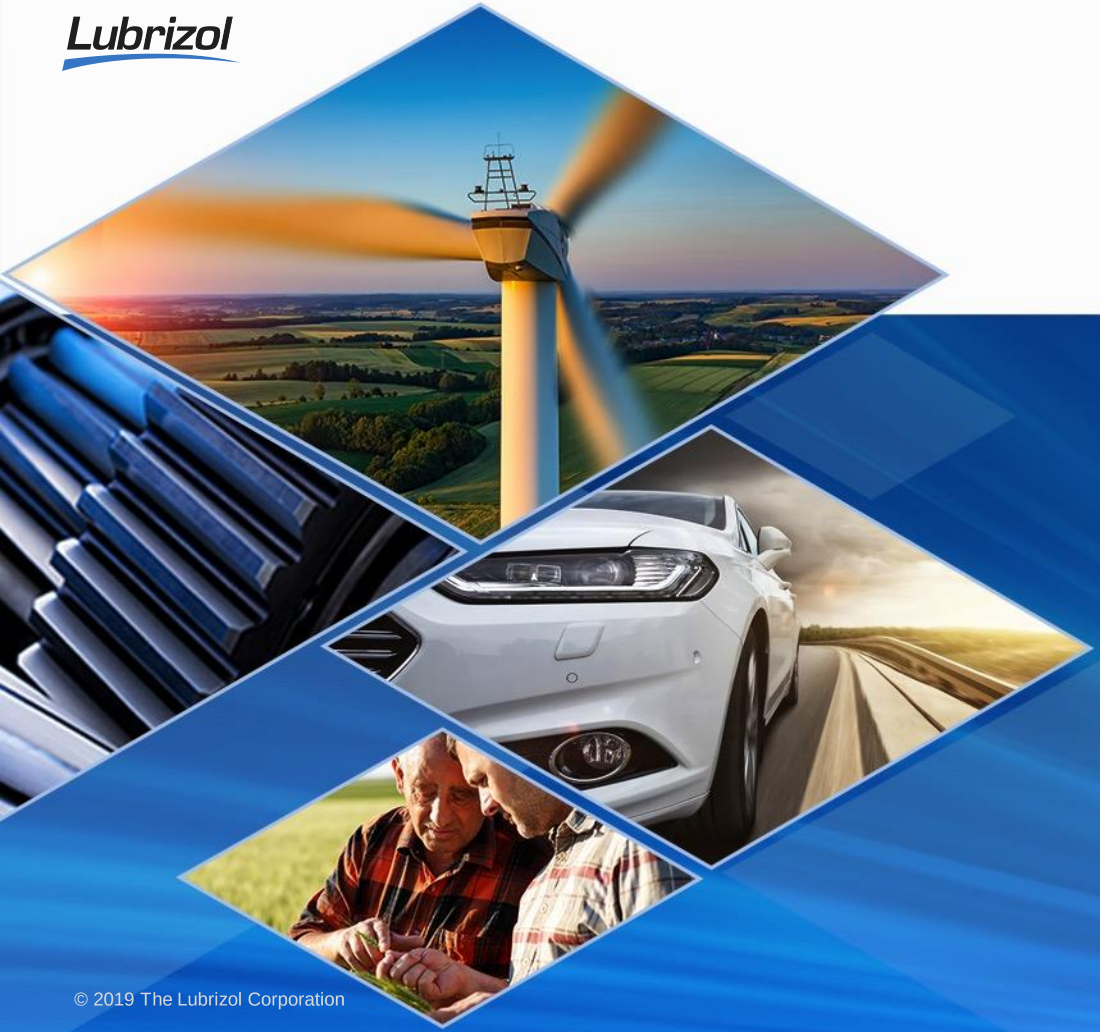


Unlocking Hydraulic Efficiency with Durability

ICIS 2nd Asian Industrial Lubricants Conference

Nov.13.2019

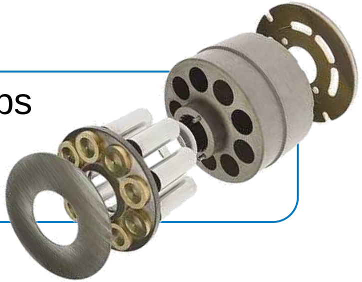
Hydraulic equipment trends

Sustainability

- Increased efficiency and productivity
- Reducing emissions and noise
- Hybridization and electrification

