On the Role of Synthetic Lubricants in Energy Efficiency

as presented at 58th Annual STLE National Meeting

By
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Topics

- Energy-Efficiency Defined
- How Synthetics Differ From Mineral Oils
- Theoretical Advantages
- Other Advantages of Synthetics
- Economics –in selected Equipment
- Summary and Conclusions

Defining Energy Efficiency

Thermodynamic Laws of Energy

- Energy Input = Energy Output (First law)

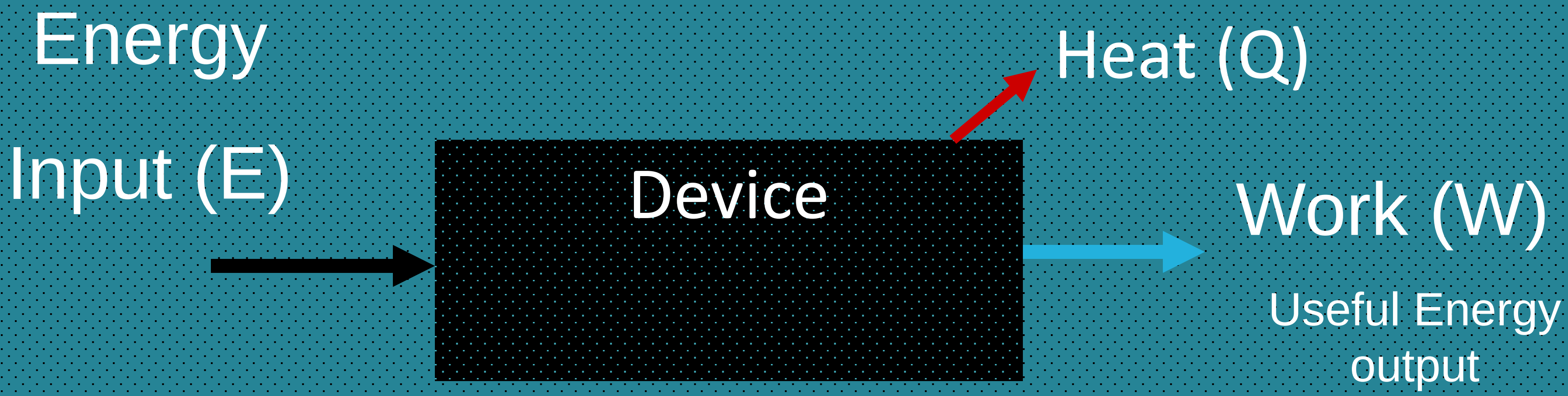
  The total energy of any systems and its surroundings is conserved.

  Or for the purists: $dU = dQ + dW$

- Energy Input ≥ <u>Useful</u> Energy Output (Work) (Second Law)

  $E = \text{Work} + \text{Heat} = W + Q$

Efficiency of Energy Conversion



Device efficiency = W / E

Remember that Energy Input ≥ <u>Useful</u> Energy Output, so that Device efficiency ≤ 1.0 (It must be!)

Common Energy Efficiencies

Device	Energy Conversion	Typical Efficiency
Electric generator	Mech./Elect.	95
Electric motor (large)	Elect/Mech.	90
Electric motor (small)	Elect/Mech.	65
Steam Turbine	Thermal/Mech.	45
Ind. Gas Turbine	Chemical/Mech.	30
Automotive Engine	Chemical/Mech.	25

Energy Efficiency --
What's the Maximum Potential?

According to a US Government Study:

- In 1994 electric motor-driven systems used in industrial processes consumed 679 billion kWh, or 23% of all electricity sold in the US;
- An estimate that 11 to 18 percent energy reduction can be achieved
  - "all cost-effective applications of mature proven efficiency technologies and practices".

Energy Efficiency Possibilities

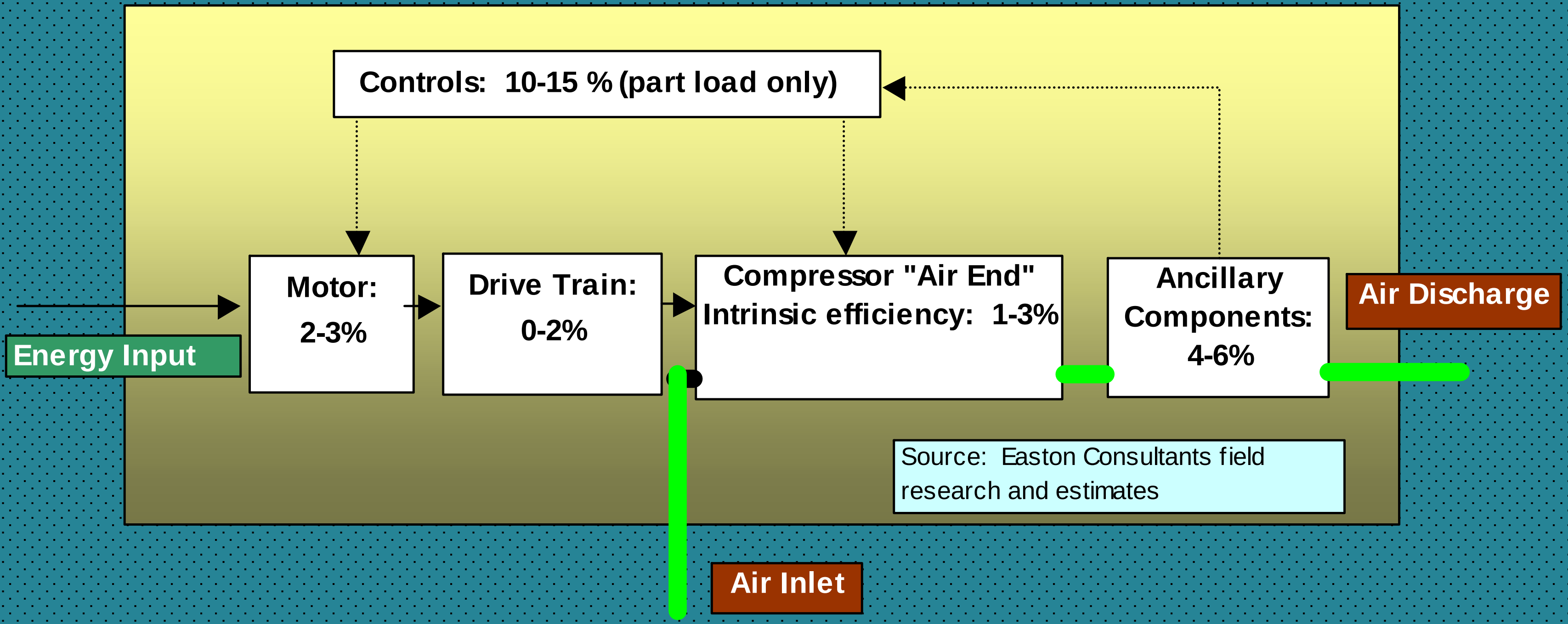
Pump Equipment	5 to 10%
Compressor Equipment	15 to 25%
Industrial Fans and Blowers	5 to 15%

Additional Savings are possible through improved operating and maintenance practices

National Market Transformation Strategies for Industrial Electric Motor Systems (Volume II: Market Assessment). U.S. Department of Energy, Office of Energy Efficiency and Alternative Fuels Policy and Office of Industrial Technologies. DOE/PO-0022. May 1996.

