degussa.

RohMax Oil Additives

Influence of Oil Viscosity and Pressure on the Internal Leakage of a Gear Pump

STLE 2002 – Houston, TX

Steven Herzog - RohMax USA

Christian Neveu – RohMax France

Doug Placek – RohMax USA

Overview

Relationship of Viscosity and Pressure to Pump Efficiency

Model Development to Estimate:

- Internal pump leakage
- Actual viscosity in an operating pump
- Operating shear rate

Laboratory Pump Rig used to Establish Model

Model can be used to estimate the performance of different Hydraulic Fluid grades

Pump Efficiency in a function of Fluid Viscosity and Pressure

In a pump, if the oil viscosity is low and the output pressure is high, internal leakage may take place between the gears and the pump housing.

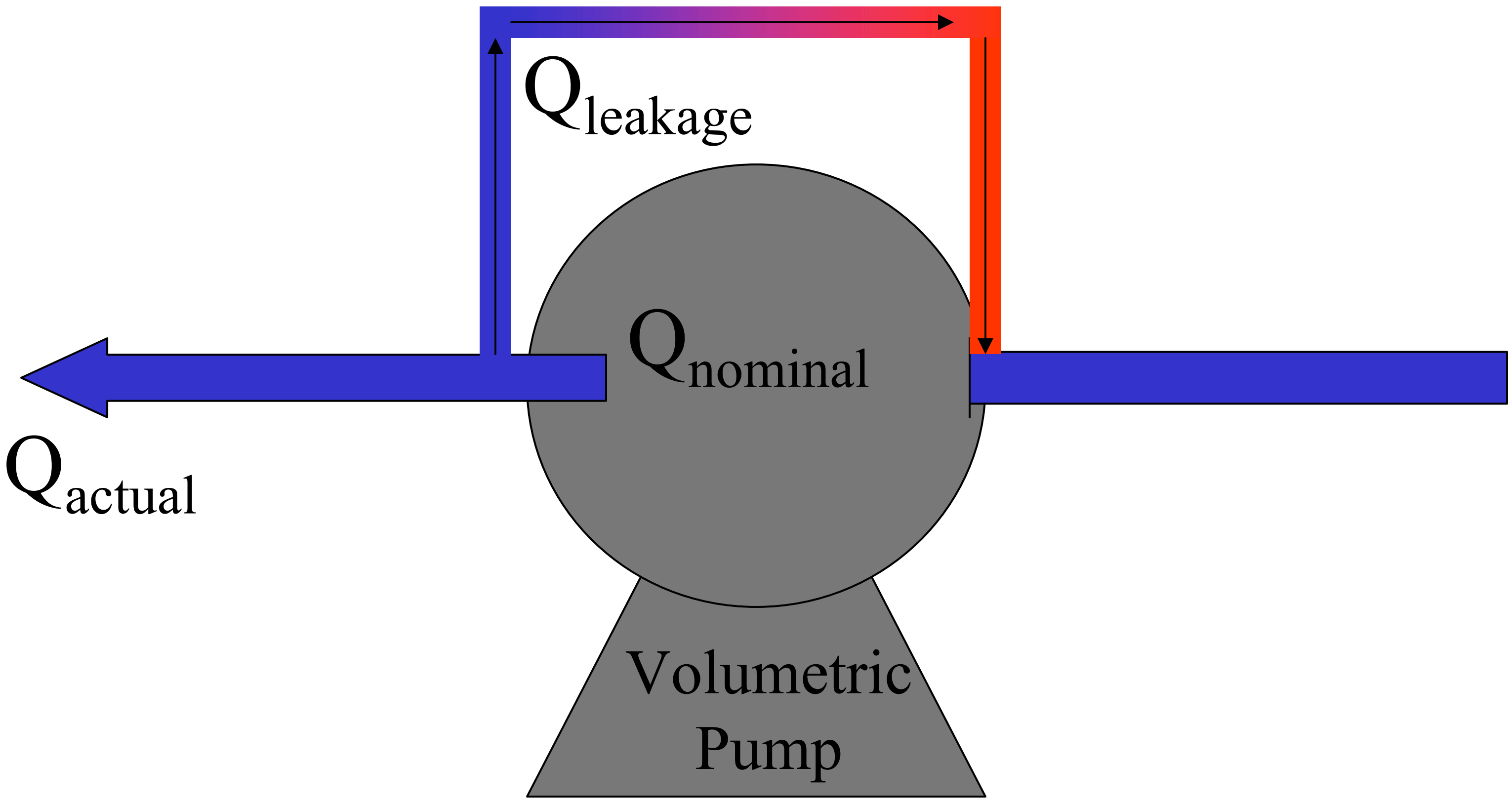
The actual flow rate of a pump is thus equal to the nominal flow rate less the internal leakage.

