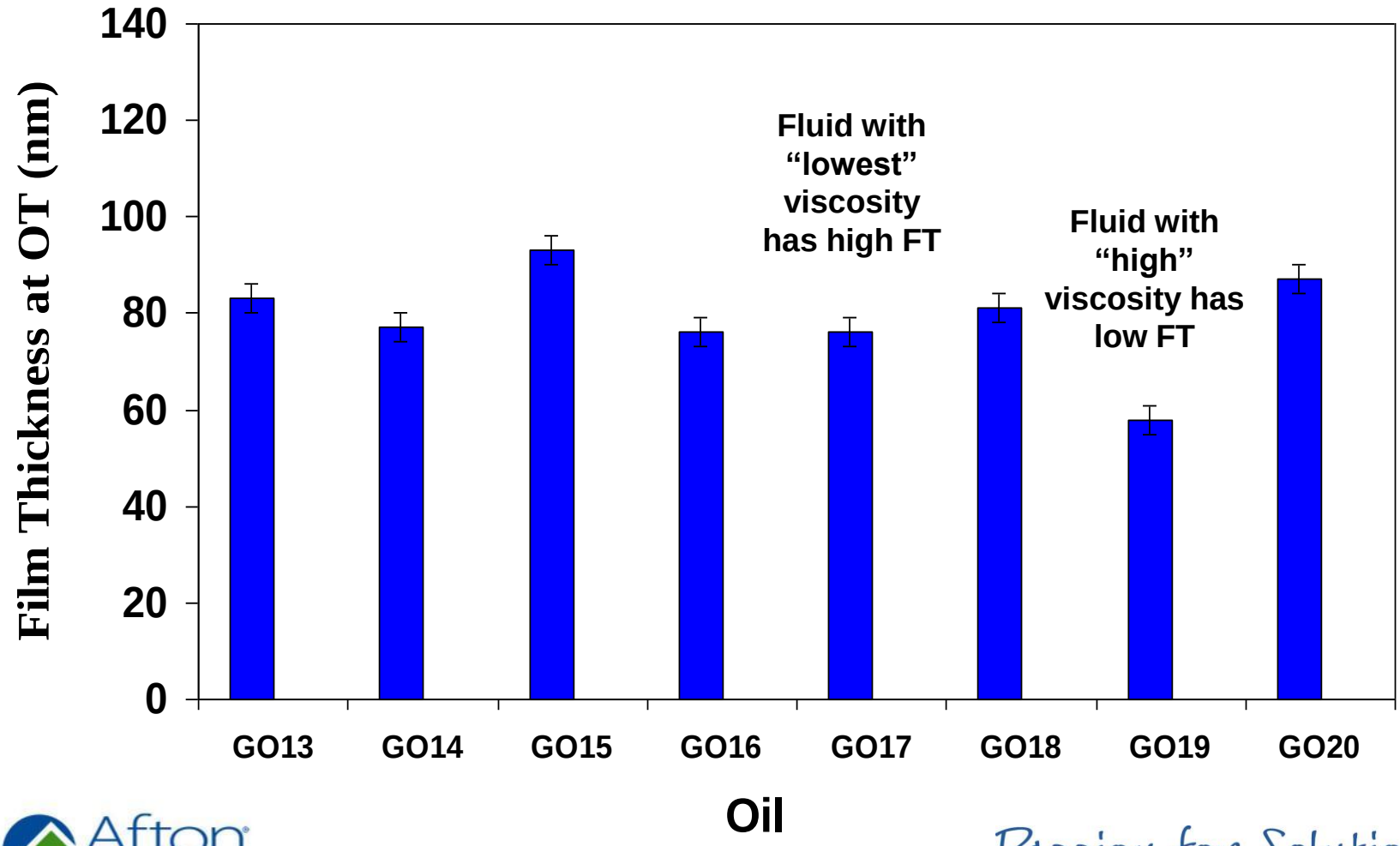
# Film Thickness at Operating Temperatures

- **So Film Thicknesses Not What We Designed**

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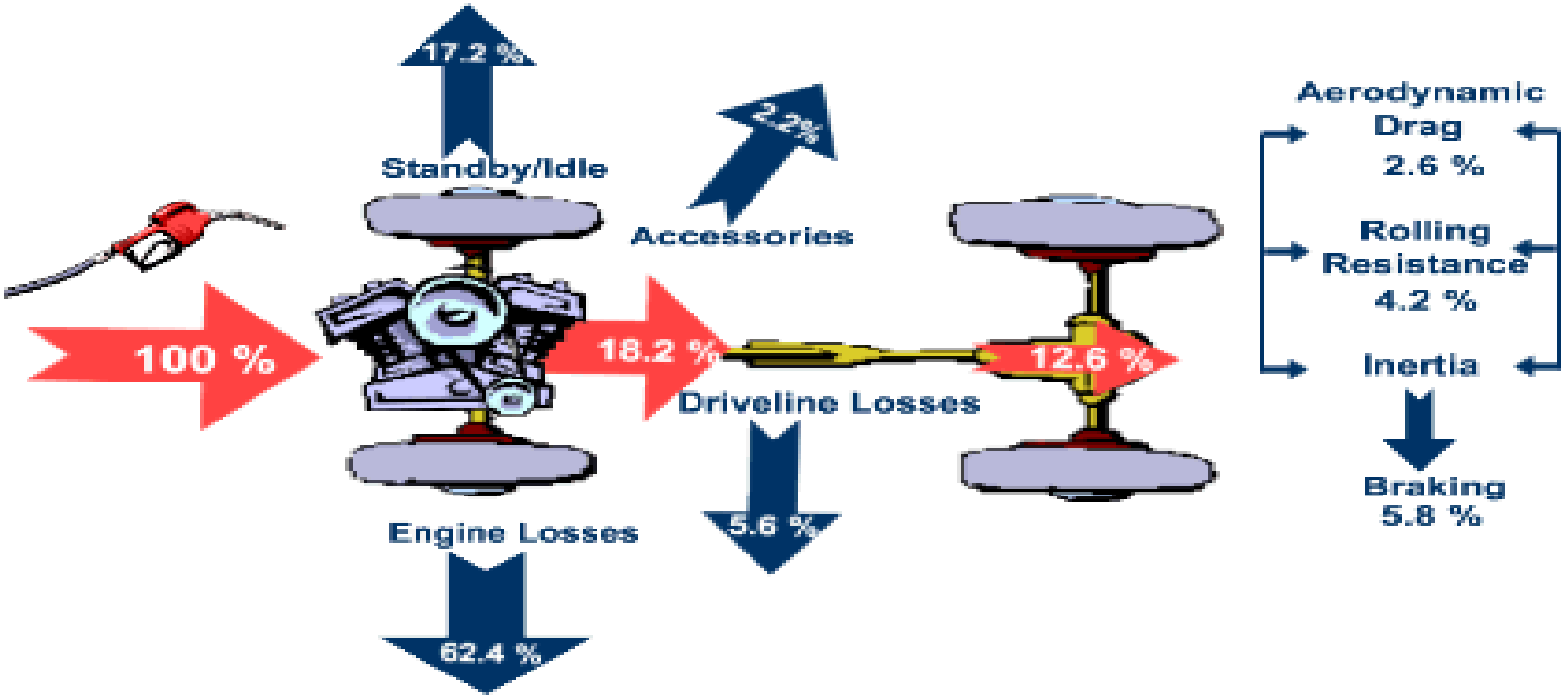
# However, if you get enough of the right data….

- **Physical Properties of Lubricants that Affect Efficiency**
  - High Temperature High Shear Viscosity
  - Boundary Friction
  - Thin-Film Friction



# Physical Properties that Affect Fuel Efficiency

Optical Interferometer

High Temperature High Shear Viscosity

High shear viscometer

Film Thickness

Fluid

Thin film friction

High Frequency Reciprocating Rig

Boundary Friction Coefficient

Mini Traction Machine

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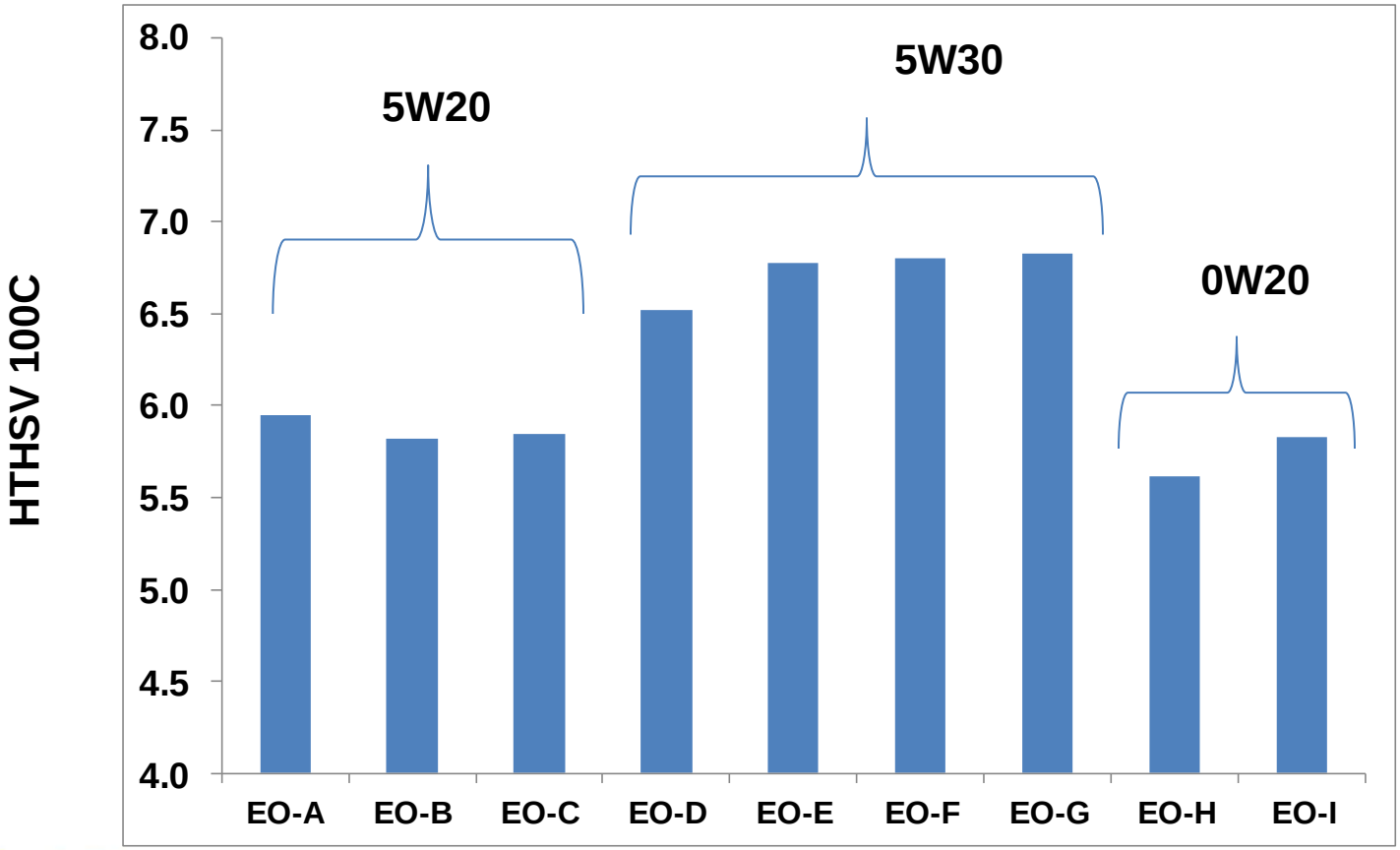
# High Temperature High Shear Viscosity

