DOE-NETL Cooperative Agreement #DE-EE0005445

Lubricant Formulations to Enhance Engine Efficiency (LFEEE) in Modern Internal Combustion Engines:

Project ID FT019

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Agenda

I. Objectives

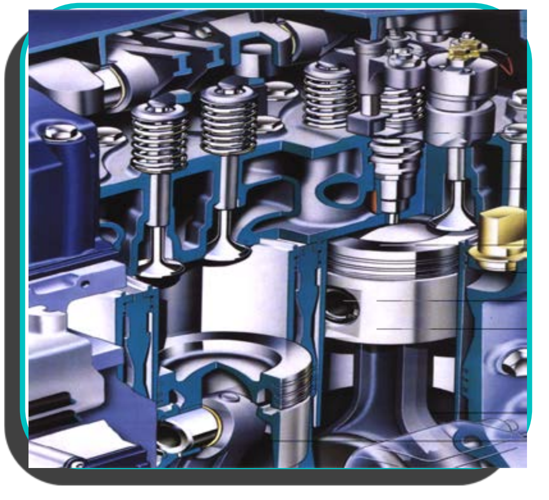
II. Background and Approach

III. Accomplishments
   1. Power Cylinder Modeling
   2. Valve Train Modeling/Experiment
   3. Engine Experiment

IV. Conclusions

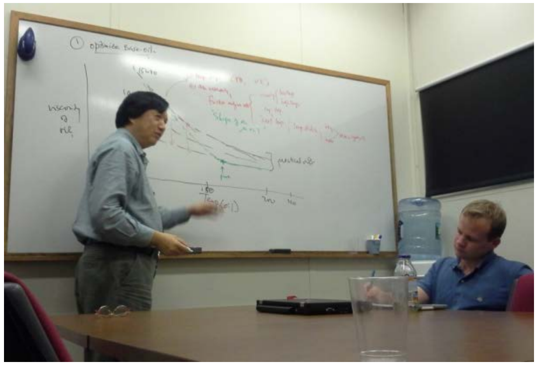
Project Objective

"Investigate, develop, and demonstrate low-friction, environmentally-friendly and commercially-feasible lubricant formulations that would significantly improve the mechanical efficiency of modern engines by at least 10% (versus 2002 level) without incurring increased wear, emissions or deterioration of the emission-aftertreatment system"



Lubricant Formulations for Enhanced Engine Efficiency (LFEEE)

- DOE Vehicle Technologies (VT) Program
  - 3 year
  - 3 grad students
  - Industry Partners
    - Infineum
    - Kohler
    - Cummins Filtration
- Related Projects
    - Supertruck

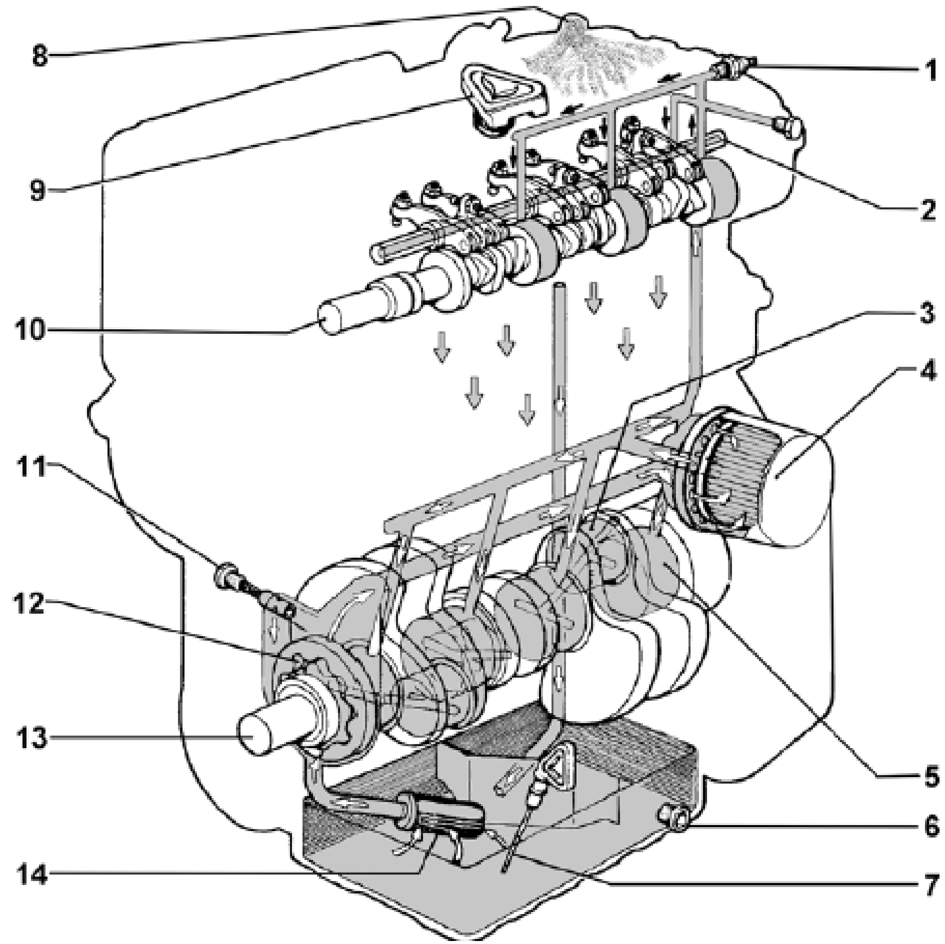


Phases – LFEEE (Lubricant Formulation to…)

Phase 1:
Investigate ideal formulations tailored to each major subsystem for best performance

Phase 2:
Investigate composite formulations for combined system

Phase 3:
Demonstrate mechanical efficiency improvement for best formulation over a range of operating conditions



Project Timeline

Lubricant Formulations to Enhance Engine Efficiency in Modern Internal Combustion Engines

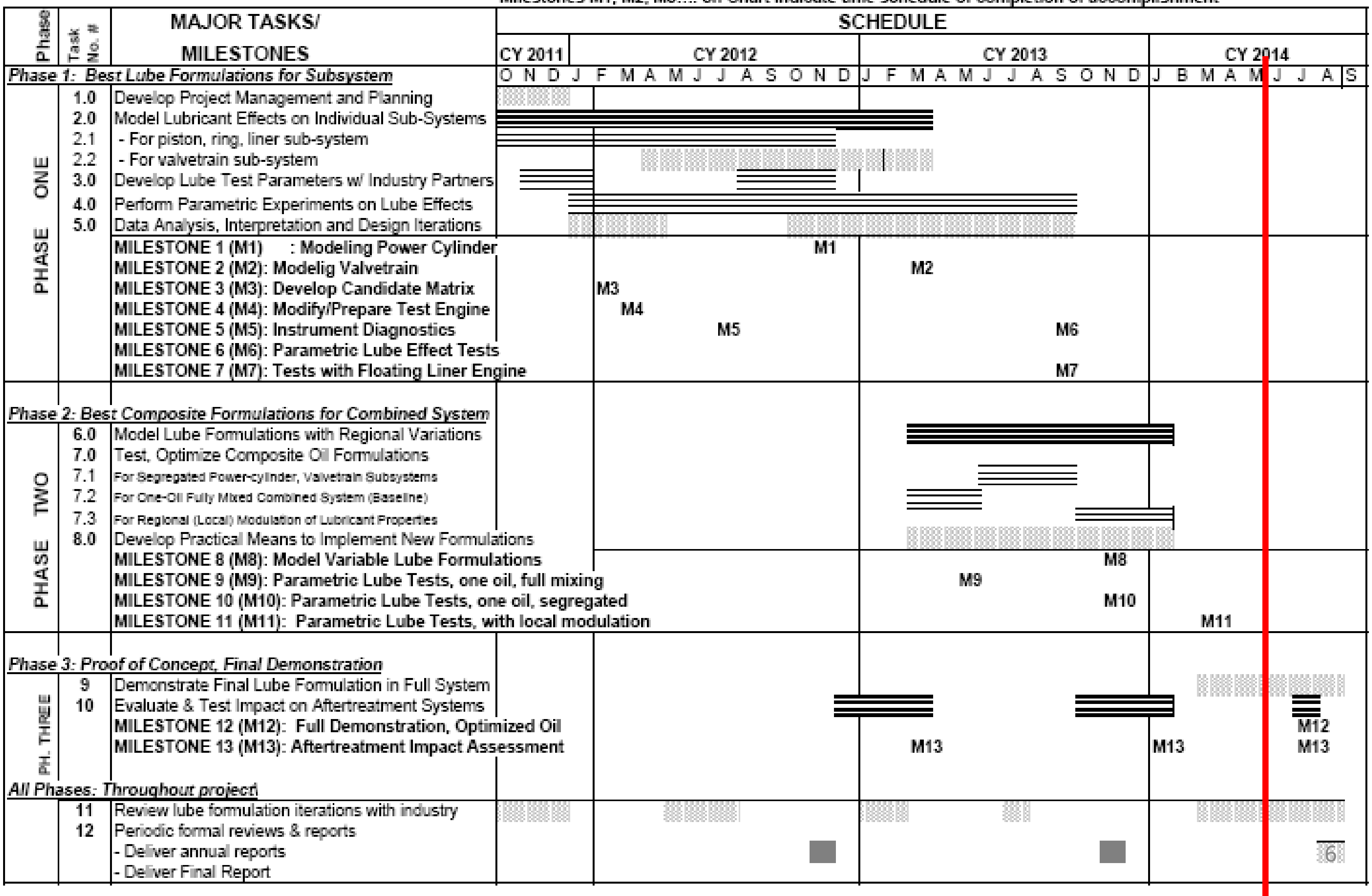
DOE-NETL Cooperative Agreement #DE-EE0005445

