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Research on Fuels & Lubricants

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Diesel Engine Emissions Reduction Conference
Newport, RI
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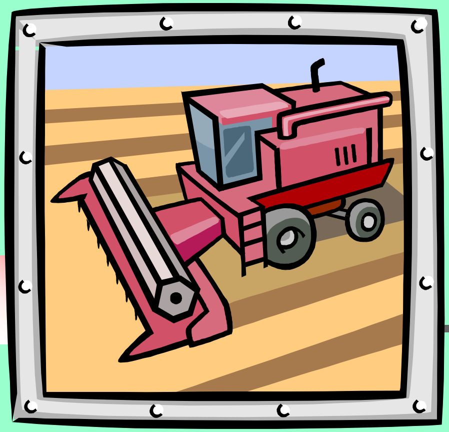
Penn State's Slippery Bunch:

- 1950's Dew Line Lubricants, New Base Oil & Additive Technology
- 1960's SR 71 Blackbird Hydraulic Fluids, Super Refined Lubricants (Type II)
- 1970's Oxidation, Greases, Metals
- 1980's VPO, Adiabatic Engine, MeOH Oils
- 1990's Environmentally Friendly Fluids Extended Drain Oils

Current Projects

- Fuel Studies
  - DME
  - Biodiesel
  - ULSF
- Vegetable Oils
- High Temperature Liquid Lubricants
- Coatings & Lubricants
- Role of Chemical Structure



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Penn State "Green" Project

1. Over 200 pieces of farm & construction equipment on campus.
2. Conversion to Environmentally Friendly Lubricants initiated.
3. Use of Biodiesel in farm equipment.
4. Conversion of waste oils to Biodiesel – Undergraduate Engineering Project

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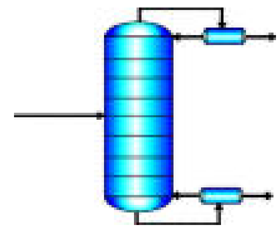
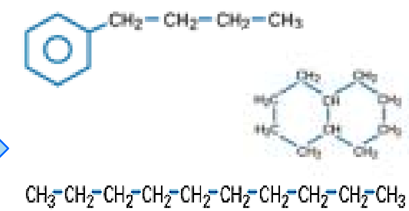
FUELS

Diesel Fuels

Petroleum cut boiling ~ 282-338°C, #2, LSDF and ULSDF
- 300 ppm S
- 32 ppm S
- ULSD (< 15ppm S)



Distillation



Hydrocarbon mixture

Soybeans

+ ROH $\xrightarrow{\text{catalyst}}$

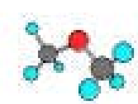
Biodiesel Fuels

Blends of methyl esters made from vegetable oils

Dimethyl Ether

Converted from Syngas

Hydrocarbon → Syngas → DME



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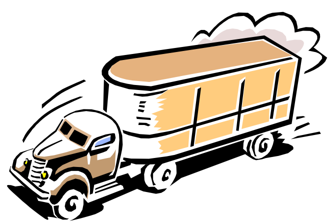
DME Research

DME   Methane + H_2 + CO

DME is environmentally benign

Decomposes rapidly

Doesn't harm ozone layer



Reduces diesel engine emissions

Addition of oxygen into combustion zone

Engine and Vehicle Tests

Problems include low viscosity (wear), high vapor pressure, and material compatibility

→ Laboratory Tests

- Viscosity Studies
- Injector Studies
- O-Ring Studies

Fuel Injector Studies

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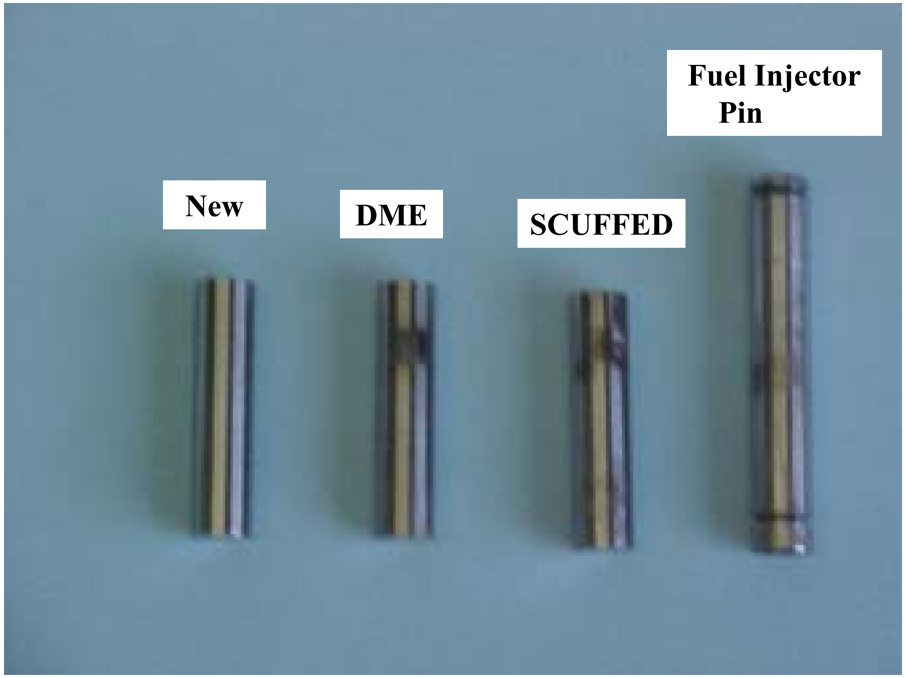
Modified Cameron – Plint Machine

Test Pins



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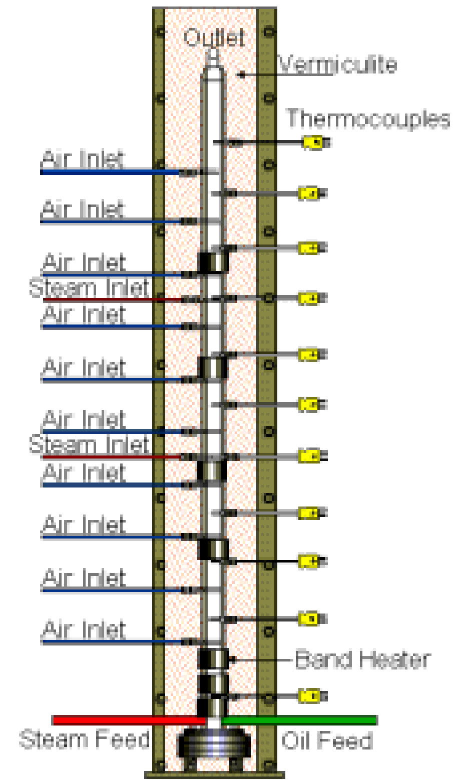
Biodiesel Fuel Studies

Previous work involved study of VPO of diesel and biodiesel fuels in pilot plant [10]

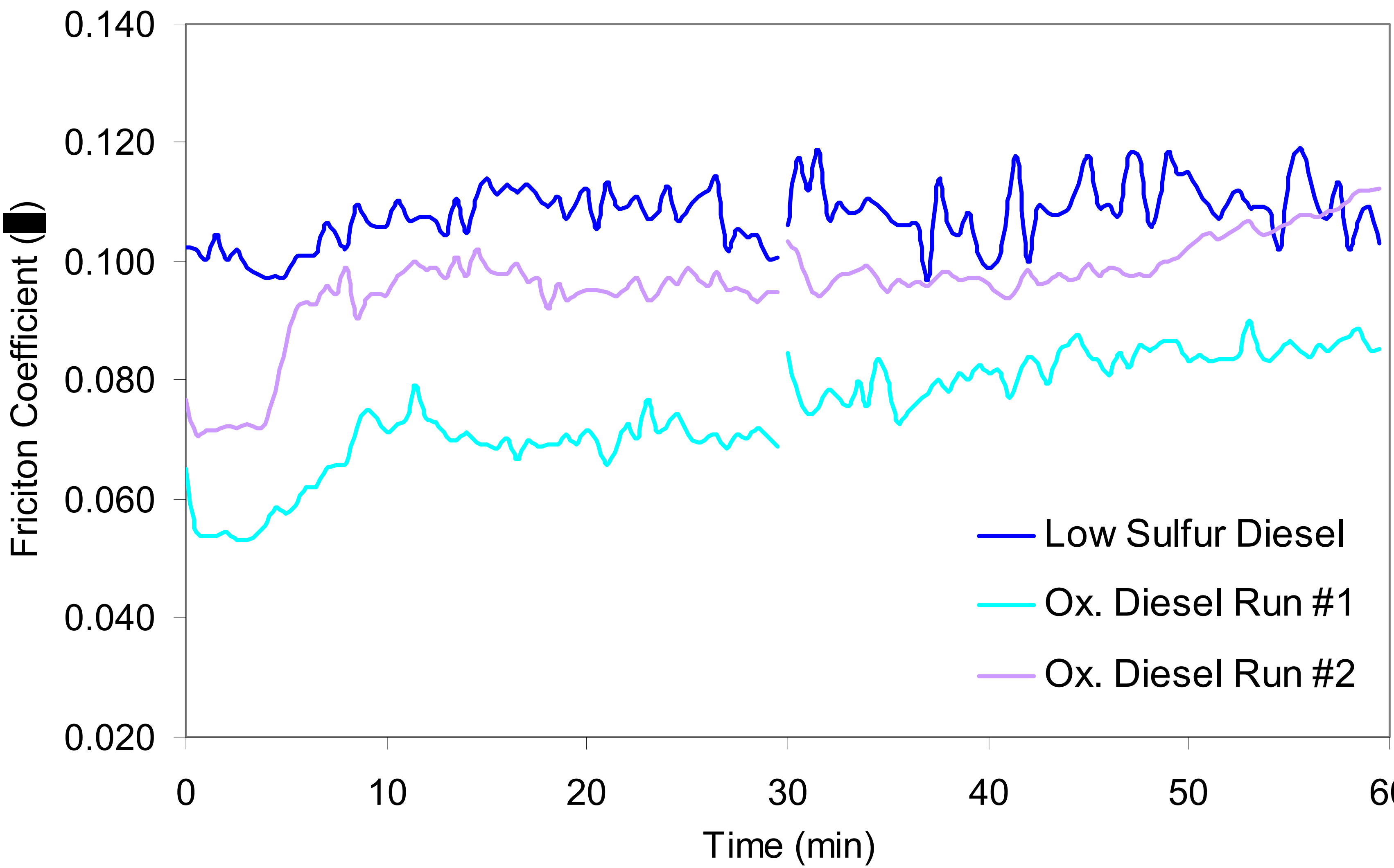


Demonstrated in laboratory tests that addition of oxygen to biodiesel resulted in improvement in friction

