KUWAIT FLOW MEASUREMENT TECHNOLOGY CONFERENCE
2017

KUWAIT 3RD FLOW MEASUREMENT TECHNOLOGY CONFERENCE

19 - 21 NOVEMBER 2017

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شركة نفط الكويت

Kuwait Oil Company

إحـــدى شركـــات مؤســســة البتـــرول الكـويتيـة

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2017

Improving Flow Measurement in Heavy Oils with a Multiparameter System

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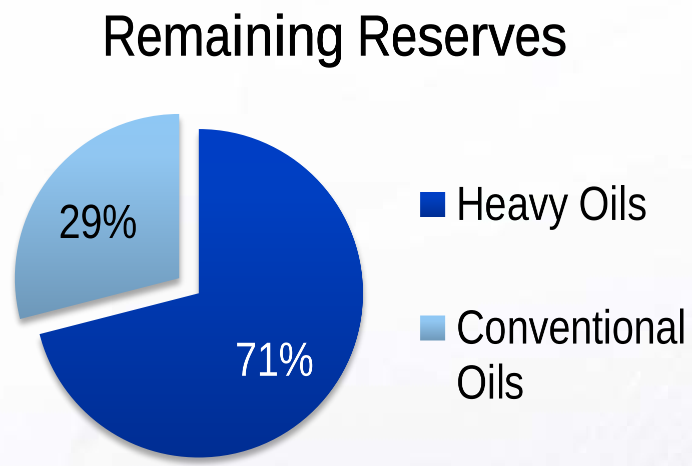
THE NEED