Massachusetts Institute of Technology

Project Start Date: Oct 1, 2011

Proposed Project Completion: Sep 30, 2014

Milestones M1, M2, M3.... on Chart indicate time schedule of completion of accomplishment

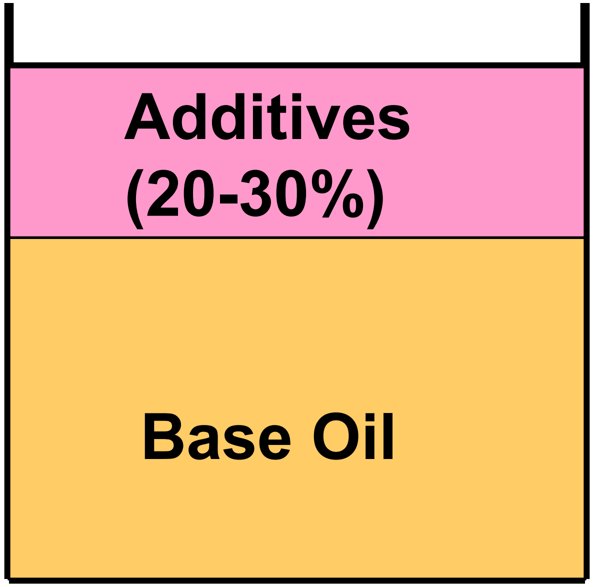


Background - Functions of lubricant/additives:

1. **Base Oil:** API Groups: I, II (low S), III (low S, high VI), IV: synthetic, V other

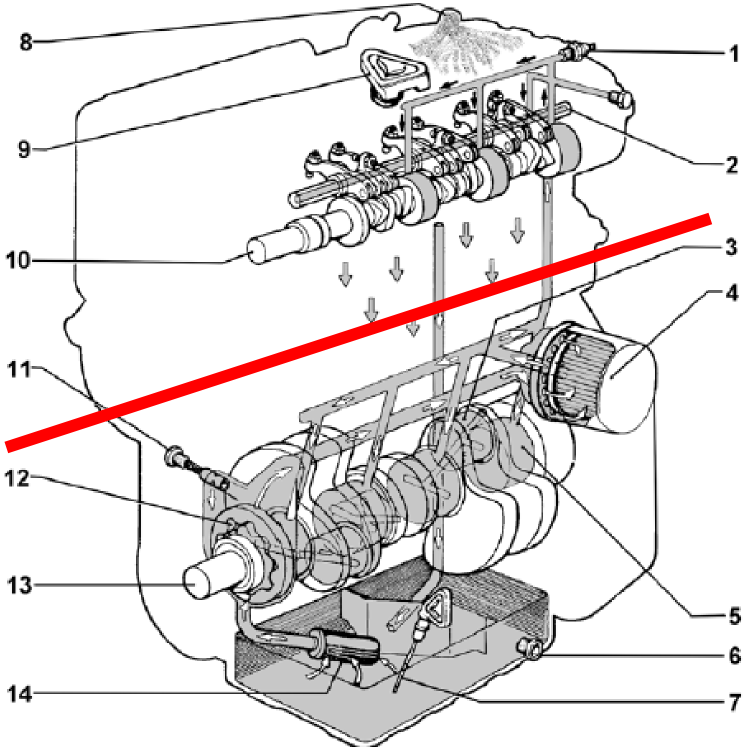
2. **Additives:**
   - Detergents
   - Dispersants
   - Anti-Wear
   - Anti-oxidants
   - VI and Friction Modifiers
   - Anti-foam
   - Pour-point depressants
   - Extreme-pressure wear, etc

automotive lubricant

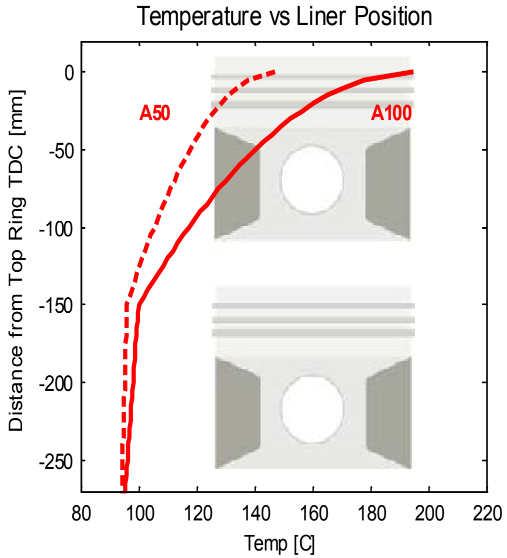


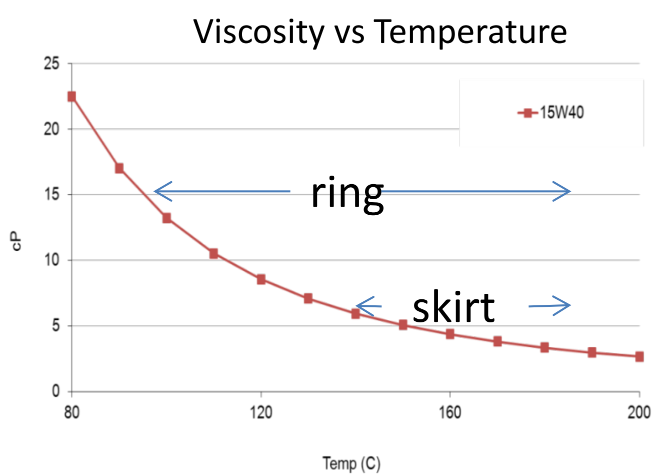
Background - Functional Requirements

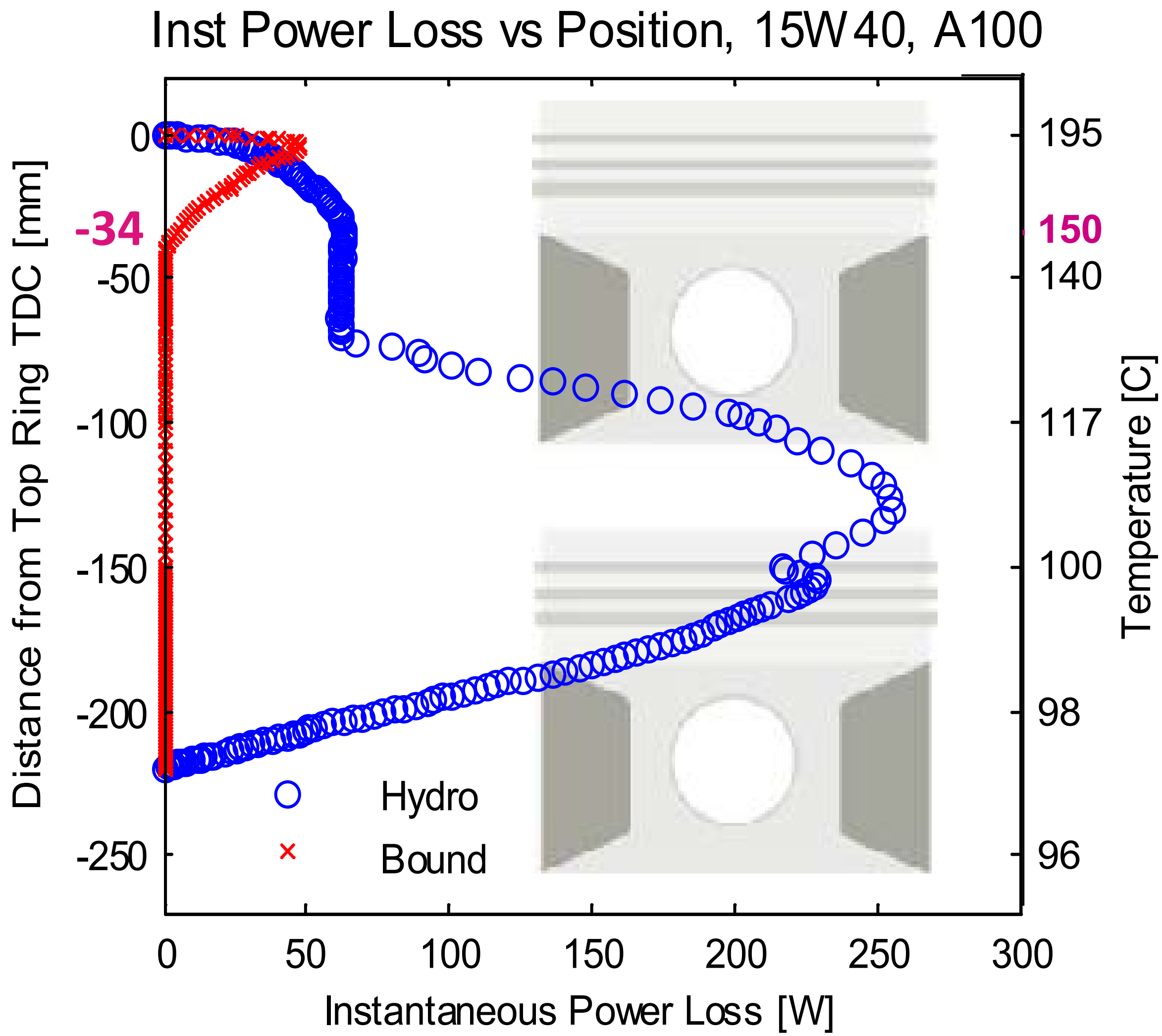
- Valvetrain
  - High EHD pressures (~2000 MPa)
  - Low Temp
  - No combustion gas/soot
  - No path to tailpipe
- Power Cylinder
  - Predominantly hydro
  - High Temp (rings ~250C)
  - Hostile (acidic) environment