- Related to Viscosity Grade
- Affected by Base Oils and Viscosity Modifiers

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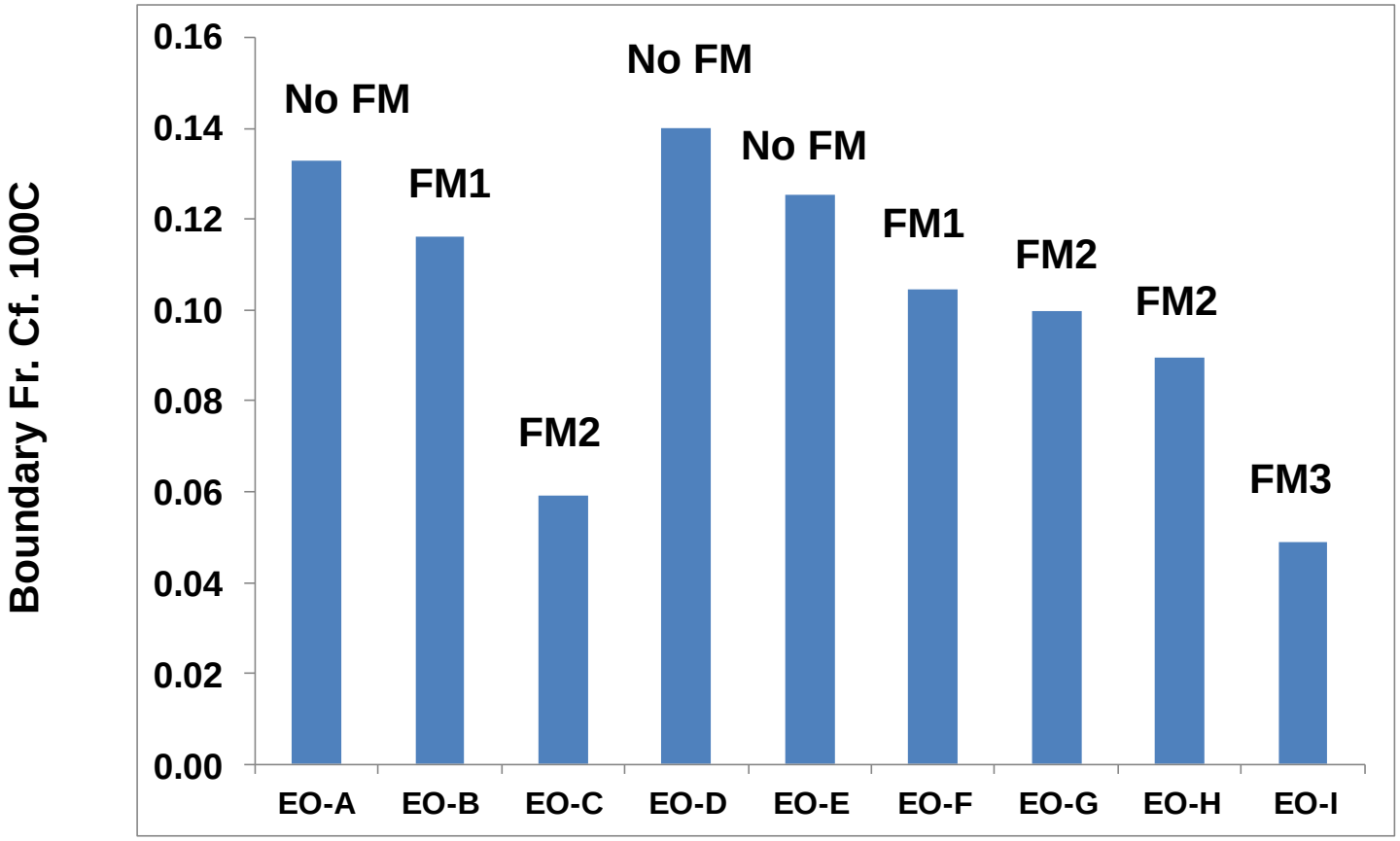
# Boundary Friction

- **Related to Addition of Friction Modifiers**

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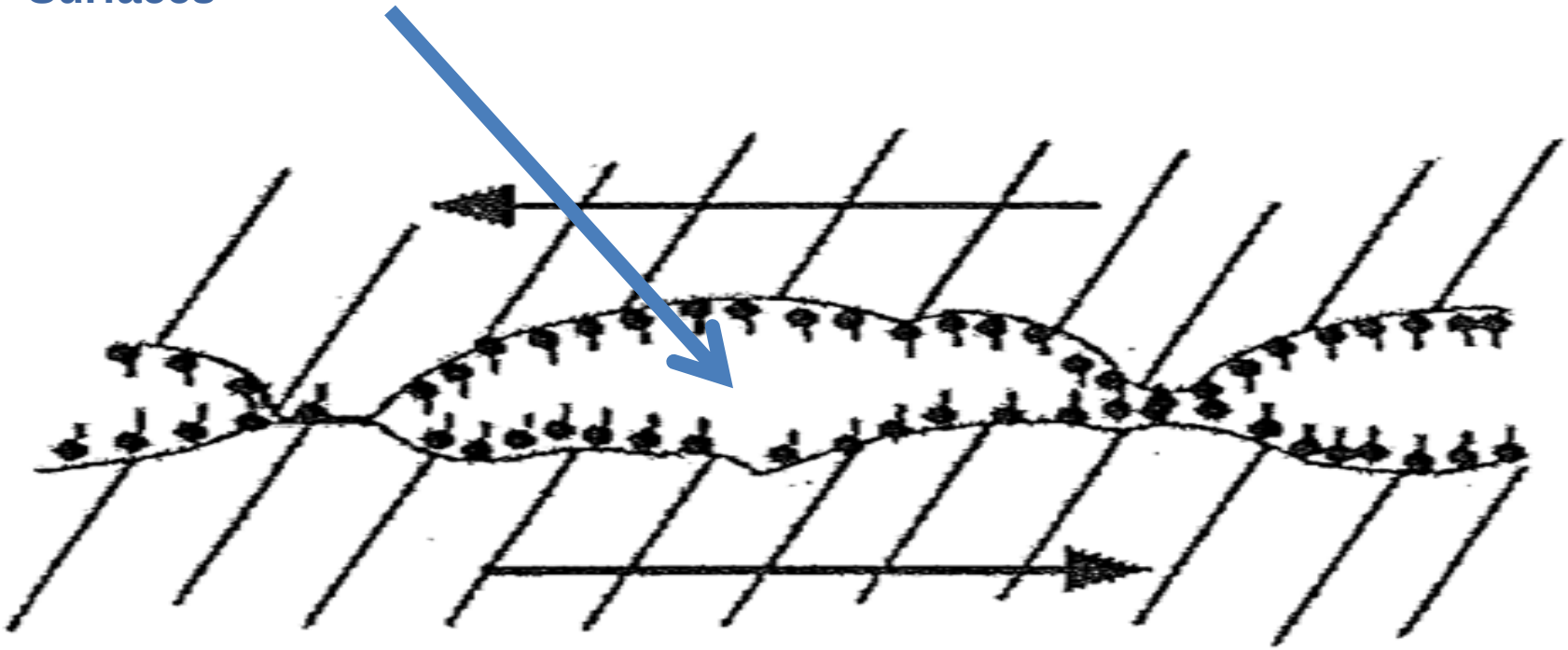
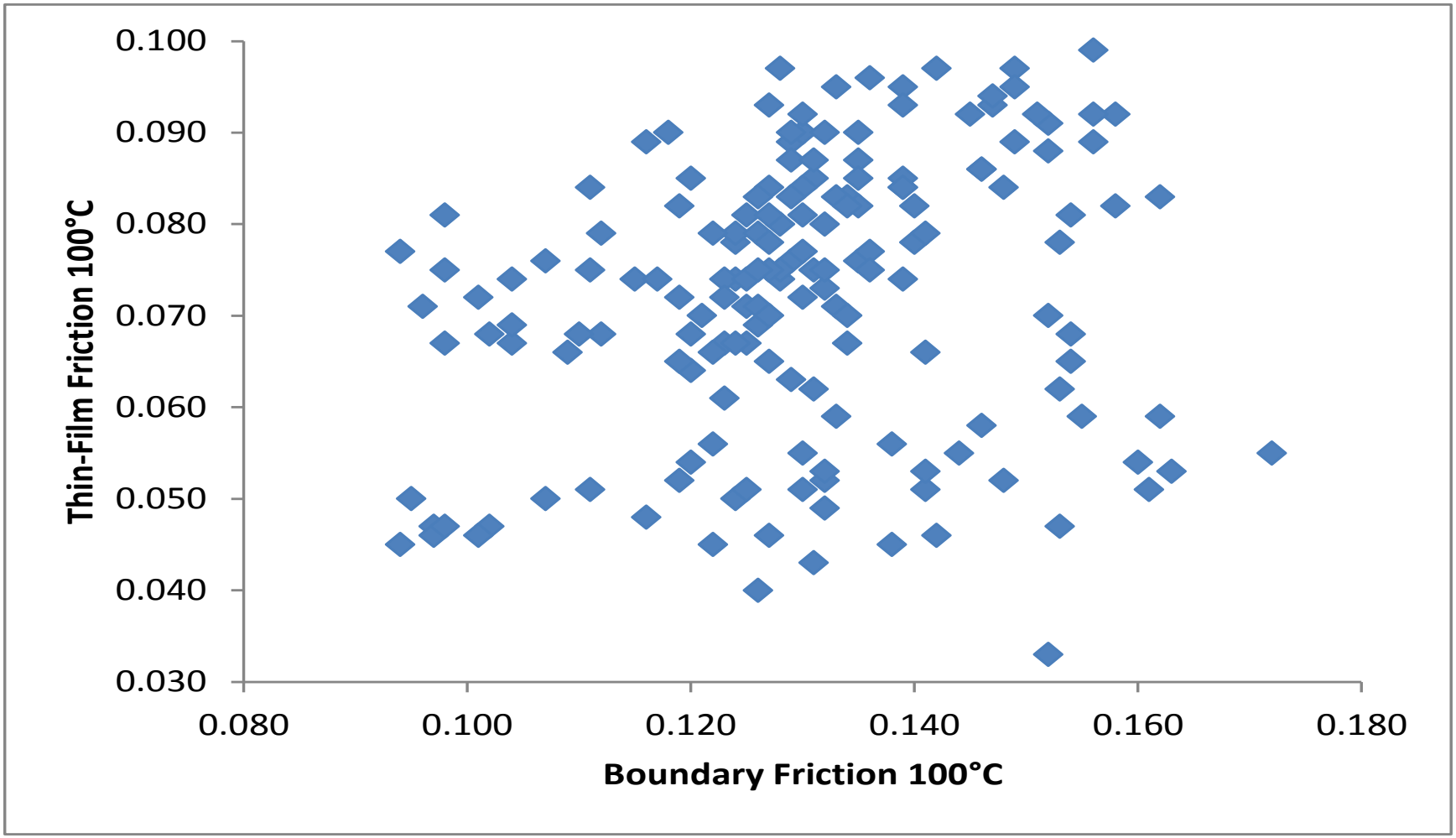
# Thin-film Friction Modification – Something Different

- **Some Additives Bind to Surface to Change Friction**
- **Small Space Between Surfaces Still Exists**
- **Need to Understand Behavior of Fluid in Small Space Between Surfaces**