Example of a Energy Saving Possibility

Summary of Plant Air Compressor Savings Potential by Package Component: 15-25% Possible Savings



Controls: 10-15 % (part load only)

Energy Input

Motor: 2-3%

Drive Train: 0-2%

Compressor "Air End" Intrinsic efficiency: 1-3%

Ancillary Components: 4-6%

Air Discharge

Air Inlet

Source: Easton Consultants field research and estimates

Energy Efficiency Comparison - Synthetic vs. Mineral Oil-based Lubricants

Examples Taken From Published Papers

The Influence of Synthetic Oil and Mineral Oil on Friction Losses

- Friction loss decreases with increasing viscosity and with increasing rotational speed at relatively high loads
- Friction loss in high load range are dependent on the kind of lubricating base oil, i.e. mineral oil and synthetic oils.

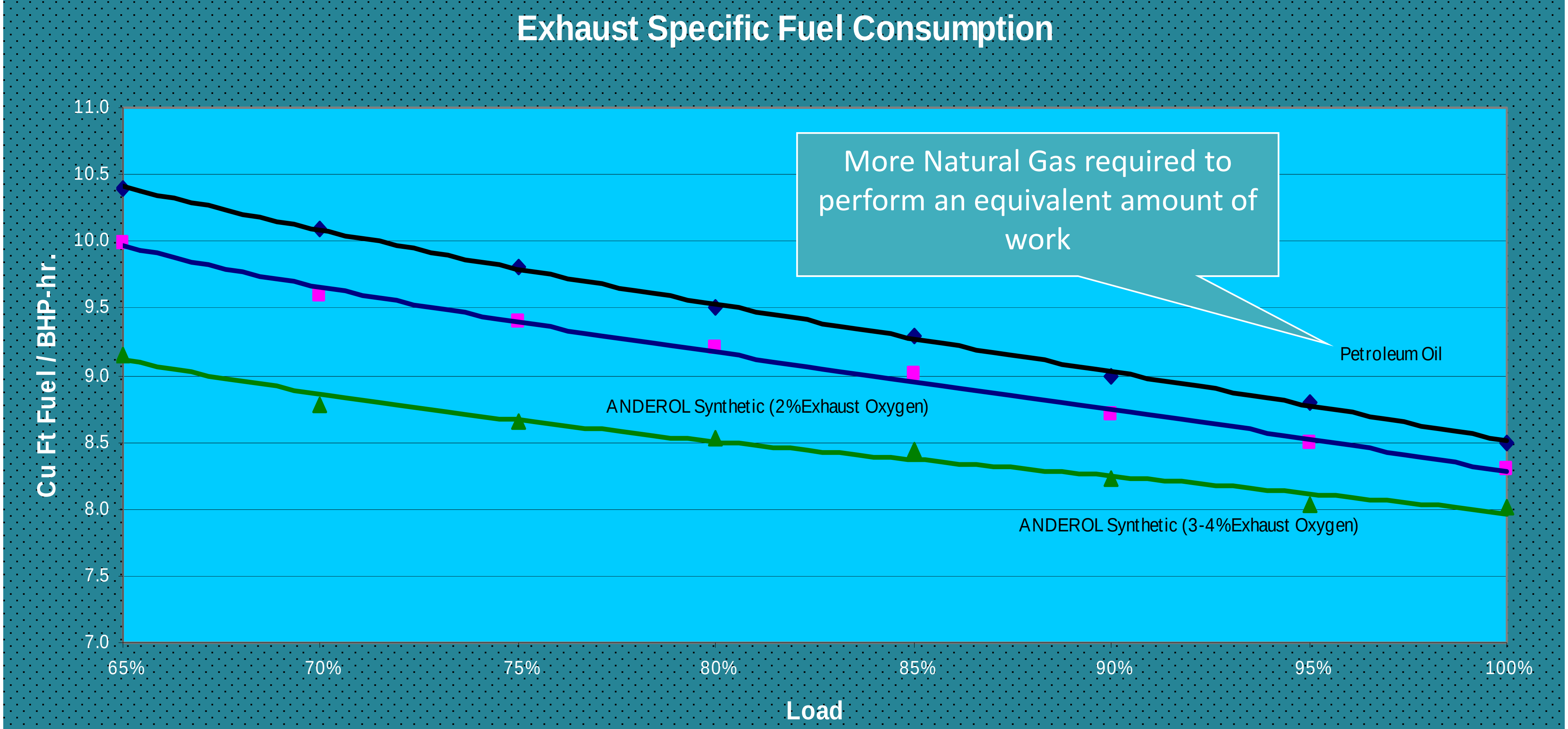
Influence of Oil Viscosity, Chemical Oil Structure, and Chemical Additives on Friction Loss of Spur Gears (Concerning the Influence of Synthetic Oil and Mineral Oil). By Chotaro Naruse, Ryozo Nemoto, Shoui Haizuka and Masatoshi Yoshizaki. Tribology Transactions, volume 37 (1994), 2, 358-368.

Integral Natural Gas Compressor – Ester Based Synthetic Lubricant

- Energy Savings depends on Load and Fuel-Air mixture ratio
  - Average Energy Savings 3.6% to 6.8%
- Engine thermal efficiency improved by approximately 1.5% throughout the load range tested.
- Oil consumption showed a 55% reduction

"Gas Engine Lubricants – Synthetic v. Petroleum" by Allen F. Gerber, (ANDEROL Inc.). Presented at the A.G.A. Transmission Conference, May 4-6, 1981 in Atlanta, GA.

Integral Natural Gas Compressor



Exhaust Specific Fuel Consumption

More Natural Gas required to perform an equivalent amount of work

"Gas Engine Lubricants – Synthetic v. Petroleum" by Allen F. Gerber, (ANDEROL Inc.). Presented at the A.G.A. Transmission Conference, May 4-6, 1981 in Atlanta, GA.

PAO-Based Synthetic Lubricants in Industrial Applications

- “Decreased operating temperature of a piece of rotating equipment at constant output was observed.”
- “An indication of lower internal friction and wear and other beneficial performance of the lubricant was also reported.”

"PAO-Based Synthetic Lubricants in Industrial Applications", by L. D. Moore, D.R Fels, A.B. Seay, C. Lopez, K. E. Harris and D.A. Peck

Improvements in Industrial Gearing Efficiency With Synthetic Lubricants

An FZG gear rig assessed the benefits of synthetic lubricants on spur gear operation:

“…a synthetic lubricant generates an energy savings of 3.7 percent vs. a mineral oil for the conditions examined in this FZG spur gear test work”

“Improvements in Industrial Gearing Efficiency Through Application of Synthetic Lubricants", by Alan Blahey, Doug Hakala, Bill Sweet, John Straiton, and Mariam Juves. By permission of the authors and Imperial Oil