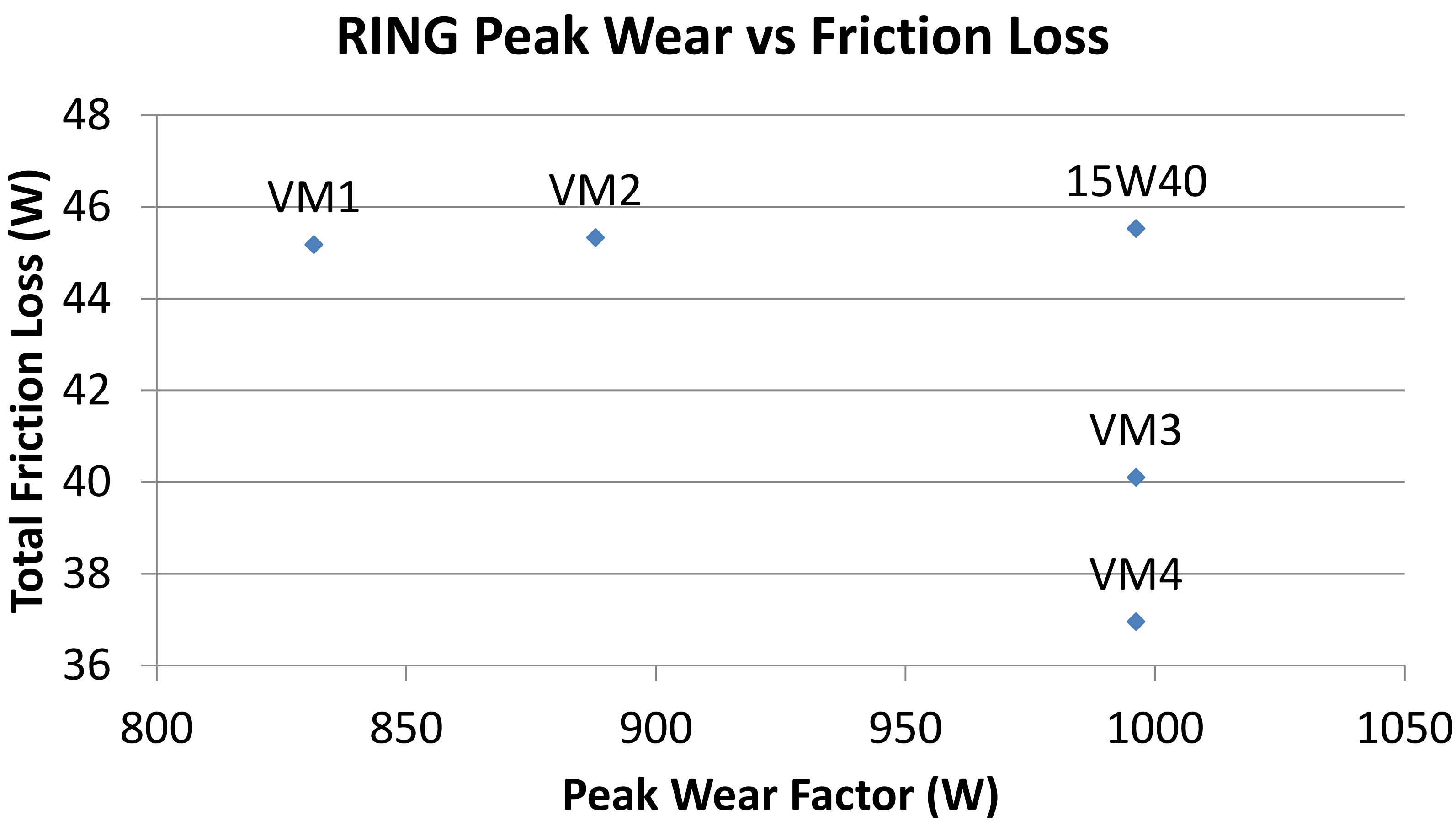
Friction (Top Ring, Skirt), Position & Temperature Domain