Higher power density

- High efficiency pumps
- Higher pressures
- Smaller size



Reliability

- Digital automation
- Connectivity and smart systems
- Data analytics and condition monitoring

Changes in the Hydraulic Equipment Market

Equipment Sophistication

- Higher power densities
- System complexity
- Downsizing
- Running hotter and at higher pressures for longer

Fluid Performance Needs

- Increased wear protection
- Wider operating temperature range
- Lower energy consumption
- Need for extended oil life

Hydraulic fluid performance must meet the needs modern systems demand

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Hydraulic efficiency and end user needs

Total cost of ownership =
purchase + maintaining + running

Efficiency

There are no industry standard tests to measure hydraulic efficiency.

How to describe efficiency?

- Productivity or cycle time
- Energy consumption per unit time
- Work done per amount of fuel
- Temperature reduction

Durability

There are many industry standard tests for hydraulic durability.

Value and definition of efficiency vary by end user

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Energy Efficiency in Today's Market

- Understanding total system efficiency is critical
  - Pump efficiency is only one element of hydraulic system efficiency
  - Energy losses occur in pumps, motors, hoses, filters, valves and coolers
- Thorough understanding of both hardware and fluid is key to delivering real efficiency
- Total lubricant formulation works together enable real efficiency without compromising durability.

Delivering real world efficiency is a valuable proposition to industrial end users

Designing Durable Efficient Fluids

Lubricant performance validation

1 Bench testing

- Tribology
- Rheology

2 Total system efficiency rig

- Benchmarking
- Candidate screening
- Fundamental knowledge

3 Whole vehicle testing

- Whole system analysis
- Benchmarking
- Final candidate selection

4 Field testing

- Real world proof of performance

Stage 1

Bench Testing

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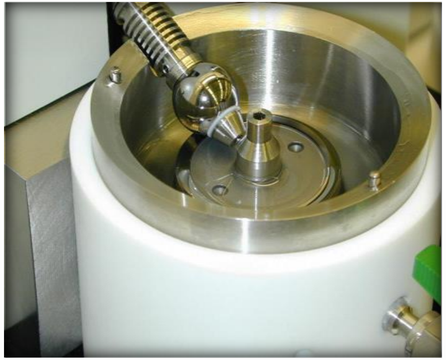
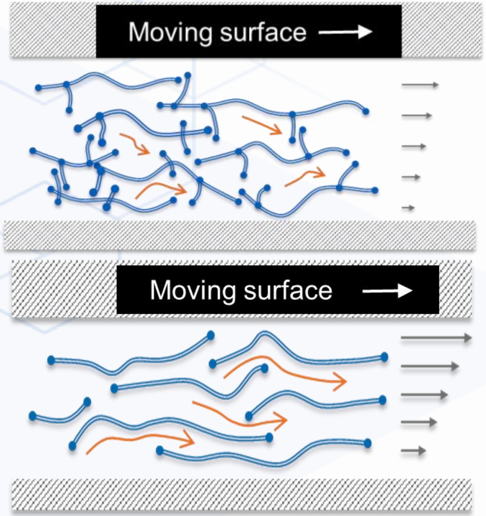
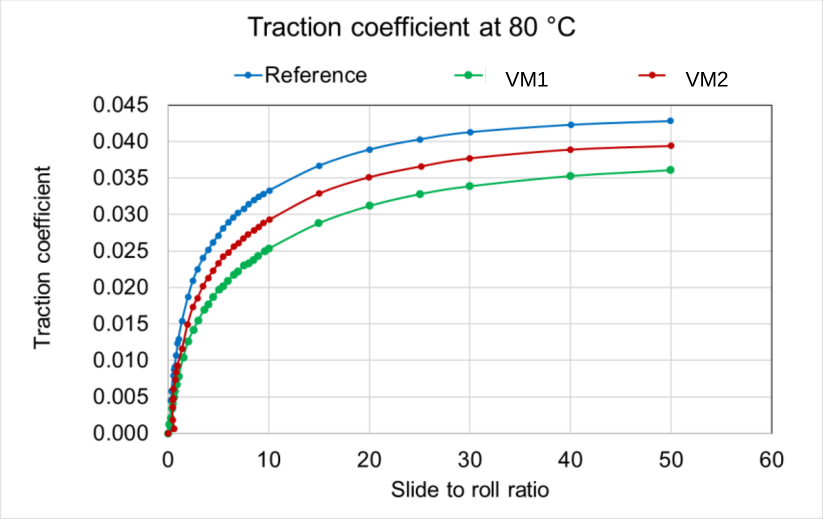
Bench Testing