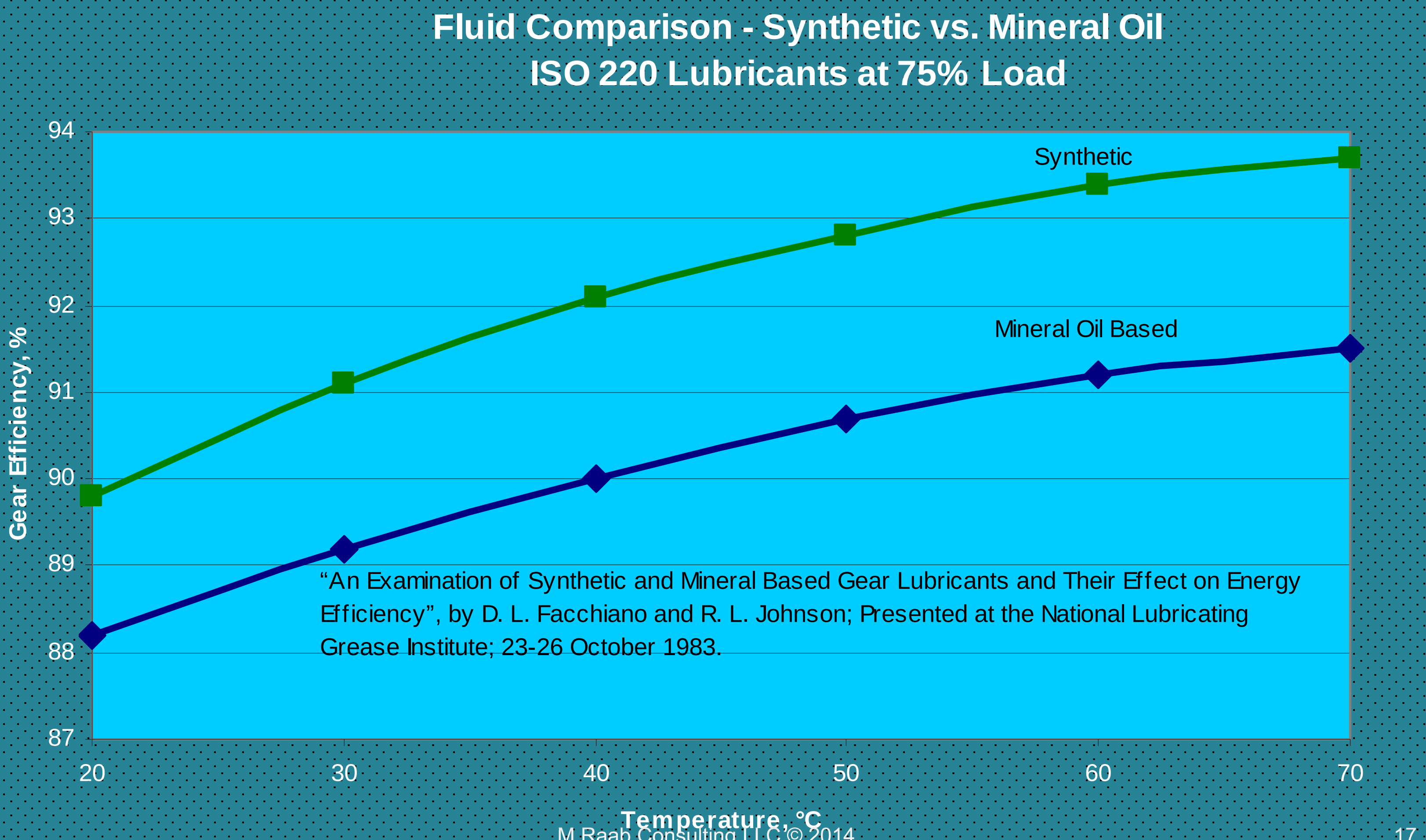
Improvements in Worm Gears: Results at a Coal-Fired Utility

Specific Power (kVAh/kg/s)

Load	*Mineral Oil*	*Synthetic*	*Energy Improvement*
50%	*0.919*	*0.831*	*+9.6%*
60%	*0.832*	*0.760*	*+8.7%*
70%	*0.765*	*0.700*	*+8.5%*

"Improvements in Industrial Gearing Efficiency Through Application of Synthetic Lubricants", by Alan Blahey, Doug Hakala, Bill Sweet, John Straiton, and Mariam Juves. By permission of the authors and Imperial Oil

Worm Gear Efficiency Improvement



“An Examination of Synthetic and Mineral Based Gear Lubricants and Their Effect on Energy Efficiency”, by D. L. Facchiano and R. L. Johnson; Presented at the National Lubricating Grease Institute; 23-26 October 1983.

Synthetic & Mineral Based Gear Lube: Effect on Efficiency

Synthetic vs. Mineral Oil @75% Load Capacity

Temperature, °C	Mineral Base	Synthetic	Increase in Efficiency
20	88.2	89.8	1.8%
30	89.2	91.1	2.1%
40	90.0	92.1	2.3%
50	90.7	92.8	2.3%
60	91.2	93.4	2.4%
70	91.5	93.7	2.4%

“An Examination of Synthetic and Mineral Based Gear Lubricants and Their Effect on Energy Efficiency”, by D. L. Facchiano and R. L. Johnson; Presented at the National Lubricating Grease Institute; 23-26 October 1983.

Synthetic vs. Mineral Reported Energy Improvement

Equipment	Min% Reported*	Max % Reported*
Spur Gears	1.1	3.2
Worm Gears	1.1	30
Helical Gears	1.1	3.8
Nat Gas Compressor	3.6	6.8

* Based on published literature (under defined operating conditions)

Synthetic vs. Mineral
Reported Energy Savings

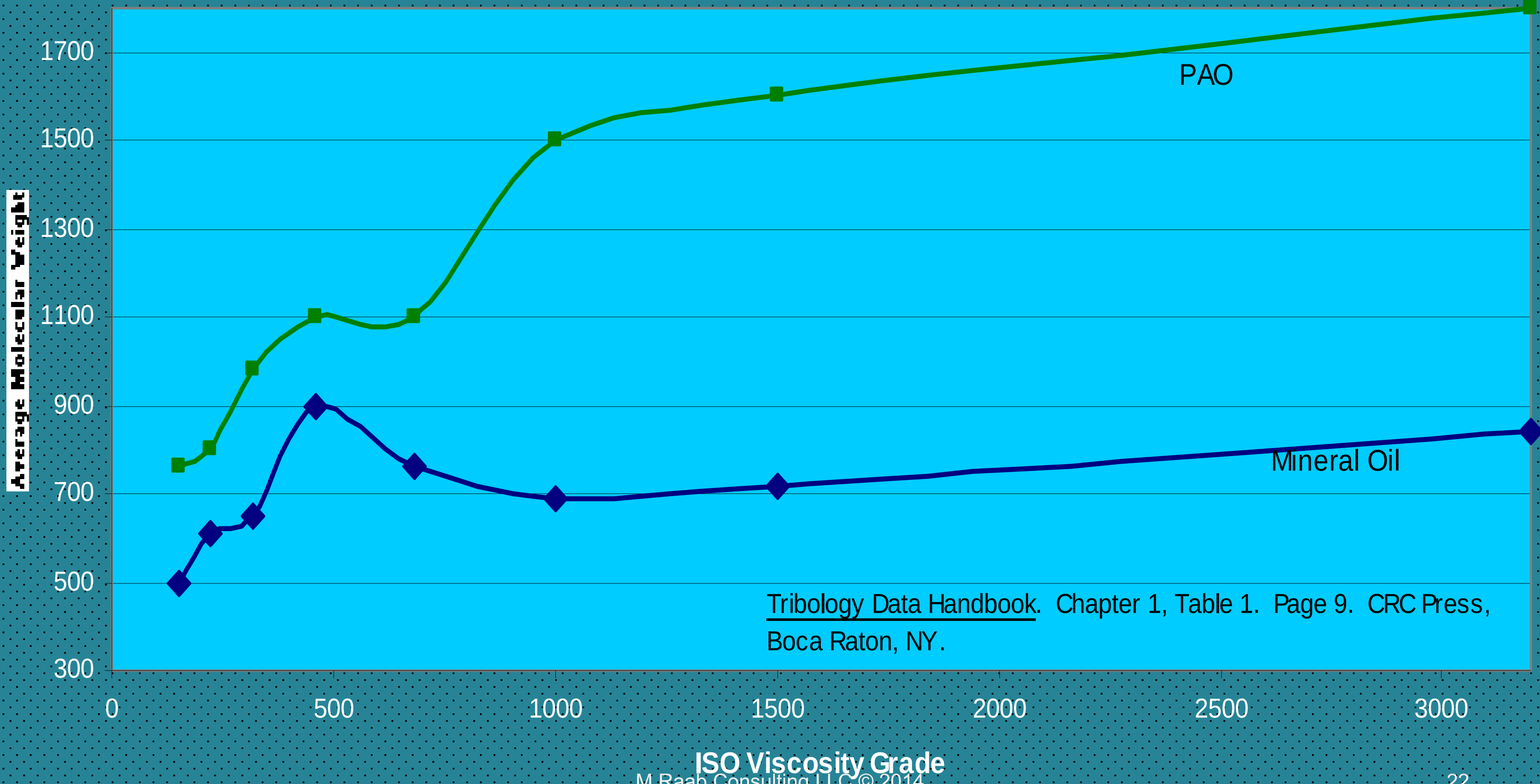
Equipment	Savings %
Rotary Compressors	8.3 (average)
Recip Compressors	7.4 (average)
Centrifugal Compressor	3.5 (average)
FZG Rig Testing	3.7 (sdp)
Truck Transmission	1.4 (sdp)
* Based on published literature	sdp = single data point