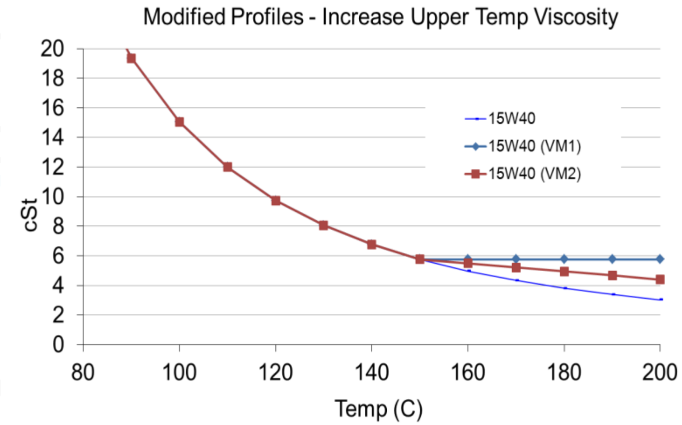


Optimizing –Upper and Lower Temperature Viscosity vs Friction and Wear

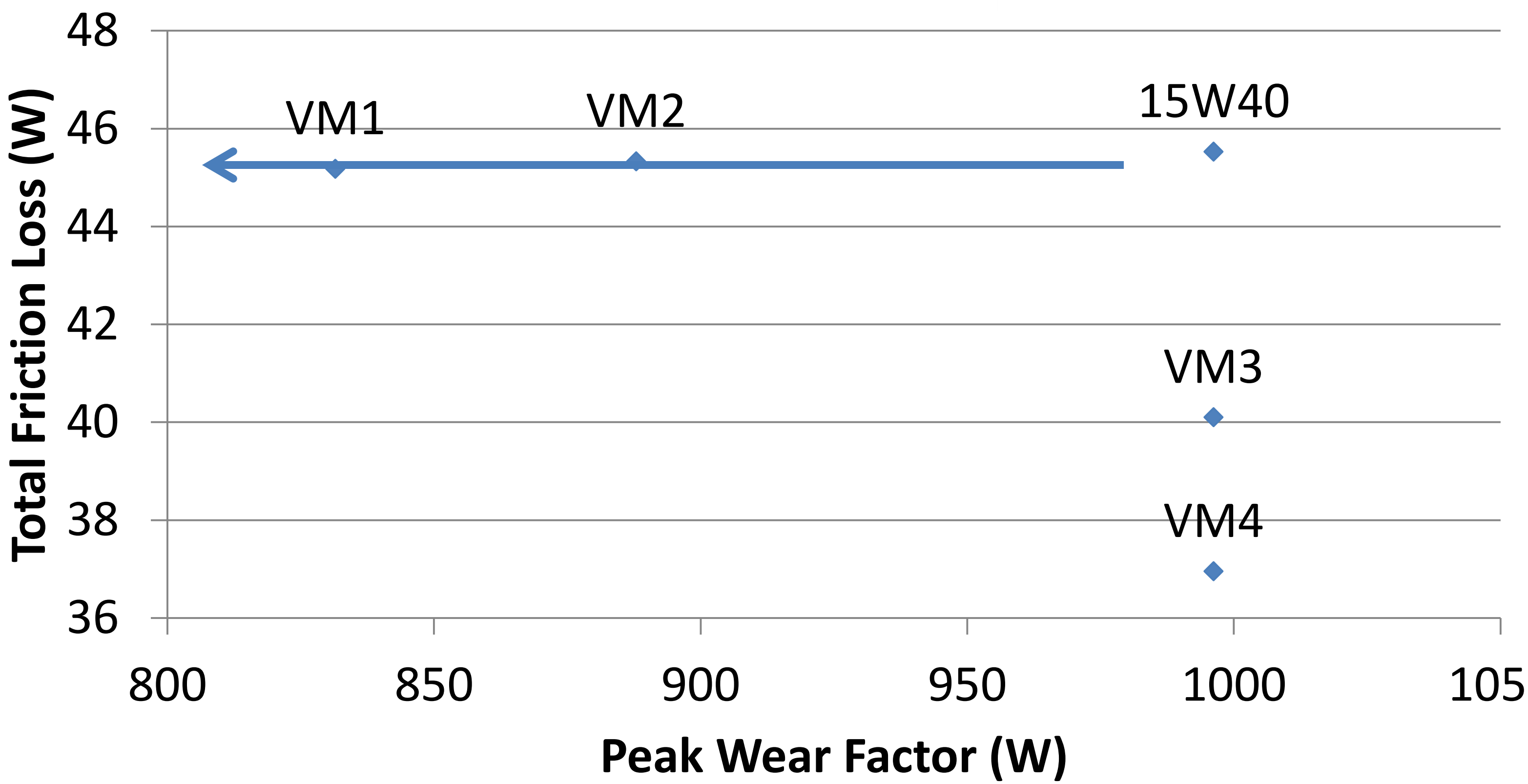


wear

Optimizing –Upper and Lower Viscosity vs Friction anc

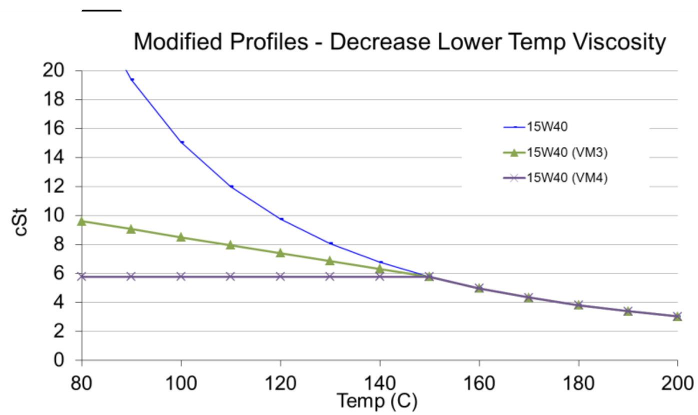


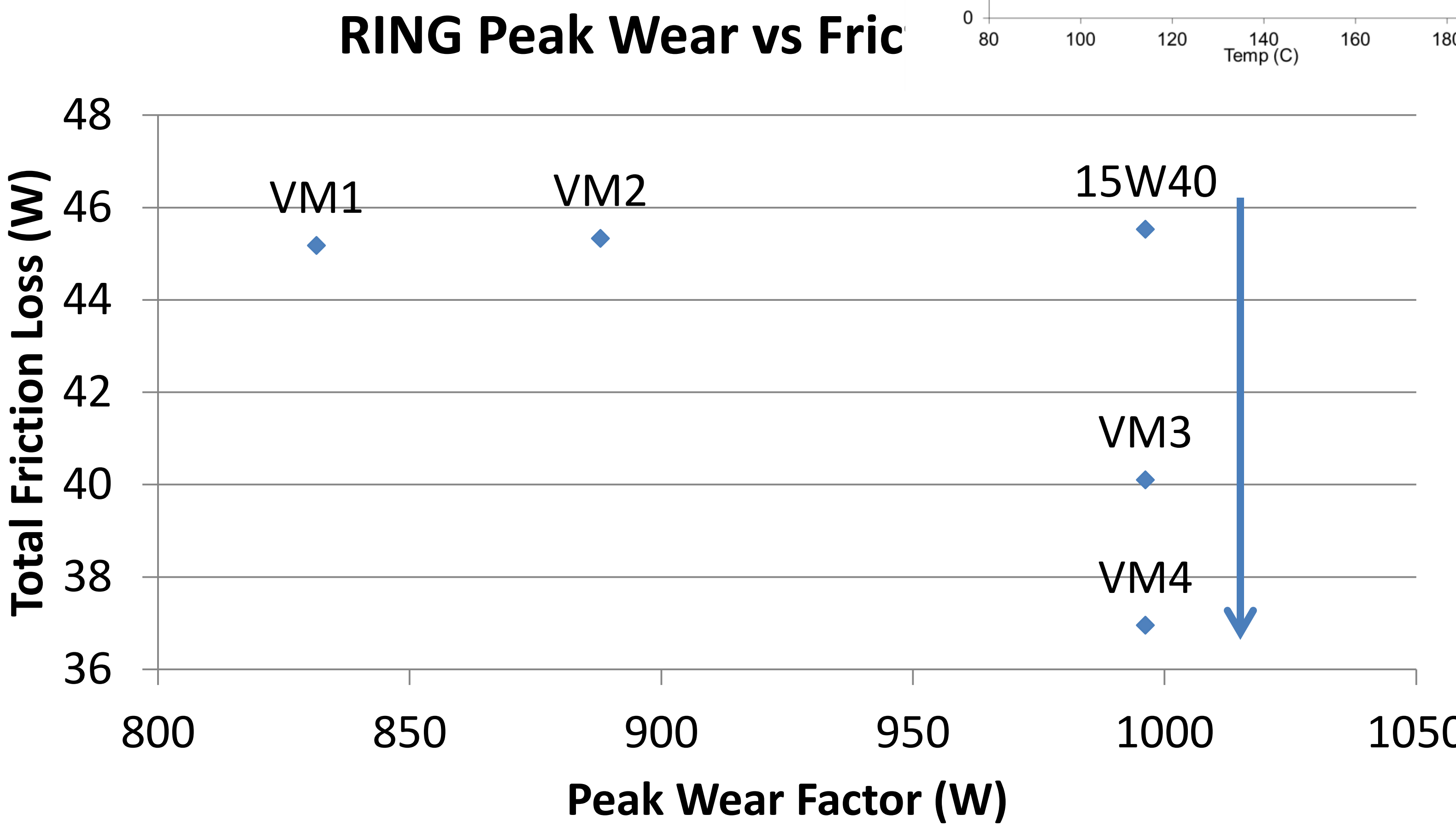
RING Peak Wear vs Fricti



wear

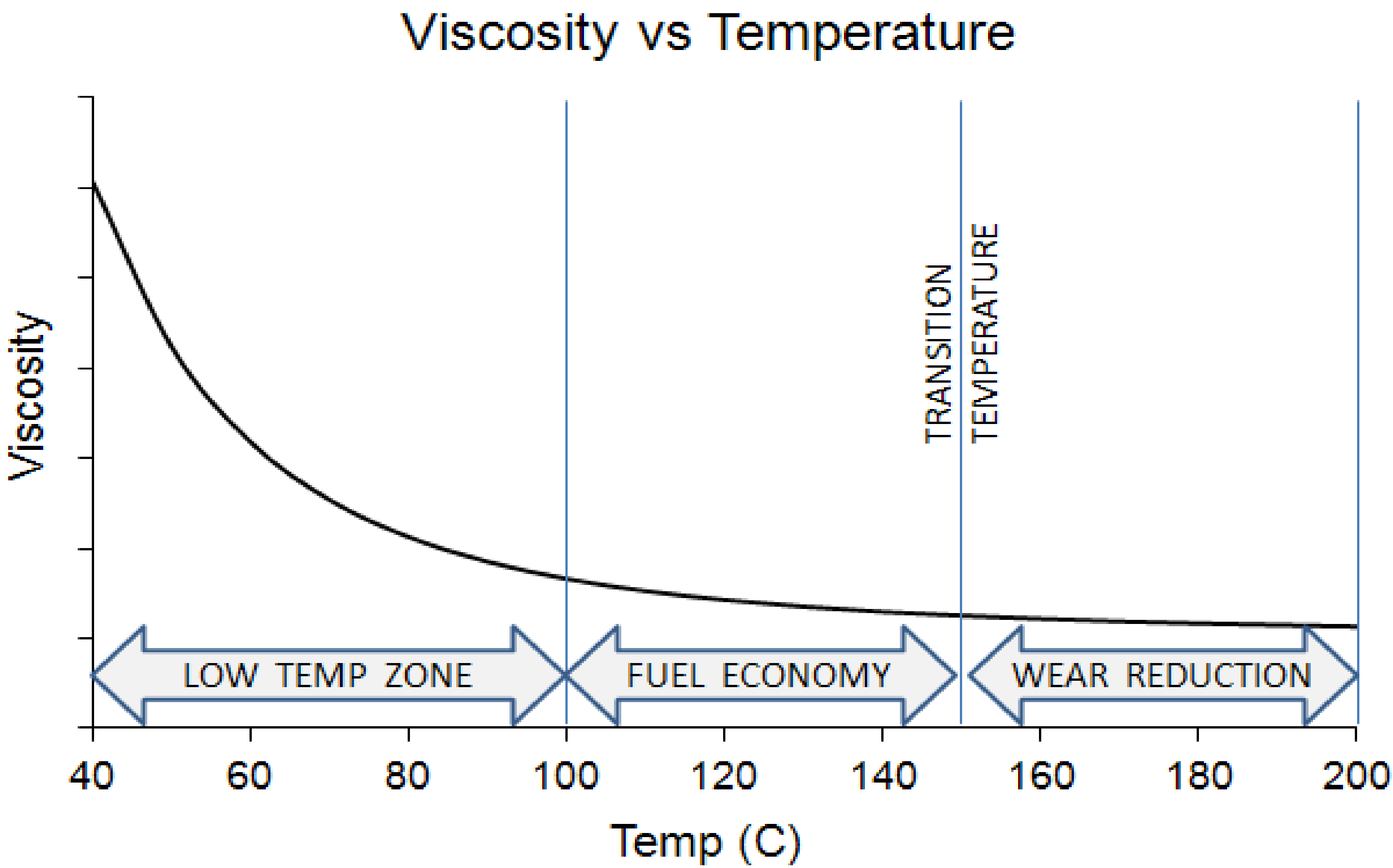
Optimizing –Upper and Low Viscosity vs Friction a