Run #1	Run #2
Temp- 325°C	Temp- 375°C
Feed Rate- 1000 g/hr	Feed Rate- 1000 g/hr
O_2/Feed Mole Ratio- 1.0	O_2/Feed Mole Ratio- 1.0

(10) Wain, K. Perez, J. " Oxidation of Biodiesel Fuels for Improved Fuel Lubricity" Proceedings of the Internal Combustion Engine Division, Lubrication and Friction Committee ASME Rockford, IL #2002-ICE-447 (2002)

Low Sulfur & Oxidized Diesel Fuels



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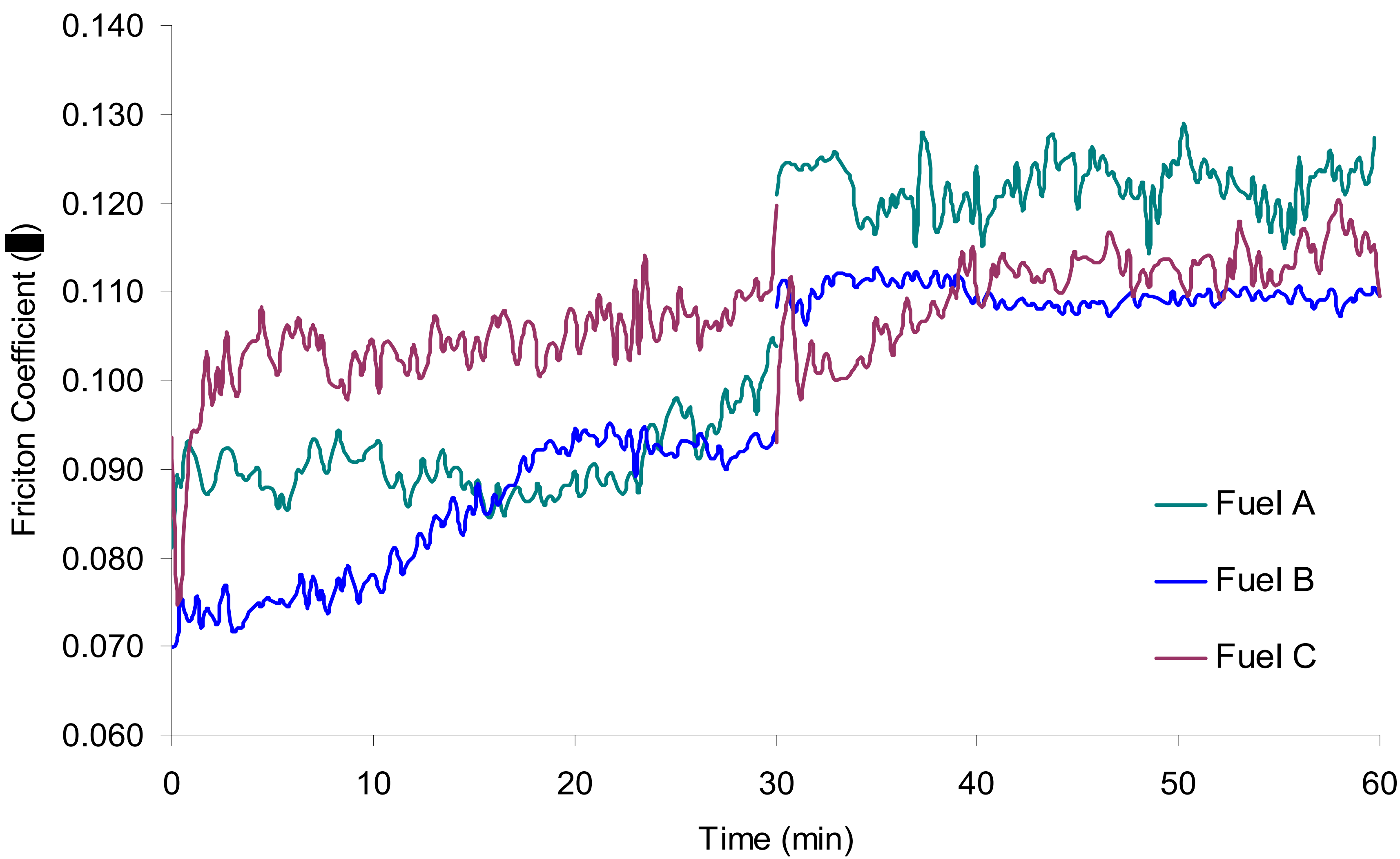
Friction Traces for ULSDFs



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Fuel Deposit Tests

Micro-oxidation test

10ml of test fuel into glass test tube
One stainless steel pan
Heat to 150°C for 7 days
Weigh and characterize deposits on pan

Fuel also filtered through Al column to remove additives and analyzed

Test Fuels

A,B,C	Ultra low sulfur fuels, different manufacturers
D	Low sulfur diesel
E	Kerosene
G	#2 diesel

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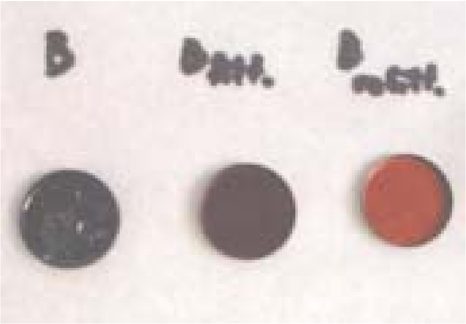
Fuel Deposits



Progressively less deposits as B is filtered

Order of deposit thickness, most to least:
B>>A>D>C✍G>E

Progressively less deposits as G is filtered (not as dramatic as B)

*Filtered fuel shows little or no deposits on walls of glass micro-oxidation tubes as well as on coupons

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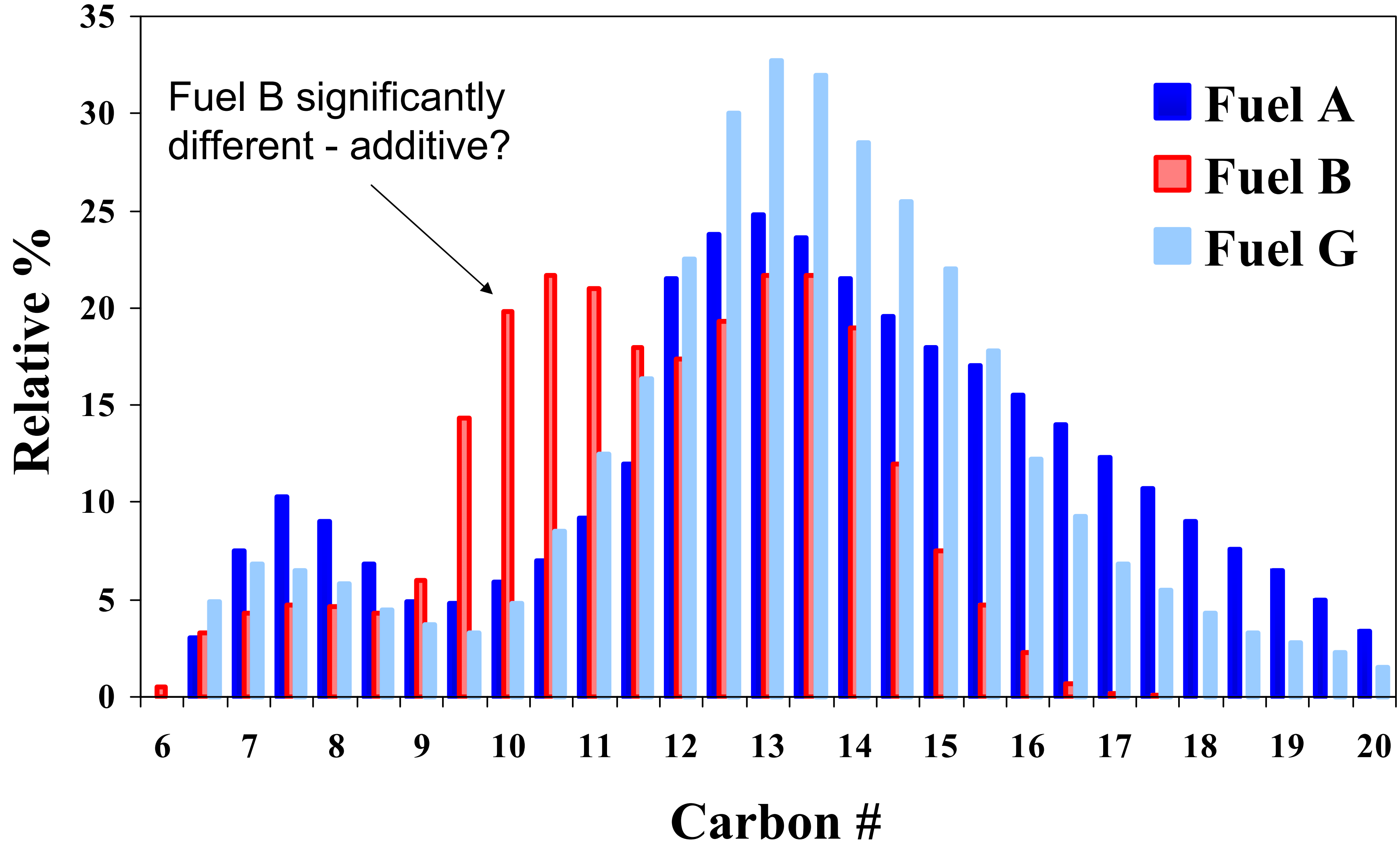
GC Analyses - Fuels



Fuel C, D similar to A

LUBRICANT RESEARCH

Does the Chemical Structure of the Base Fluid affect its effectiveness in protecting the surface against wear?