Properties of Synthetic Lubricants Contributing to Observed Efficiency Improvement

Examples

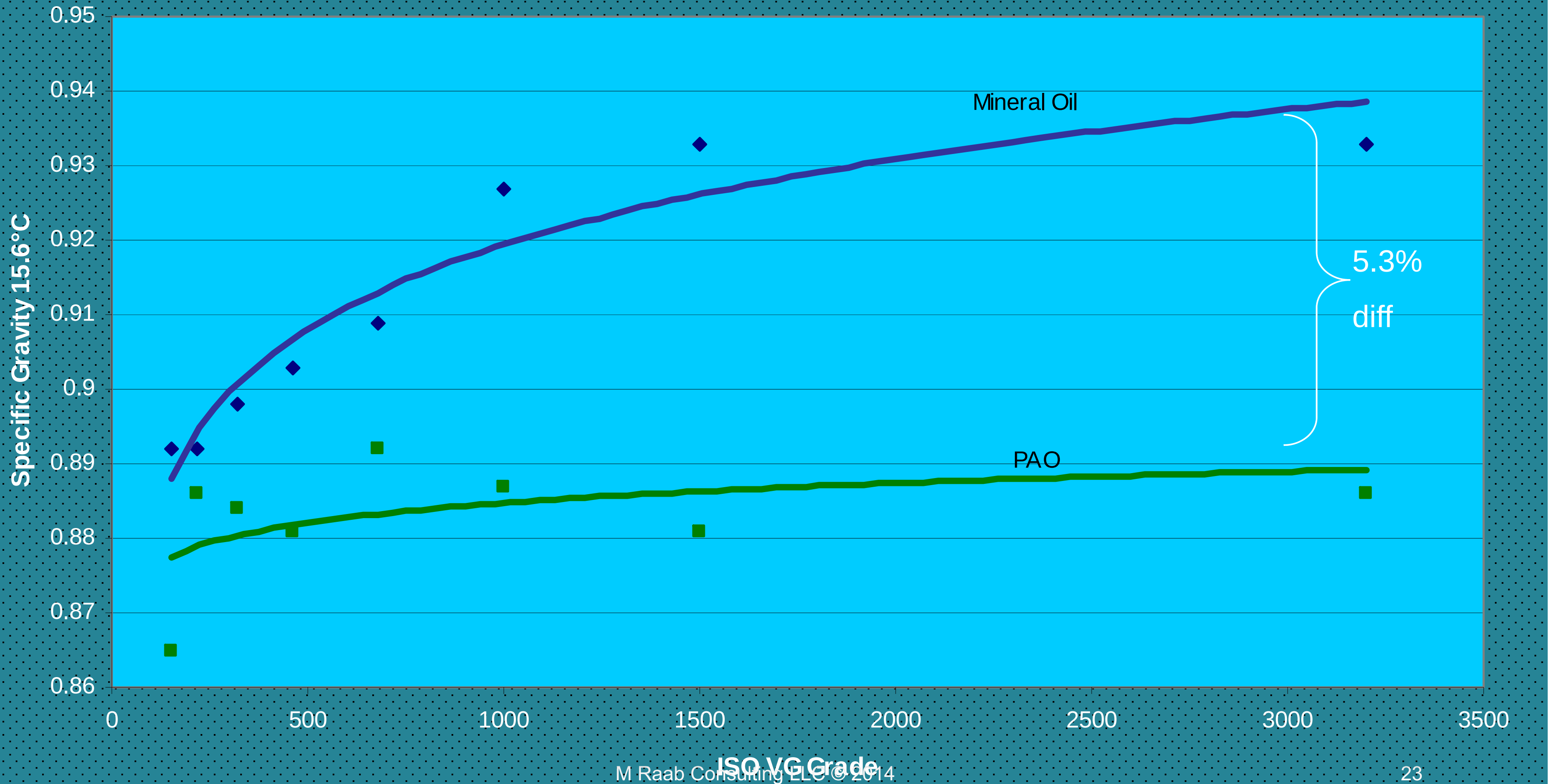
Higher Molecular Weight

Affects Densities and Thermal Properties



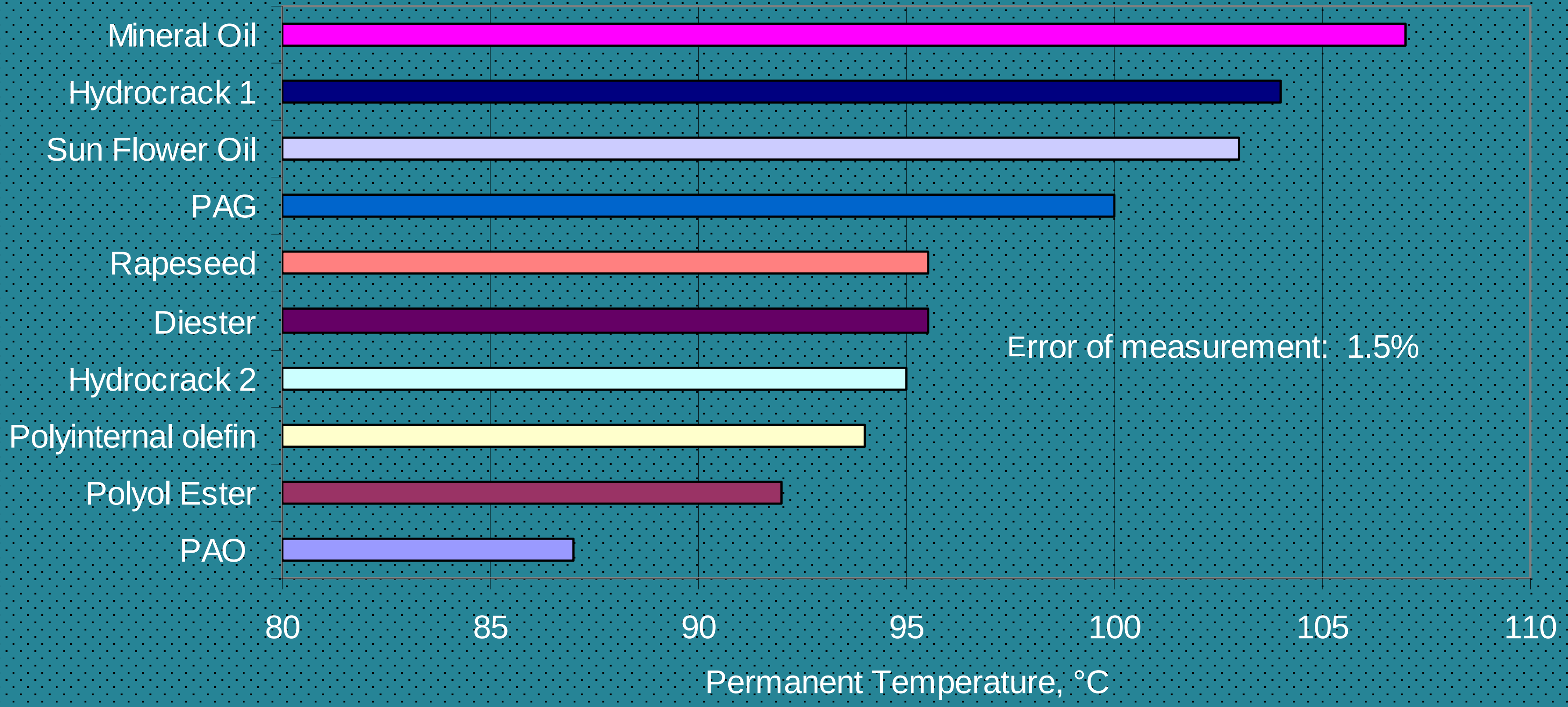