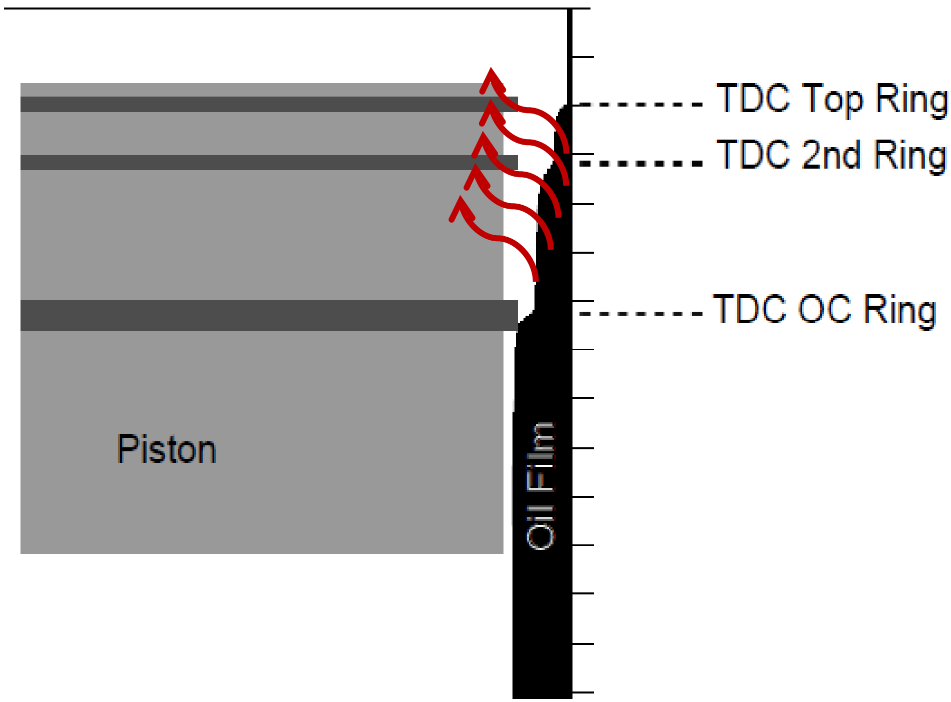


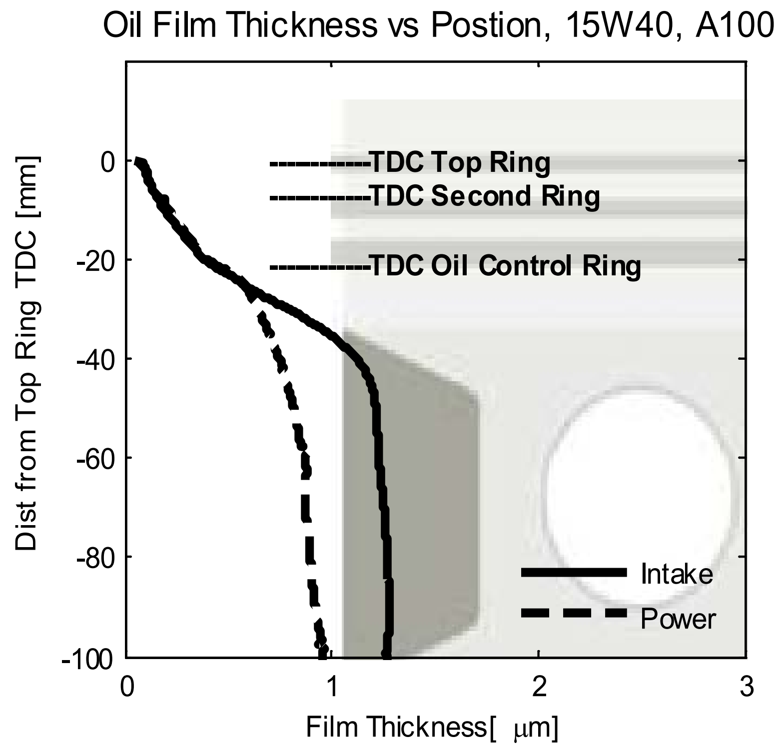
wear

Viscosity vs Temp design parameters for η_{mech}

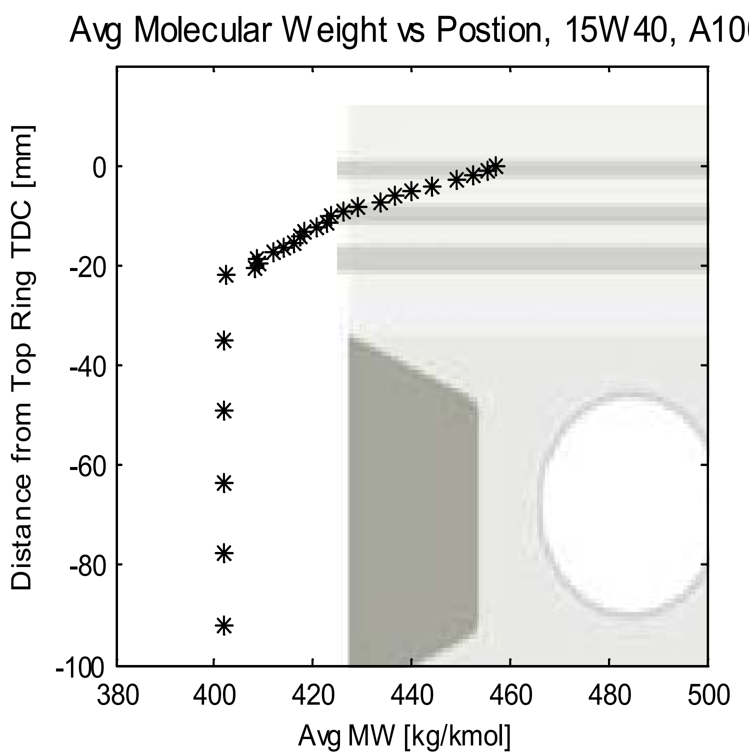


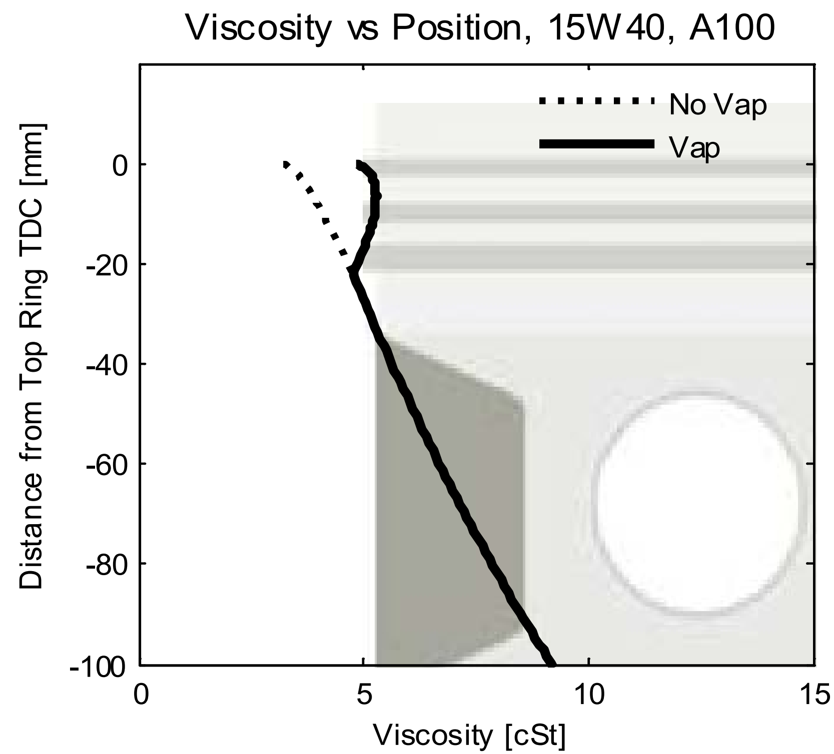
Vaporization/Friction Models





Vaporization/Friction Models





+ 1.1% total top ring friction
-15.0% boundary friction
+ 1.6% hydrodynamic friction
-17.0% wear factor

