The Impact of non-Newtonian Fluid Behaviour on Well Performance for the Orinoco Belt Reservoirs

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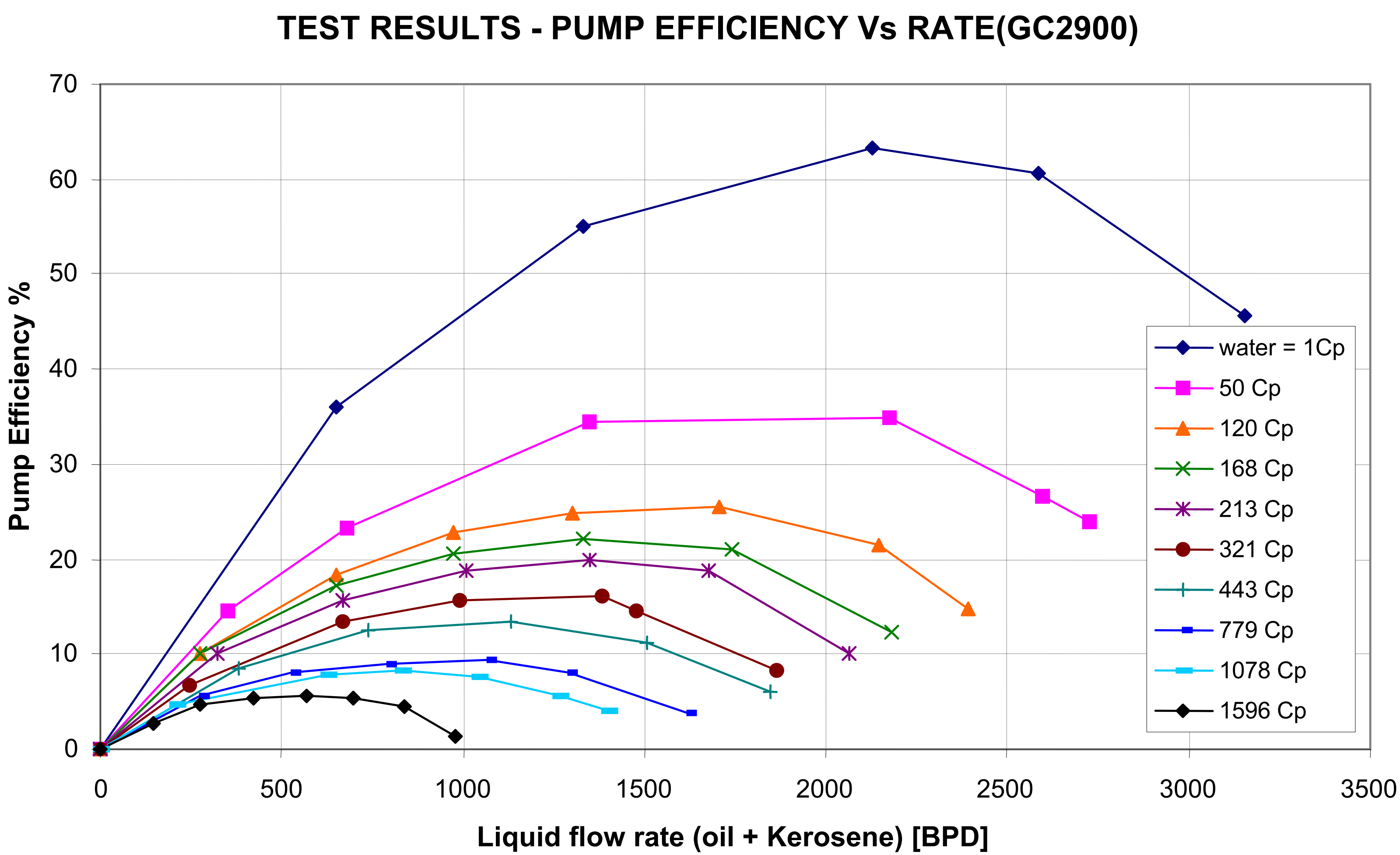
- Current methodology and criteria
- Laboratory testing and results
- Well performance modelling with new correlations
- Proposed methodology and change of paradigm

Background

- Rheology of heavy crudes is poorly understood
- Common viscosity correlations are temperature based
- Initial work (Layrisse et al, 1980) indicated fluid behaves as Newtonian for most shear rates
- Power factors for ESP sizing range from 1.8 - 3.2
- IPR and VLP are very difficult to match
- PCP has improved performance in these type of wells

Background



LABORATORY TEST RESULTS (Courtesy of Intevep)

Current Methodology

1. IPR is generated and “adjusted” using *skin* or *h* to match measured
2. Viscosity values are also “adjusted” and specific fluid correlations are selected
3. VLP and system’s curves are generated using conventional ESP data
4. Pump size selected and then PF applied based on supplier’s experience

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Viscosity Correlations

Current viscosity correlations for heavy crudes f(API & T)

