Phosphorus Volatility of PCMO Lubricants in Bench and Engine Tests

ESCIT May 4th 2006

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Summary of Presentation

- Background to phosphorus Volatility Issue for PCMO Lubricants.
- PEI Datasets.
  - Savant PEI250.
  - Sequence IIIG.
  - Test Comparisons.
- Viewpoints on ESCIT and issues for ILSAC GF-5.
- Infineum viewpoints on options to proceed.

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Background to phosphorus Volatility Issue

- Phosphorus is a known catalyst poison.

- Attempts to develop a meaningful performance test failed.
  - OPEST I and II failed to meet their objectives.
  - Current ILSAC GF-4 engine oil phosphorus limit is 0.08% max.
- Need for improved emission control durability drives need to further reduce phosphorus poisoning effects.
  - Industry recognizes ZDDP chemistry affects phosphorus volatility in lubricants.
- ESCIT activities breathes new life into this area highlighting the options for moving forward.

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Savant NOACK phosphorus Volatility Test

- Test was developed by Savant Inc.
- Testing conditions at 250 °C temperature.
  - 65 gram of oil sample.
  - 20 mm water vacuum.
  - One-hour testing time.
  - Volatile component is collected and analyzed for phos volatility
- phosphorus Emission Index at 250 °C (PEI250).
  - PEI Unit: mg phosphorus per liter of lubricant.
  - Most of the lubricants in today's market have PEI250's in the range of from 5 mg/L to 50 mg/L.
- PEI250 now recognized to have poor correlation to field test and engine performance tests such as IIIG and VIB.
  - Recent new studies provide some encouragement that different Savant PEI test conditions will establish a better correlation.

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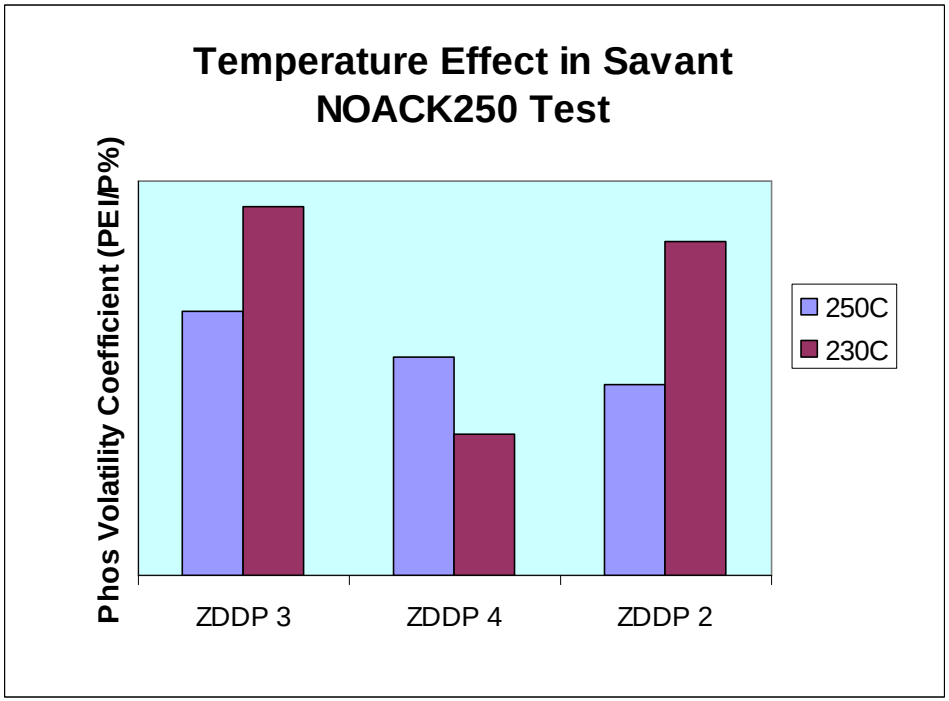
Temperature Effects in Savant NOACK Test

- PEI250 and PEI230



- Standard Savant NOACK test is operated at 250C.
- phosphorus volatility appears temperature dependent.
- Changing temperatures (here 230 deg C) gives confusing oil responses.