Tribology Data Handbook. Chapter 1, Table 1. Page 9. CRC Press, Boca Raton, NY.

Fluid Density Differences



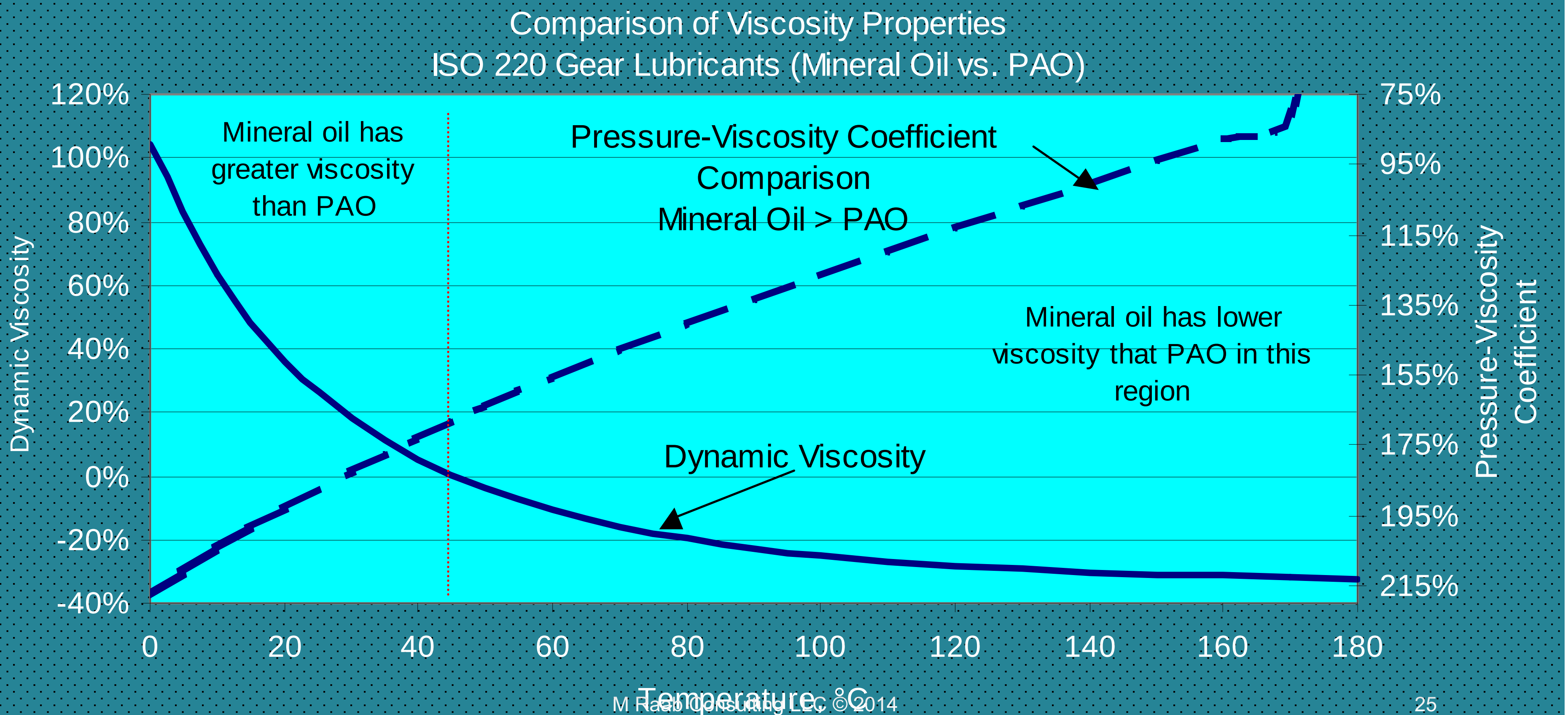
The Base Stock Affect With Respect to Oil Temperature

(comparable viscosity fluids and test conditions)