# Boundary Friction and Thin Film Friction are Different

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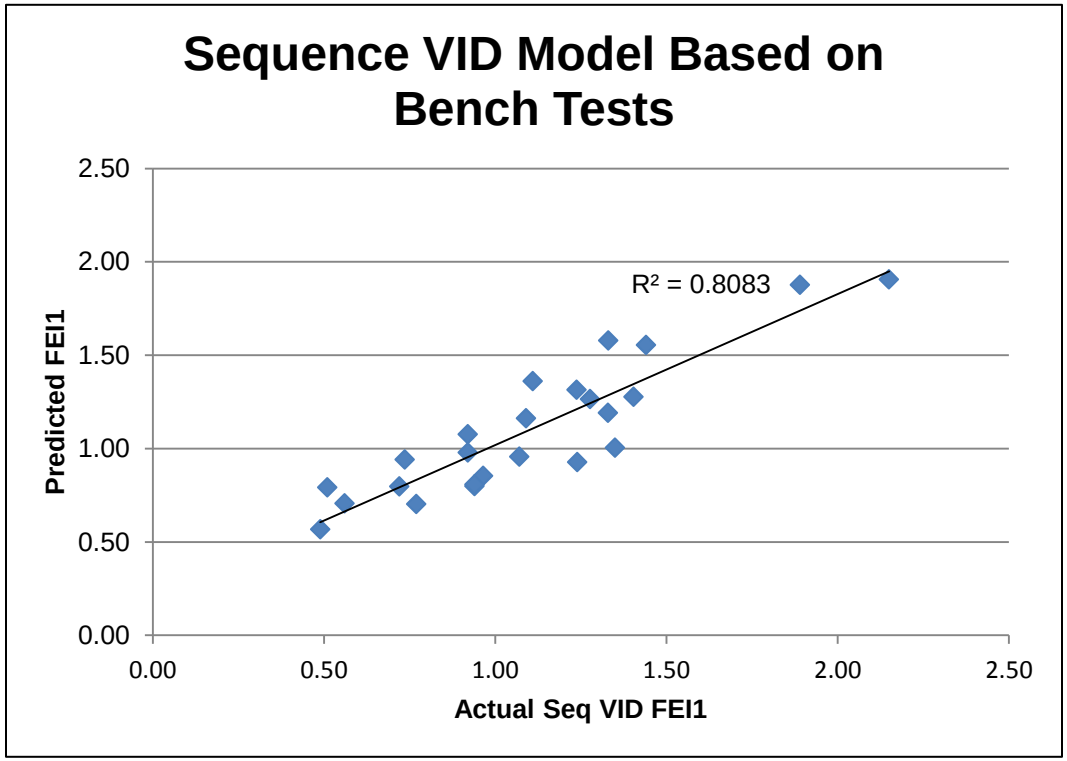
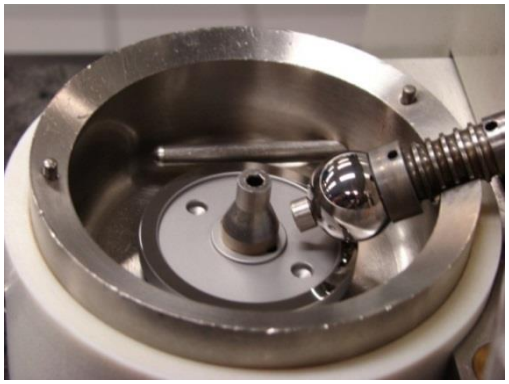
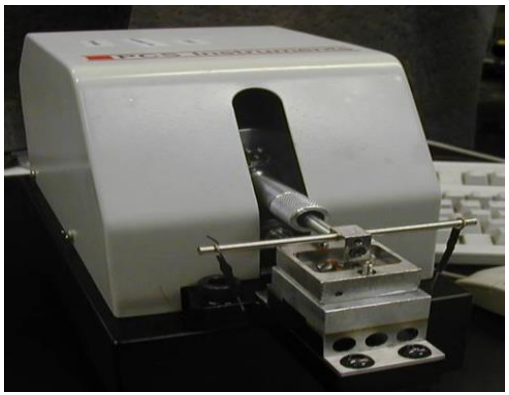
# Can Create Correlations to Physical Properties

- **Viscosity, Boundary Friction, Thin-film Friction are used for component screening and predicting engine response**



MTM

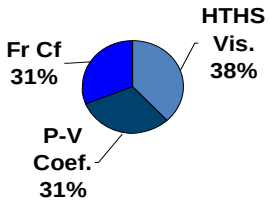


HFRR

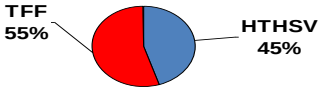
# And Correlation is Different in Each Application

## Engine Oil Vehicle and Seq. Test Models

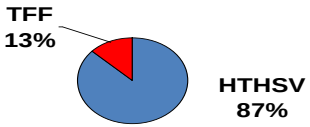
Vehicles (A, B and C combined)
SAE982503



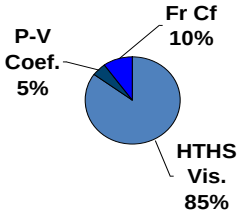

Vehicle D



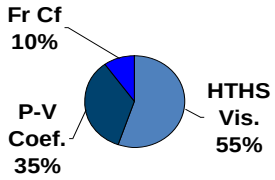

Vehicle E



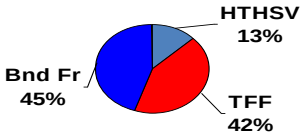

Seq. VIA




Seq. VIB




Seq VID

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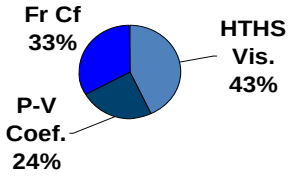
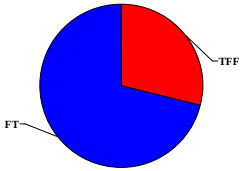
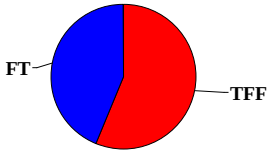



## Axle Oil Efficiency Rig

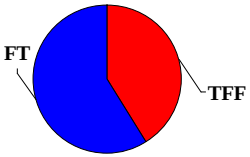
418 ft*lb / 500 RPM




189 Ft*lb / 3000 RPM

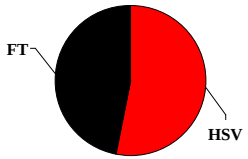



242 Ft*lb / 2730 RPM

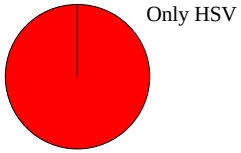



## ATF NEDC Cycle Different Vehicles

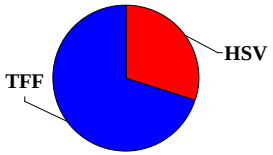
Vehicle 1




Vehicle 2




Vehicle 3

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# What about “Non-Automotive” Applications

- **Hydraulic Efficiency**
  - Compare Theoretical and Measured Torque Output
  - Measure Efficiency at 1 RPM, 50C and 1000 to 4000 psi


| Orbital Motor | Cam-Lobe Motor | Axial Piston Motor |
|---|---|---|
| Eaton VIS 30 | Poclain MS02 | Sauer-Danfoss Series 90 |
| 325cc , 19.8 cu. in. | 190cc, 11.59 cu. in. | 100 cc, 6.1 cu. in. |

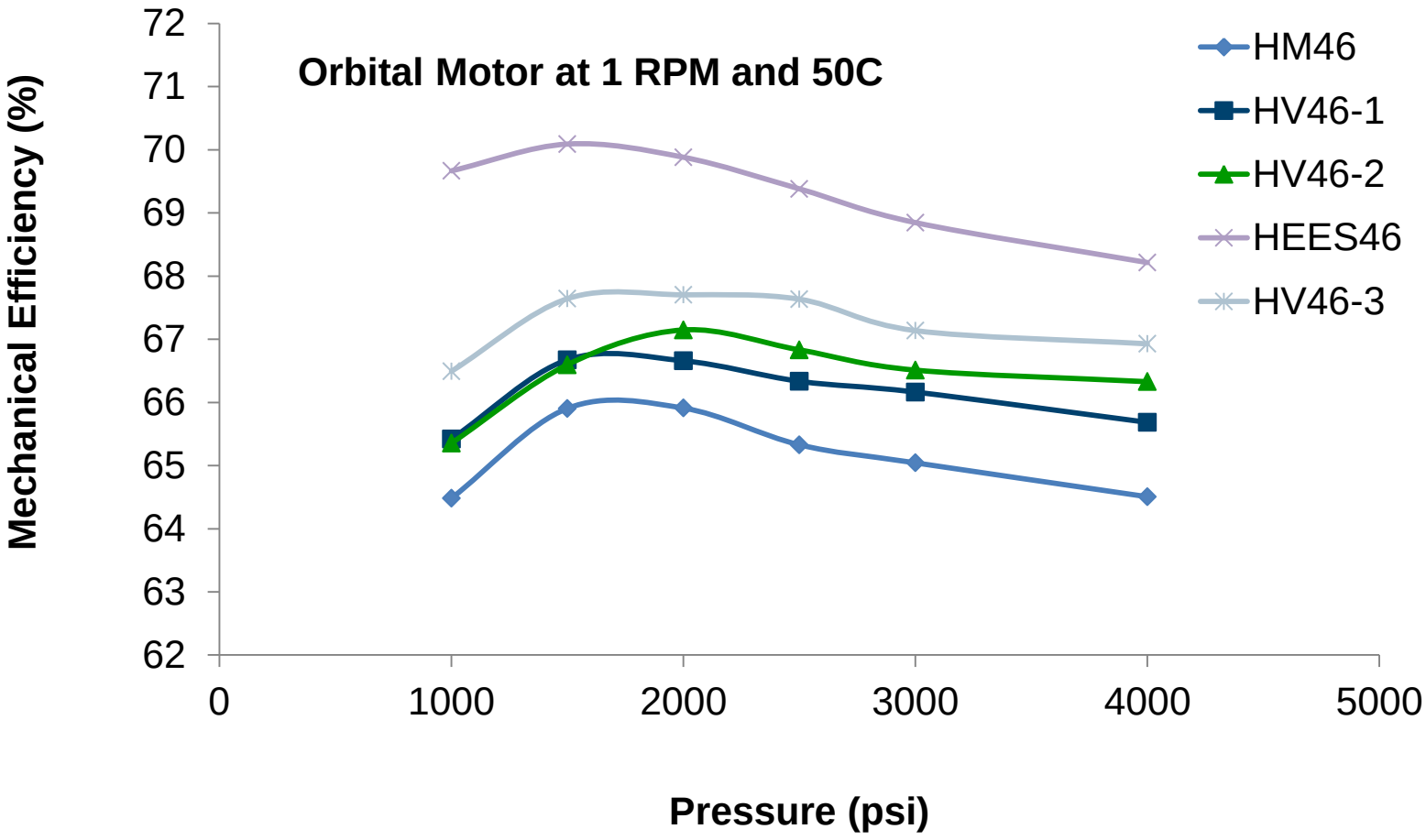
# Fluids Tested

- **Vary Fluid Composition to Vary Physical Properties**

| Fluid | Description | Grade | Viscosity Index |
|---|---|---|---|
| HM46 | Straight grade mineral oil | ISO VG 46 | 100 |
| HV46-1 | Multi-grade mineral oil with PMA | ISO VG 46 | 200 |
| HV46-2 | Multi-grade with functionalized PMA | ISO VG 46 | 200 |
| HEES 46 | TMP Trioleate synthetic ester | ISO VG 46 | 200 |
| HV46-3 | Multi-grade mineral oil with PMA and Boundary FM | ISO VG 46 | 200 |