Ghetto, Paone & Villa
[9° - 21°] API

$$Pb = 15{,}7286.\left[\left(\frac{Rs}{\gamma_g}\right)^{0{,}7885} \cdot \frac{10^{0,\,0020.T}}{10^{0,\,0142.^{o}API}}\right]$$

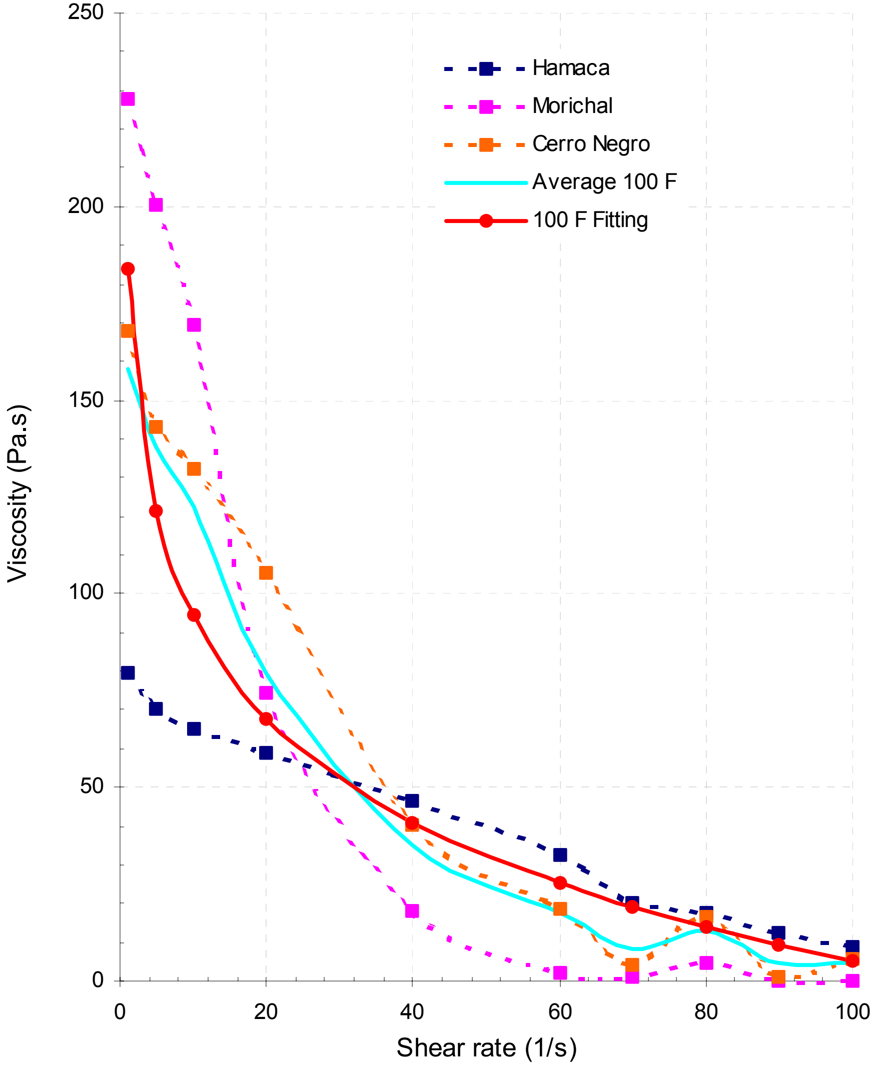
Total
[<10°- 45°] API

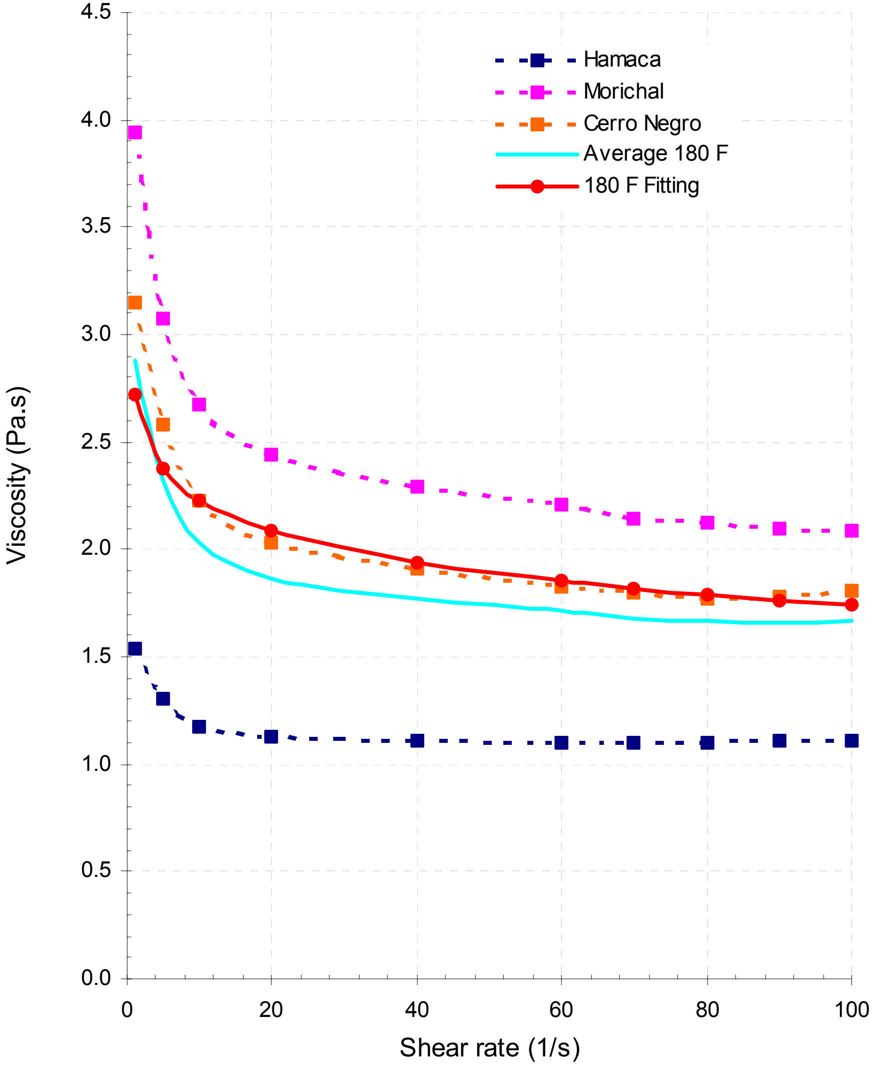
$$Pb = A.\left(\frac{Rsb}{\gamma g}\right)^{B} .10^{(C.T - D.^{o}API)}$$