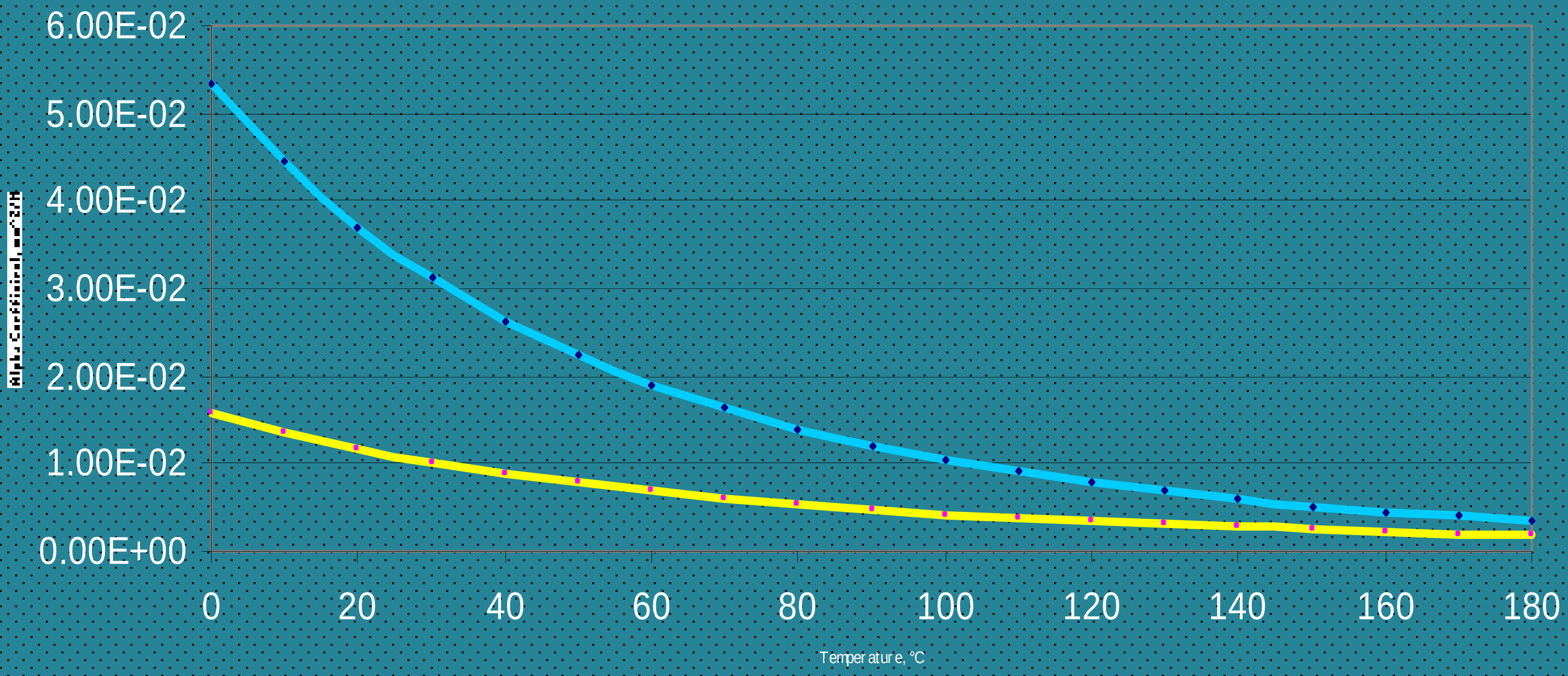
Source: "Influence of Gear Oil Formulation on Oil Temperature", by Wienecke, D. and Bartz, W. J., SAE 2002-01-1693

Synthetics: Superior Viscosity Temperature Properties & Lower Alpha-Coefficients



Comparison of Viscosity Properties
ISO 220 Gear Lubricants (Mineral Oil vs. PAO)

Lower Alpha Coefficients



(A Typical ISO 460 Mineral Oil Compared to a PAO-based Gear Lubricant)

Influence of Lubricant Selection on Energy Efficiency in Gear Systems

Example 1

Power Loss in a Gear System

P_{total} = **gear losses + bearing losses + sealing losses + auxiliaries losses**

Or,

$$P_{total} = t_o \bullet P_o + (1 - t_o) \bullet P_{load}$$

Where t_o = the fraction of time that the system is unloaded (utilization rate)

P_o = power loss of the system without load

P_{load} = power loss of the system with load

The Primary Losses Are Due to Fluid Churning and Friction

$$P_{total} = t_o \bullet (P_{CHo} - P_{CH}) + (1 - t_o) \bullet P_F + P_{CH}$$

Meaning: for a given utilization rate, increased churning power & frictional power losses directly increase total power losses. Churning losses occur under both load and no-load conditions.

Churning Losses in Gears

(oil and speed related parameters)

$$P_{CH} = K \bullet \rho \bullet \eta^{0.6} \bullet \nu^{2.15}$$

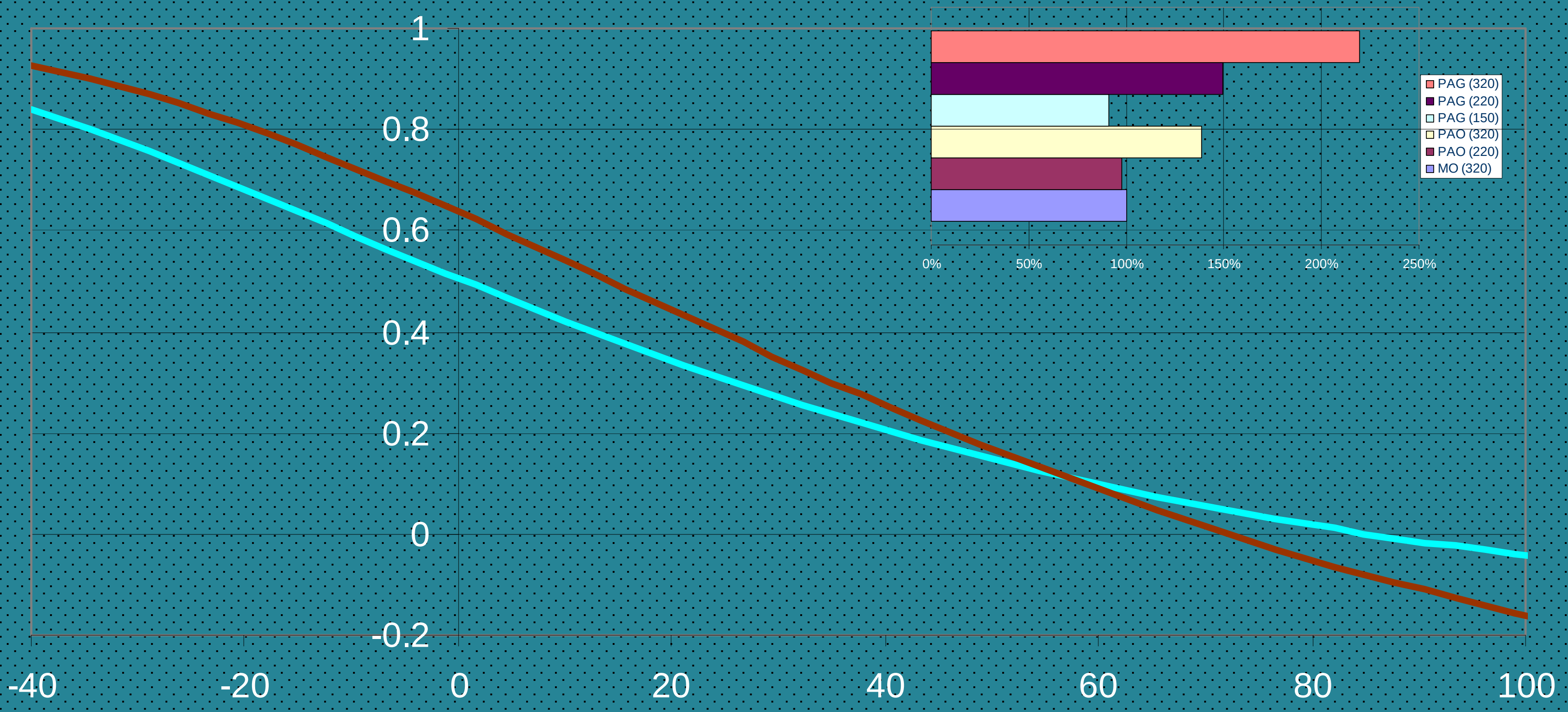
Where:

ρ = Oil density (as a function of Temperature)
η = Kinematic viscosity (as a function of Temperature)
ν = Peripheral speed of the gear
K = gear wheel constant dependent upon radius and width of the gear and other geometric properties

Meaning: lower viscosity and/or density decreases churning losses

Churning Losses – Relative to Mineral Oil

(Equivalent Dynamic Viscosity at Operating Temperature of 80°C)