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Effect of Structure

- Alcohol + Acid $\rightleftharpoons$ (catalyst, heat) Ester + Water

To evaluate structure effect use same acid (2-ethylhexanoic) and different alcohols

- **Neopentyl Glycol** $(CH_3)_2C(CH_2OH)_2$
- **Trimethylol propane** $CH_3CH_2C(CH_2OH)_3$
- **Pentaerytritol** $C(CH_2OH)_4$

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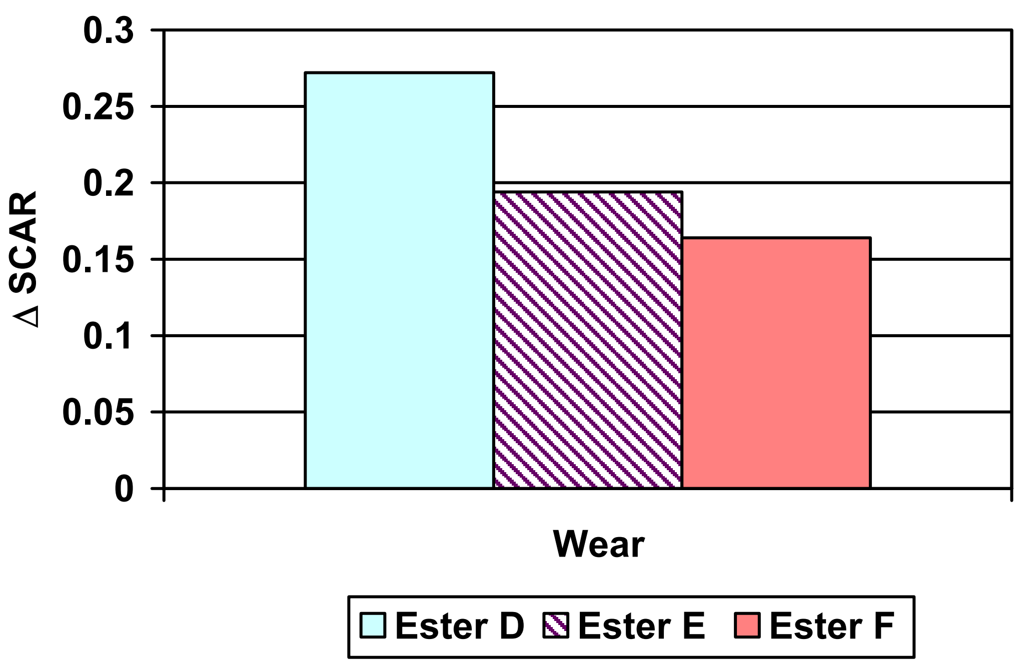
Effect of Acid Chain Length on Wear

- **Trimethylol propane = alcohol**



<u>Acids</u>:

D = nC5

E = nC7

F = mixture of nC8 & C10

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Wear Index =

$$\frac{\text{(Total Carbons)(Effective Chain Length)}}{\text{(Polar Value + Branching Value)}}$$

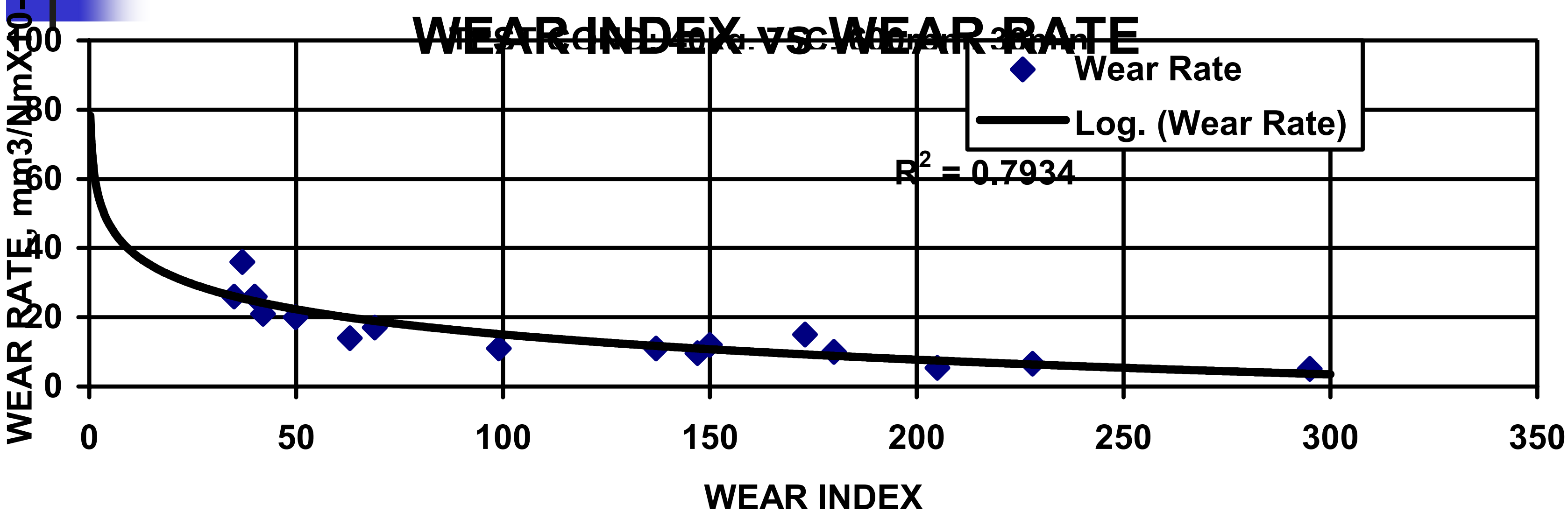
where:

Total Carbons = total carbons in the molecule

Effective Length = longest free chain of carbons available to form a film.

Polar Value = No. of carboxyl groups + No. of hydroxyl groups

Branching Value = (0.5 x No. of branches) + No. of double bonds.



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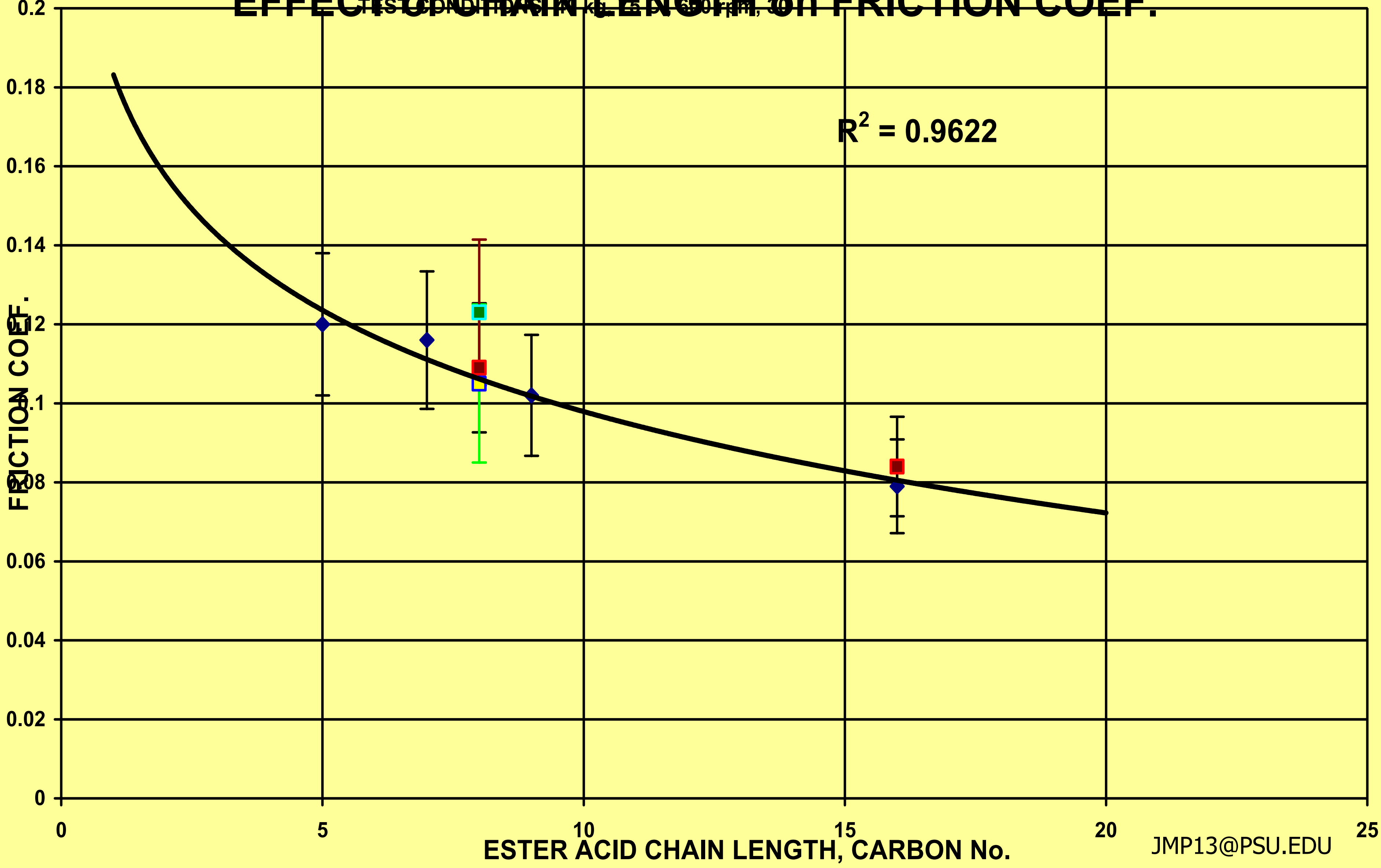
EFFECT of CHAIN LENGTH on FRICTION COEF.