Fluid Characterization Process

- **Used samples from Cerro Negro, Hamaca, Morichal, Boscan**
- **Temperature range [100 – 200] °F**
- **Shear rates ranges [1 – 100] 1/s**
- **Tested at the laboratory in Brunell University, UK**
- **Test measured fluid behaviour and effect of magnetic field and mechanical energy**

Test Results





Test Results Summary

- **Non-Newtonian behaviour – shear thinning – , where viscosity is affected by mechanical energy (shear). The temperature also affect the viscosity**
- **Results consistent with other equivalent fluids such as chocolate, grease and Al slurries**
- **Viscosity correlation can be expressed in a general manner as:**

$$\mu = - C\, T^{-A} \ln \dot{\gamma} + K\, T^{-B}$$

Where: A, B , C, K = fluid constants,
T=Temperature
$\dot{\gamma}$ = shear rate

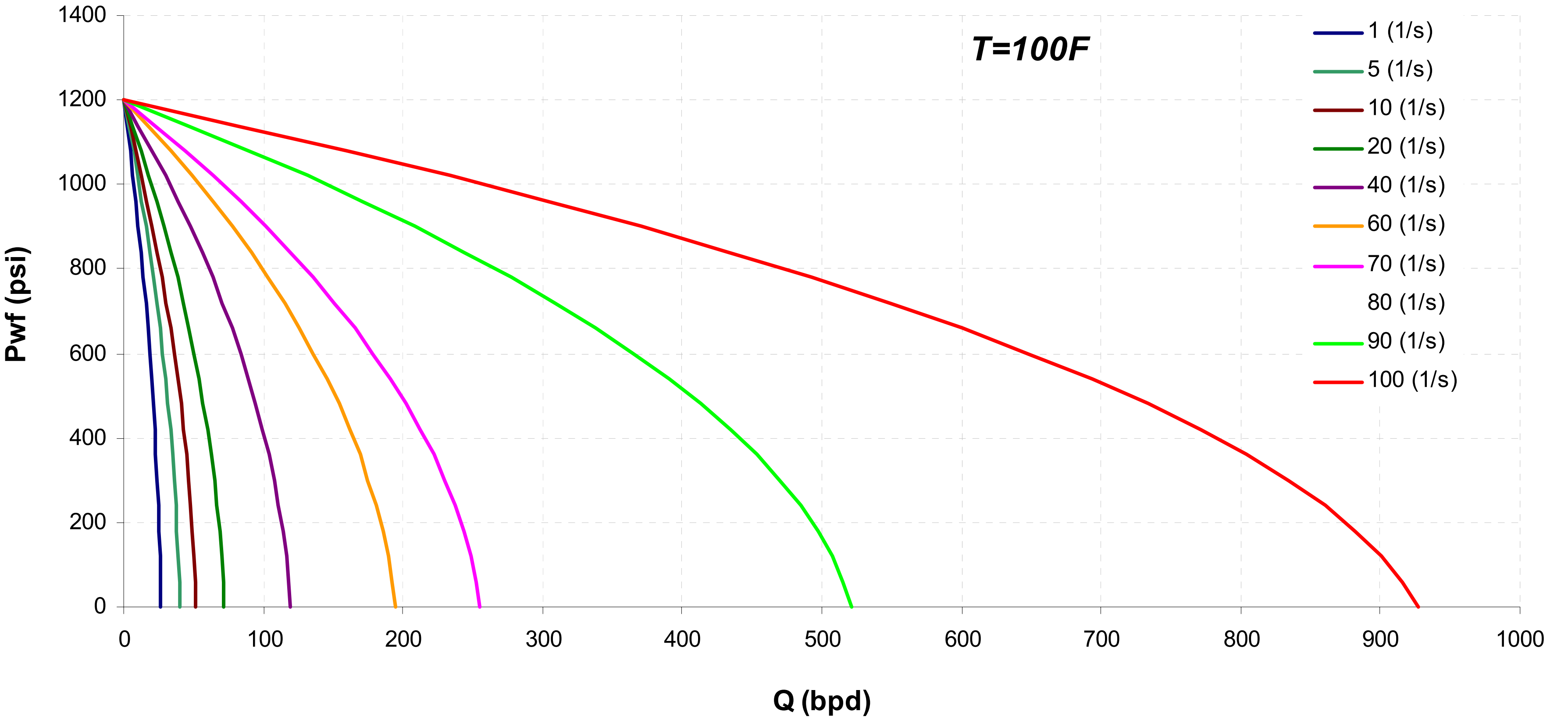
Well Performance Analysis

- Well performance model developed based on Joshi's model for horizontal wells, with shear rate included
- Data from Morichal field, operated by PDVSA

$$PI = \frac{0.007078 \cdot k_h \cdot h}{\left(-C \cdot T^{-A} \ln \gamma + K \cdot T^{-B}\right) Bo \cdot \ln \left[\frac{a + \sqrt{a^2 - \left(\frac{L}{2}\right)^2}}{\frac{L}{2}} \right] + \left(\frac{h}{L}\right) \ln \left(\frac{h}{2r_w}\right)}$$