Measuring the actual flow rate can thus provide, after proper calibration, a means to estimate:

- the shear rate prevailing in the pump
- the actual in service viscosity of an oil
- volumetric pump efficiency

Actual vs. Nominal Flow Rate

$$Q_a = Q_n - Q_l$$



Modeling can Estimate System Performance

Identify pump limitations

Avoid overheating the oil

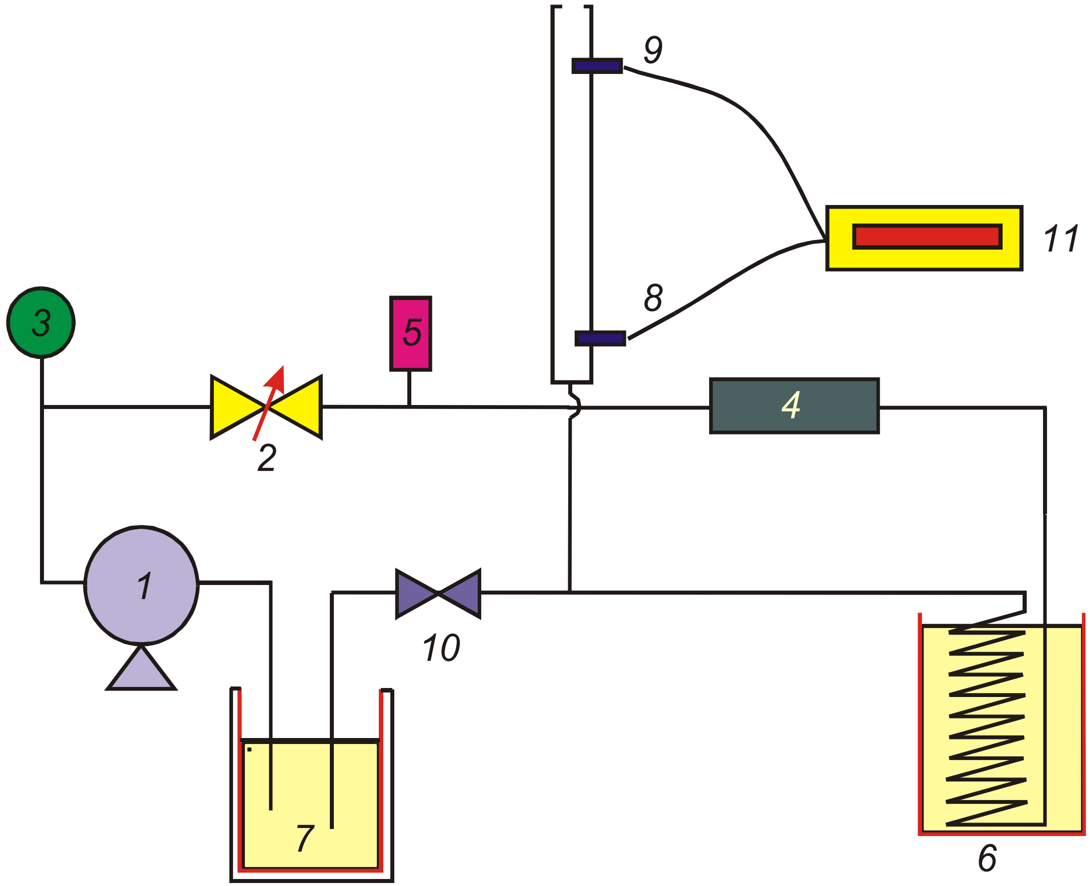
Reduce energy costs and improve pump efficiency

Select optimum hydraulic fluid grade

What is the most cost effective solution?