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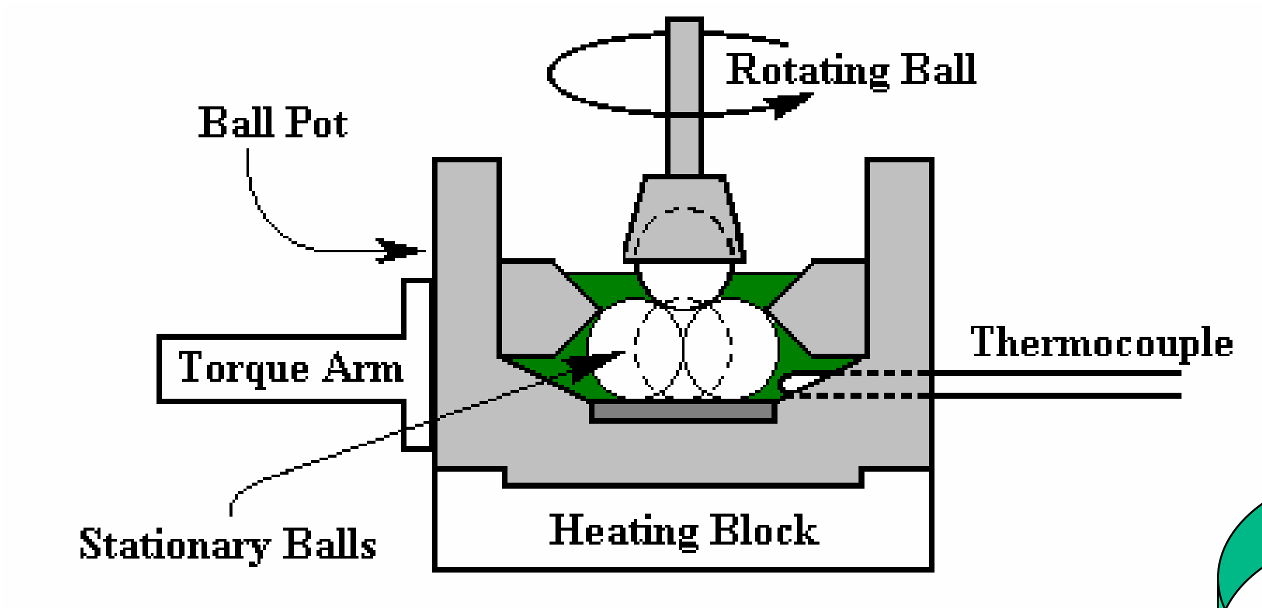
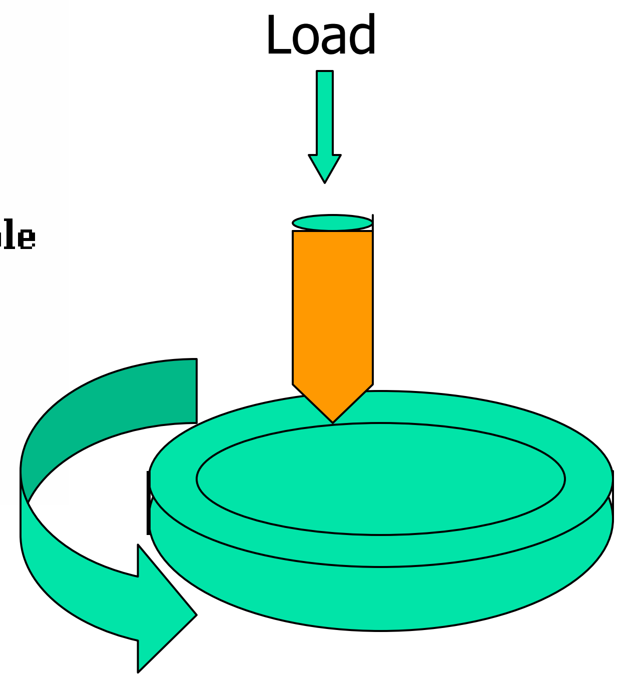
Test Methods





Test Conditions

Four Ball Wear Tester:	Pin – on – Disc:
ANSI 52100 stainless steel balls	Variable Speed
Test Time: **30 min Run-in** **30 min Steady State** **30 min Surface Eval'n**	Variable Load
Test temp. = RT, 60°C, 75°C	This study: 10 RPM 20 N Room Temp.
Speed = 600, 1200 RPM	
Loads = 1,10, 40 Kg	

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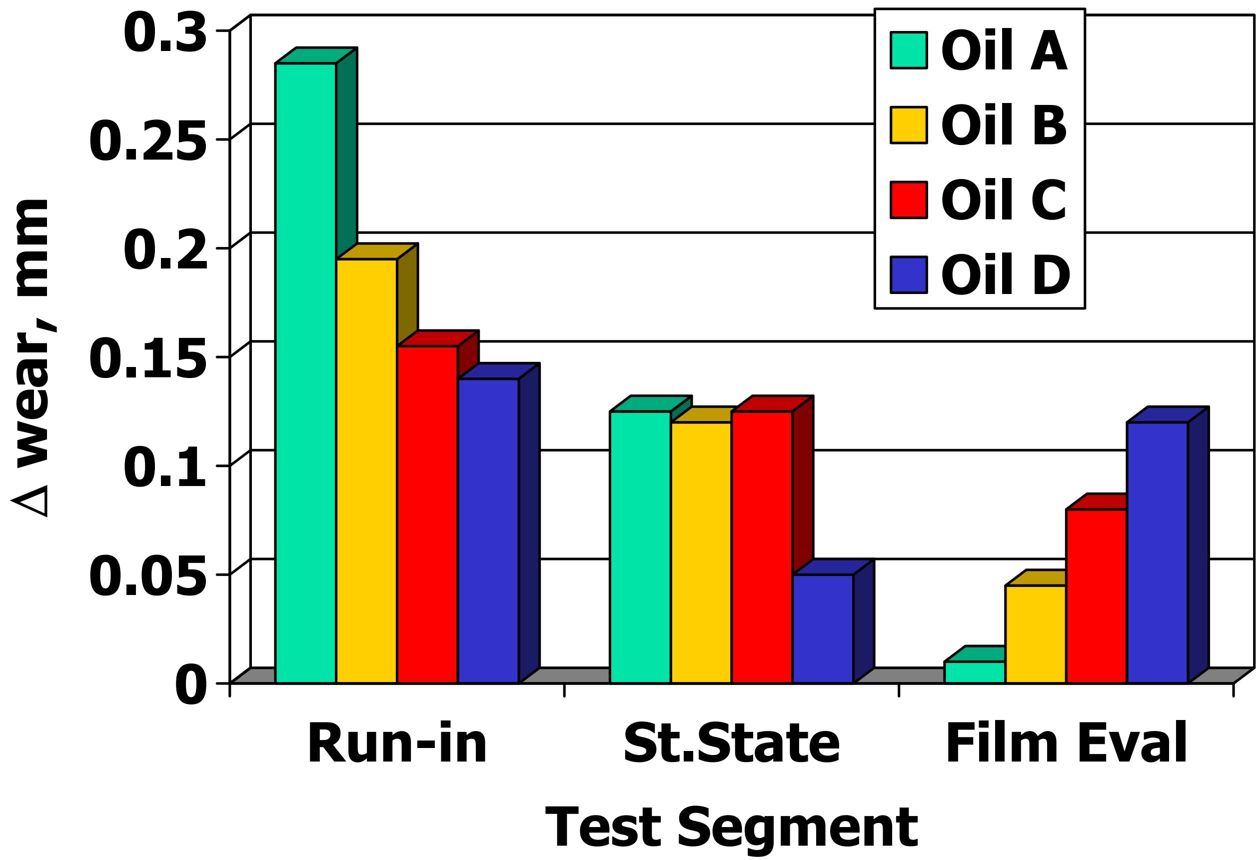
Properties of Test Oils

Oil → / Properties ↓	Oil A	Oil B	Oil C	OIL D
cSt Visc @ 100 ^oC (ASTM D 445)	3.9	4.99	8.29	24.4
cSt Visc @ 40 ^oC	16.9	28.8	66.8	215
Viscosity Index (ASTM D2270)	123	97	91	120
Flash Point, ^oC (ASTM D 92)	219	226	254	>>200

Effect of "Chain Length" of Hydrocarbon Oils on Wear – 4Ball Test



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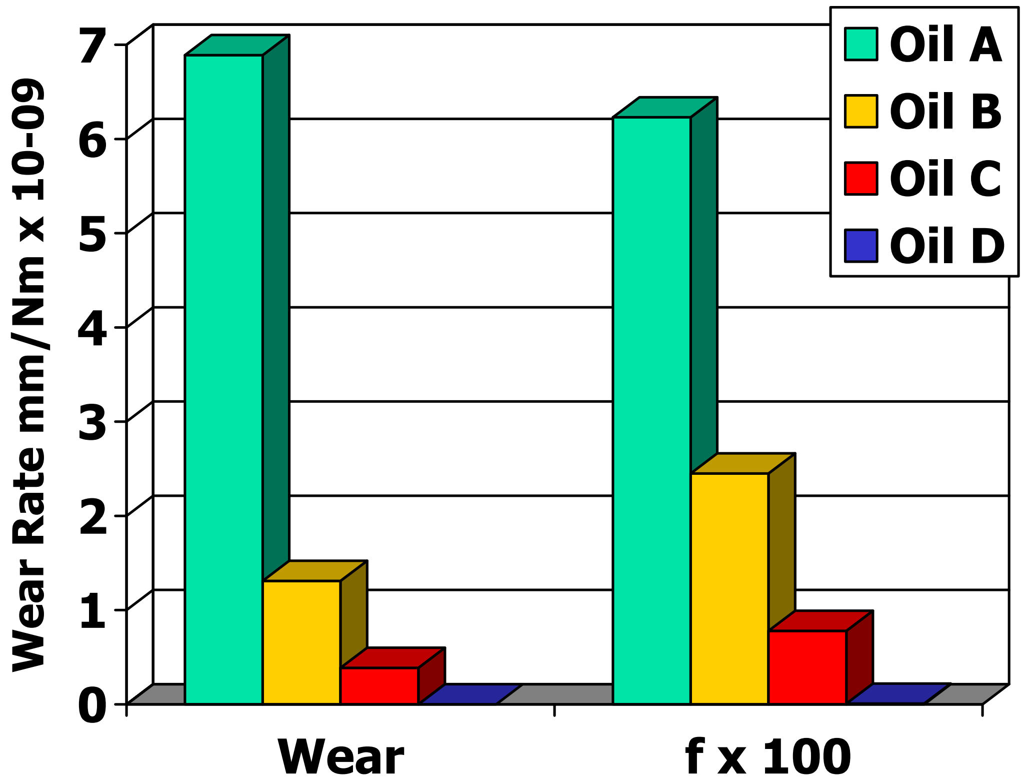
Effect of Oil "Chain Length" – Tribometer (CSEM)