# Hydraulic Efficiency Results

- **Efficiency Changes with Pressure and Fluid**

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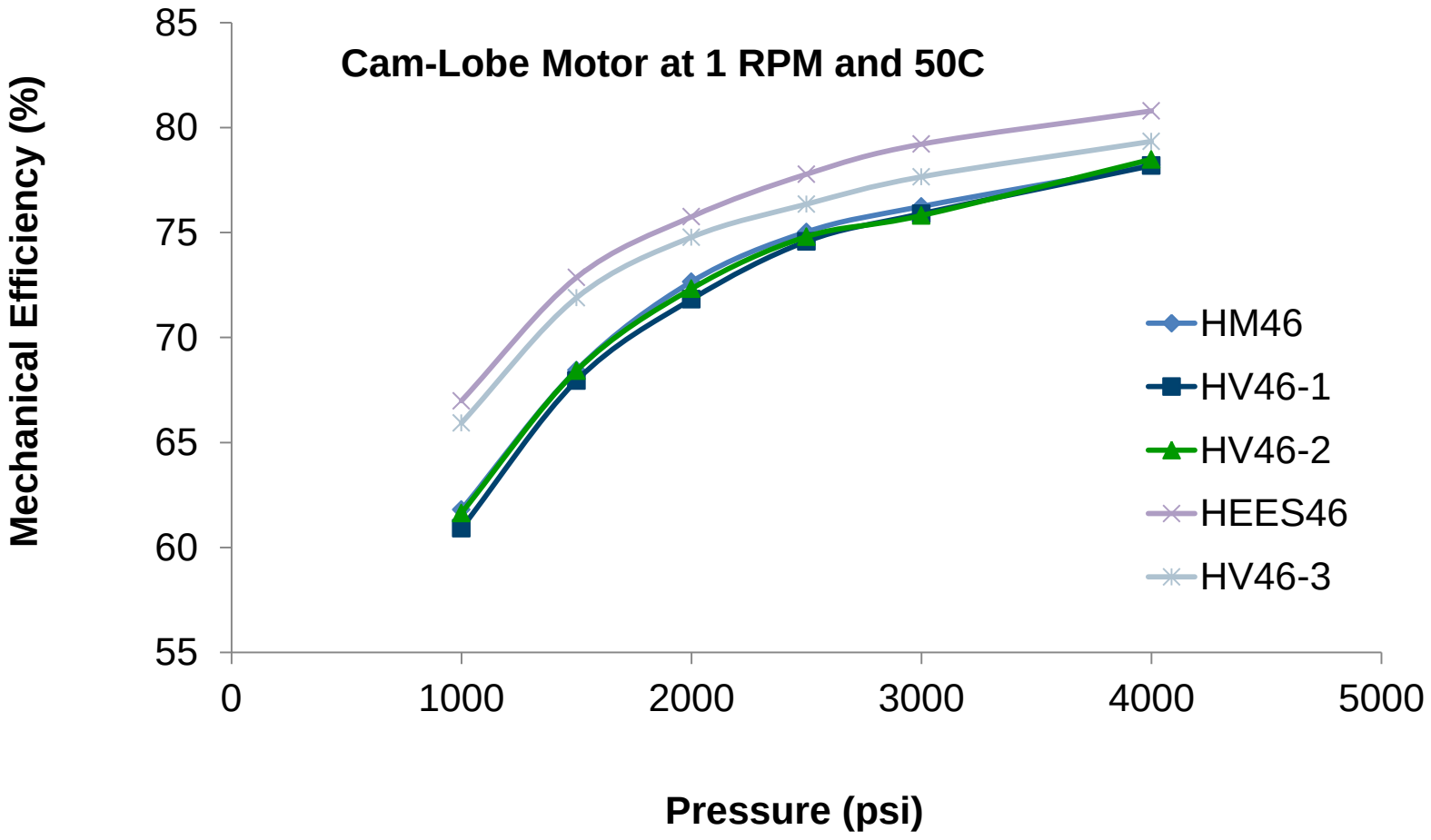
# Hydraulic Efficiency Results

- **Efficiency Changes with Pressure and Fluid and Motor**

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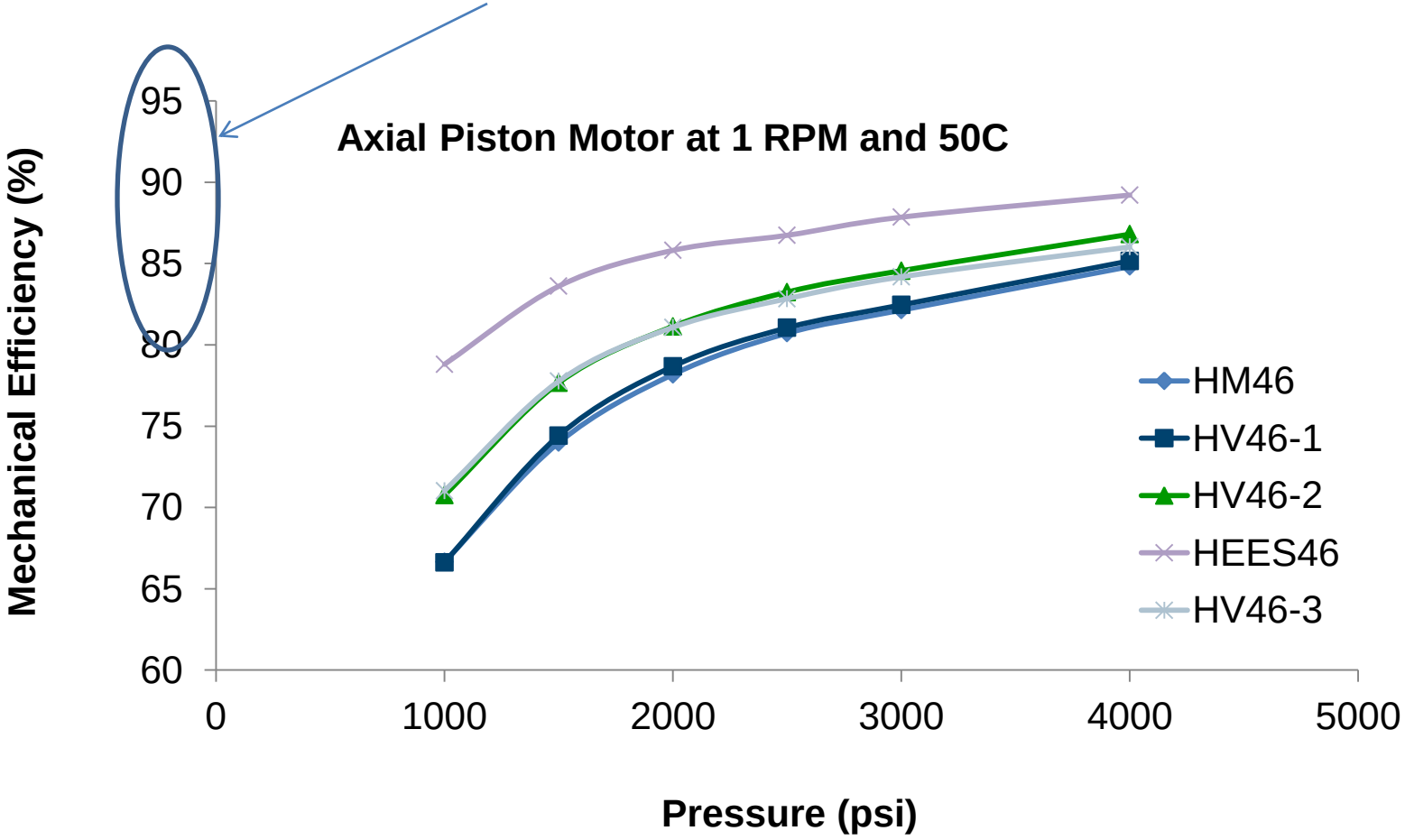
# Hydraulic Efficiency Results

- Efficiency Changes with Pressure and Fluid and Motor
- This Motor is Extremely Efficient  so Optimization of Fluid is Not Easy

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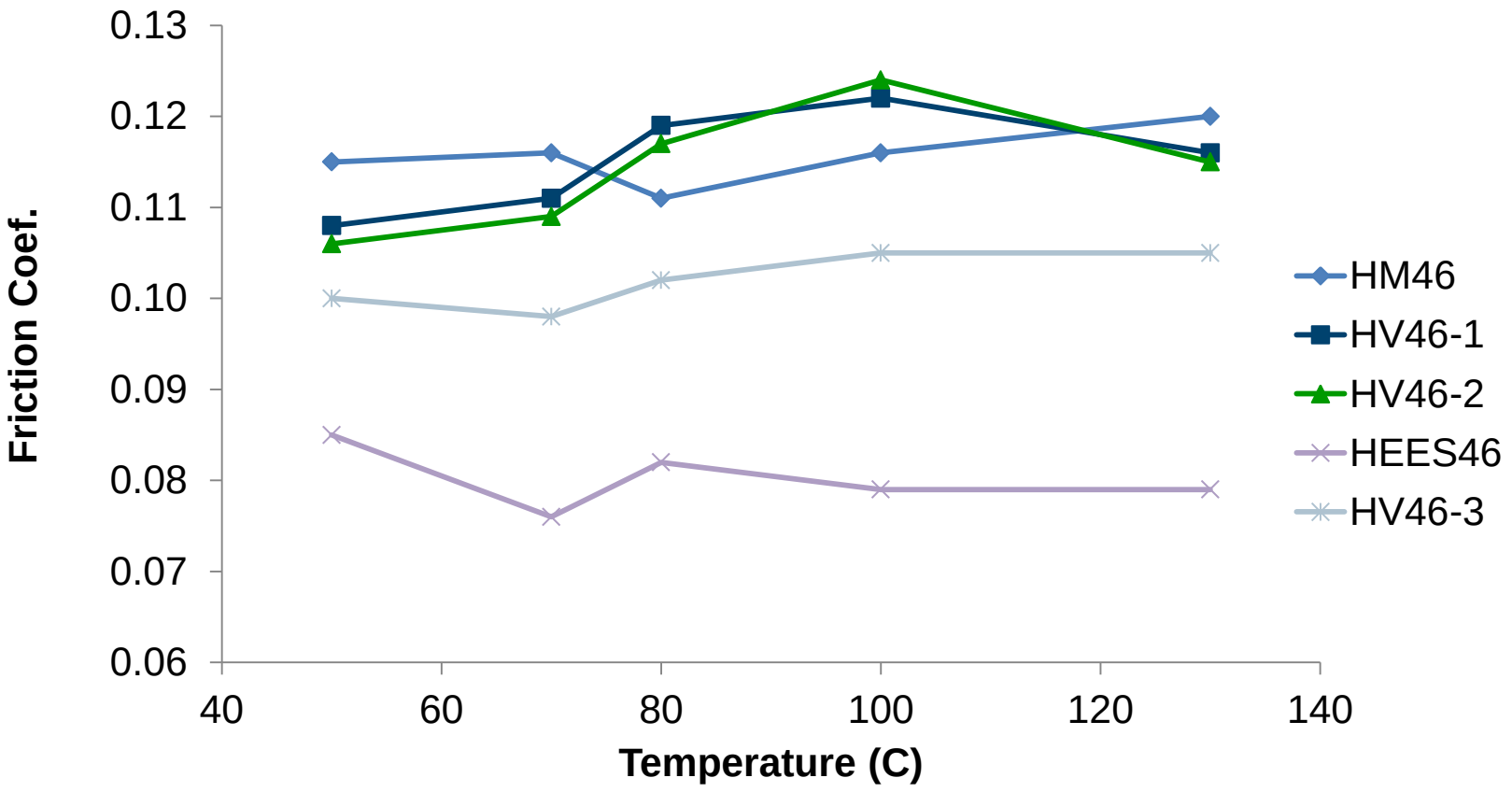
# Fluid Frictional Properties