- Larger pump
- Improved oil cooling (heat exchanger or larger sump)
- High VI hydraulic fluid for wider TOW

Test Rig used for Model Development



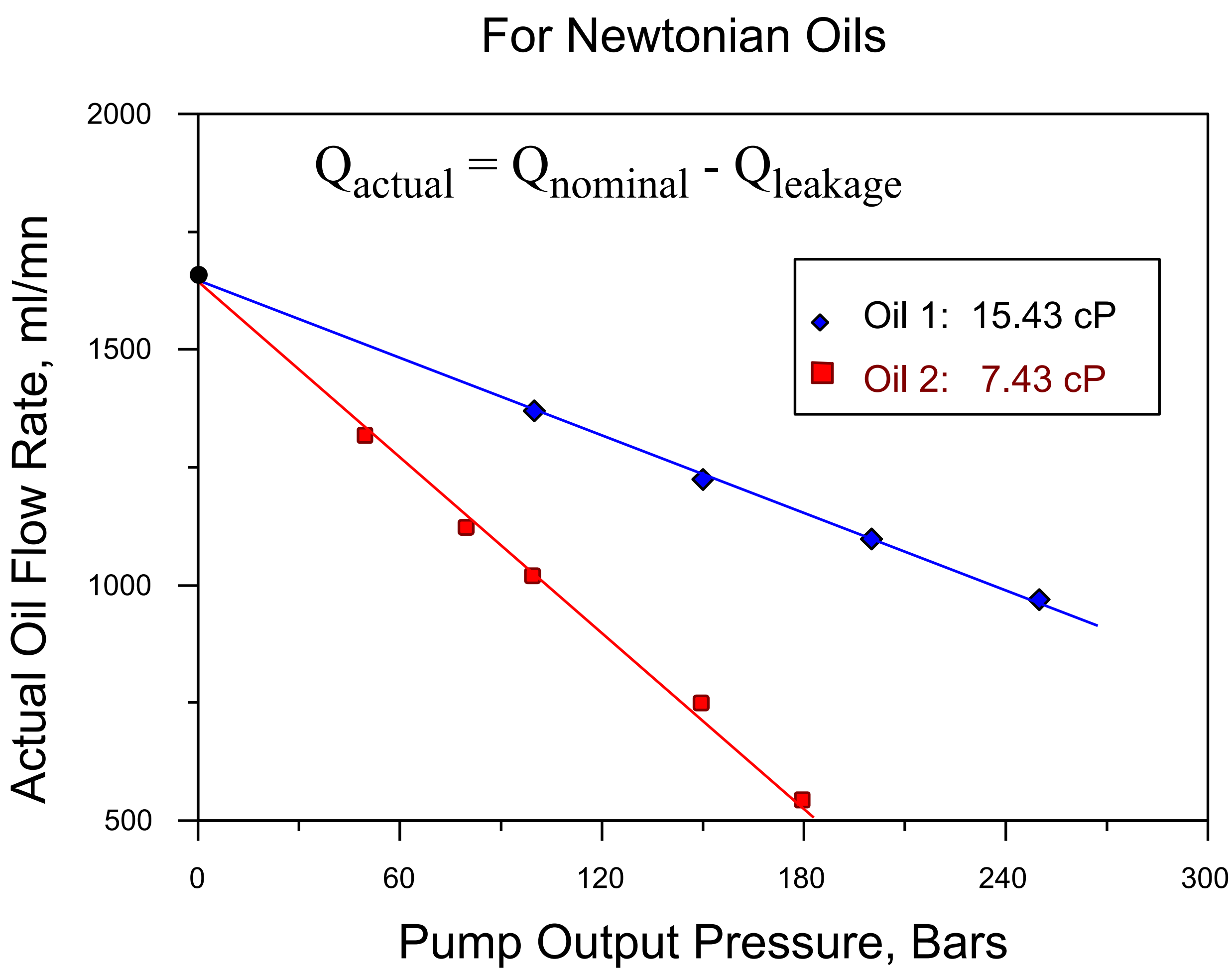
1 Pump*
2 Throttle Valve
3 Pressure gauge
4 Oil Filter
5 Pressure Switch
6 Heat Exchanger
7 Oil Reservoir
8 Optical cell
9 Optical cell
10 Valve
11 Timer