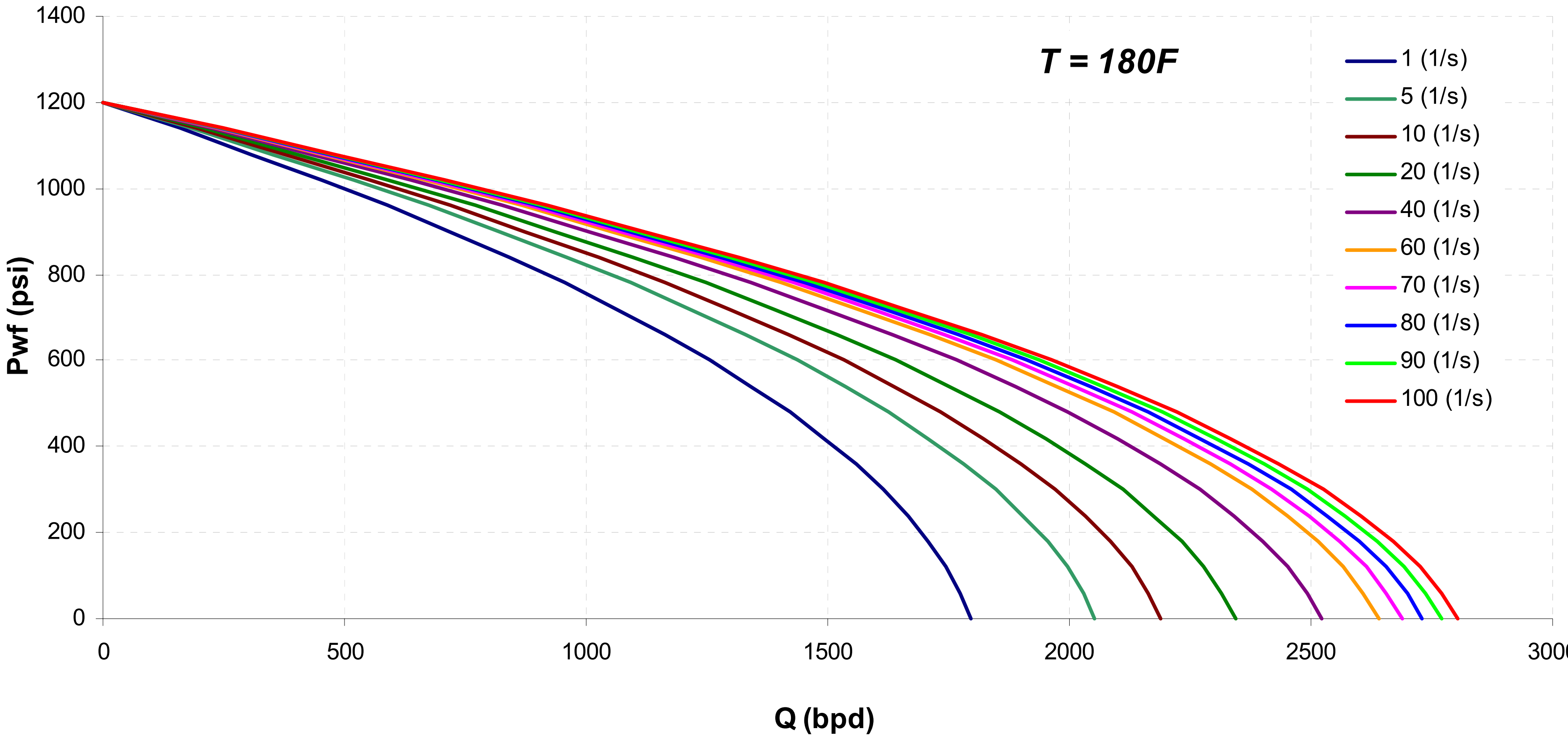
IPR - Horizontal well model

Pr = 1200 psi,
h = 2000 feet



IPR - Horizontal well model

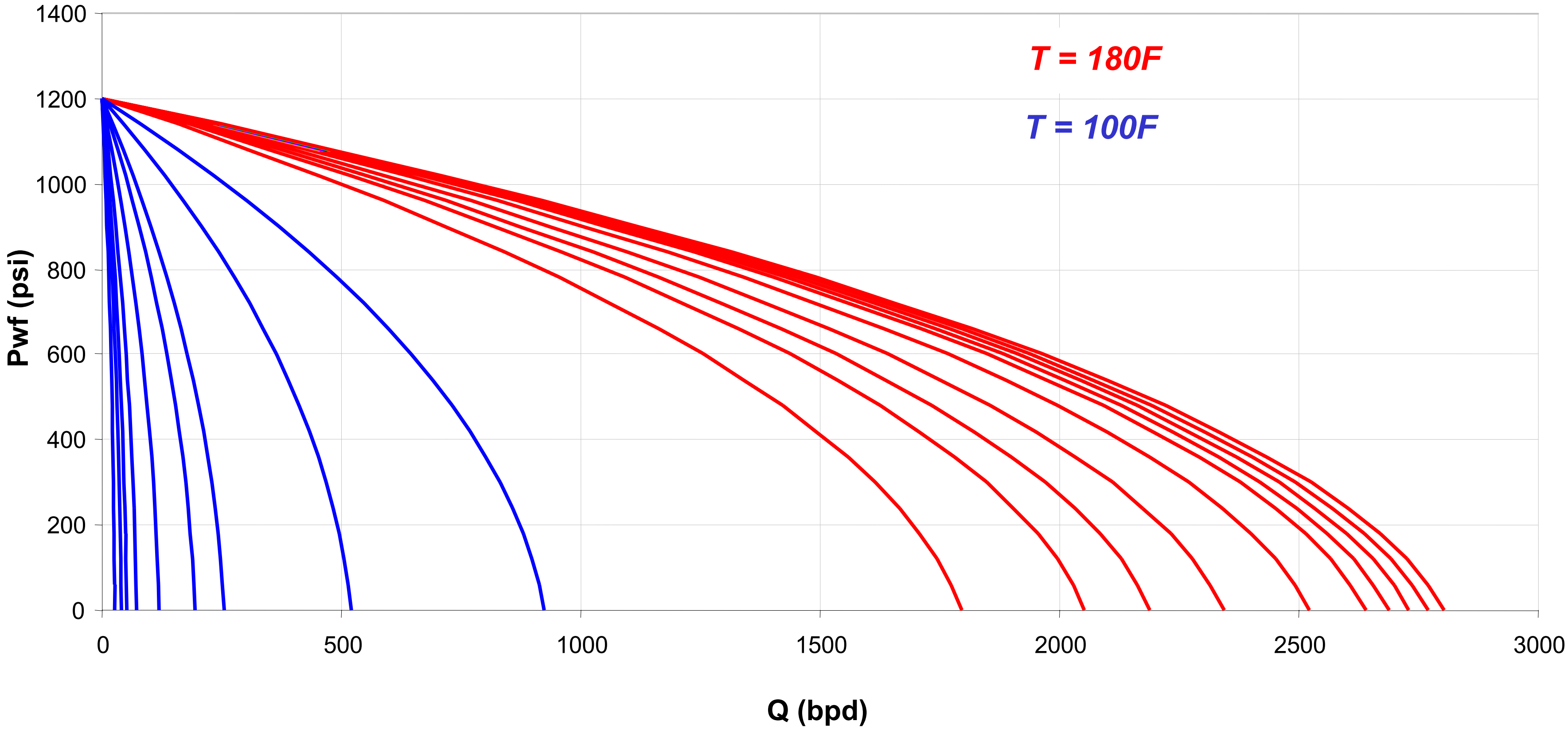
