Lubricant Design – Impacts on Energy Efficiency

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Outline

• World Energy Outlook
• Trends in Transportation Industry
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• Design Options for Improving Energy Efficiency
• Design Tools and Application Examples
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World energy outlook

- Surging energy demand
- Supply will struggle to keep pace: end of “easy oil”
- Environmental stresses are increasing: CO₂, water, resource constraints

These three hard truths will shape the future of the energy system
Energy demand driven by the population & prosperity of rapidly growing economies

Population

1975 2000 2025 2050

- North America & Europe
- Latin America
- China & India
- Asia & Oceania
- Middle East & Africa

Energy demand per person - History

1971-2005

- USA
- South Korea
- Europe (EU15)
- Japan
- China
- Brazil
- India

GDP per capita (PPP, €'000 2000 USD)

World energy demand is on track to double by 2050

“Business as usual” energy consumption by sector

- Heavy industry
- Services
- Agriculture & other industry
- Transport
- Residential
- Non energy use (e.g. petrochemicals)

Source: Shell International BV and Energy Balances of OECD and Non-OECD Countries©OECD/IEA 2006
Shell’s Energy Scenarios for 2050

- **Scramble** – supply focus & late response
- **Blueprints** – energy sustainability and early action

**Total primary energy**

**Direct CO₂ emission from energy**

Source: Shell International BV and Energy Balances of OECD and Non-OECD Countries/OECD/IEA 2006
Potential pathways for sustainable energy

1. Increase the efficiency of operations
2. Establish substantial capability in CO$_2$ capture and storage
3. Develop aggressively low-CO$_2$ sources of energy
4. Help manage demand by growing market for products and services
5. Work with governments and advocate need for more effective CO$_2$ regulation
6. Continue research to develop technologies that increase energy efficiency and reduce emissions
Benefits of energy efficient lubricants

- Energy loss due to friction & wear ~ 10% GNP; use of good tribological principles ~ 1-2 % GNP (Jost, 1966)

- $ 20 B/yr spent in the US overcoming friction in internal combustion engines (Rabinowicz, 1986)

- For heavy duty vehicles, total energy lost due to friction ~ 160 M barrels diesel fuel/yr (US DoE 1999)

- In the UK, benefit of reducing fuel consumption by 5% would result in 4 M tons of CO$_2$ reduction & € 2 B /yr (R I Taylor, 2005)
Emissions & fuel economy legislations

- For the first time CO₂ / FE legislation is being introduced across the world with very challenging targets

- Emission legislations continue to tighten worldwide

Ricardo 2008
Power Train Technology Advancements

Driven by improved fuel efficiency and reduced emissions targets

- Engine Designs
  - Downsizing & Boosting, GDI, advanced valve trains
  - Exhaust Gas Recirculation
- Aftertreatment Devices
  - Particulate Filters, NOx Traps, Selective Catalytic Reduction
- Transmissions
  - CVT & increased number of forward gears
- Advanced electronics
- Hybrids
- Advanced materials
  - Lightweight composites and alloys
  - Coatings & textured surfaces
Base oil & bio-fuels trends

• Base Oils
  – Group 1: demand declining
  – Increased supply of Group II & III
  – Bio-based oils and re-refined base oils
  – Increased availability of GTL in coming years

  ➢ Base Oil composition - important in energy efficient lubricant designs (Gunsel et al, 1999)

• Bio-fuels
  – Fuels with higher content of biodiesel and ethanol
  – Development of 2nd generation biofuels

  ➢ Lubrication of biofuelled engines –becoming an important area of research
Impacts on engine oil technology

Challenges

- Improve energy efficiency, maximize friction reduction, reduce CO₂
- Reduce or eliminate detrimental effects of oil on emission systems
- Extended Life
  - High temperature stability, deposit control
  - Antiwear protection/durability
  - Low temperature performance, sludge control
  - Soot control
  - Fuel economy retention
- Compatibility with biofuels and new materials

Achieving improved fuel economy while maintaining good durability - becoming more challenging due to the legislation of S and P limits
Energy Losses in Vehicles (urban driving)

Lubricant—important design parameter in reducing friction losses, 10% reduction in mechanical losses leads to 1.5% reduction in fuel consumption

Types of mechanical losses

- Engines & transmissions contain several differing types of contact regimes where energy dissipation occurs
  - Hydrodynamic lubrication
  - Elastohydrodynamic lubrication
  - Boundary lubrication
  - Churning

- Important to minimize friction in all regimes
  - Lubricant Formulation
  - Surface Engineering
  - Component redesign
Relative importance

Engines – **Typical Result**

Losses are mainly hydrodynamic and boundary

Transmissions - Losses are mainly churning and EHD friction
Lubricant Properties that Influence Friction

- Additives important here
- Viscosity important here

Friction Coefficient

- High Wear
- Low Wear

Film Thickness

- Boundary
- Mixed
- Fluid-film (HD, EHD)

Plain bearings
- Piston rings
- Skirt
- Valve train

HD film thickness
\[ h \propto \left( \frac{U}{W} \right)^{0.5} \]

EHD film thickness
\[ h \propto \frac{(U \eta_0)^{0.7} \alpha^{0.5}}{W^{0.1}} \]

\( \eta \): viscosity
\( \alpha \): pressure-viscosity coefficient

Boundary-surface films
Lubricant design approaches for improved friction: Use of lower viscosity lubricants

- Reduces friction in HD conditions
- Reduces churning losses
- Lower EHD traction coefficients

But leads to thinner HD and EHD films; larger proportion of contact operates in mixed regime

Balance of low viscosity with durability and volatility is important

Korcek & Nakada, 1996
Lubricant design approaches for improved friction: Low friction boundary films

Solid-like boundary films reduce shear strength at load-bearing asperity contacts

- Soluble organomolybdenum friction modifiers
- Organic friction modifiers
- Nano-colloidal particles

Surface competition and interaction with other surface active additives - important

Some additives (e.g. ZDDP and detergents) form high friction films
Lubricant design approaches for improved friction: Low friction boundary films (cont.)