Power Cylinder modeling - Accomplishments/Looking Forward

Inspired strategies:

- Lubricant formulation strategy – maintain temp, vary lubricant….
  - Developing optimal power cylinder lubricant with Infineum/DDC
  - Presence of heavy component may provide wear benefit and allow lower viscosity midstroke

- In situ control strategy – maintain lubricant, vary temperature
  - (Supertruck program efforts)

Power Cylinder modeling - Accomplishments/Looking Forward

Publications:

- Plumley, Wong, Molewyk, Park. “Optimizing Base Oil Viscosity Temperature Dependence For Power Cylinder Friction Reduction” SAE Paper 2014-01-1658
- Molewyk, Wong. “In Situ Control of Lubricant Properties for Reduction of Power Cylinder Losses through Thermal Barrier Coating” SAE Paper 2014-01-1659

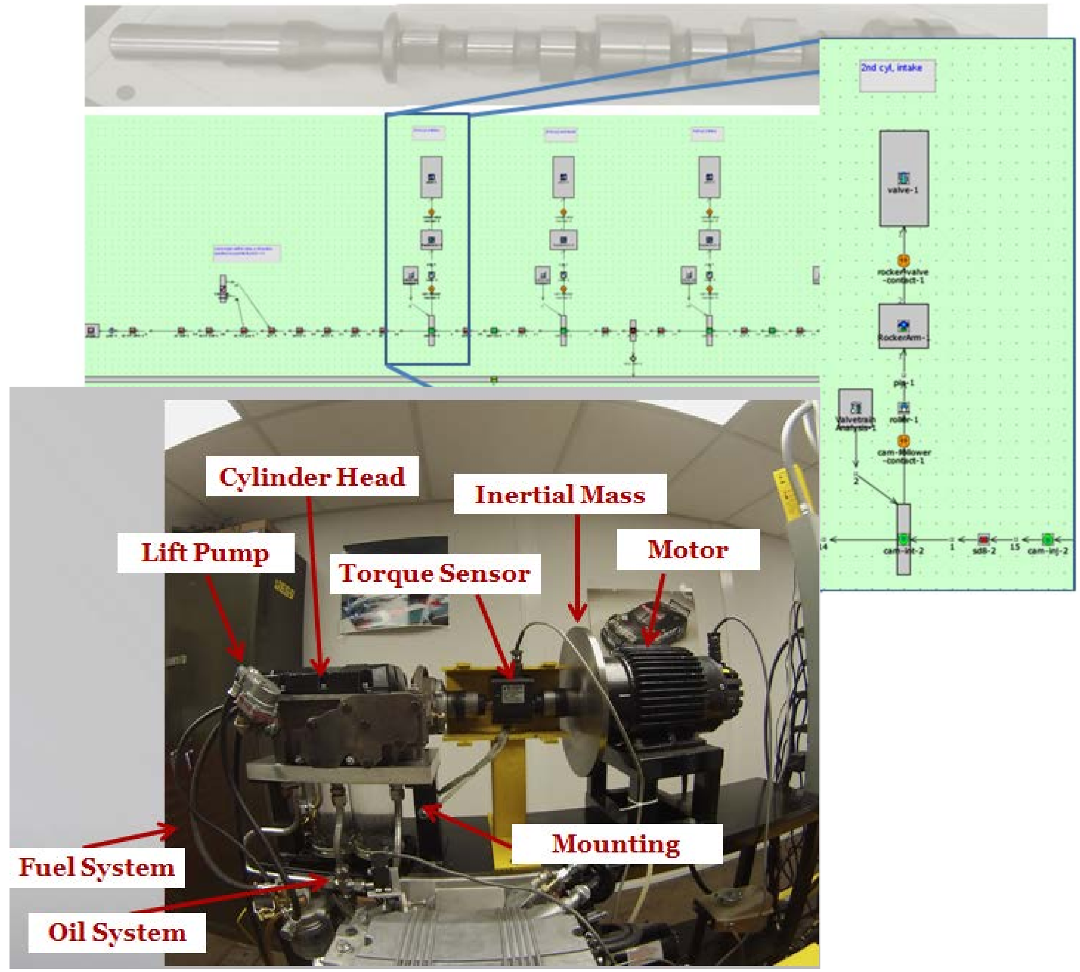
Acknowledgements

This work was supported by Cooperative Agreement DE-EE0005445 from the U.S Department of Energy. We gratefully thank our project sponsors, Dr Steve Przesmitzki and project monitor Nicholas D'Amico, for their support. We also appreciate the many helpful interactions with, and insights from, Dr Jai Bansal and Maryann Devine of Infineum, and our other program partners with whom we periodically exchanged ideas.

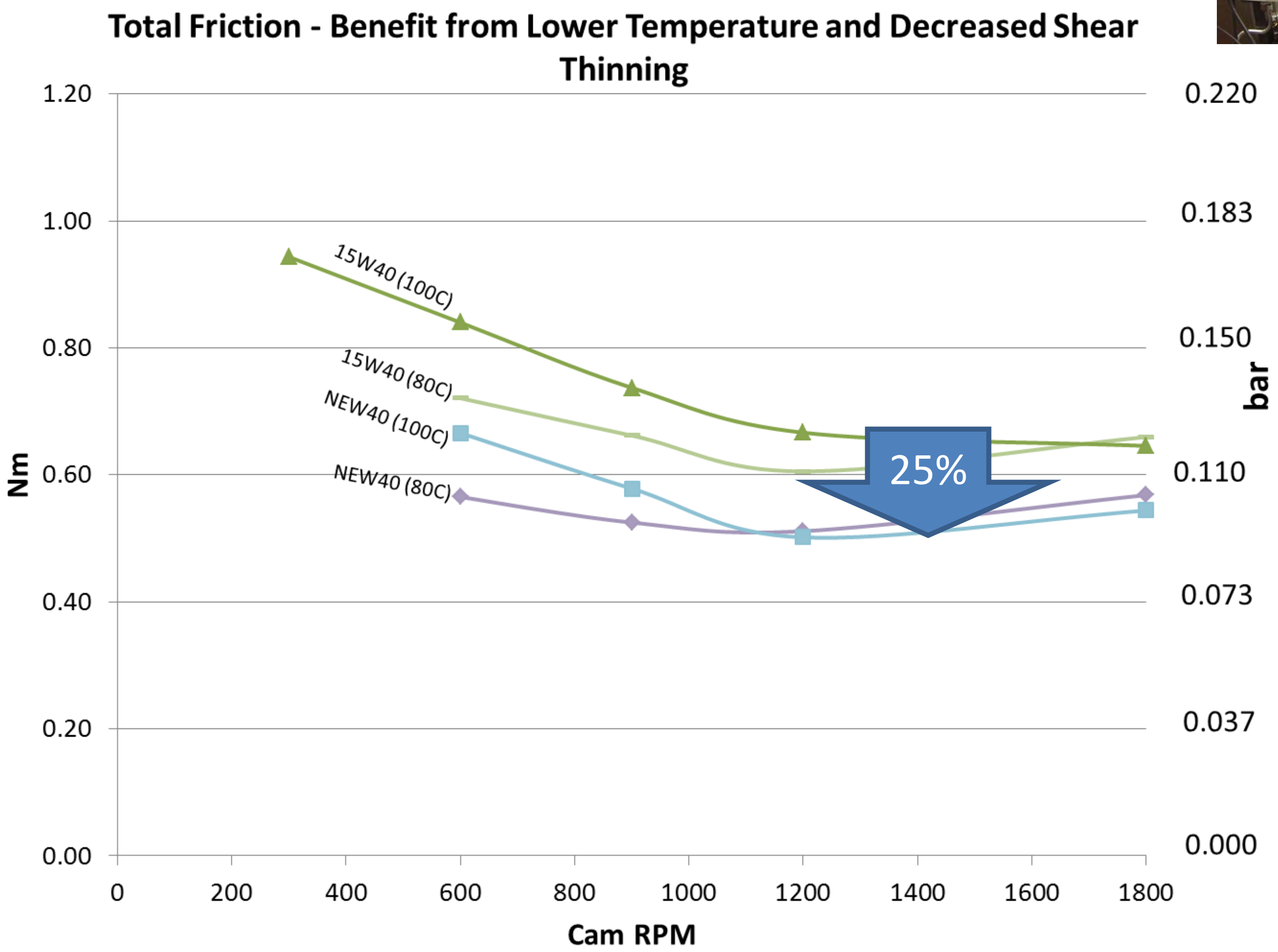
References

Valvetrain Temperature Dependence

- Valve Train modeled with GT Suite
- Experimental Bench Tests



Significant boundary friction identified at low speed in actual system



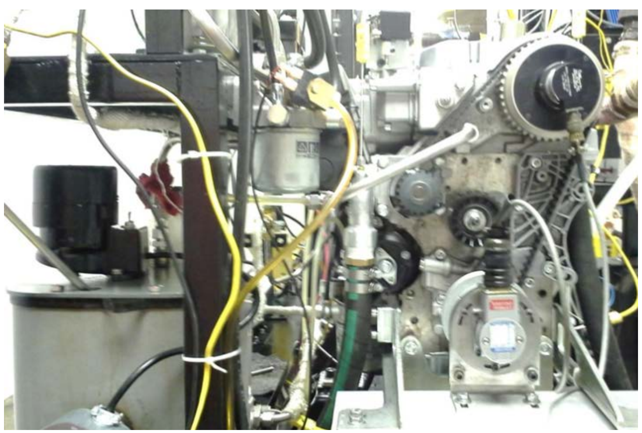
Valvetrain Studies- Accomplishments/Looking Forward

