Synthetic Liquid Lube Oil Development: Lessons Learned

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OHVT Mission

To conduct, in collaboration with our heavy vehicle industry partners and their suppliers, a customer-focused national program to research and develop technologies that will enable trucks and other heavy vehicles to be more energy efficient and able to use alternative fuels while simultaneously reducing emissions.

Synthetic Liquid Lubricant

Anticipated Problem with "Adiabatic" or Low Heat Rejection (LHR) Diesel Engine

- European engine companies working on LHR engines indicated a need for a high temperature liquid lubricant
- Roy Kamo used Stauffer's SDL-1
- Program evolved to develop advanced synthetic liquid lubricant
  - Improve understanding of high temperature liquid lubricant technology
  - Develop comprehensive technology base
    - Increase rate of further development
    - Commercialization of advanced lubricants
- Conventional anti-wear and overbase additives cause deposit formation
  - Top ring reversal temperatures 370- 425 °C
- Conventional anti-wear agents (zinc dithiophosphates) ineffective temperatures >345 °C
- Looking for combination ashless anti-wear additives
  - Function temperature range ambient 600 °C
- Ashless to prevent
  - Ring clogging
  - Other deposit formation

Stauffer/Cummins Synthetic Liquid Lubricant Program

- Stauffer developed SDL-1 used in Kamo's adiabatic diesel engine
  - Ideas for improving
- Stauffer developed synthetic lube oils used in most aircraft gas turbine engines
- Stauffer working with Cummins in Columbus (precontract)
  - Demonstrated synthetic liquid lube that allows operation at TRR temperature of ~875 °F for 275 hours
  - No other testing reported at these temperatures
- LE-55 (LHR Engine Program)
  - Did not require high temperature synthetic lube oil
  - Current engines do not require synthetic liquid lube oil
    - Porsche and Mercedes recommend synthetic lube oil

Basestock Function As:

1. Dispersants
2. Viscosity index improvers
3. Pour point depressants
4. Seal swelling agents
5. Anti-wear agents

Synthetic Lubricant Basestock Candidates

1. Diesters
2. Polyol esters
3. Phosphate esters
4. Poly-α-olefins
5. Silicones
6. Ethers
7. Alkyl benzenes

9. Petroleum base oils

Criteria for Basestock for Crankcase Lubrication

1. Good film former
2. Carrier for additives
3. High oxidation resistance
4. Carrier for blow-by products and fluid decomposition
5. Localized cooling medium
6. Proper viscosity characteristics
7. Compatible with additives and engine materials
8. No deposits if decomposition
9. Available in quantity at reasonable cost

Basestock Experience

1. Basestocks either decomposed via predictable, concerted mechanism
   - yielding volatile decomposition products

   or

2. Basestocks decomposed via a random, high energy pathway
   - resulting in polymers and carbon deposits

Basestock Incorporating Additive Demonstrated Enhanced Performance

- Elimination of polymeric viscosity index improvers
  - Lessens deposit
  - Stabilizes viscosity to shear down
- Elimination of polymeric pour point suppressants
  - Lessens deposits
  - Eliminates cold start fluctuations
- Elimination of antioxidants
  - Reduces costs
  - Precludes catastrophic lubricant failure due to additive depletion
- Extends drain intervals

Lubricants Based on Ester Basestock

1. Thermally stable and resists oxidation
   - Less likely to form deposits
2. Ester based lubricant would assist the additive package with
   - Dispersancy
   - Deposit control
   - Seal swell
   - Improved viscometrics
3. Some additives eliminated could improve performance

Ashless Additive Concerns

- Conventional oil additives cannot be used
  - Not compatible with synthetic basestocks
  - Poor performance at high temperatures
- Viscosity index improvers and pour point depressants at elevated temperatures
  - Tendency to degrade rapidly
  - Deposit formation

Viscosity Index Improvers

- Polymeric additives which alter basestock temperature/viscosity curve
- Allow low temperature flow properties while preventing thinning of basestock at high temperatures
- Polymers not stable under high shear stress or at high temperatures
- Synthetic basestock must provide proper viscosity index for temperature

Anti-wear Additive

- Zinc dithiophosphates (ZDP)
  - Classical anti-wear additive petroleum oils
  - Also an anti-oxidant
  - Effective in conventional engines to 315 °C
  - Does not work well with ceramic surfaces
- Problem above 315 °C
  - Deposit formation of non-volatile zinc salts or oxides
  - Typically found in ring groove area
    - Contributes to ring stressing
- Approach
  - Replace ZDP with ashless anti-wear agents
    - Phosphate and dithiophosphate esters
  - Also need ashless anti-oxidants to function in synthetic basestock

Pour Point Suppressants and Advanced Synthetic Basestocks

- Pour point suppressants
  - Inhibit wax formation
  - Enhance low temperature fluidity
  - Thermally unstable
  - Lead to deposit formation
- Advanced synthetic basestocks
  - No wax
  - Can provide wide temperature viscosity
  - No pour point suppressants

Primary Ashless Additives Incorporated to Improve

1. Anti-wear properties
2. Oxidation resistance
3. Anti-foaming properties
4. Detergency and dispersancy
5. Corrosion inhibition