- **Boundary Friction Differences Between Fluids Varies with Temperature**

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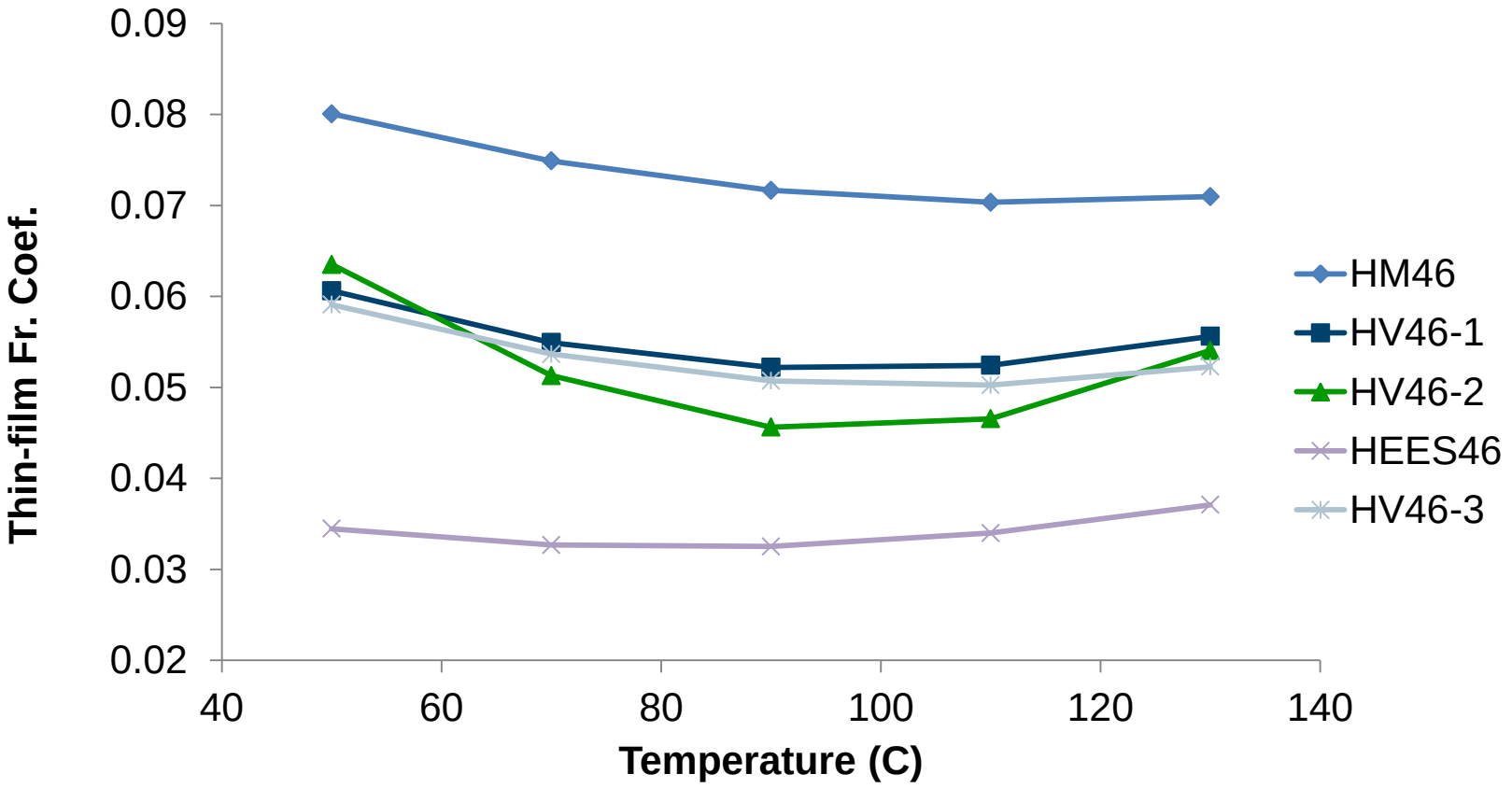
# Fluid Frictional Properties

- **Thin-film Friction Differences Between Fluids are not the Same as Boundary Friction Differences**

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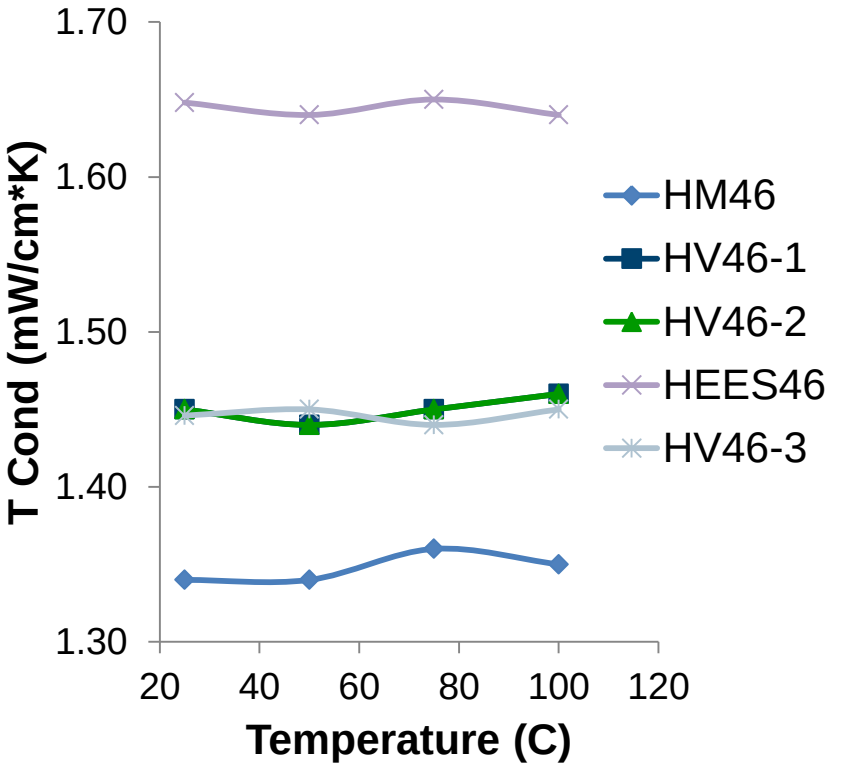
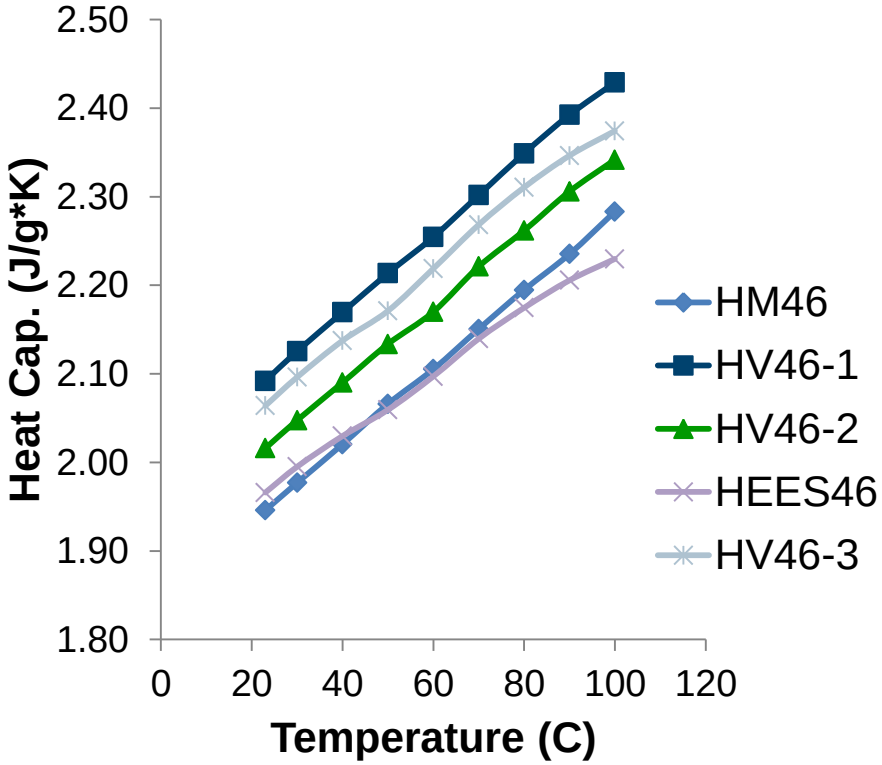
# Thermal Properties of Fluids

- T in Contact is Function of Bulk T and “Flash” T
- “Flash” T Depends Upon Thermal Conductivity and Heat Capacity

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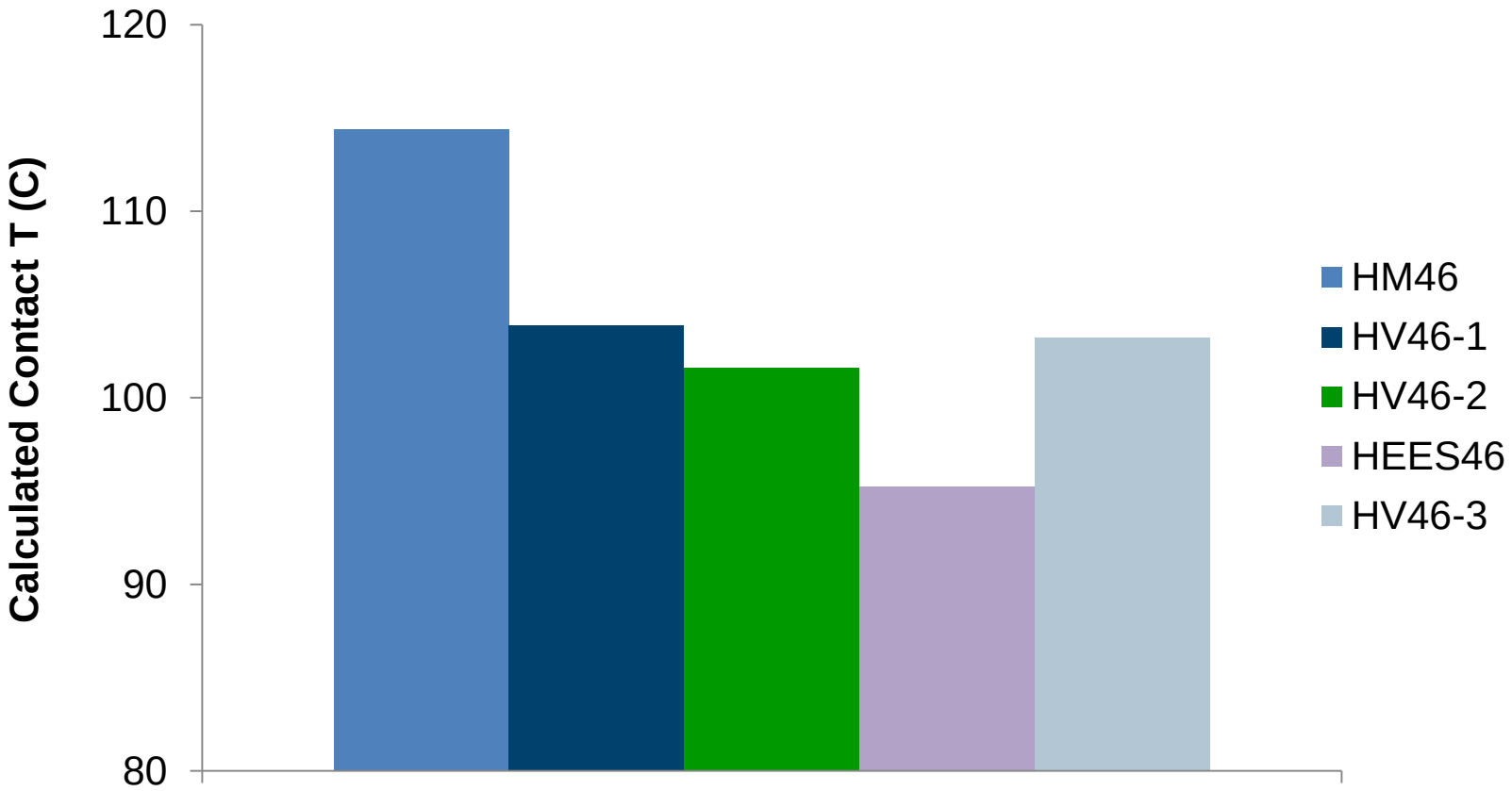
# Calculated Contact Temperatures