Polymer choice affects fluid traction



- Fluid traction is the internal friction of the squeezed lubricant film
- Low fluid traction contributes to efficiency
- Different viscosity modifiers can affect traction coefficient



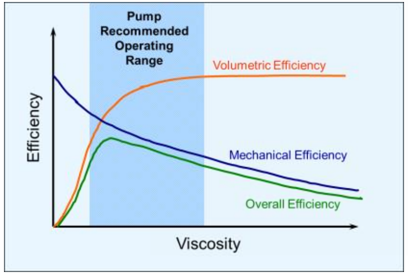


Stage 2

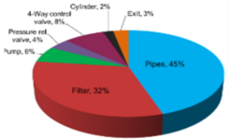
Lubrizol Total Hydraulic System Efficiency Rig

Hydraulic Efficiency – Pump vs Total System

Hydraulic pump efficiency
• Volumetric efficiency (η_v) • Mechanical efficiency (η_m)
• Volumetric efficiency – Internal leakage
• Mechanical efficiency – Friction – Pumping
• Overall efficiency $\eta_o = \eta_v \times \eta_m$



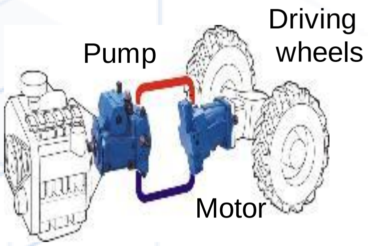
Total hydraulic system efficiency
• Volumetric efficiency (η_v) • Mechanical efficiency (η_m) • System losses
• Volumetric efficiency – Leakage in different components ○ Pump, motor, valve, seal fitting
• Mechanical efficiency – Friction – Pumping – Pressure/ line ΔP – Circuit design ○ Excess flow ○ Excess pressure
• Overall efficiency is more complex

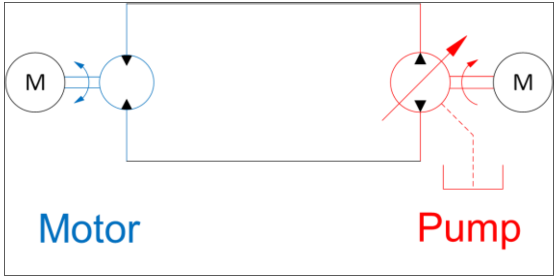


* Green, D. A. *World Tribology Congress 2009, Japan*, B2-212

Lubrizol Total Hydraulic System Efficiency Rig

- Lubrizol's laboratory based hydrostatic transmission rig
  - Representative of real world mobile equipment
  - Uses a hydraulic motor for the working load
  - Instrumented to measure efficiency across multiple parts of the hydraulic system
  - Flow, temperature, pressure sensors installed around motor, lines, pump, filter, cooler
  - Most other studies have focused only on pump efficiency