Example- MoDTC: widely used in engine oils
- friction reduction results from MoS$_2$ formation in the rubbing contact

Grossiord et al., 1998

Graham et al., 2001
Lubricant design approaches for improved friction: Viscous boundary films

Boundary films of enhanced viscosity enable transition from BL to mixed at lower speeds

- Functionalized polymers
- Liquid crystals
- Other?
Lubricant design approaches for improved friction: Viscous boundary films (cont.)

Functionalized viscosity modifier polymers form thick viscous boundary films

Friction & wear benefits observed

(Gunsel et al, 1996)
Lubricant design approaches for improved friction: Smart viscometrics

Provide high viscosity under low speeds, but lower viscosities at high speeds:

Shear thinning - viscosity modifier polymers shear thin under high shear stresses

- shear thinning in mid stroke lowers HD friction
- important in designing fuel efficient lubricants

Wright et al. SAE 830027
Lubricant design approaches for improved friction: Smart viscometrics

Viscoelasticity - polymer behaviour under transient conditions

Enhanced squeeze behaviour during halting & viscoelastic response to acceleration/deceleration (Gunsel, 98)

With polymer, the film forms much faster during acceleration, and decays more slowly during deceleration.
Lubricant design approaches for improved friction: Surface & Lubricant Design

- Development and application of low friction coatings advancing e.g. DLC, CrN,….
- Requires lubricants compatible with non-ferrous surfaces
- Fuel economy improvements > 4% (Fox, 2005)
- Very low friction (superlubricity, $\mu \sim 0.01$) possible (J.M.Martin et al, 2005)
- Surface texturing - effective in reducing hydrodynamic friction

Design Tools for Developing Energy Efficient Lubricants

- Models for predicting lubricant behavior
  - Molecular Dynamic simulations
  - Computational Fluid Dynamics
  - Mathematical models of individual machine components
  - Empirical models

- Laboratory screener tests

- Engine & specialized testing rigs
e.g. driveline rig - allows contributions from individual drivetrain components to be measured

- Field trials
Examples of energy efficient lubricants in automotive applications

Passenger cars

Energy efficiency improvements by lubricant design in engine tests

R.I. Taylor, 2008

Heavy duty trucks

Improvements in heavy duty field trials (5W40 vs 15W40)
Examples of energy efficient lubricants in automotive applications

Energy efficiency improvements by lubricant design
industry standard fuel economy tests

M111

Seq. VIA

R I Taylor, 2008

Taylor & Coy, 2000
Examples of energy efficient lubricants in industrial applications

Modeling of energy losses in industrial systems e.g. Hydraulic Systems
Examples of energy efficient lubricants in industrial applications

Lubricant design provides ~ 19% energy savings in hydraulic system (Vickers Vane Pump)

~ 12% energy savings achieved in plastic molding injection machines field trials
Summary / Recommendations

Energy Challenge- the three hard truths are very hard

• Surging energy demand
• Supply will struggle to keep pace, end of easy oil
• Increasing environmental stresses

Political and regulatory choices are pivotal

Tackling all three hard truths together is essential for a sustainable future

Technology plays a major role- development of technologies that increase efficiency and reduce emissions
Summary / Recommendations

Key drivers for new technology development in transportation industry: improved resource utilization, environmental protection and customer satisfaction.

The ability of the lubricant to reduce overall friction loss in practical systems depends on a number of different properties, depending on the prevailing lubrication regime.

In designing energy efficient & sustainable lubricants, it is essential to minimize all types of friction and ensure compatibility with emission systems.
Summary / Recommendations

Energy efficient & sustainable lubricant designs require

- Lower mechanical friction
  - Lowest possible viscosity base oil without volatility and durability issues
  - Optimized surface films through carefully balanced additive chemistry; friction modifiers, viscous surface film formers, synergistic additive combinations for combating high friction films
  - Optimized rheology of viscosity improver polymers

- Emission system compatibility
  - Low P, S, Sulfated Ash (low SAPS)
  - Improved soot tolerance

- Improved oxidation, dispersancy & wear performance

- Higher quality base oils with low volatility, high viscosity index, narrow boiling range & oxidation stability
Summary / Recommendations

Energy efficient & sustainable lubricant designs require continuing research on:

- Lubricant/Biofuels Compatibility
- Compatibility with non-ferrous surfaces
- Surface texturing impacts on lubricant behavior
- New additive technologies
- Development of screener tests and models – important design tools
- Simulations of the lubricated system as a whole that relate lubricant properties to energy efficiency
- Carbon footprint analysis

Energy efficient and sustainable lubricant benefits achievable in both automotive and industrial applications.
Thank You