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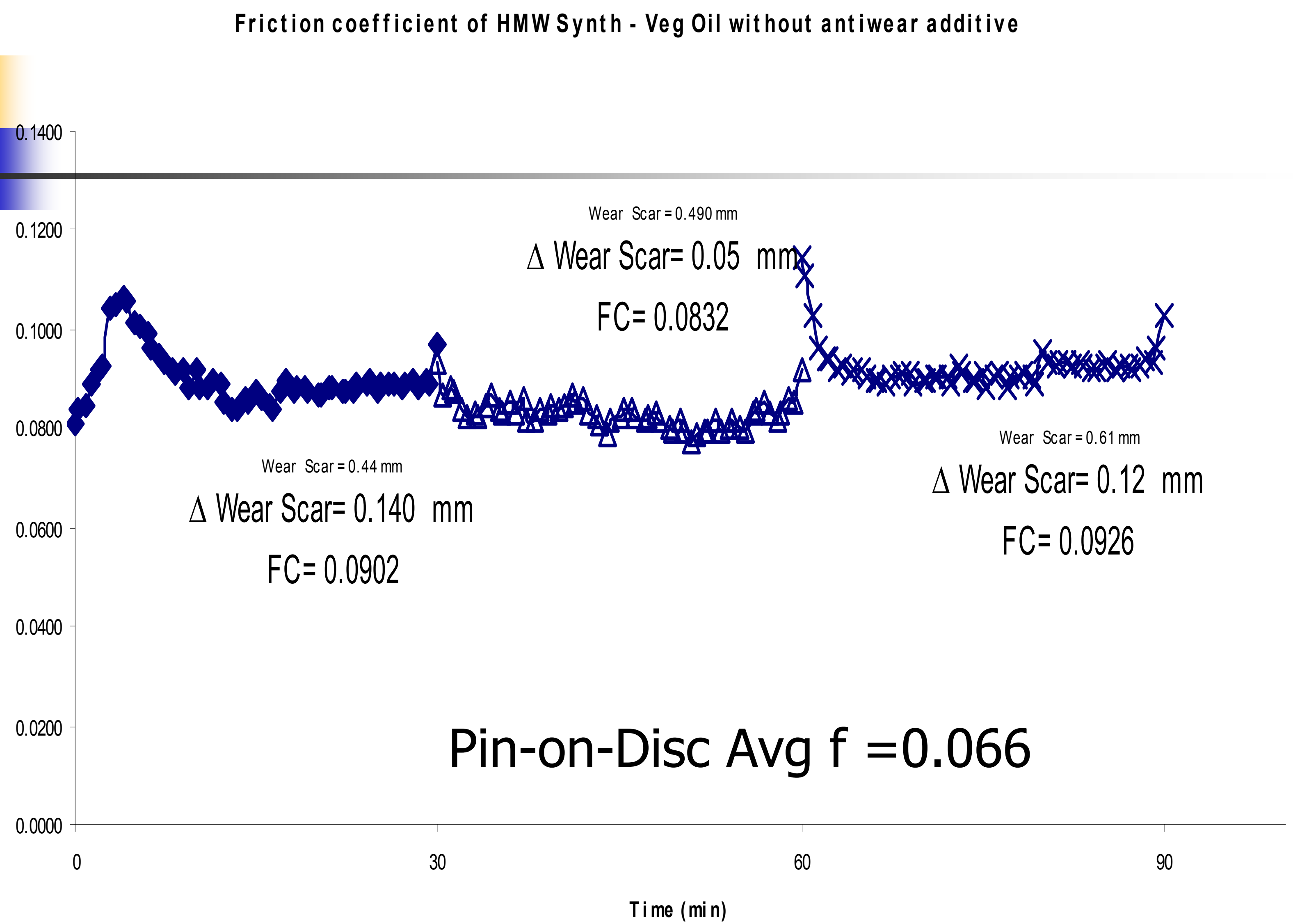

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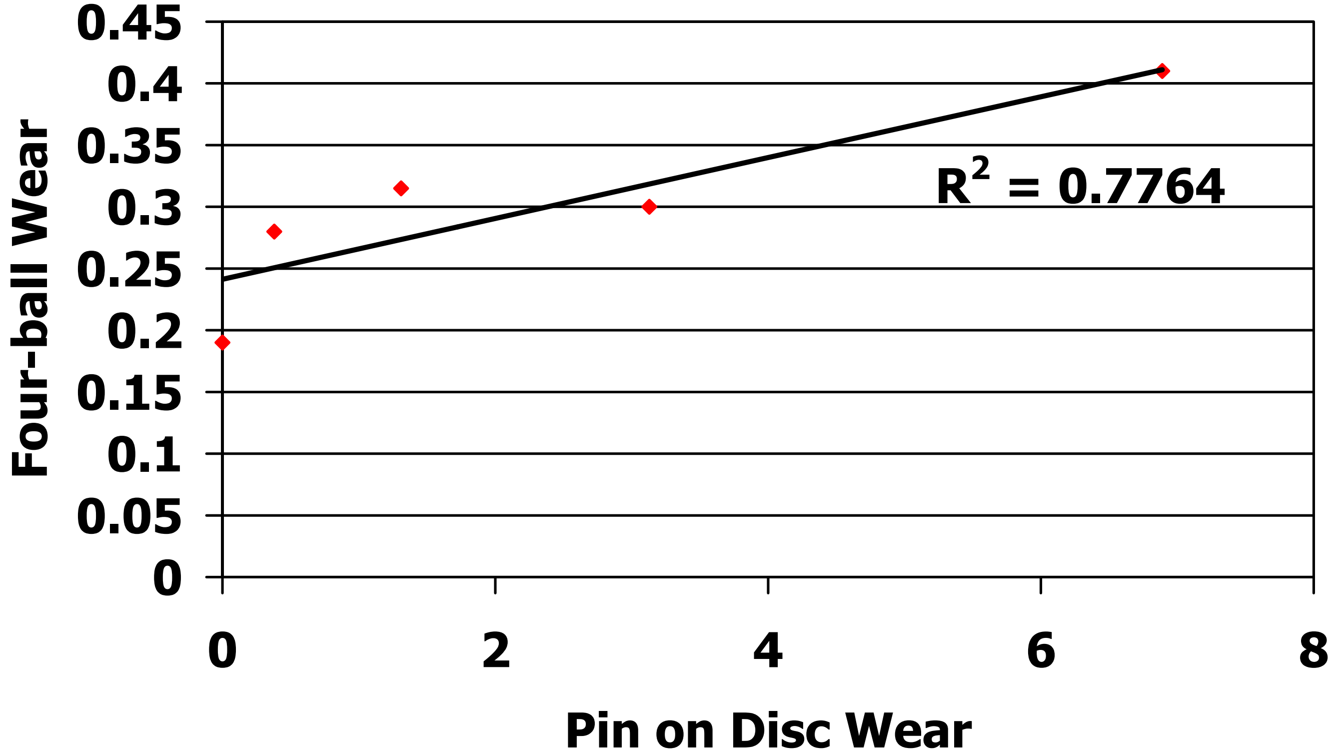
Effect of "Chain Length" of Hydrocarbon Oils on Wear – 4Ball Test vs Tribometer



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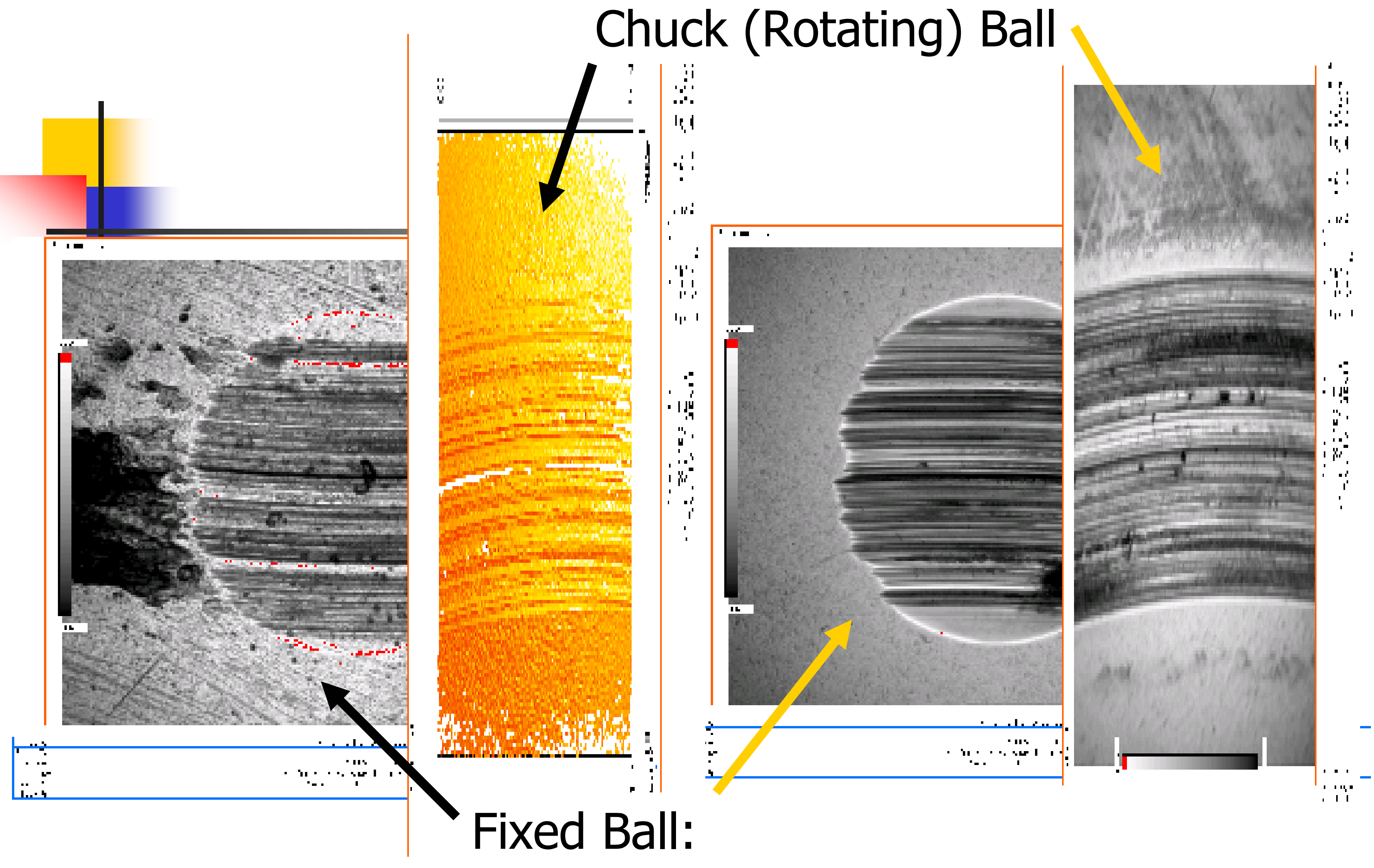