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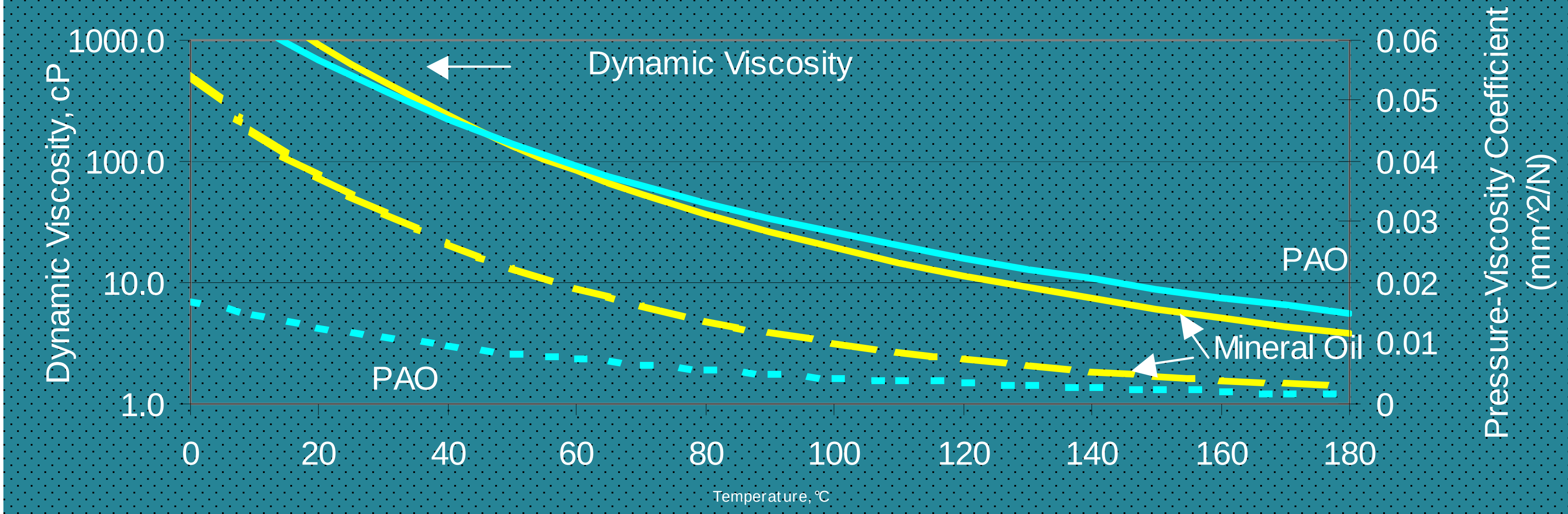
Comparing Viscosity Properties

PAO vs. Mineral Oil (ISO 220 Gear Oil)



Mean Gear Mesh Power Loss

$$P_F = P_a \bullet \mu_{mz} \bullet H_v$$

P_F is the gear mesh power losses
P_a is the transmitted power
μ_{mz} is the mean coefficient of friction, and
H_v is the gear power loss factor. (It is a function of the gear ratio, number of pinion teeth, helix angle at base circle, profile contact ratio, and addendum contact ratio of the pinion and the gear).

Meaning: lowering the mean coefficient of friction decreases gear mesh power loss

Coefficients of Friction in Gear Application

- "It is evident that for the mineral oils of very different viscosities and additive levels, virtually the same values for the coefficient of friction are found.
- For these operating conditions, the polyalphaolefins show a mean value of 80 percent and the polyglycols show a mean of 70 percent of the coefficient of friction of the mineral oils.
  - For the polyglycols, the lower values are measured for water-soluble products compared to oil soluble products."

"Influence of Lubricants on Power Loss of Cylindrical Gears" by K. Michaelis and B. R. Hohn. Gear Research Center, Technical University of Munich. Tribology Transactions, Volume 37 (1994), 1, 161-167.

Comparison of Coefficients of Friction (continued)

Product	ISO Viscosity Grade	Mean Gear Friction Coefficient
Mineral Oil base, EP Gear Oil	220	0.048
PAO based Gear Oil	220	0.036
PAG based Gear Oil	220	0.033

“Influence of Lubricants on Power Loss of Cylindrical Gears” by K. Michaelis and B. R. Hohn. Gear Research Center, Technical University of Munich. Tribology Transactions, Volume 37 (1994), 1, 161-167.

The Efficiency of Synthetic Gear Lubricants is Supported in Theory

- Lowers the Churning Losses
  - At low temperatures
  - Dependent on the density and oil viscosity
- Lowers the "Mean Coefficient of Friction"
  - Depends on the lubricant chemistry

Energy Saving Using a Synthetic Gear Lubricant Compared to a Mineral Oil (example)

Power Use Calculations	Factor	Costs based on Use of Synthetic	Baseline Mineral oil
Unit horsepower		60	
Divide by efficiency	0.92	65.2	
Divide by Power factor	0.773	84.4	
Convert hp to kWh	0.7457	62.9	68
kW per day	24	1509.9	1632
kW per Operating Year	260	392,584	424,320
Annual Cost of Power	$ 0.06	$ 23,555	$ 25,459
Annual power cost savings, %		**7.5%**	

Based on published information

Economics in A Rotary Screw Air Compressor

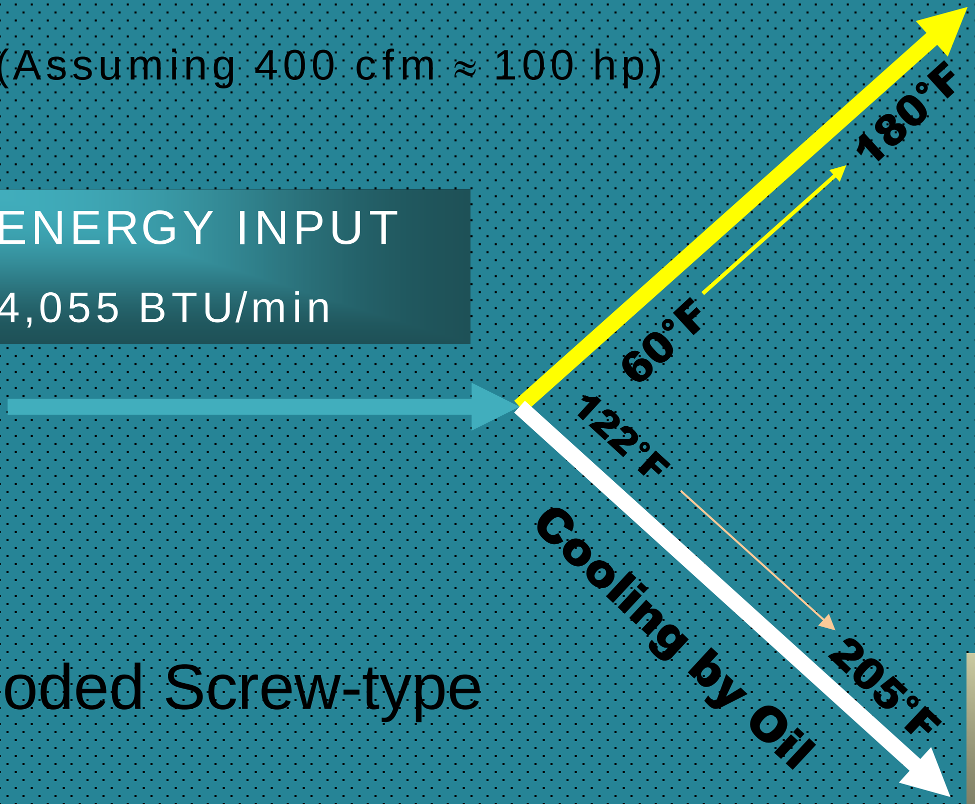
Example 2

Typical Heat Flow In A Rotary Screw Air Compressor

(Assuming 400 cfm ≈ 100 hp)