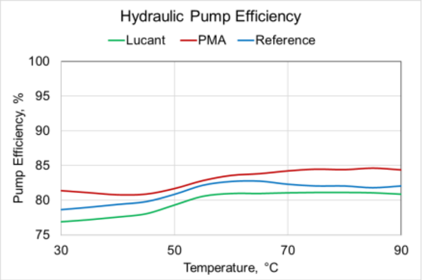


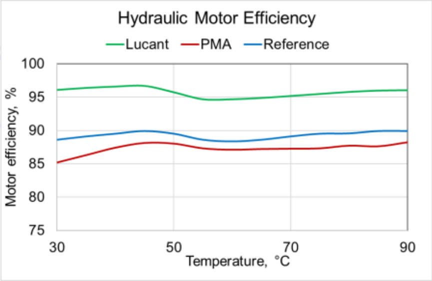


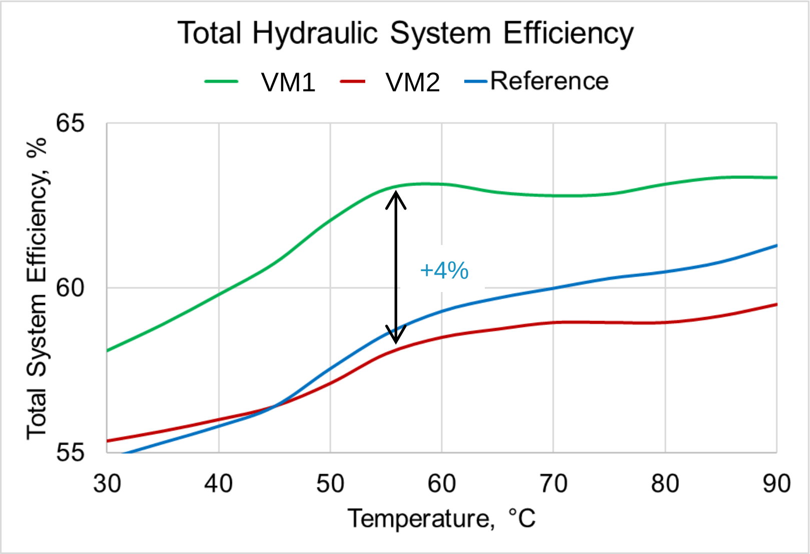
Lubrizol fixed hydraulic efficiency rig

Total hydraulic system efficiency

- Small difference in pump efficiency, large difference in motor efficiency
- Total system efficiency shows VM1 to be more efficient







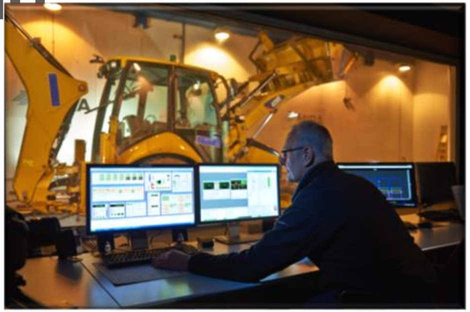
Stage 3

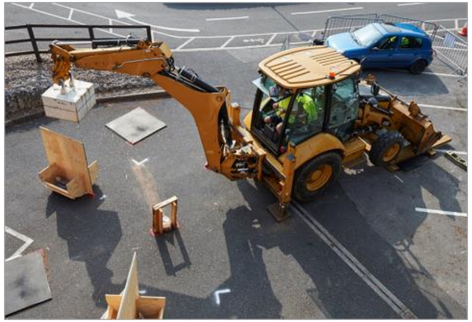
Whole Vehicle Testing

Controlled Whole Vehicle Testing

Proof of performance

- Total system field trial
  - Extensive instrumentation
  - Robust structured testing protocol
  - Big data approach – millions of data points
  - Statistical analysis
- Quantification of efficiency by duty cycle
  - Loaded and unloaded front lifts
  - Loaded and unloaded rear lifts