Before Cleaning

After Cleaning

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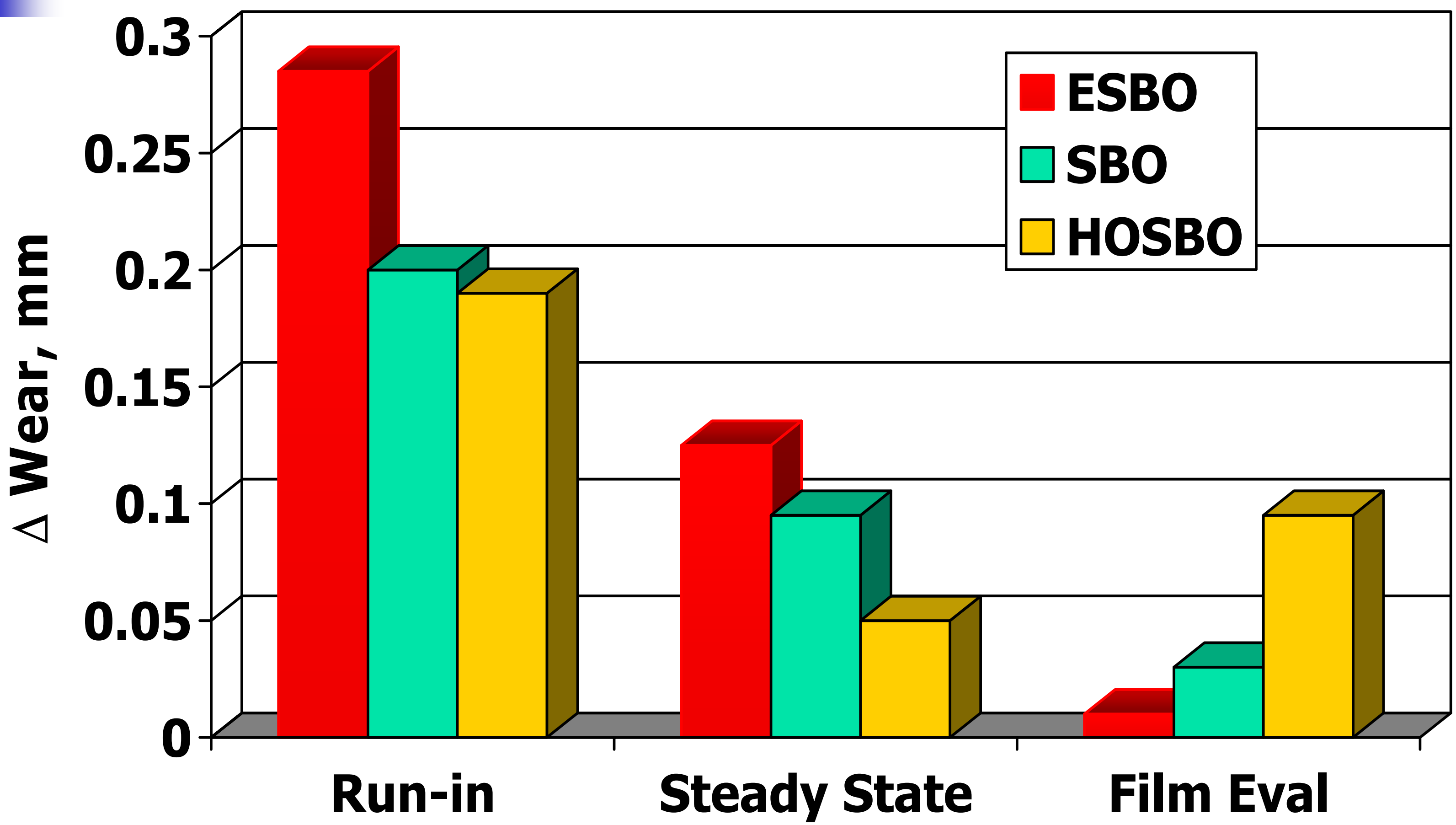
Effect of Double Bonds – Veg Oils



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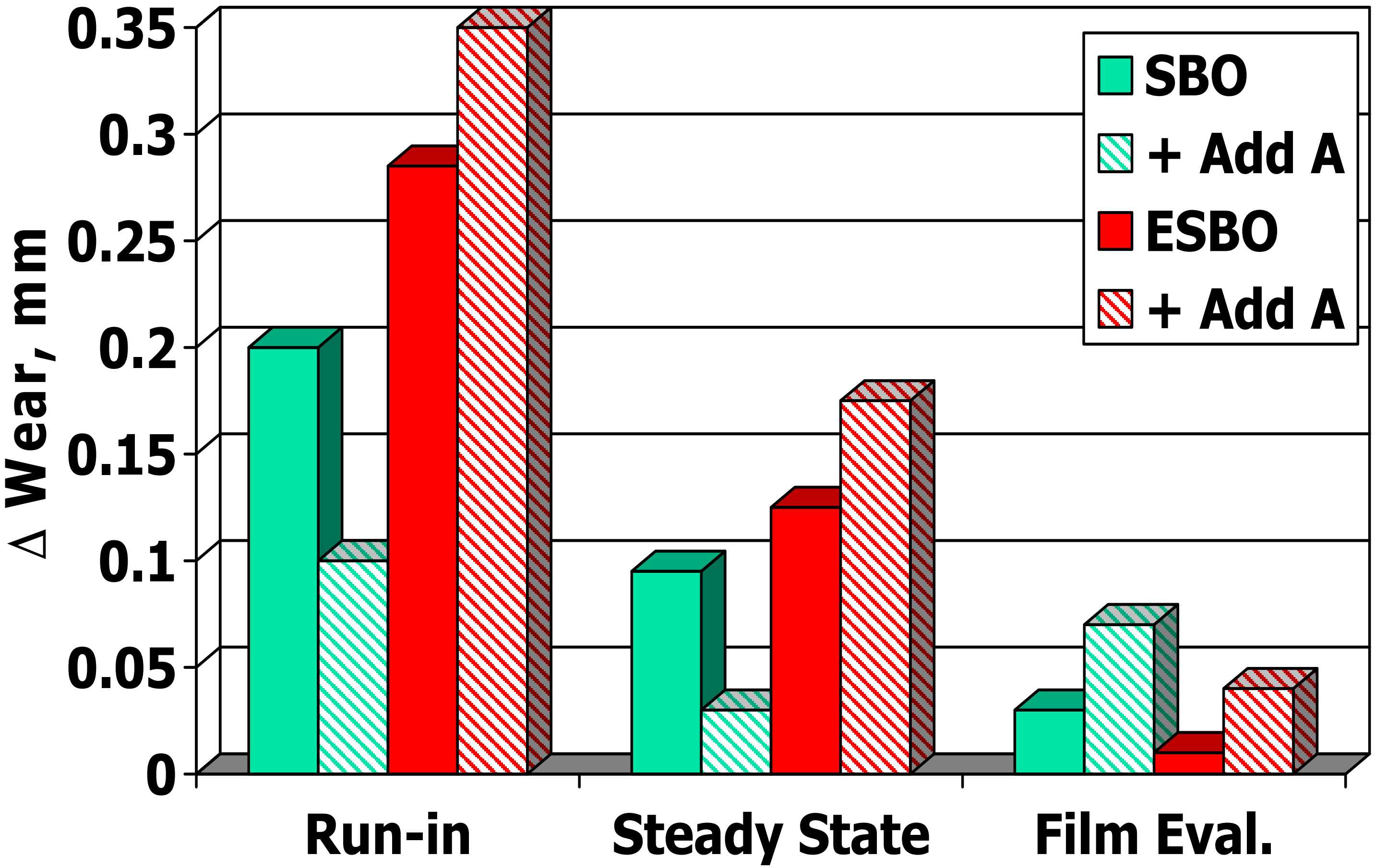
Additive Effectiveness - Additive A