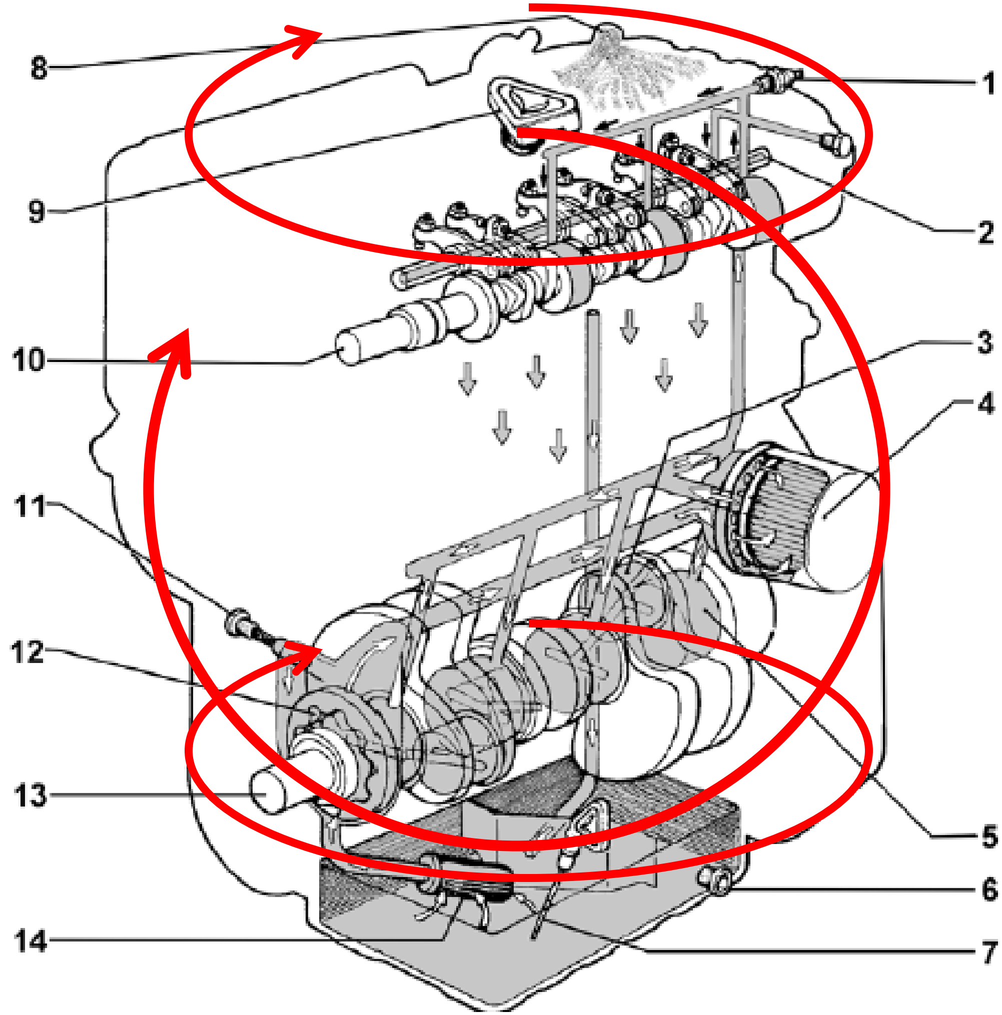
- Inspired strategies:
  - In absence of fuel system, significant boundary friction at low speed
    - Reduce shear thinning (developed pure Newtonian SAE 40)
    - Reduce temperature (split lubricating system option)

- Presentations:
  - Plumley, Wong, Devine, Bansal. "Analysis of shear-thinning on engine friction using mineral and PAO base oils" *STLE 2014 Annual Meeting*
  - Martins, Plumley, Wong. "Engine Lubricant Viscosity Optimization for Valvetrain and Power Cylinder Systems" *STLE 2014 Annual Meeting*