Pr = 1200 psi,
h = 2000 feet



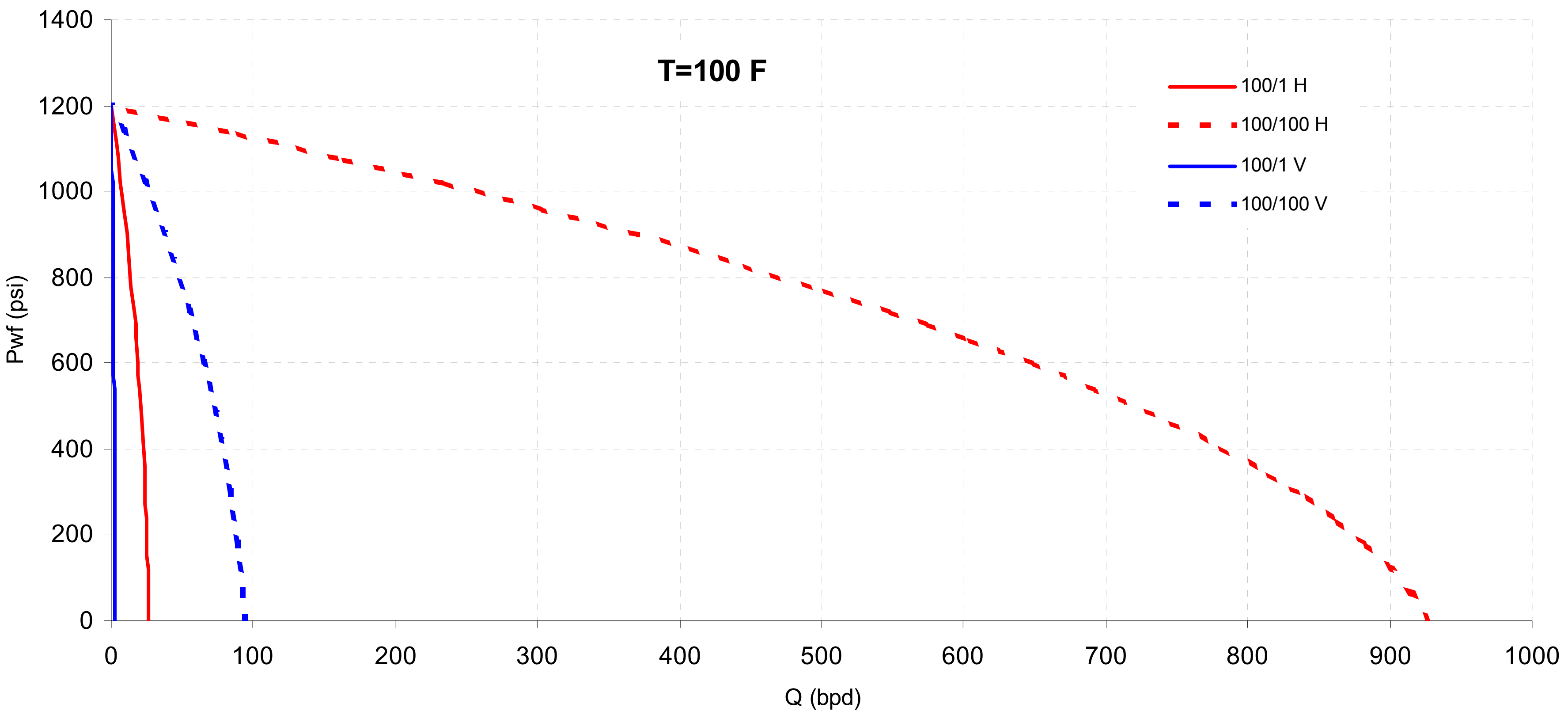
IPR - Horizontal well model

(including both temperatures)

