An Assessment of the Properties of Internal Combustion Engine Lubricants Using an Onboard Sensor

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Outline

- Goal and motivation
- Background
- Research objectives
  - Research methodology
    - Bench-top experiments
    - Engine experiments
- Conclusions
Goal and Motivation

• Monitor lubricant degradation in internal combustion engines through direct, in-situ measurement of lubricant properties

• Benefits
  – Cost and energy usage
    • Lubrication improvements may save up to 20% of the total annual energy consumed by vehicles in the US (~14 billion US dollars)
  – Logistics
    • Tailor oil change intervals to actual vehicle needs
  – Environmental
Background

• Current Methods
  – Algorithms based on driver inputs or supplemented with oil property measurements (e.g., dielectric constant)

• Disadvantages
  – Contamination might be overlooked
  – Over or underestimation of oil change interval

• Needs and Challenges
  • Measure oil properties accurately, directly and in-situ
  • Validate threshold values indicative of oil degradation
  • Identify potential causes of measured lubricant condition
Research Objectives

• Quantify the accuracy and precision of lubricant property measurements from an on-board oil-condition sensor

• Correlate changes in the physical properties of the lubricant with likely causes of oil degradation

• Quantify changes in the physical properties of the lubricant with respect to engine operating time
Research Methodology

• Properties measured by the sensor
  – Temperature (55°C to 150°C)
  – Density (0 to 1.5 g/cm³)
  – Viscosity (0 to >50 cP)
  – Dielectric Constant (1.00 to 6.00)

• Lubricant type
  – Rotella T 15W-40

• Bench-top experiments
  – Quantify accuracy of sensor output
  – ASTM standards or reference instruments

• Engine experiments
  – Monitor properties changes with respect to engine operating time
Results from Bench–Top Experiments: Temperature and Density

- Sensor requires ~20 min to reach thermal equilibrium
- Agreement with reference reading to within 2°C
- Viscosity measurements conducted with the sensor are within 6% of ASTM D445 values
Results: Dielectric Constant

- Sensor output compared to a reference instrument (Brookhaven’s BI-870 dielectric constant meter)
- Accuracy of the reference instrument validated a priori
- Sensor reading ~ 6.5% less than reference instrument
Dielectric Constant: Thermal Cycle Results

- Strong dependence of dielectric constant trends on the lubricant additive package.
Results: Fuel-Contaminated Oil (1)

- Condemning limit for kinematic viscosity (18%) was reached at fuel concentrations of 9.4% (ASTM) and 7.4% (sensor)
- The flash point (ASTM D 92) decreased by 11.8 % from the baseline measurement as fuel contamination increased from 0.5% to 10.5%
• Dielectric constant measurements are marginally insensitive to fuel contamination
• Dielectric constant trends measured during a thermal cycle are similar between non-contaminated and fuel-contaminated oil samples
Engine Experiments: Initial Tests

• Objective
  – Quantify changes in the physical properties of the lubricant as a function of engine operating time

• Experimental setup
  – Diesel engine
  – Sensor installed prior to oil filter
  – Operated for 73 hrs at 2,200 RPM and 75% maximum load
  – Oil sampled after the warm-up period and then approximately every 6 hrs. in 150mL increments
Results: Dielectric Constant

- Decrease of 11% over the course of engine tests
- Increase of 1.5% upon the addition of new oil
Results: Viscosity

- The viscosity increased by 10% over the course of engine tests.
- Detected increase of 4% upon the addition of new oil.
Results: Property Trends

- The increase in dielectric constant might be attributed to additive depletion.
- Increase in oxidation by-products causes a viscosity increase.
- A simultaneous decrease in viscosity and increase in dielectric constant suggests the additive package depletion to have a dominant effect.
Conclusions

• Baseline measurements
  – Kinematic viscosity
    • Sensor output and ASTM D445 agree within 6%
  – Dielectric constant
    • Sensor output and reference instrument agree within 6%

• Fuel-contaminated oil
  – Kinematic viscosity
    • As fuel contamination increases to 10.5%, the lubricant viscosity decreases by 21.5% (sensor) and 23.7% (ASTM)
  – Dielectric Constant
    • Marginal sensitivity to fuel contamination (0.5% to 10.5% by vol.)

• Engine experiments
  – Dielectric constant decreased 11%
  – Viscosity increased 10%
  – Correlation between dielectric constant and viscosity
Research Areas for Future Work

- Establish a dielectric constant threshold indicative of oil degradation

- Quantify correlations between thresholds in lubricant properties
  - Response surface methodology

- Quantify correlations in lubricant properties over longer periods of engine operation
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