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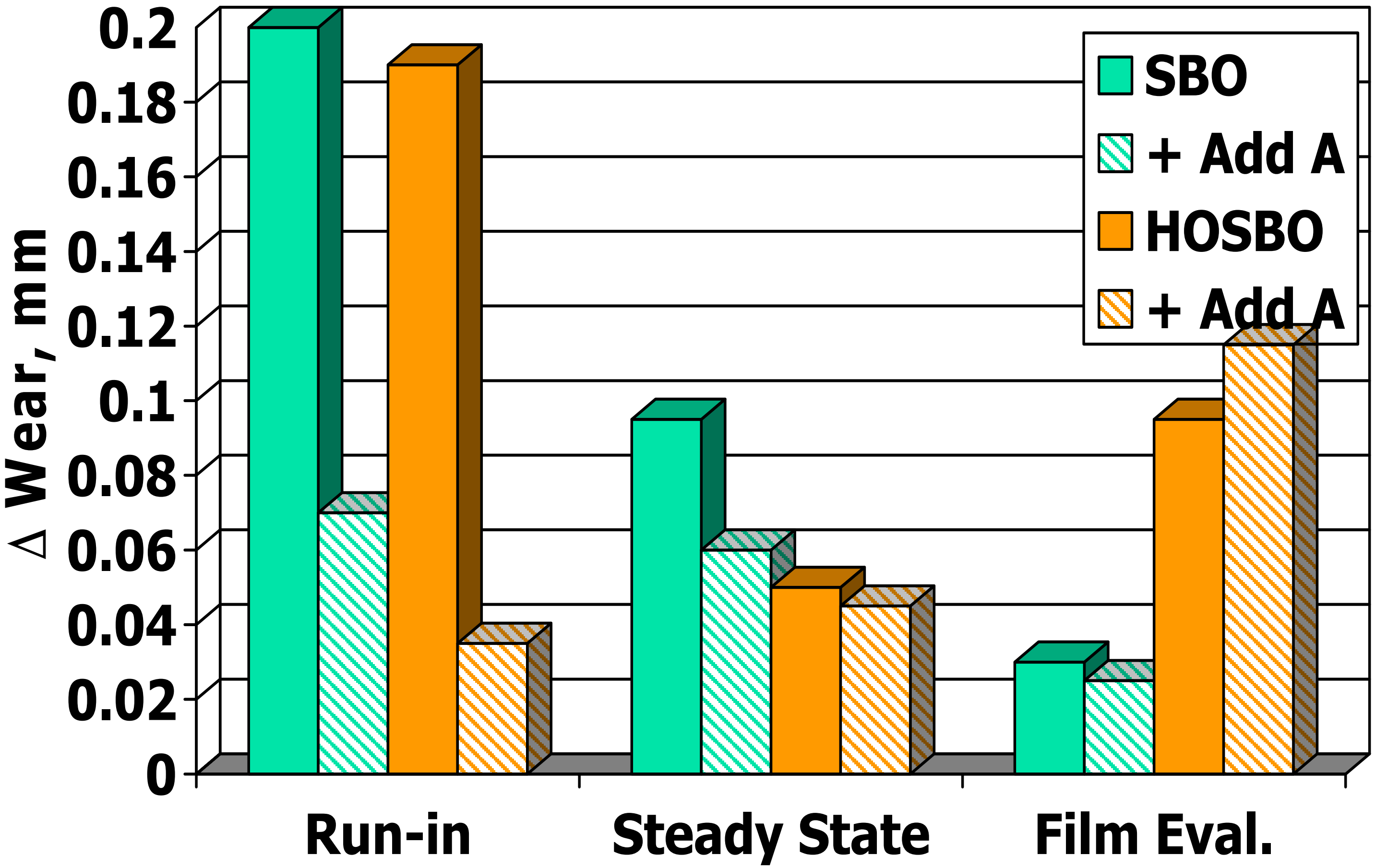
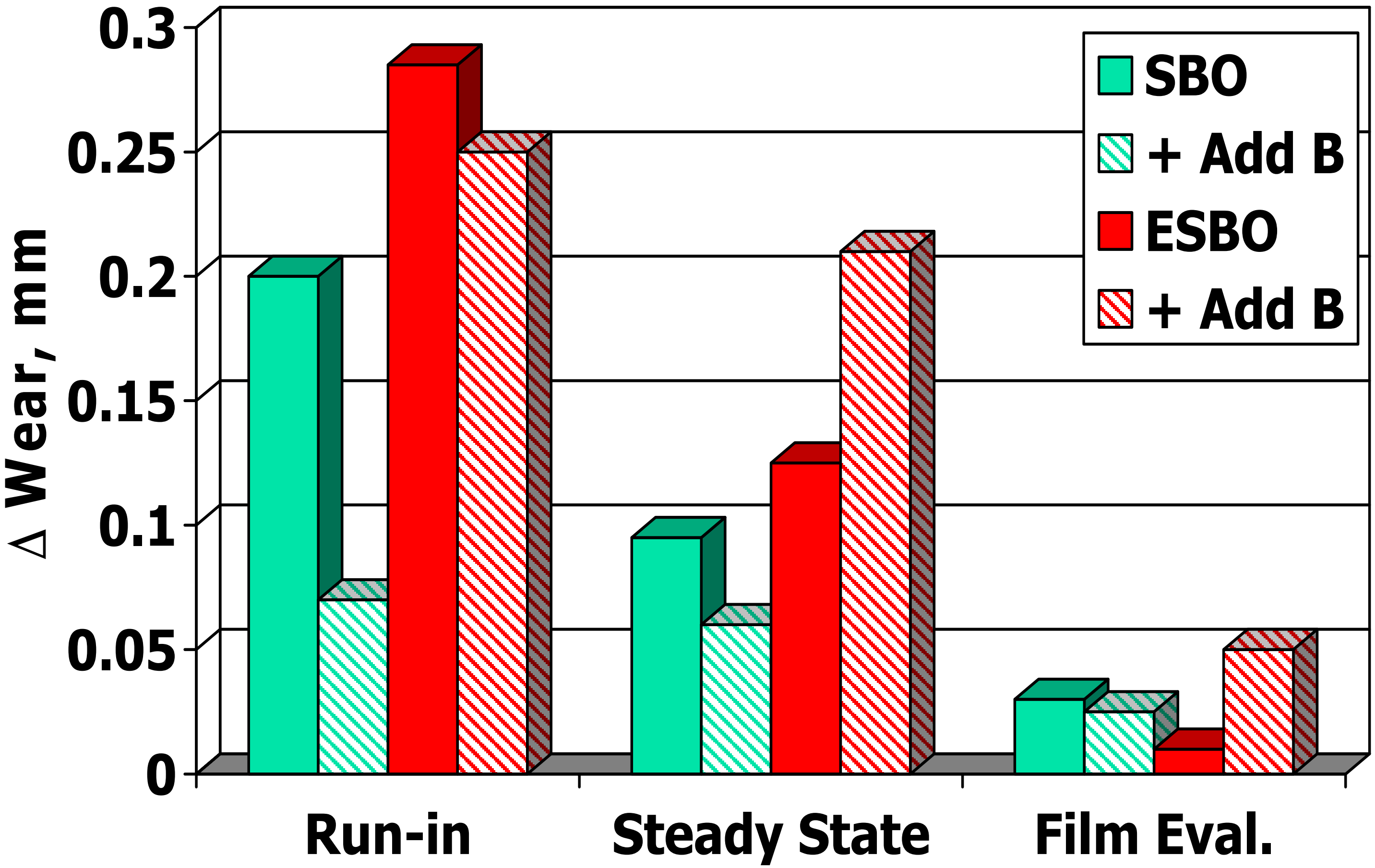
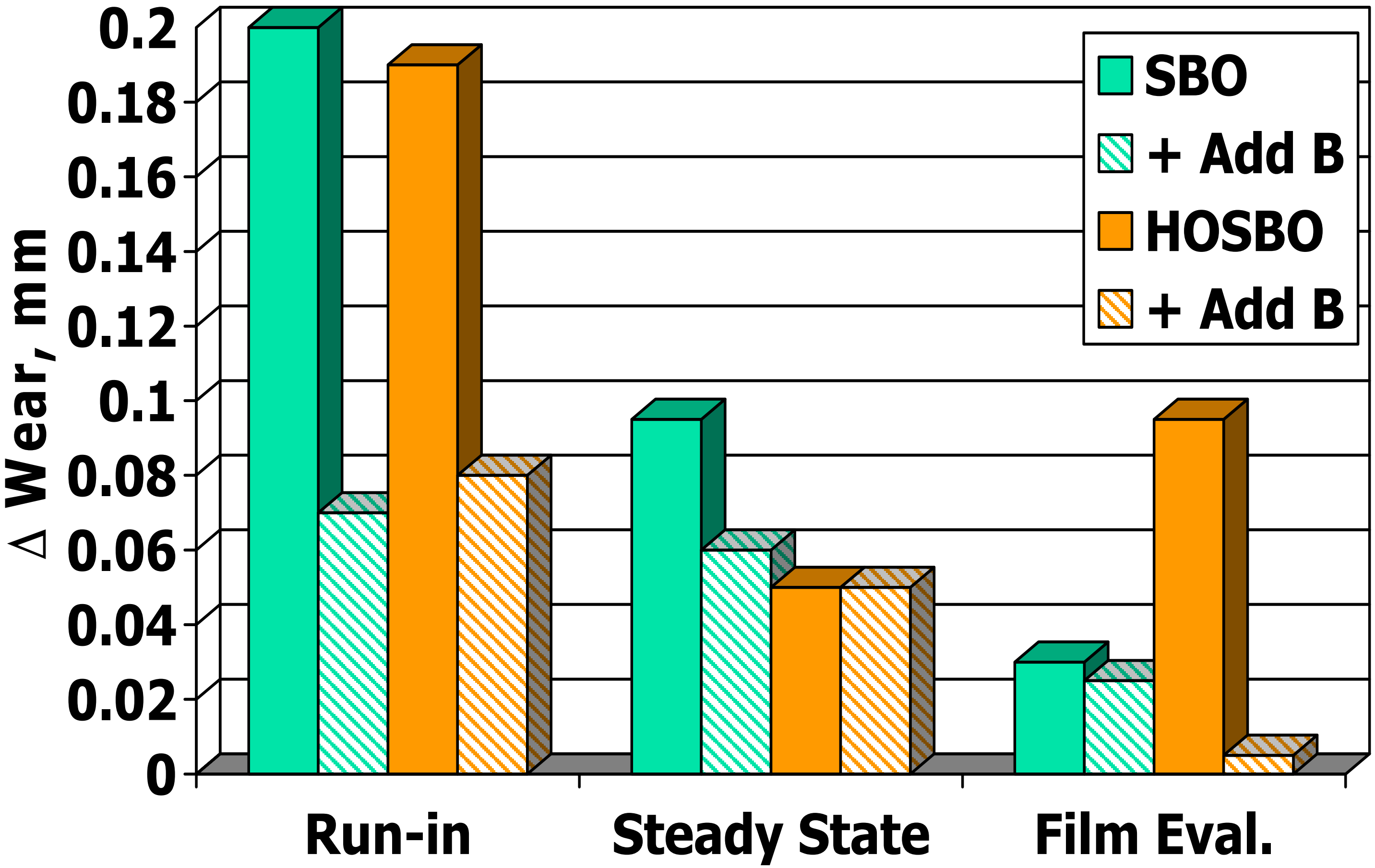
Effect of Unsaturation - Additive A