Pr = 1200 psi,
h = 2000 feet



IPR - Horizontal vs. Vertical



AOF - Horizontal vs. Vertical well

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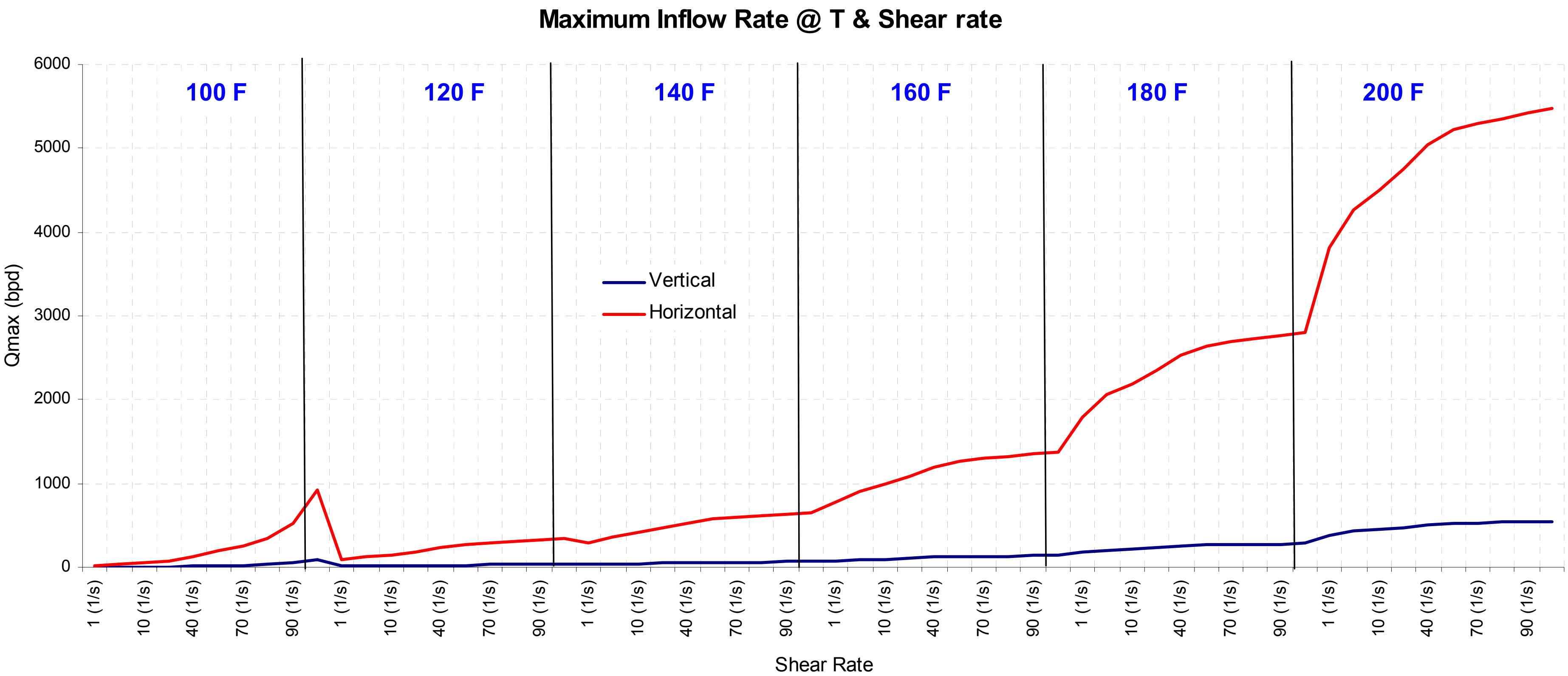
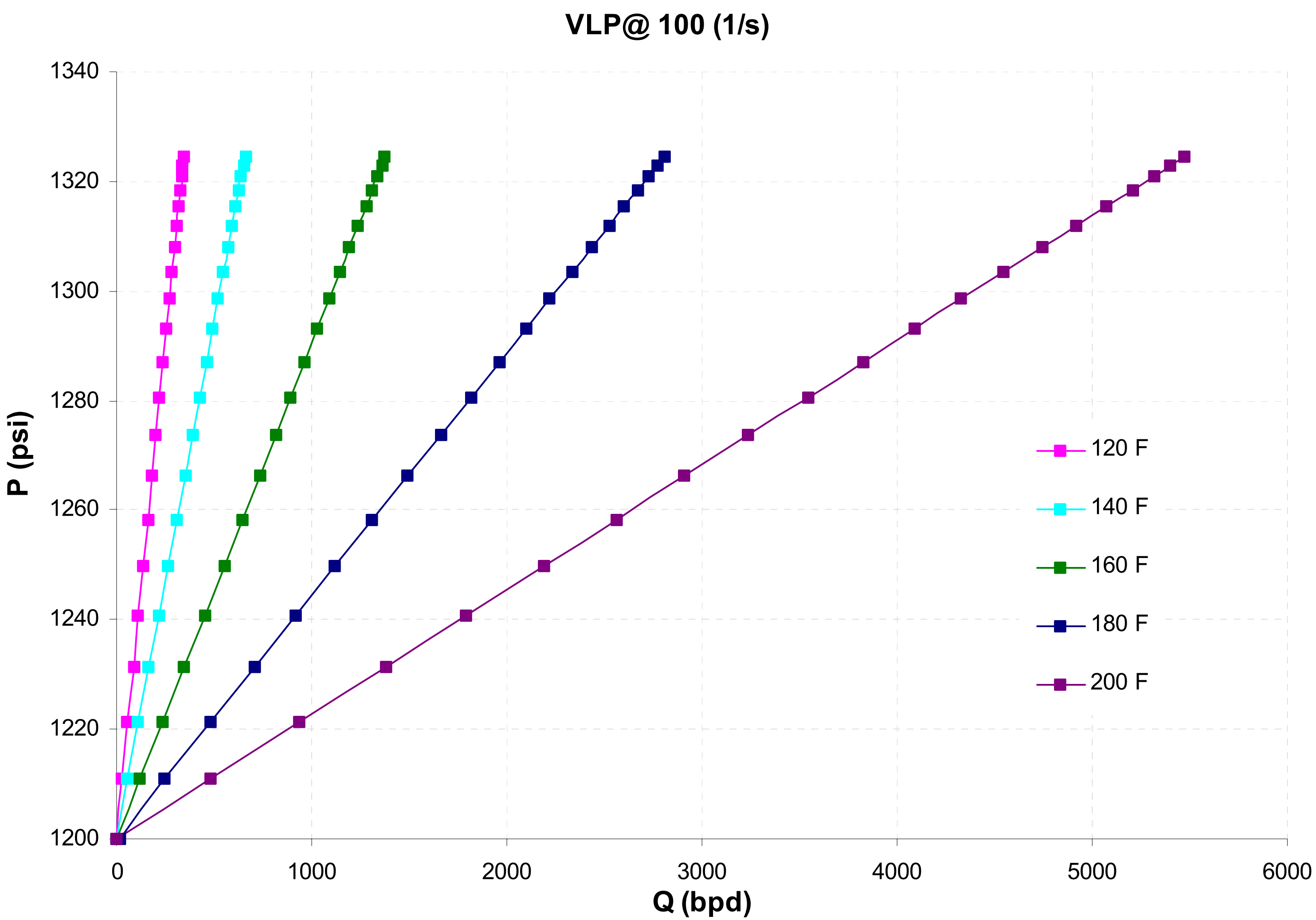
- **All temperatures and shear rates**