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Stationary Engine Test Data

- Infineum has looked extensively at PEI measurements from the Sequence IIIG.
  - PEI's are typically higher than Savant PEI250 numbers.
- Principles of tracking calcium with phosphorus changes for PEI calculations are widely known.
- Assumptions:
  - Amount of liquid oil leakage is linear within each time period and determined by the concentration of Ca in Oil.
  - Ca is not volatile.
- PEI's are calculated by taking the differences between the total phos loss and liquid phos loss.

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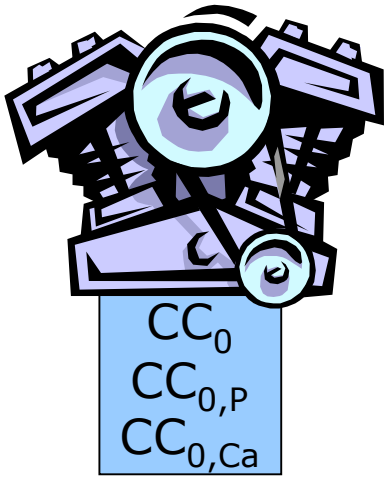
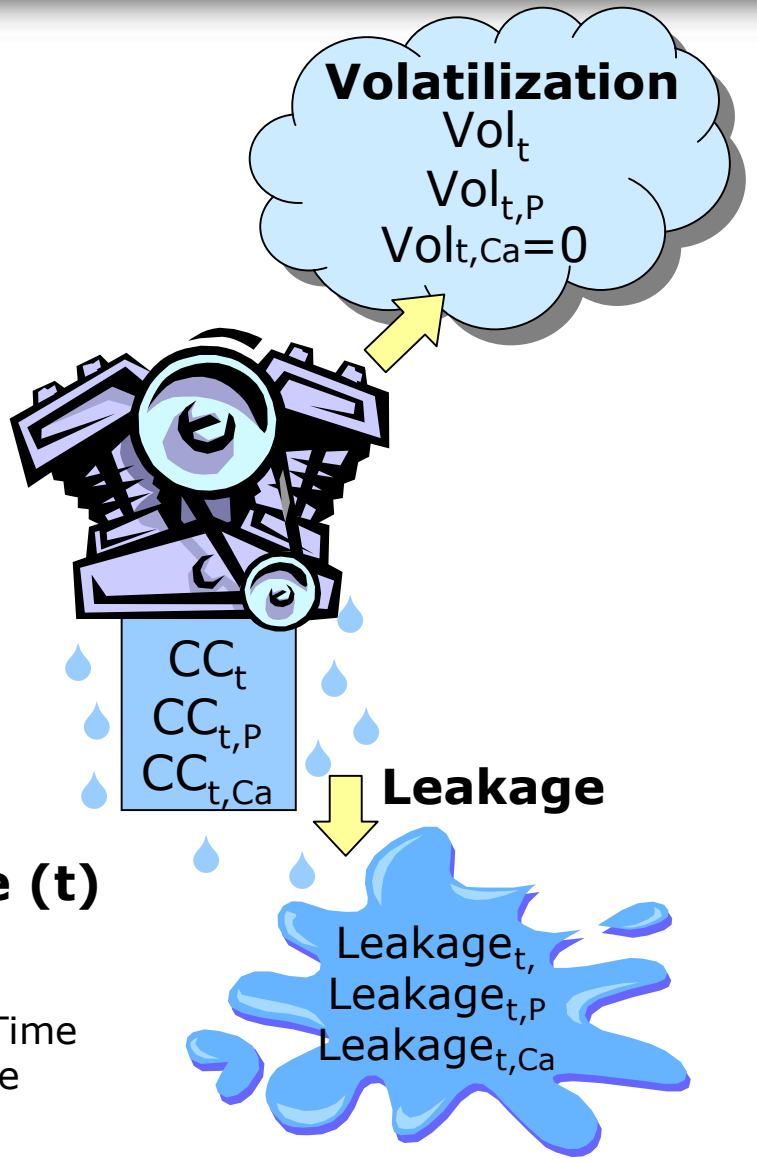
Definition of Terms

- Phosphorus either stays in the crankcase, is lost via liquid leakage, or volatilizes.
- Calcium either stays in the crankcase or is lost via liquid leakage (does not volatilize).