Additive Effectiveness - Additive B



Effect of Unsaturation - Additive B



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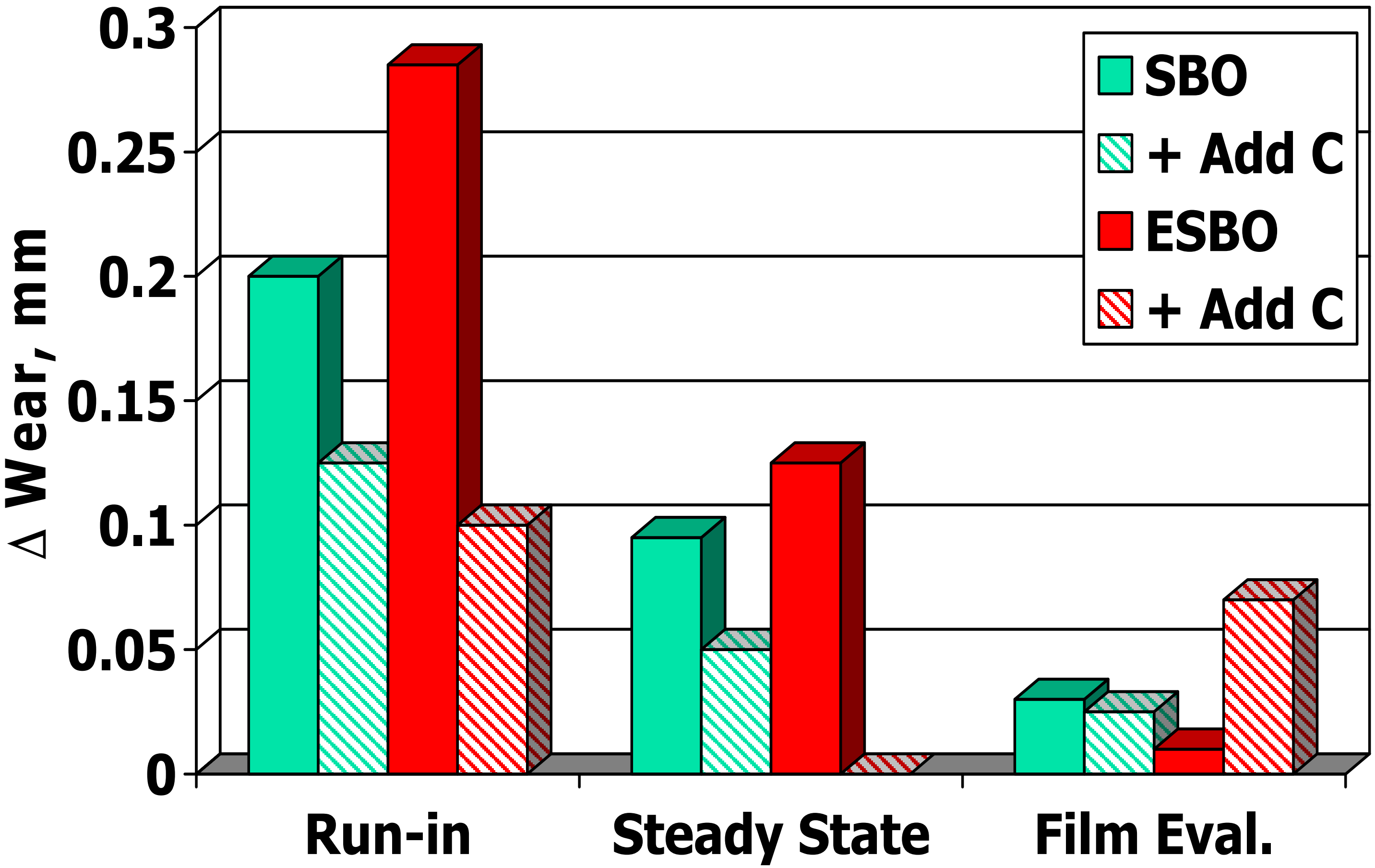
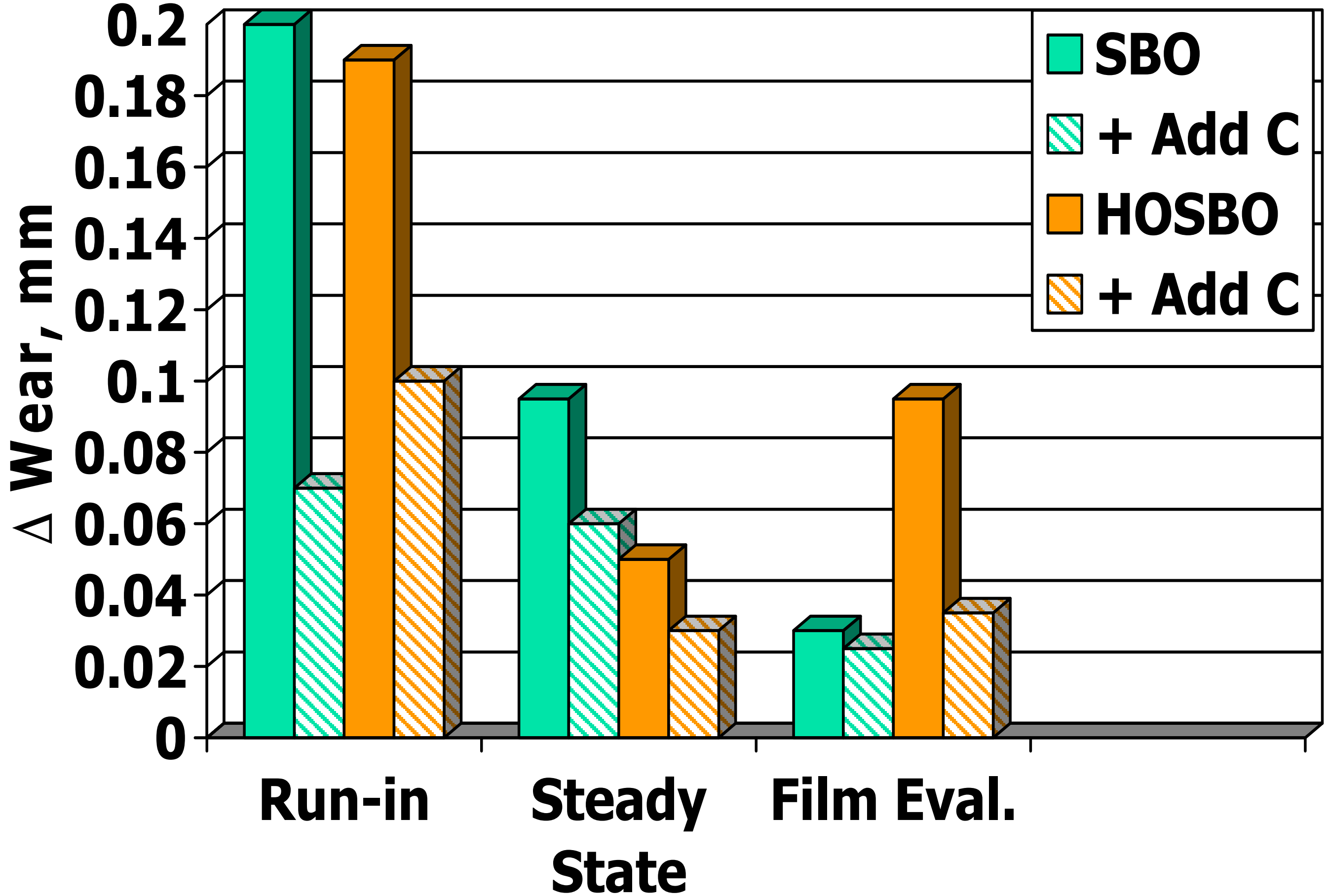
Additive Effectiveness - Additive C



Effect of Unsaturation - Additive C



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Summary

- EFF & L - research studies & demonstration projects.
- Oxygenated Alternative Fuels - reduce particulates.
- DME - potential wear problems.
- VPO Biodiesel - effective f & wear additive.
- ULSF's – wear, deposits, filter plugging.
- Chemical structure of base fluids and additives - significant factor in future lubricant formulation.
- New test methods - key to understanding surface interactions. (Optical, Advanced Photon Source, etc.)
- Surface engineering–materials, coatings & lubricants.

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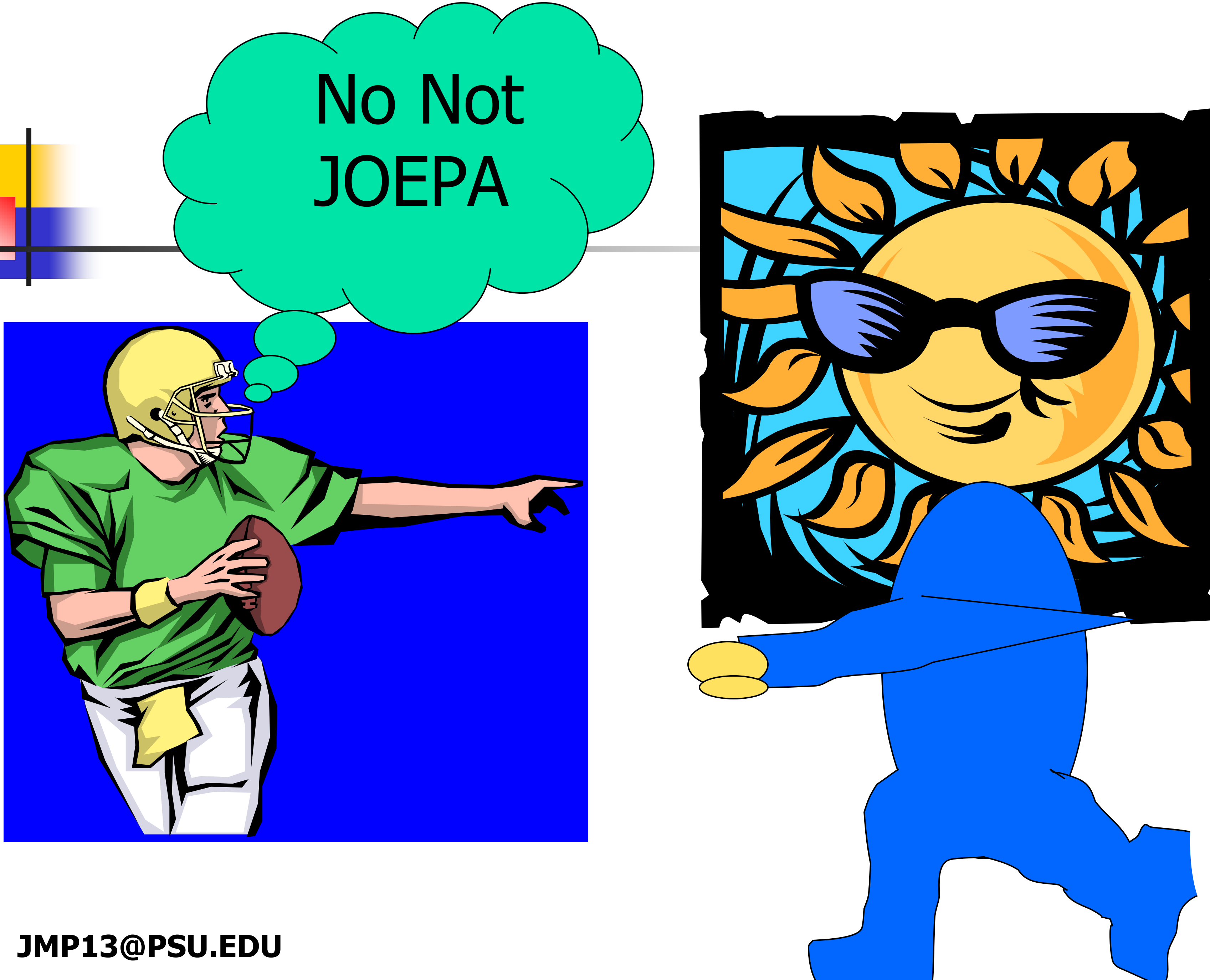
  - David Weller – Chemical Characterization
- Northwestern University:
  - Ashlie Martini - Pin-on-disc studies,
  - Mark Sturino - Pin-on-disc studies, Optical Microscopy



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Is Tribology Important?

- Lack of Tribological Solutions results in Big Business:
  - 1980 Survey - Over 20 Billion lost due to friction and wear annually

    ASME Research Committee, circa 1980
  - 1995 - Over 1.5% of the gross national product is lost due to friction and wear

Amato, Ivan, " Better ways to Grease Industry's Wheels" Fortune, Sept 1995; 256 [B]-256[K]