Vertical Lift Performance



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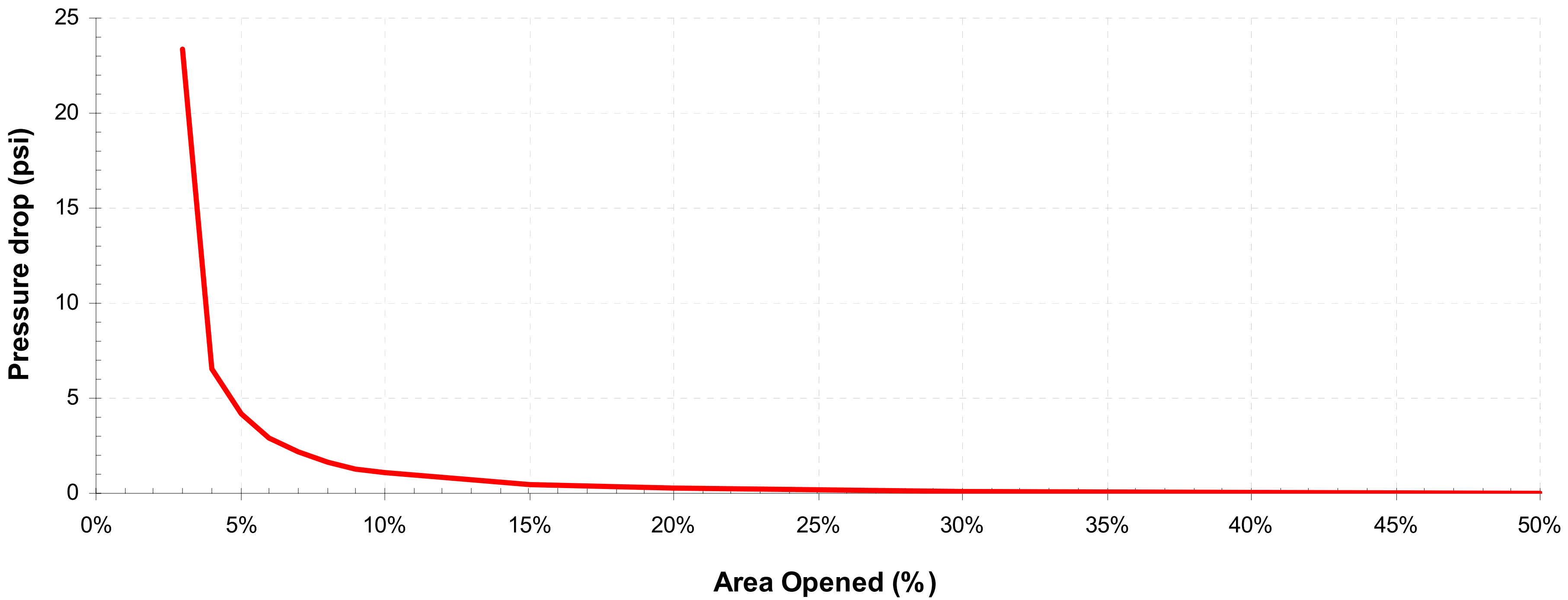
Lower completion

- OH with slotted liner configuration used, based on LA-22 (Sincor)
- Flow area of SL ~ 3%
- OH diameters 6” & 8 1/2”
- Q ~ 500 - 1000 bopd

Lower completion

- Pressure losses behaviour with variable viscosity
- OH diameter 8 1/2”
- Slotted Liner OD = 7”



Conclusions

- The laboratory results indicate that these crudes behave in a non-Newtonian manner –shear thinning– (viscosity varies with shear rate)
- Current correlations based on temperature/density are not representative for these crudes
- New correlations were developed accounting for the Non-Newtonian and integrated with current WP models
- Non-Newtonian behaviour has a major impact on well performance hence on well design & equipment selection
- The current thinking that larger areas is good to minimise friction is being challenged and must be reviewed

The Challenge Ahead

At reservoir level little that can be done to take advantage of non-Newtonian behaviour but from the near wellbore area there are interesting possibilities such as:

- Shorter horizontal sections and smaller flow areas
- Lower perforating densities
- Smaller casing and tubing sizes at sand face
- Enhanced pumping equipment with less HP and lower energy consumption

A change of paradigm is required in terms of completion design, starting by changing the perception that friction is undesired. Viscosity management is the key