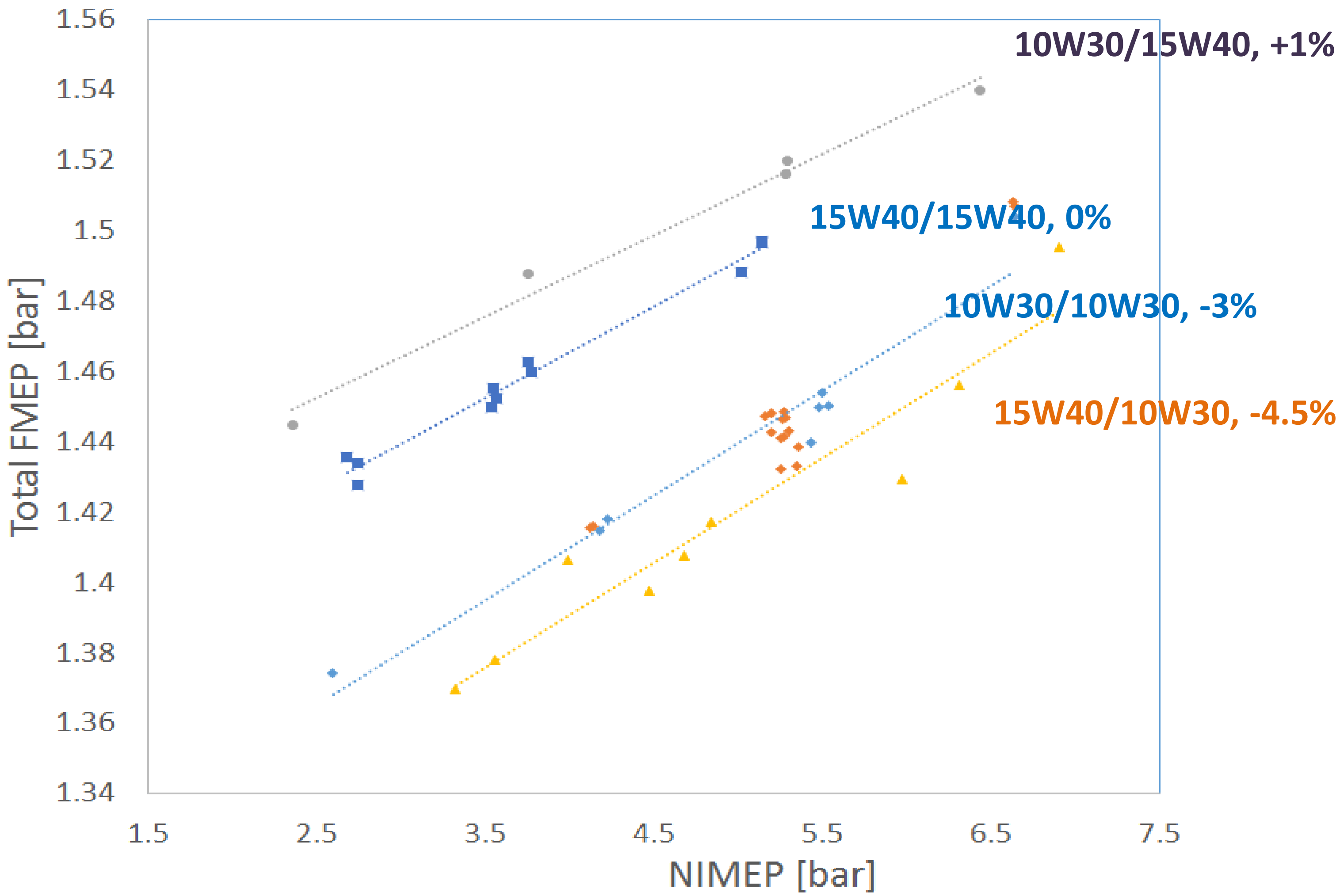
Split System Engine Tests

- Diagnostic tool

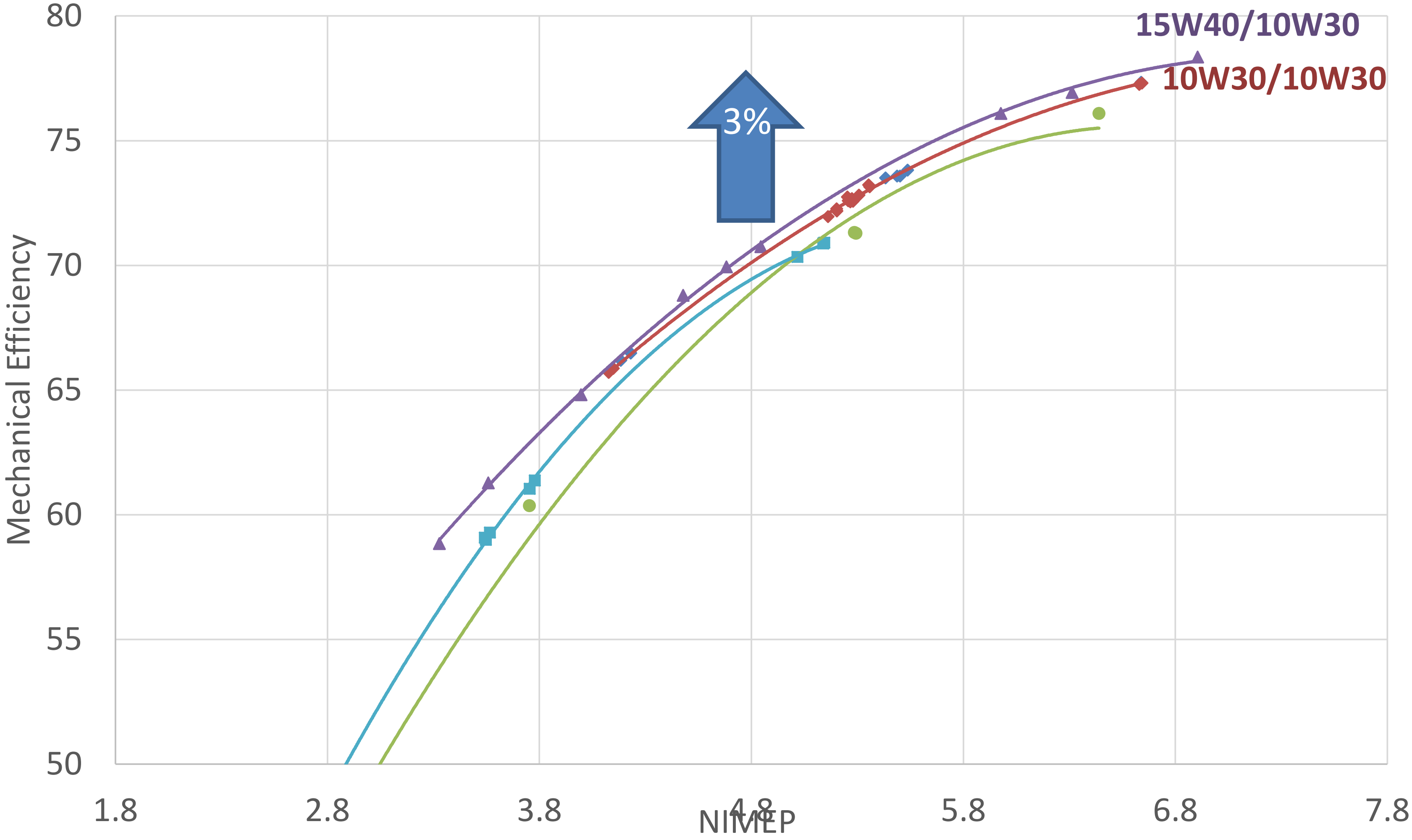




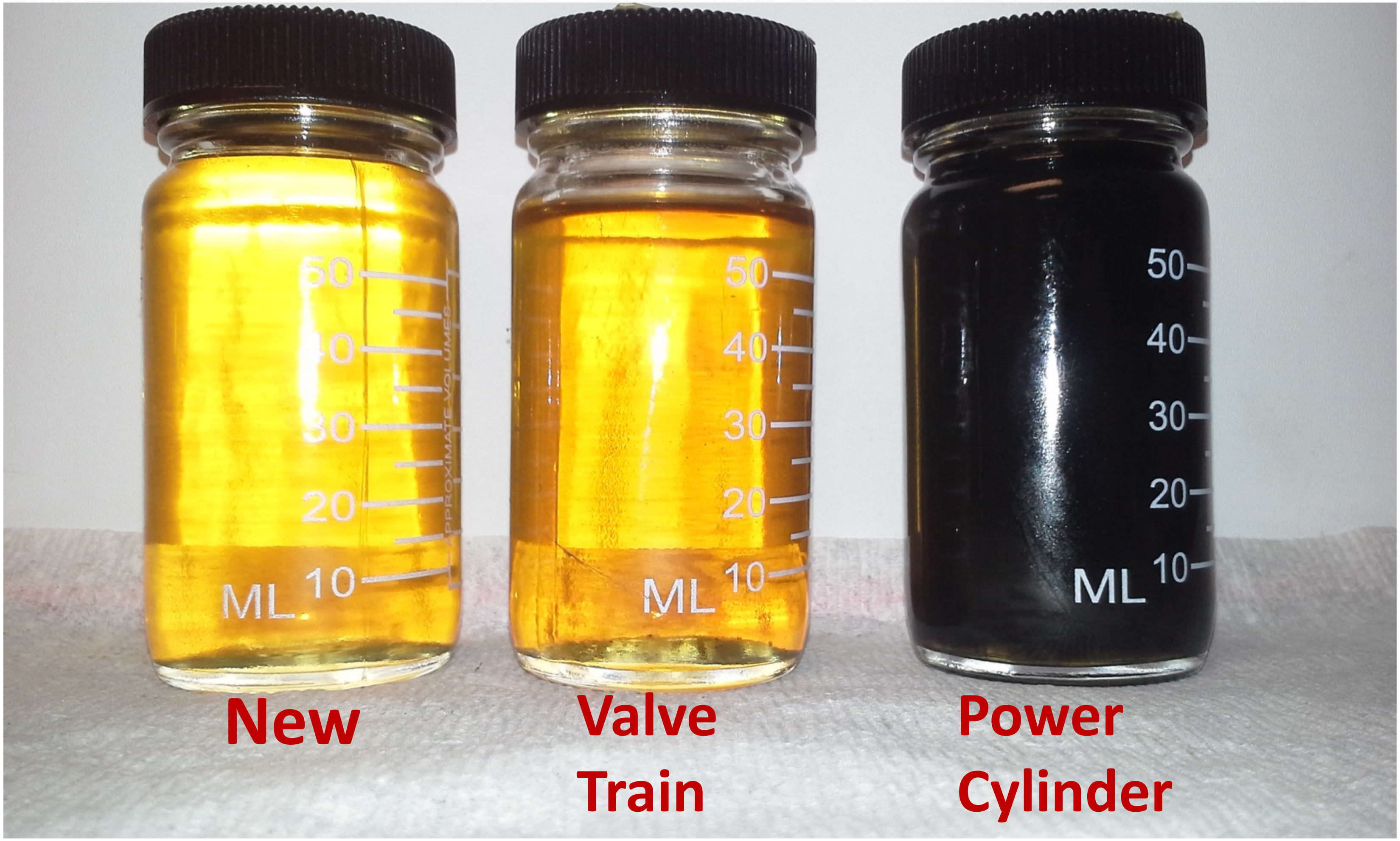
Slight total engine friction benefit with lower multigrade in power cylinder



Slight Total Mechanical Efficiency benefit with lower multigrade in power cylinder



Oil Aging - NEW40 sample, 8 hours in test engine



Whole Engine Studies- Accomplishments/Looking Forward

- Accomplishments:
  - Established working split system prototype
  - Demonstrated split system benefit with base oils
- Presentations:
  - Plumley, Wong, Devine, Bansal. "Analysis of shear-thinning on engine friction using mineral and PAO base oils" *STLE 2014 Annual Meeting*
  - Martins, Plumley, Wong. "Engine Lubricant Viscosity Optimization for Valvetrain and Power Cylinder Systems" *STLE 2014 Annual Meeting*

SUMMARY – Milestone Progress

- **M1: Initial modeling power-cylinder** ↑
- **M2: Initial modeling Valve Train** ↑
- **M3: Initial spec for test matrix w/ industry** ↑
- **M4: Modify engine for split system** ↑
- **M5: Diagnostic instruments on test engine** ↑
- **M6: Parametric Effects Tests** ↑
- **M7: Floating liner test** X

↑ = milestone reached

SUMMARY – Milestone Progress

- **M8: Model local variable formulations** ↑
- **M9: Parametric Tests, one oil, full mix** ↑
- **M10: Parametric Lube Tests, one oil, split** ↑
- **M11: Parametric Lube Tests, 2 oils, split** ↑
- **M12: Full Demo, Optimized Oil** – (July '14)
- **M13: Aftertreatment Impact Assessment** – (July '14)

CONCLUSIONS

- **The research team has identified and formulated lubricants that optimize the power cylinder friction**
- **The research team has identified and formulated lubricants that optimize the valvetrain friction**
- **The benefit (lower overall engine friction) of the split lubricant circuits has been demonstrated**
- **All scheduled milestones were met**