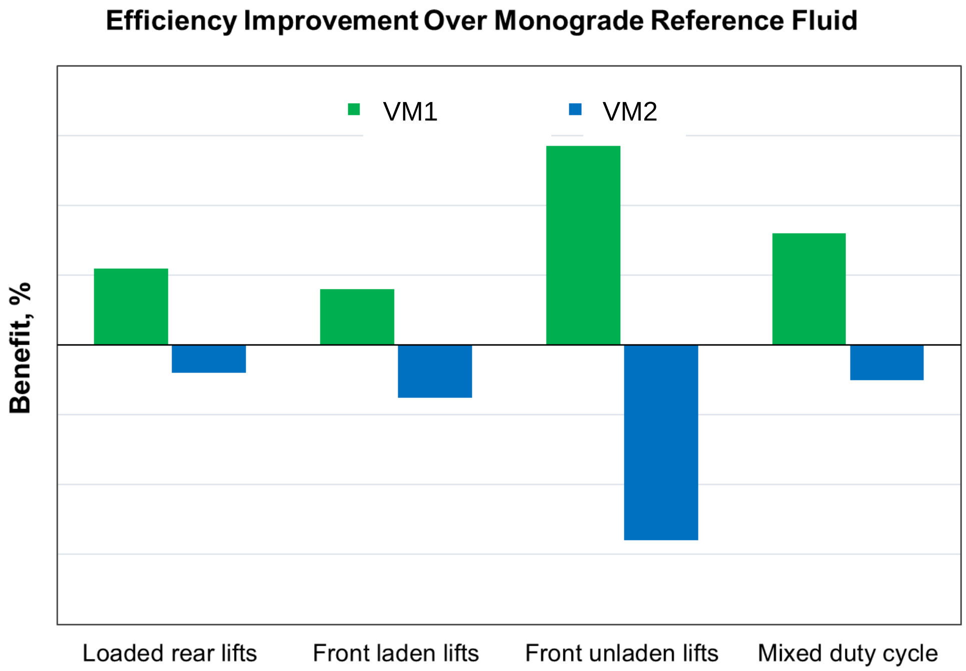
Measured fuel consumption of two candidates

Whole Vehicle Testing – Test Method

Rear boom lift course

Front lift laden

Controlled Whole Vehicle Test Results



VM1 offers superior improvements in hydraulic energy efficiency

Stage 4

Field Testing

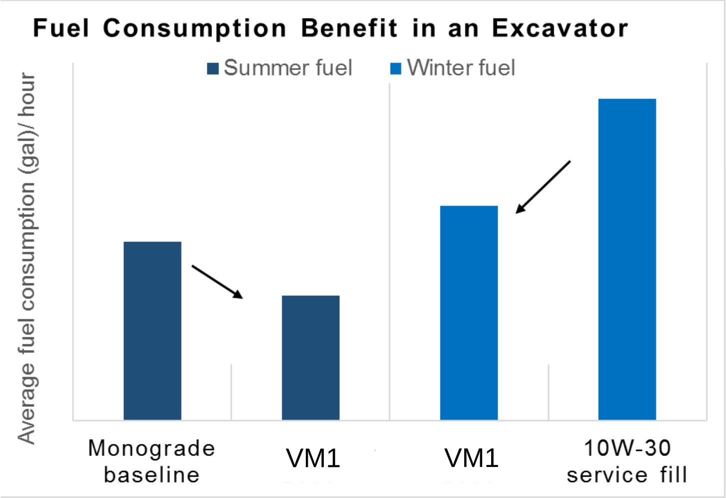
Field Trial

Local Excavating Company

- 2015 980M Caterpillar Wheel Loader
- Trial over 3 months
  - Data logged for 120 hours

Fluids on test

Factory fill: Monograde (Baseline)	ISO VG 46
Test Fluid: VM1	ISO VG 46
Shop Oil: Service Fill	SAE 10W-30