Start Time (t=0)



Time (t)

CC_0 is the total oil in the Crankcase at Start Time
$CC_{0,P}$ is the total phosphorus in the Crankcase at Start Time
$CC_{0,Ca}$ is the total calcium in the Crankcase at Start Time

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Definition of Terms

- Oil Consumption = Oil loss due to volatility + oil non-volatility loss (oil leak) = Vol_t + $Leakage_t$ = CC_0 – CC_t
- Oil volatility = Oil evaporated from engine (no Ca loss)= Vol_t
- Oil non-volatility loss: oil leaked from engine (with Ca loss)= $Leakage_t$
- P Loss due to volatility = $Vol_{t,P}$
- Phosphorus loss in oil leaked from engine = $Leakage_{t,P}$
- Total Phos loss = $Vol_{t,P}$ + $Leakage_{t,P}$ = $CC_{0,P}$ – $CC_{t,P}$

- **Phosphorus Emission Index (PEI) in IIIG = P Loss due to Volatility (mg) / Total Volume in engine (L) = $Vol_{t,P}$/ CC_0**

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Sequence IIIG PEI Calculations

- Sequence IIIG.
  - Oil filter block temperature: 150 °C.
  - Coolant outlet temperature: 115 °C.
- Phos Volatility in Seq IIIG.
  - Phos volatility can be calculated by mathematically balancing the elemental content of used oils.
  - Mass balance is calculated at every 20-hour test interval.
  - The amount of phos deposited on the metal surface is assumed to be negligible compared to the total phosphorus content in the bulk oil.

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IIIG PEI: Effect of ZDDP Type

- There are relatively limited phos volatility differences between current but different ZDDP types with similar molecular weight.

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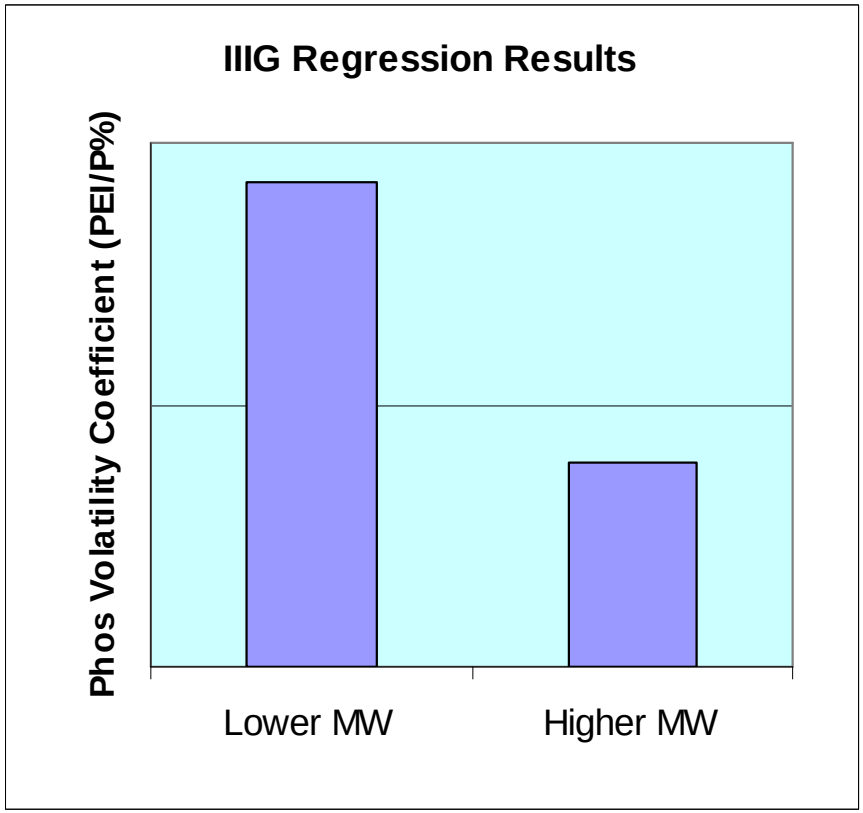
IIIG PEI: Effect of Higher Molecular Weight