*Bosch Gear Pump, 1 ml/rev, 1500 rpm

Composition and Characteristics of Test Oils

	Oil 1	Oil 2
Base oil	350N BSS	350N
Additive %	1.0	1.0
% VI Polymer	0.0	0.0
KV 100°C, mm^2/s	18.05	8.87
Specific Gravity at 100°C	0.855	0.836
Dynamic viscosity at 100°C, mPa.s	15.43	7.43

Pump Flow rate vs. Output Pressure



Definition of a Model to Estimate Internal Pump Leakage

Data from the previous graph fit the equation:

- $Qa = Qn - K*P$
- with K being a constant for a Newtonian oil

K decreases with increasing viscosity, leading us to consider a new model of the form:

- $Qa = Qn - k*P/\eta$

Poiseuille Law

$Q_l = (Pout-Pin)*b*h^3/(12*L*\eta)$	**for an orifice**
$Q_l = (Pout-Pin)*\pi*R^4/(8*L*\eta)$	**for a capillary**

Definition of a Model to Estimate Internal Pump Leakage

If we consider that P_{in} is equal to 1 Bar and P_{out} to at least 25 bars, we can simplify the equation into:

$$Q_l = C1 * P_{out} / \eta$$

- For the capillary model we have:
  - $C1 = \pi * R^4 / (8 * L)$ R=radius, L=length
- For the orifice model we have:
  - $C1 = b * h^3 / (12 * L)$ b=width, h=height, L=length

Relationship Shear rate vs. Pressure

In a slot or a capillary, the shear rates varies from the wall to the axis with a maximum at the wall given by:

- (dV/dr) = C2*Ql
- C2 is a geometrical factor which depends on the dimension of the opening.
- In the case of the capillary model
  $C2 = 4/(\pi * R^3)$