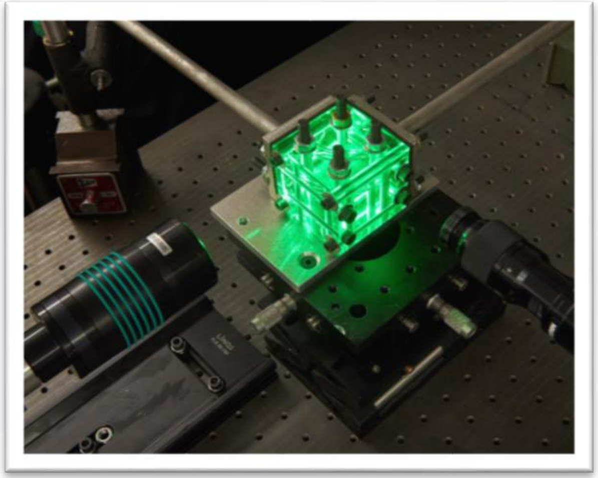


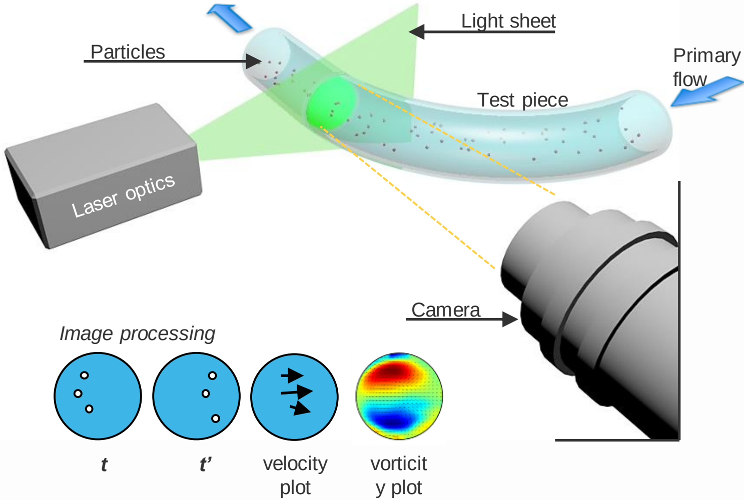
How VM1 improves efficiency?

Measuring Secondary Flow: Data Acquisition

Particle image velocimetry (PIV)

- Tracer particles with sizes (~5-20μm) are added to the fluid
- The light scattered by the particles is recorded at ~ 30,000 frames per second by high speed camera
- The displacement of the particle images between the successive frames allows the measurement of the planar 2 dimensional velocity field





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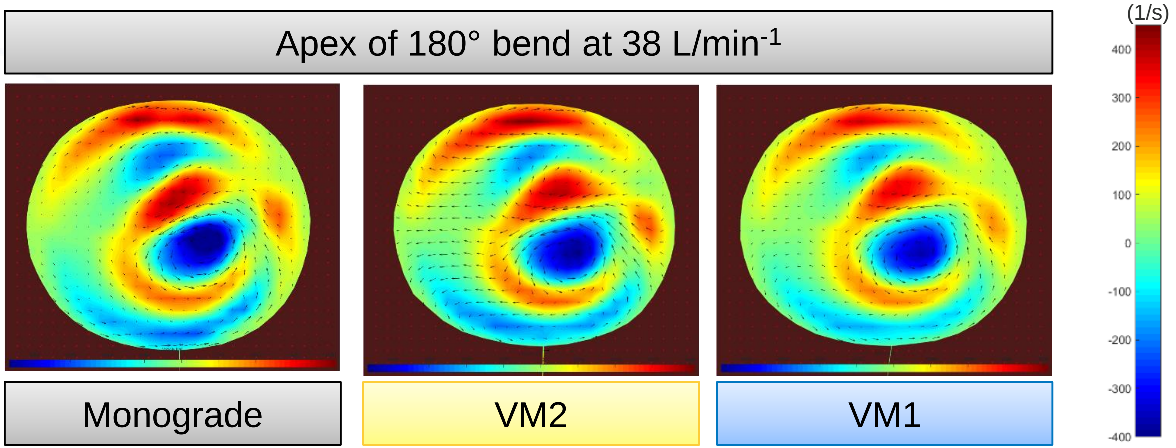
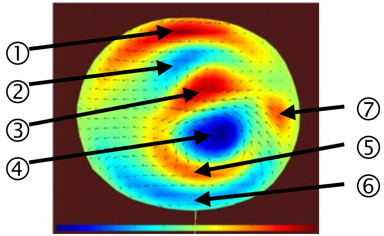
Particle Image Velocimetry Data