ENERGY INPUT

4,055 BTU/min



ENERGY ABSORBED IN AIR

1061 BTU/min or 26%

100 PSIA, 400 cfm

Oil flow of 11 gpm

ENERGY ABSORBED IN OIL

3,175 BTU/min or 74%

Flooded Screw-type

Air-Cooled, Oil-Injected Rotary Screw Air Compressor

Theoretical power / Efficiency =

$$\text{Absorbed Power} = \underbrace{m_g \bullet C_{\rho g} \bullet dT_g}_{\text{Gas}} + \underbrace{m_o \bullet C_{\rho o} \bullet dT_o}_{\text{Lubricant}}$$

Where m_o = oil mass flow;
m_g = gas mass flow
$C_{\rho o}$ = oil specific heat;
$C_{\rho g}$ = gas specific heat
dT_o = oil temperature change;
dT_g = gas temperature change

Influence of the Lubricant in a Rotary Screw Air Compressor

$$\text{Absorbed Power}_{\text{oil}} = m_o \bullet C_{\rho o} \bullet dT_o$$

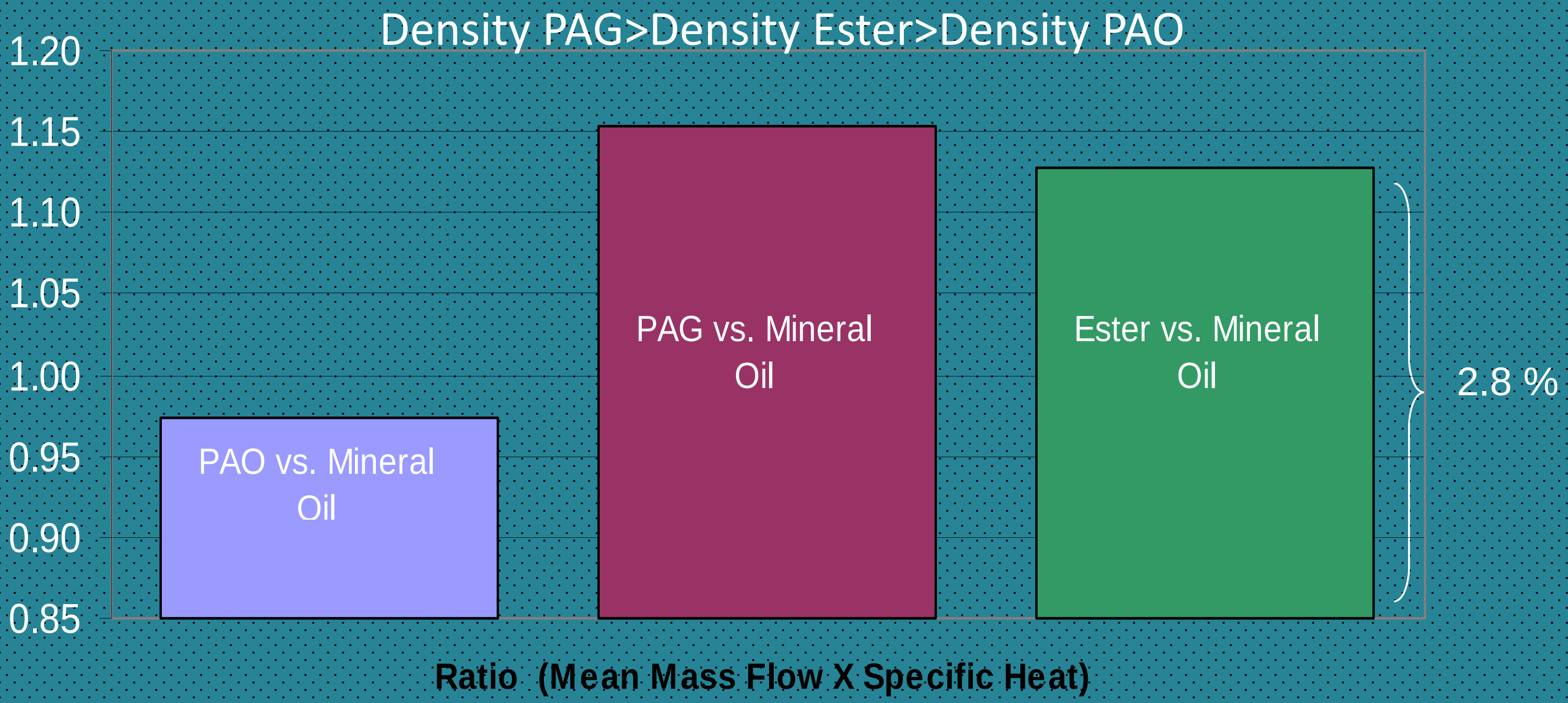
Meaning: Higher Specific Heat **C_{po}** increases Absorbed Power, which in turn, improves Efficiency

Approx 75% of absorbed power goes into oil cooling.

Note: The mass-flow **m_o** depends on the specific gravity (density) of the lubricant.

The Temperature term is generally controlled by the equipment design and operating parameters.

Synthetic Oil Selection Affects Absorbed Power



Operating and Maintenance Cost Savings - Assumptions

Downtime for oil changes	**4 hours**
Oil Sum Capacity	**20 gallons**
Labor Cost	**$30/hr.**
Cost of Premium Mineral Oil	**$8.00/gal**
Cost of Synthetic	**$25.00/gal**
Separator Element Cost	**$650 each**

Note: all costs are at consumer level

More Assumptions

Operating hrs per year	8,000
Unit Size	100 hp
Unit Capacity	400 cfm
Cost of Electricity	0.06 $/kWh
Energy Improvement over MO (predicted for formulation)	2.8 %
Annual Energy Cost - MO	$43,776

Annual Cost of Operation

(400 CFM, Rotary Screw Compressor)

	Premium Mineral Oil (2,000 hr life)	PAO Synthetic Oil (8,000 hr life)
Energy	$43,776	$42,550
Labor	$ 480	$120
Oil	$ 640	$ 500
Separator	$650	$ 650
Total Cost	$45,546	$43,820

Annual Cost Savings – 3.8%

Summary - Savings Achievable Using Synthetic Lubricants:

- Can be predicted based on theoretical considerations; and
- Can be demonstrated under real-world operating conditions with a properly designed and controlled experiment.

Summary - (continued)

- Depends on lubricant base stock and on additive chemistry;
- Viscosity, and operating temperatures and conditions have a strong influence;
- Is a function of load and other operating conditions.

M Raab Consulting LLC offers over 40 years of market-focused lubricant and chemical industry experience in: Marketing and Product Management, Sales and Technical Service, including OEM Manager and Industry Liaison. In-depth knowledge of Lubricant application markets gained through OEM and customer growth, strategic planning development and implementation; tactical budgeting and forecasting; new product introduction; product line and portfolio management.

M Raab is Certified lubricant Specialist with deep knowledge and experience in: synthetic lubricants, functional fluids and greases; food grade lubricants, military specification lubricants; technical sales and marketing; market research including market size estimates and modeling; military and aerospace applications; Rotating equipment including Air and Gas Compressors and Gas Turbines; industrial and aerospace gearbox and transmissions.

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