- Higher molecular weight ZDDP gives lower PEI values.

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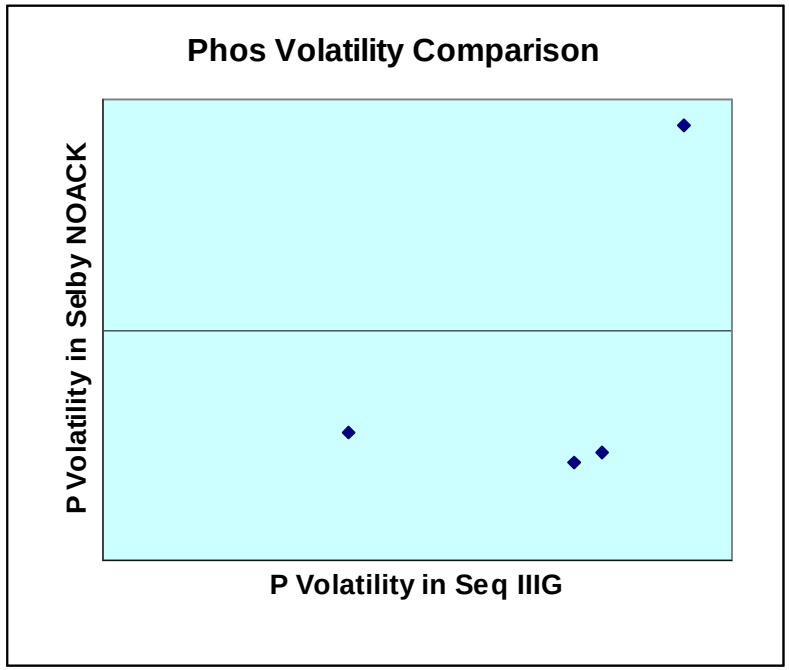
Comparison of Savant PEI250 with IIIG PEI



- Phos volatility based on Savant NOACK test does not correlate well with phos volatility based on IIIG engine test.
- Field/engine correlation with bench test is only obtained with appropriate bench conditions.

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Summary of Phos Volatility in Different Tests

- Testing conditions can be highly influential to phos volatility results.
  - Savant temperature responses to different ZDDP components are not replicated in the IIIG.
  - PEI250 from Savant NOACK test and PEI from IIIG tests do not correlate well.
  - It is critical to have field data correlation for any proposed testing to understand proper test conditions.

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Infineum Position on ESCIT Activities

- Oppose further tightening of chemical limits unless clear and unambiguous data are brought forward to justify the benefit.
- Support meaningful performance tests over tighter chemical limits.
  - OPEST I and II failed to meet their objectives.
  - Original Savant PEI test conditions at 250 deg. C do not show an acceptable field correlation.
- New ESCIT data and information encourages a renewed effort to bring forward a test and avoid the need for a reduction in the Phosphorus maximum limit for ILSAC GF-5.

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Infineum Viewpoint - Options for ILSAC GF-5

- **Option 1:** Develop through ESCIT a meaningful phosphorus volatility test which allows consideration of elimination of current constraints on P levels.

- **Option 2:** If no meaningful test can be developed continue with current limits, and consider further P reduction if credible evidence to justify is brought forward.

- Infineum believes Option 1 holds most promise for meeting both the catalyst compatibility and engine durability objectives for ILSAC GF-5.

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