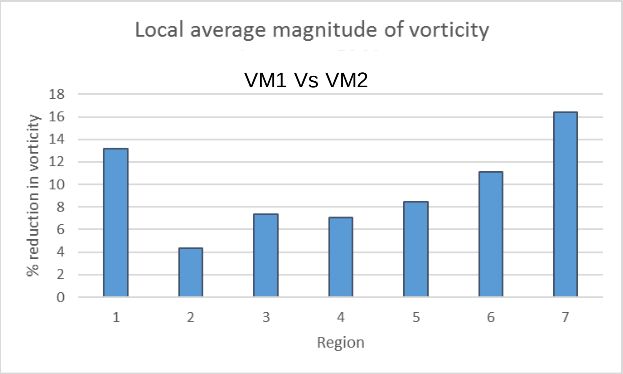
- Vorticity at the apex of the 180° channel was similarly examined
- For the degree of curvature in the test piece the maximum vorticity was anticipated at the apex
- Profile at high flow rates becomes increasingly distorted, maximum vorticity shifting to inner wall

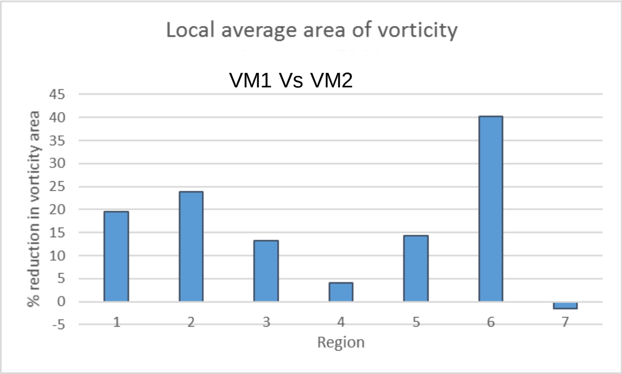


Particle Image Velocimetry Data

- Quantification of magnitude and area of vorticity can be done for each vertical region
- VM1 fluid was compared to VM2 fluid and shows noticeable differences
- **VM1 reduces the magnitude of vorticity by ~10%**
- **VM1 reduces the area of vorticity by ~18%**





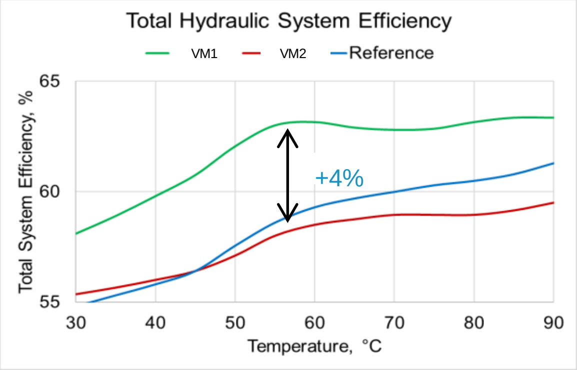


Summary

- VM1 substantially reduces secondary flows under hydraulic operating conditions
- Multigrade fluid containing VM2 does not significantly reduce secondary flows

	In comparison to monograde fluid	
	Reduction in magnitude of vorticity	Reduction in area of vorticity
VM 1	11%	20%
VM 2	1%	4%