- **Fluids Operate at Different Temperatures**

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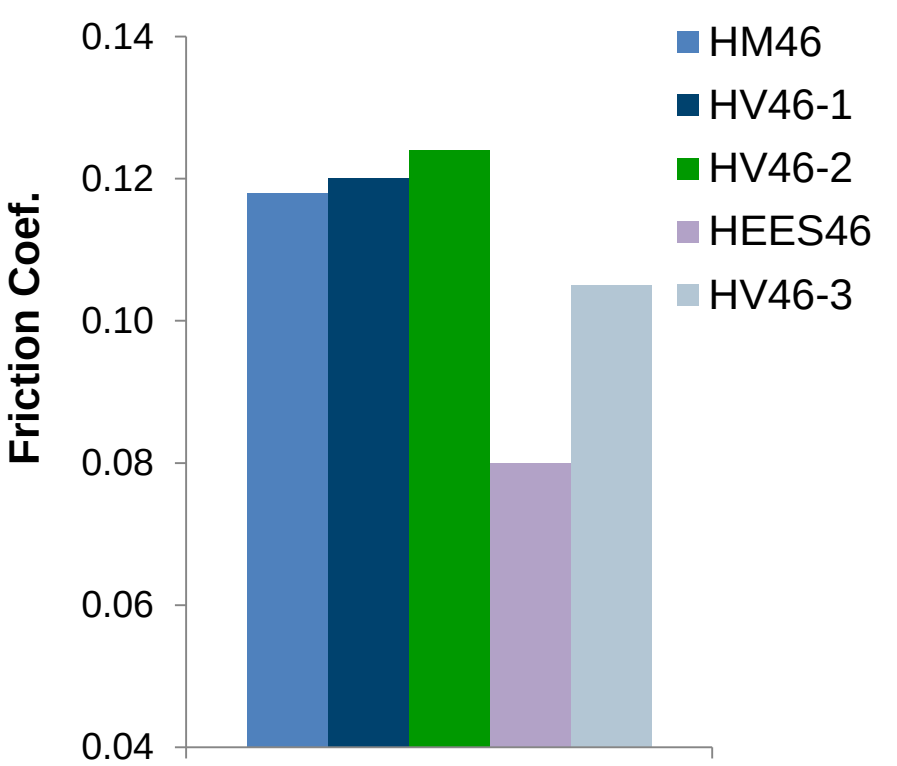
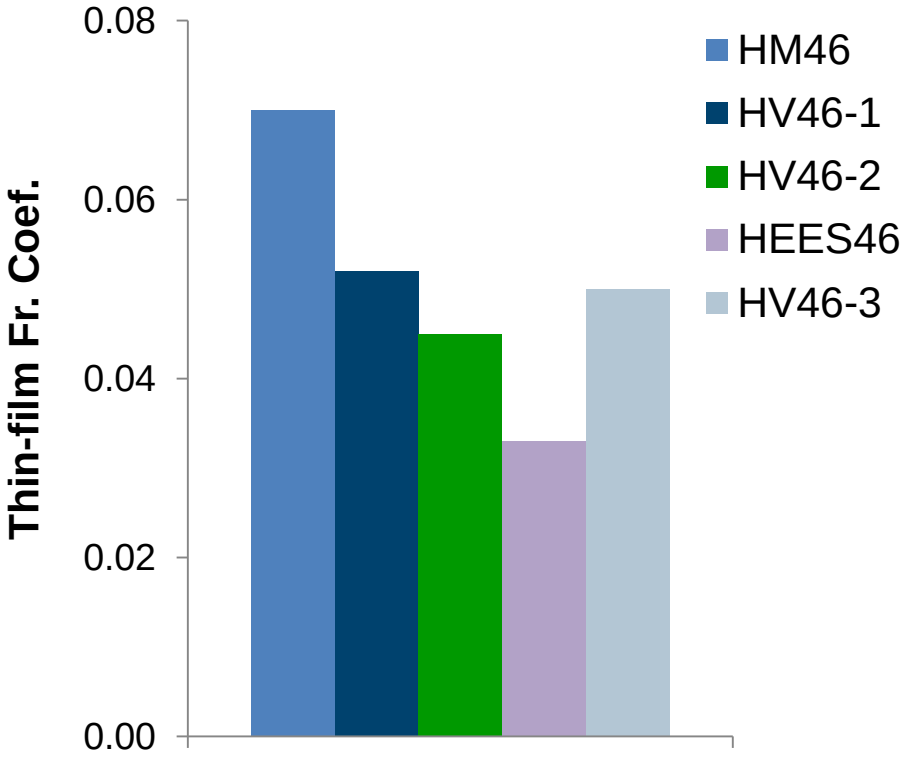
# Frictional Properties at Contact Temperature

- **Physical Properties of Fluids are Affected by Temperature**

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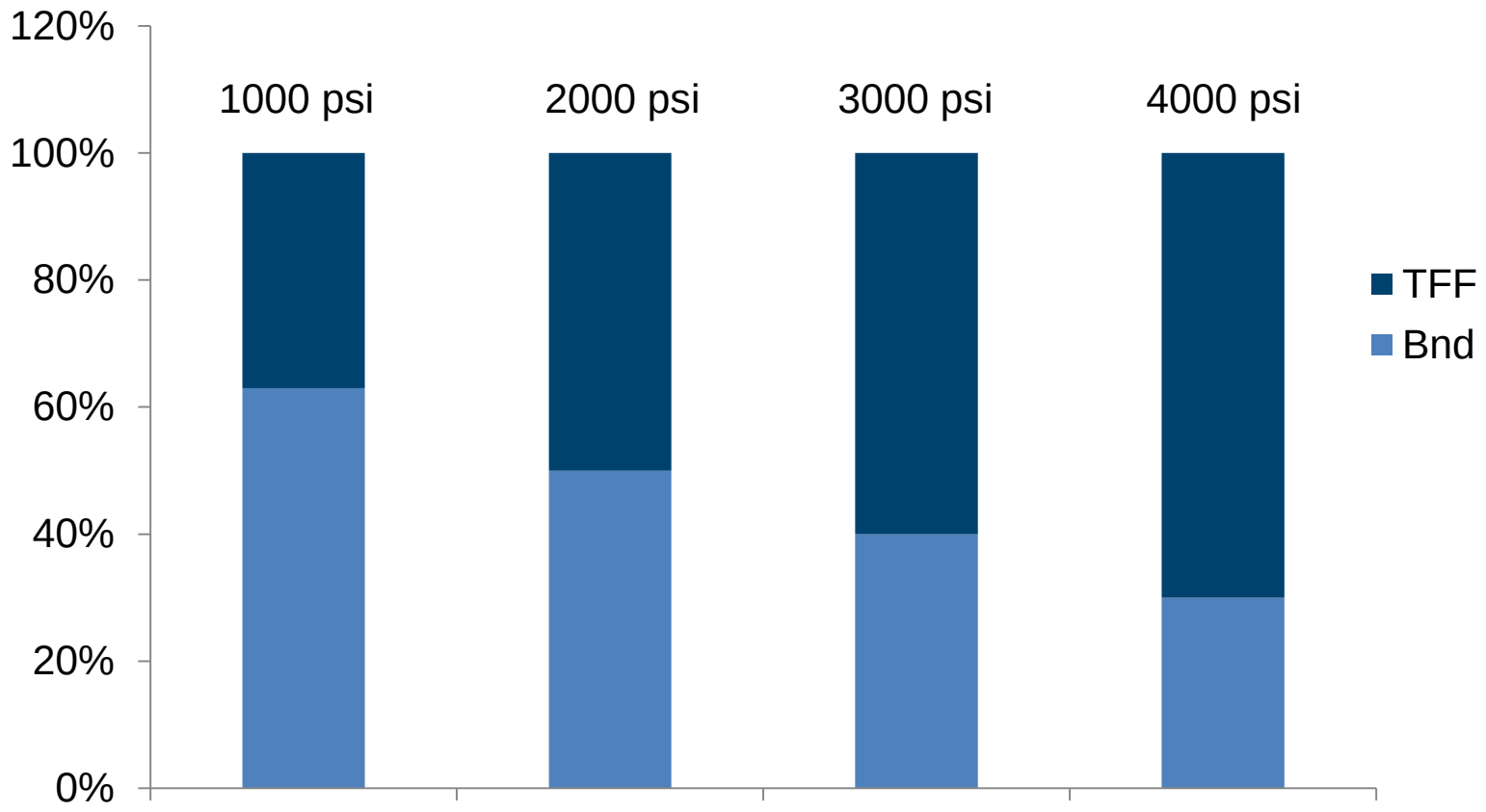
# Relative Effect of Boundary and TFF on Efficiency

- **In Orbital Motor as P Increases Thin-film Friction has Greater Effect**

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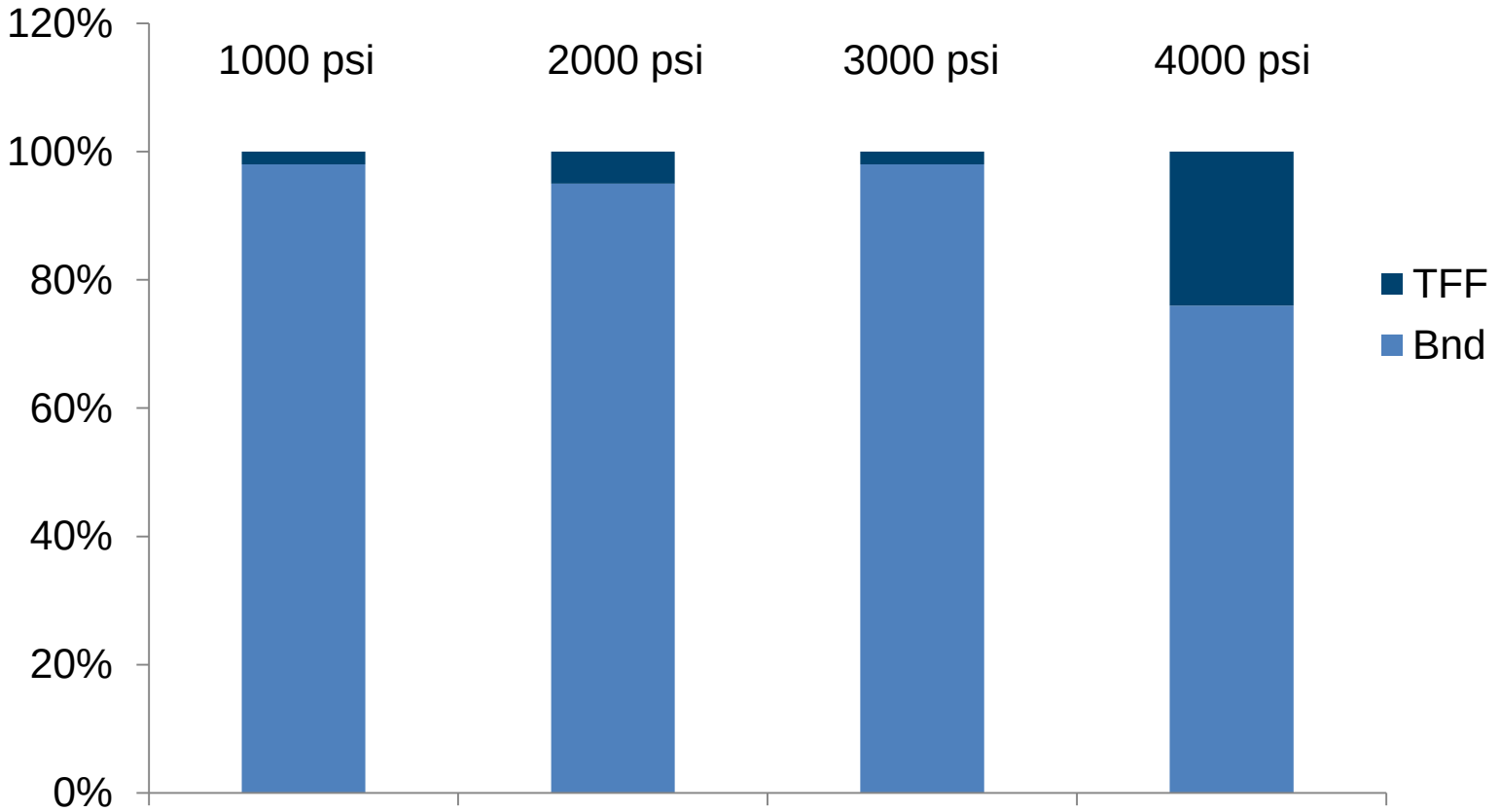
# Relative Effect of Boundary and TFF on Efficiency

- **In Cam-Lobe Motor as P Increases Boundary Friction Still the Most Important Factor**