Overbase and Detergent Additives

- Metallic salts of phenates and sulfonates
  - Neutralize acidity
  - Minimize deposit formation
- Result
  - Extending oil drain interval
  - Reduce deposits
- Problem
  - Decompose at high temperature
    - Cannot be used above 315 °C
  - LHR engine tests with conventional additives
    - 50% of ring deposits were from overbase and detergency additives
- Solution
  - Chemically active filter with alternative substances activates on filter surface

High Temperature Liquid Lubricant Formulation

Selection of the finished formulation will be based on:

1. Oxidation resistance
2. Deposit control
3. Wear particles
4. Wide temperature operation
5. Good elastohydrodynamic film forming capabilities and high temperature, high shear viscosity
6. Other properties related to high temperature operation, i.e., detergency, dispersancy
7. Materials compatibility

Diesel Engine Friction Losses

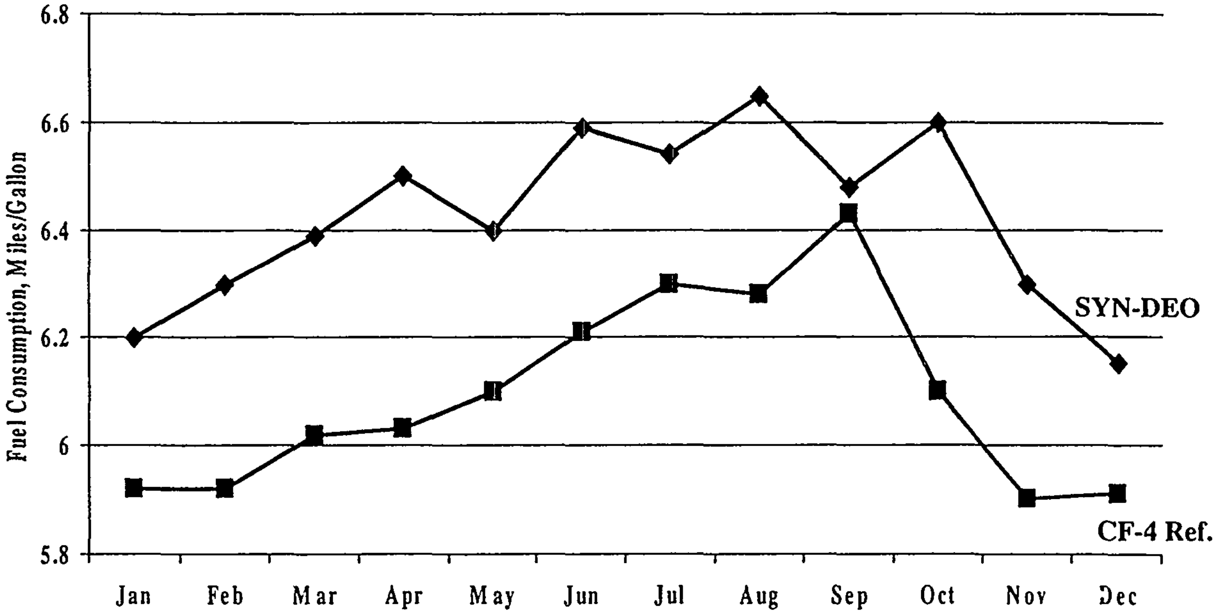
- Friction losses are an order of magnitude less than thermal losses
- Improves engine power and fuel economy from reduced friction losses
  - Piston/ring interface
  - Valve gear
  - Crankshaft and other bearings (maximum heat contributor)
  - Accessories
- 250kW heavy duty truck engine
  - 35kW heat dissipated from oil (20% from piston liners)
- Lubricant
  - Reduce friction
  - Reduce emissions
    - Priority

Performance of Mineral and Synthetic Liquid Lube Oils
(Reported at SAE by Caterpillar and Mobil)

- Fleet tests with 2 mineral oils and 2 synthetic oils in diesel engines
  - Synthetic oils improved fuel consumption by an average of 3.2%
  - Drain interval for fully synthetic diesel oils
    - 45,000 to 60,000 miles depending on engine type
    - 3 to 4 times the engine builder's standard recommendation

SAE 982718 Extended Oil Drain Performance Capabilities of Diesel Engine Oils
SAE 952553 A Synthetic Diesel Engine Oil with Extended Laboratory Test and Field Service

Series 60 engines operated on SYN-DEO versus the CF-4 reference (Petroleum base lube oil)



Ref: SAE 982718

Lessons Learned

- Basestock chosen to eliminate additives with temperature problems
- Ashless additive pack
  - Anti-wear, anti-oxidant, anti-foam, corrosion inhibitor
- TRR temperature can exceed lube oil boiling point
  - Volatile products can provide lubrication
- Achieve TBN (overbase) and detergency
  - Chemically active filter
- Ring/liner surface chemistry important
  - Only ceramic with transition metal alloyed work
- Phosphate ester- replaced ZDP
  - Reduced friction
- Current synthetics replacing petroleum oils
  - Average fuel economy benefit of 4.7%
- Need fuel economy benefit with minimal particulate emissions