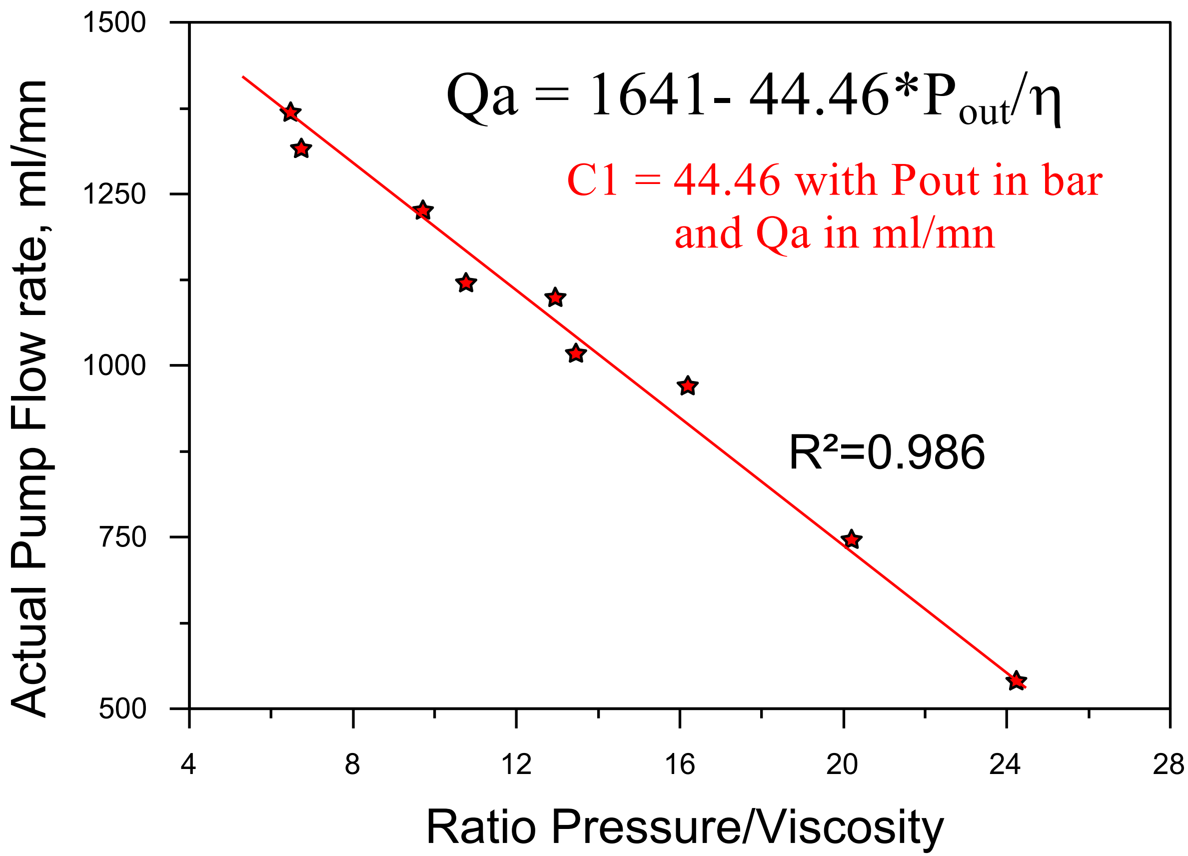
If the model applies then:

- Qa = Qn - (dV/dr) /C2 or (dV/dr) = (Qa – Qn)C2

Calculation of C2 and measurement of flow rate can estimate the shear rate in the pump

RohMax Oil Additives

Actual Pump Flow Rate vs. Ratio P/Viscosity



Volumetric Pump Efficiency

For the Bosch Gear Pump in this study:

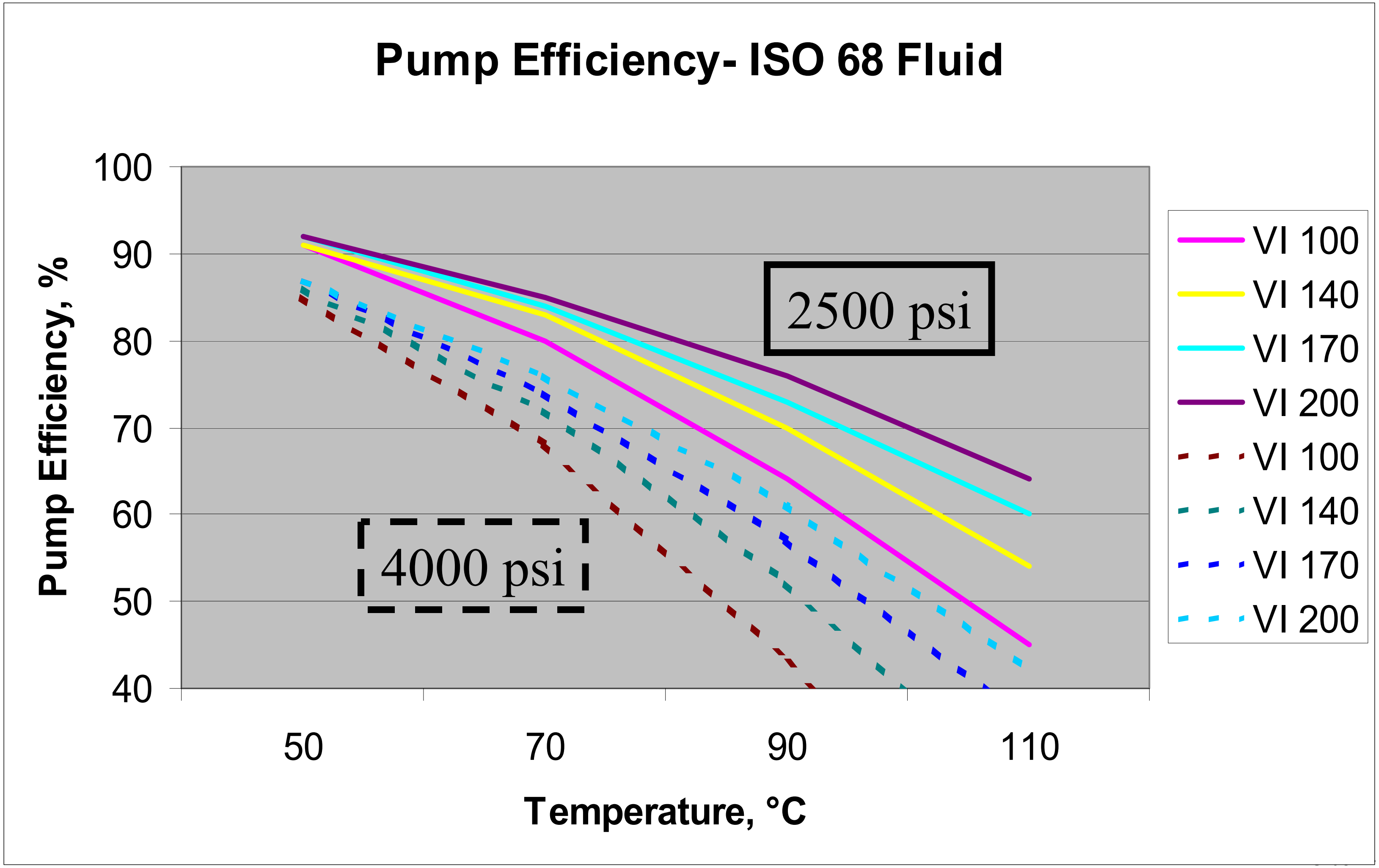
$$Qa = 1641 - 44.46 * P_{out}/\eta$$

Volumetric Efficiency = Actual Flow Rate / Nominal Flow Rate:

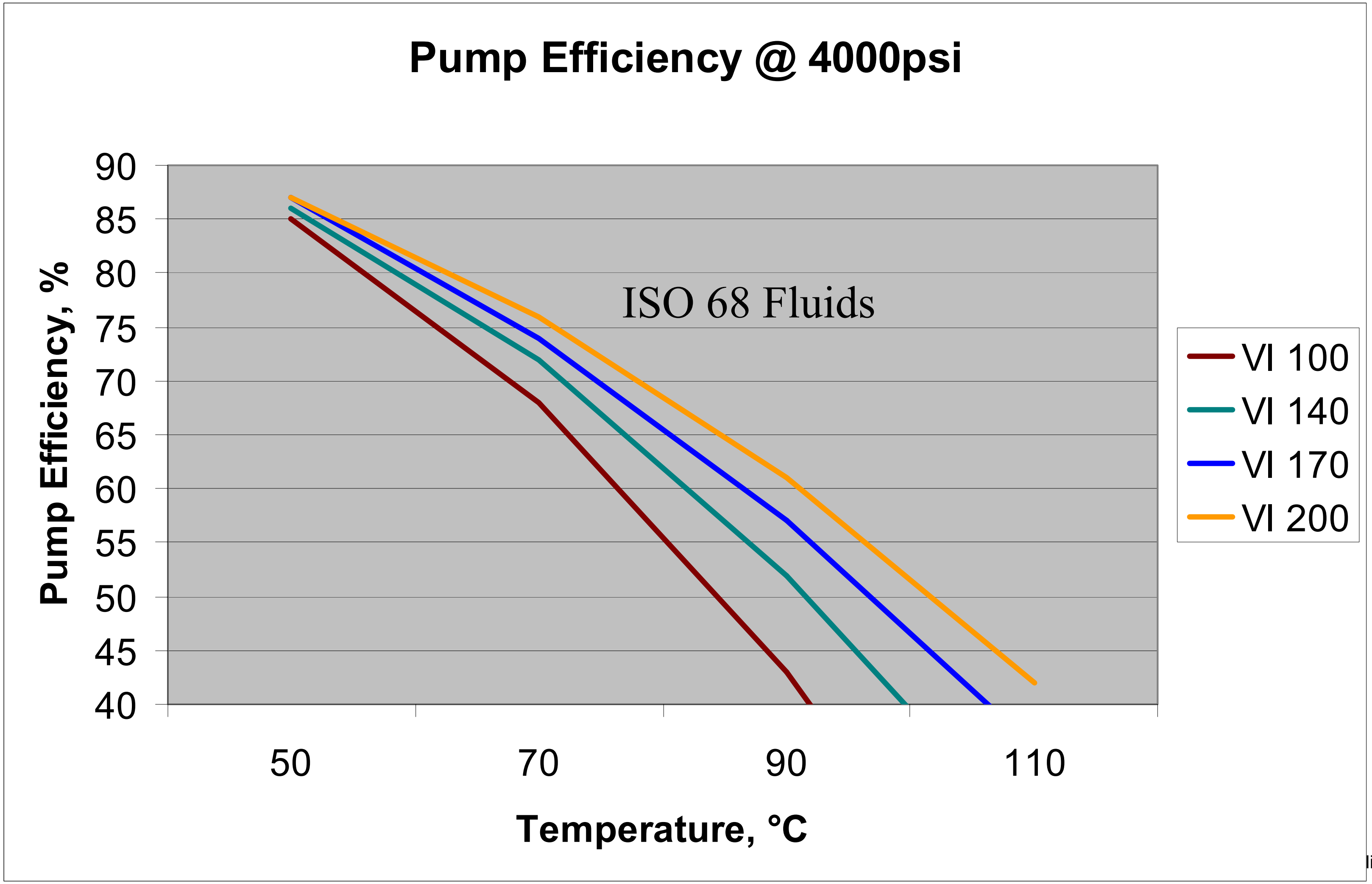
$$V_E = 100 * Qa/Qn$$

In an operating pump, measurement of oil temperature can be used to calculate oil viscosity

Impact of Fluid Viscosity Index



Impact of Fluid Viscosity Index



How Can the Optimum Fluid Grade be Selected?

Start with NFPA Standard Practice T2.13.13-2002

- Incorporates pump OEM viscosity requirements
- Considers low temperature start-up and high temperature operating conditions

Estimate the Pump Efficiency of this selection

- Review the impact of operating pressure
- Consider the Temperature Operating Window requirements
- Determine the most cost effective mode of operation
  - Pump size
  - Cooling
  - High VI, multigrade, hydraulic fluid selection

Conclusions 1

Using our test conditions, for a given oil, the flow rate of the gear pump decreased in a linear manner when increasing the pump output pressure.

For a given output pressure and temperature, the internal leakage increased when decreasing the oil viscosity.

Data generated on two Newtonian reference oils showed that the oil leakage was proportional to P_{out}/η and that a simplified form of Poiseuille's Law provided a good representation of the phenomenon.

Conclusions 2

The oil flow between the gears and the pump housing can be represented by a generalized form of any of the models which deal with fluid flow through a small opening.

Using a non-Newtonian oil with known viscosity as a function of shear rate, we showed by the internal leakage increased in a linear manner with increasing shear rate as predicted by the Poiseuille's law.

Using the capillary model, we calculated the dimensions of the equivalent capillary:

R=0.27 millimeter
L=27.7 centimeters

Conclusions 3

Selecting a hydraulic fluid with the correct viscosity is critical

Fluids with higher VI enable operation over a wider TOW

High VI fluids provide better pump efficiency

- Higher viscosity at any given temperature

Use of mathematical models can help identify the optimum cost/performance balance when selecting hardware and fluids