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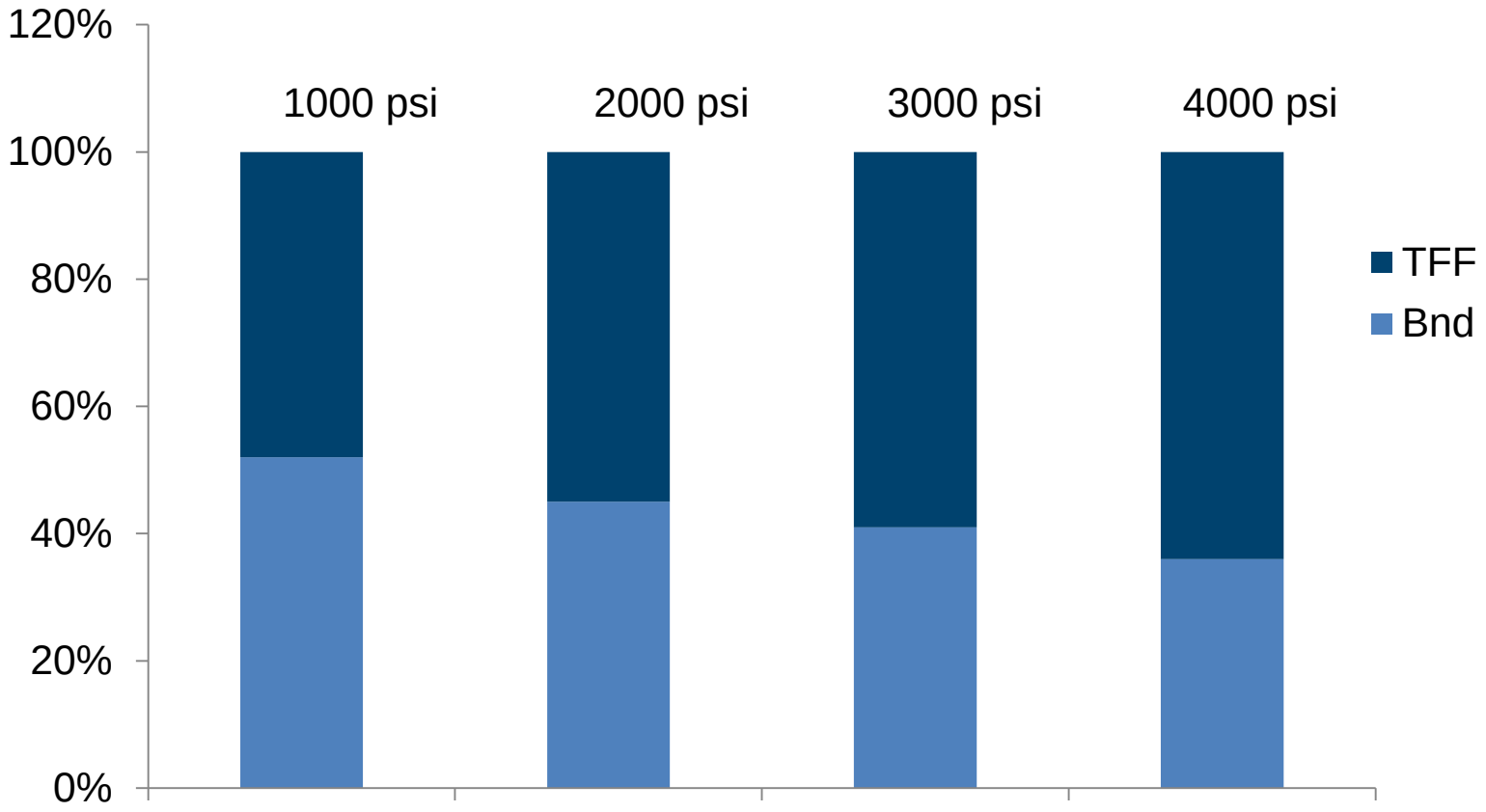
# Relative Effect of Boundary and TFF on Efficiency

- **In Axial Piston Motor as P Increases TFF has the Greatest Effect**

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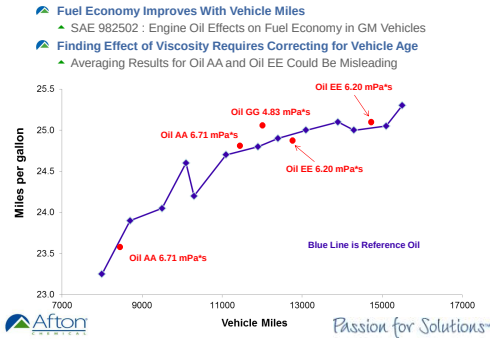
# We Know What Lubricant Properties Affect Efficiency

- High Temperature High Shear Viscosity; Boundary Friction; Thin-Film Friction

## Need to Recognize……

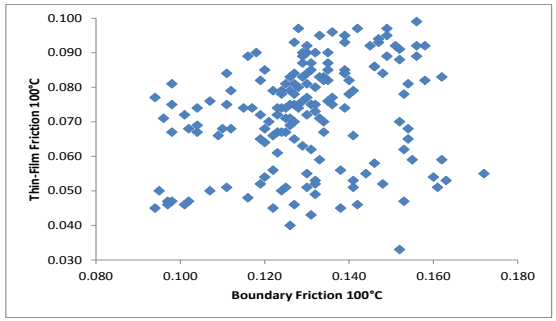
## Many Factors Affect Efficiency Measurement

Age of Vehicle



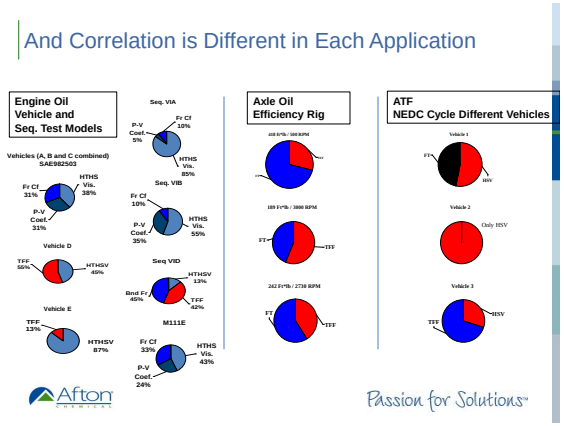

## All "Friction" is Not the Same

Boundary Friction and Thin Film Friction are Different




## Importance of Phys. Prop. Depends Upon Application

And Correlation is Different in Each Application





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"Reduction in CO2 Emissions by Optimization of Transmission Fluids for Improved Vehicle Fuel Economy", International Joint Tribology Conference, Hiroshima, Japan, Oct. 30- Nov. 3, 2011
"Effect of Operating Conditions on Torque Transfer Efficiency and Gear Fatigue", presented at MM&T Meeting, Mumbai, India, March 2011
"Effect of ATF Physical Properties on Fuel Efficiency", Presented at Fall SAE F&L, San Diego, CA, October 2010
"Bench Test Modeling for Current and Future PCMO Fuel Economy Requirements", PetroChina Lubricants Conference 2007, Ningbo, China, Sept. 17-18, 2007.
"Reduction in Axle Oil Operating Temperatures by Fluids with Optimized Torque Transfer Efficiencies", Lubrication Science 18 (1), p 7-23, 2005
"Improved Understanding of Axle Oil Rheology Effects on Torque Transfer Efficiency and Axle Oil Operating Temperature", SAE 2003-01-1972
"Relationship Between the Oil Performance in Standard Industry Fuel Economy Tests and Fuel Economy Measured in Vehicles", Additives 2001 Conference, Oxford, UK, March, 2001
"Critical Oil Physical Properties that Control the Fuel Economy Performance of General Motors Vehicles", SAE 982503


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# Quest for Lubricant Related Fuel Efficiency

*"Out of the Box"*

Originally Shown at 2010 SAE Conference

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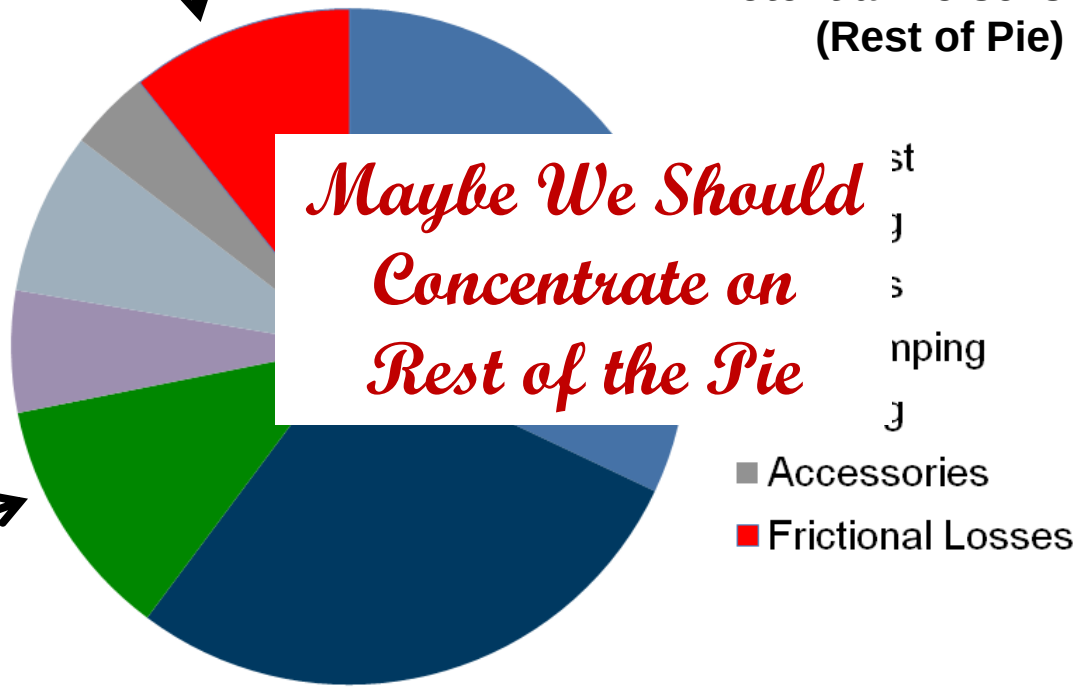
# Putting Lubricant Fuel Economy Benefits in Perspective

**We concentrate on Frictional Energy Losses**

**Potential Signal is Low**
**(~10% of Energy Lost as Friction)**
**Potential Noise is High**
**(Rest of Pie)**




*Maybe We Should Concentrate on Rest of the Pie*

**We measure useful work**

**Tribology International 37 (2004) pp 517-536**

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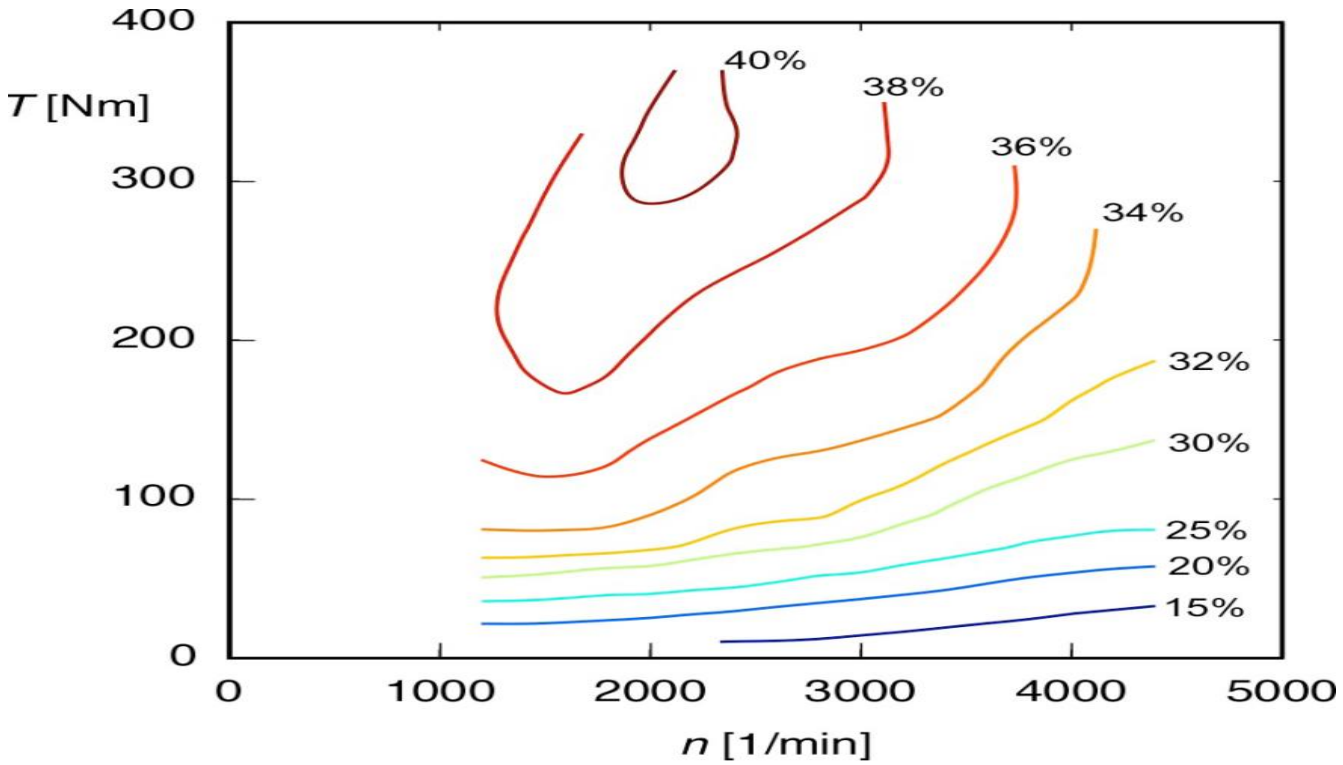
# Should We Concentrate on Making Sure that Engines Combust Fuel Efficiently?