Lubrizol total hydraulic system efficiency data



- These results support all of our hydraulic efficiency testing where VM2 and monograde fluids appear to perform similarly whilst VM1 containing fluids are overwhelmingly the most energy efficient

VM1 flow characteristics provide energy efficiency to hydraulics

Durability Testing

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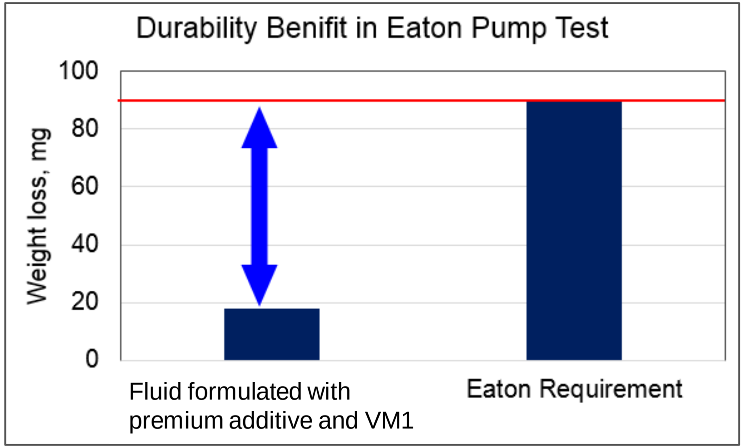
No Compromise on Durability

Strong pump performance ensure fluid durability and equipment protection for a longer time



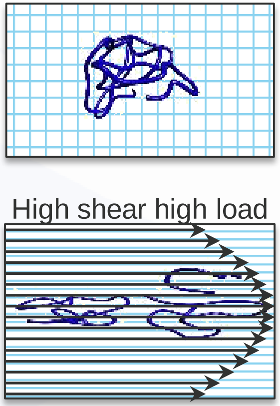
Eaton E-FDGN-TB002-E and Parker Denison HF-0 approved

Efficiency benefits with durability confidence

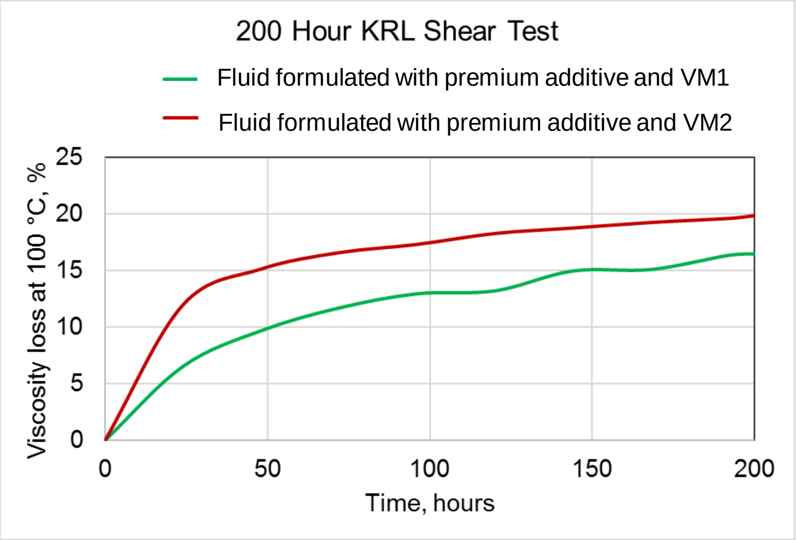
Bench testing

Extended shear stability

- Commercially relevant formulations.
- Comparison to shear stable Bosch Rexroth capable VM1 fluid and competitor example.
- VM1 <u>substantially</u> more shear stable out to 200 hours by KRL.



Rupture of coil and orientation
Permanent viscosity loss



Conclusion

Conclusion

- Fluid flow behaviour is a key variable in understanding hydraulic energy efficiency that does not correlate to viscosity index.

- Careful selection of viscosity modifier can deliver real world efficiency improvements.

- A balanced hydraulic oil formula can give both durability and efficiency.

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