- **What Technologies Can Lubricants Enable to Move into More Efficient Engine Operating Regime?**

**Typical Fuel Efficiency Map for Internal Combustion Engine**

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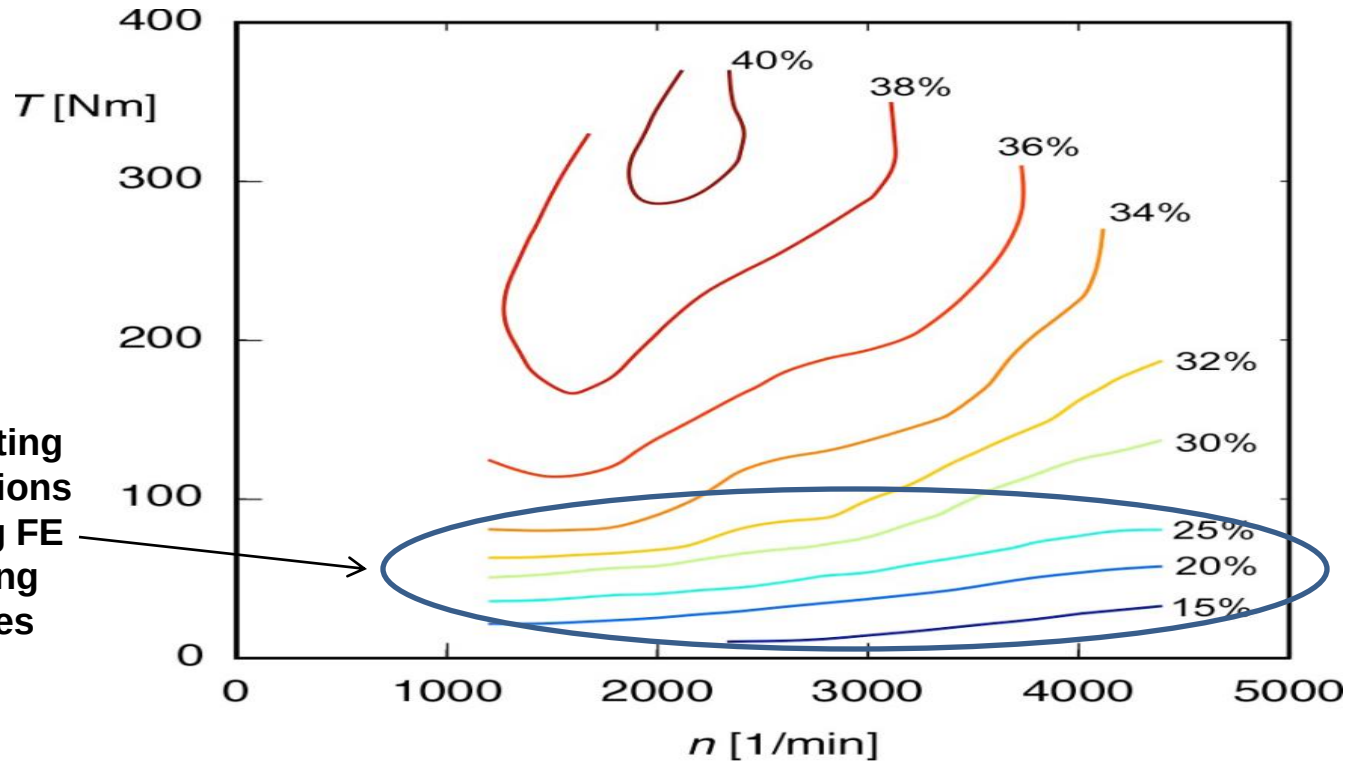


**Operating Conditions During FE Driving Cycles**

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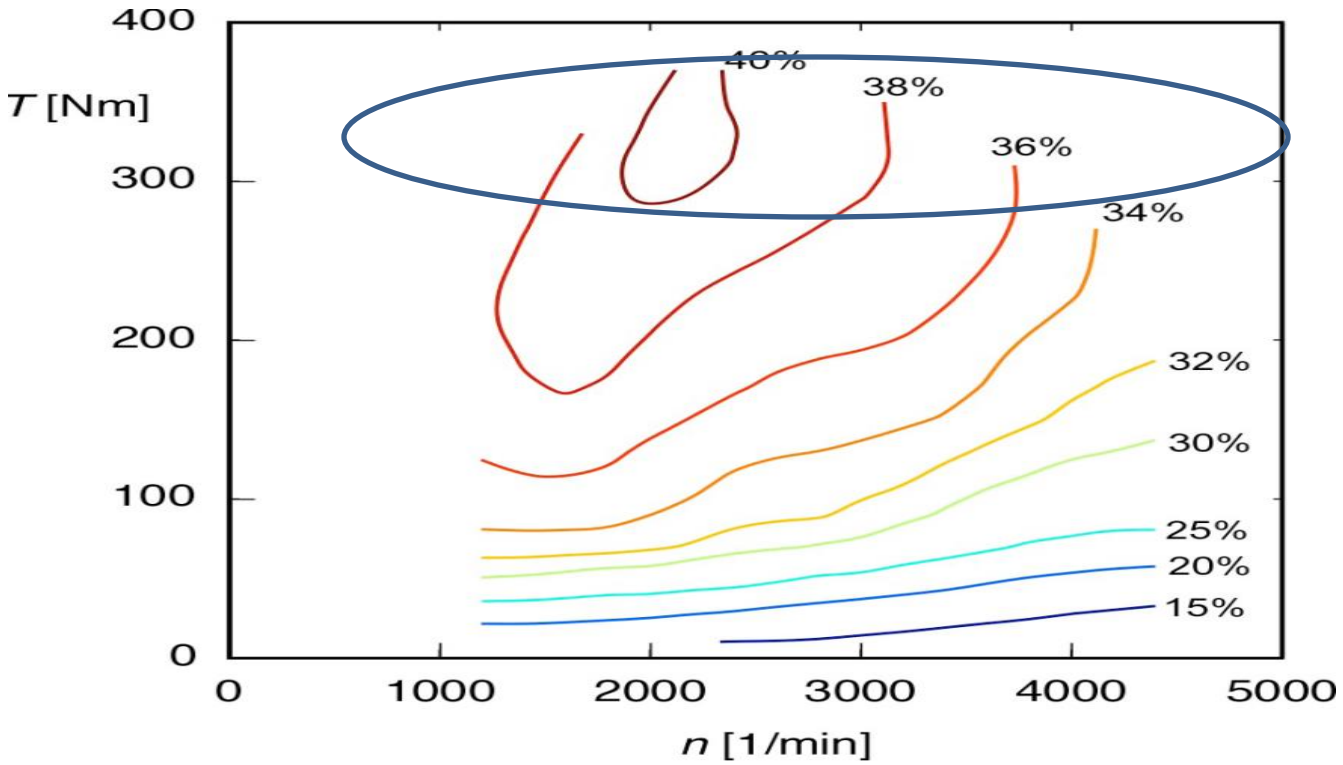


**Operating Conditions Of Hydraulic Hybrid**

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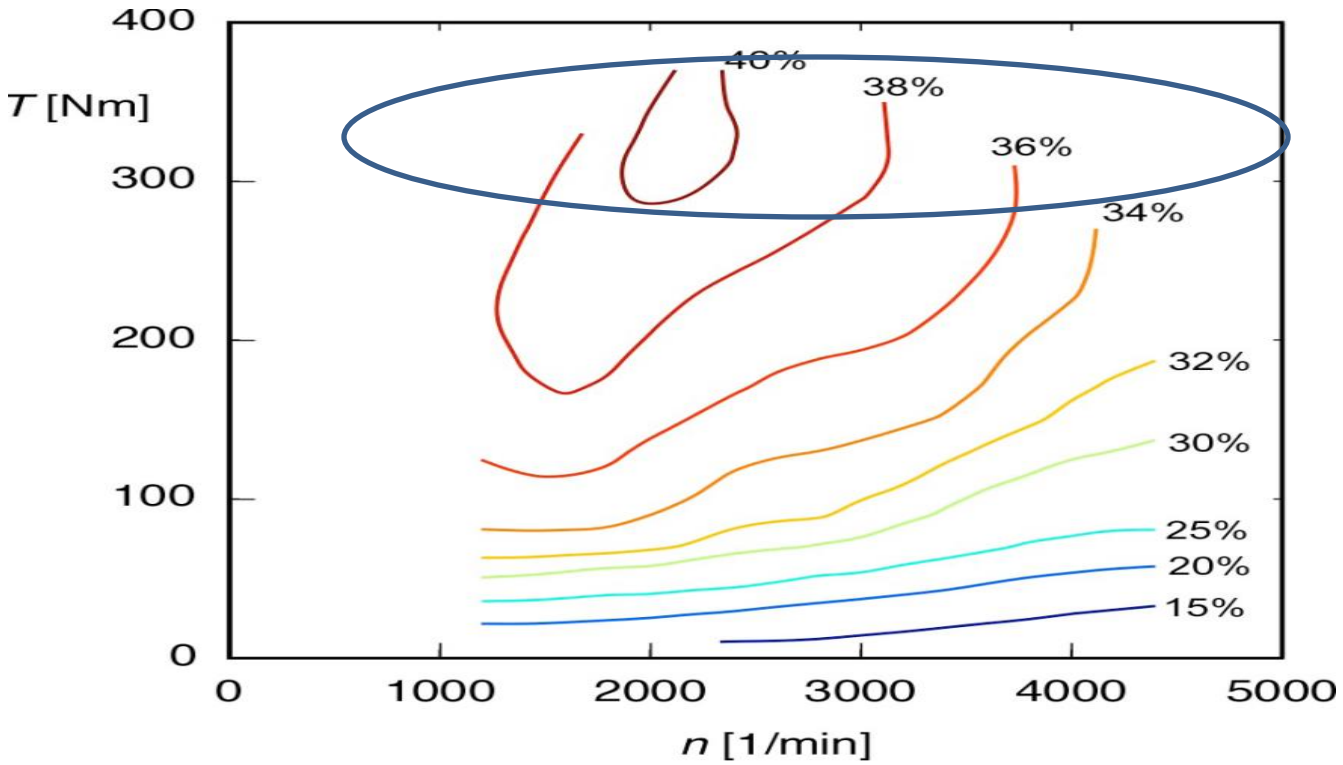


**Operating Conditions Of Hydraulic Hybrid**

**50% Increase In Fuel Efficiency**

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# Final Points to Consider

- **Continue to Focus on Frictional Losses**
  - Trust the Performance Tests (wear, fatigue) to Balance FE and Durability
  - Realize FE Testing is Not Easy or Consistent

- **If We Want to Look at a Bigger "Piece of the Pie"**
  - Develop Fluids to Enable New Hardware Options which Optimize the Combustion Process