Increasing world energy demands

Measurement issues in low Reynolds numbers

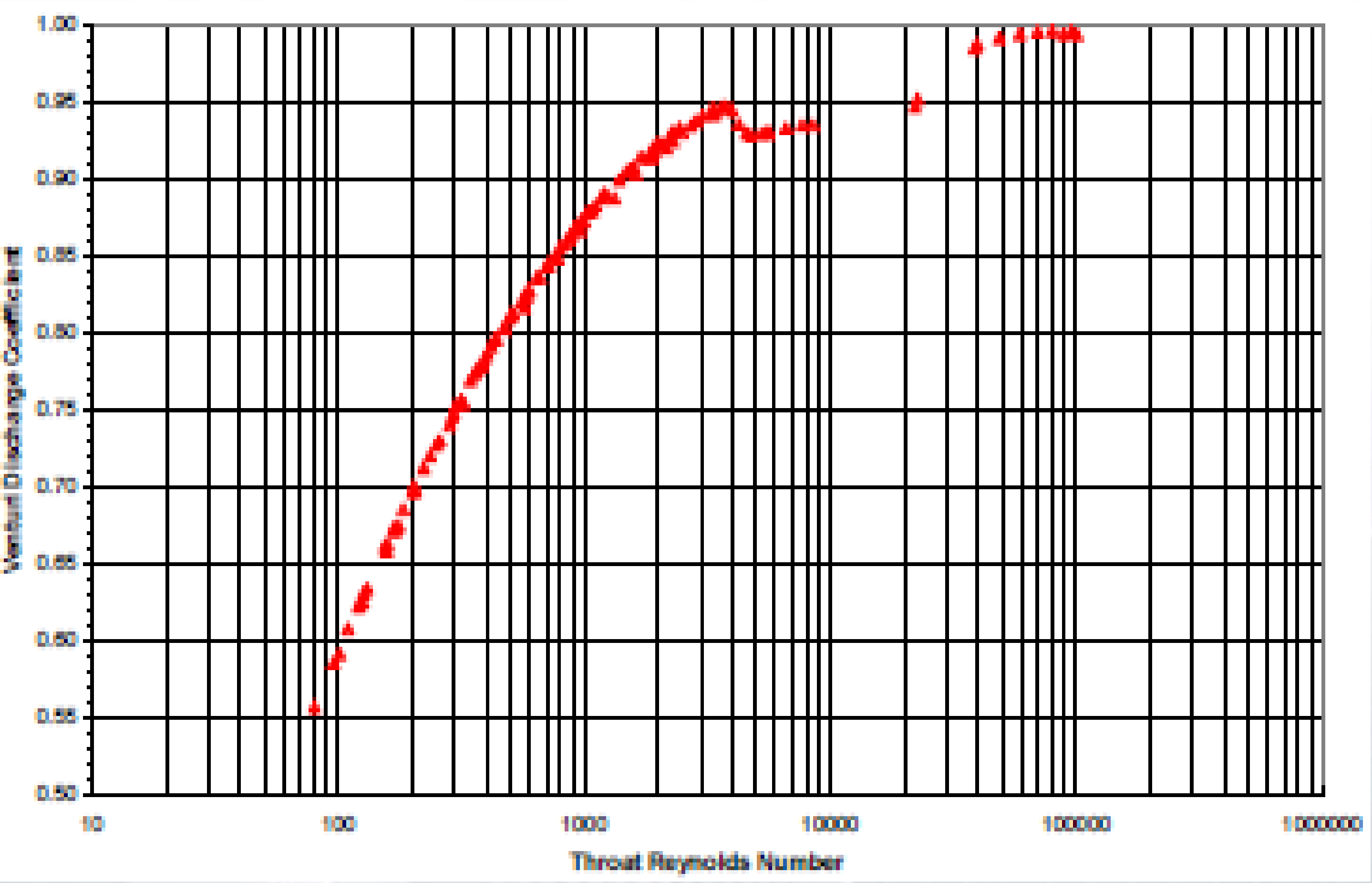
Non-linear Performance Index in low Re

؟ Need for improved performance

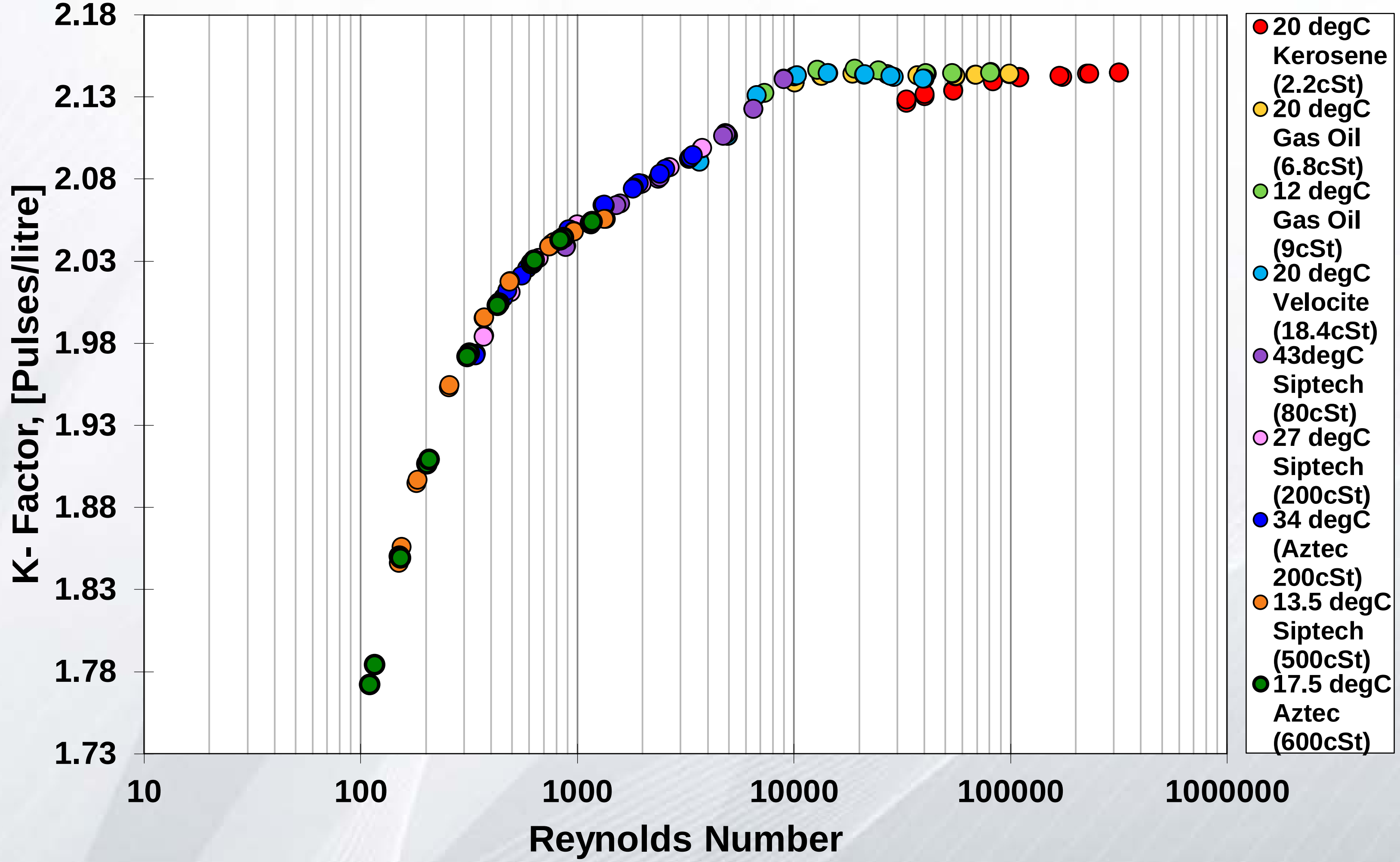


LIGHT OIL	45.5°	31.1°
MEDIUM	30.2°	22.3°
HEAVY	21.5°	10.0°
EXTRA-HEAVY	6.5°	0.1°

Venturi Performance



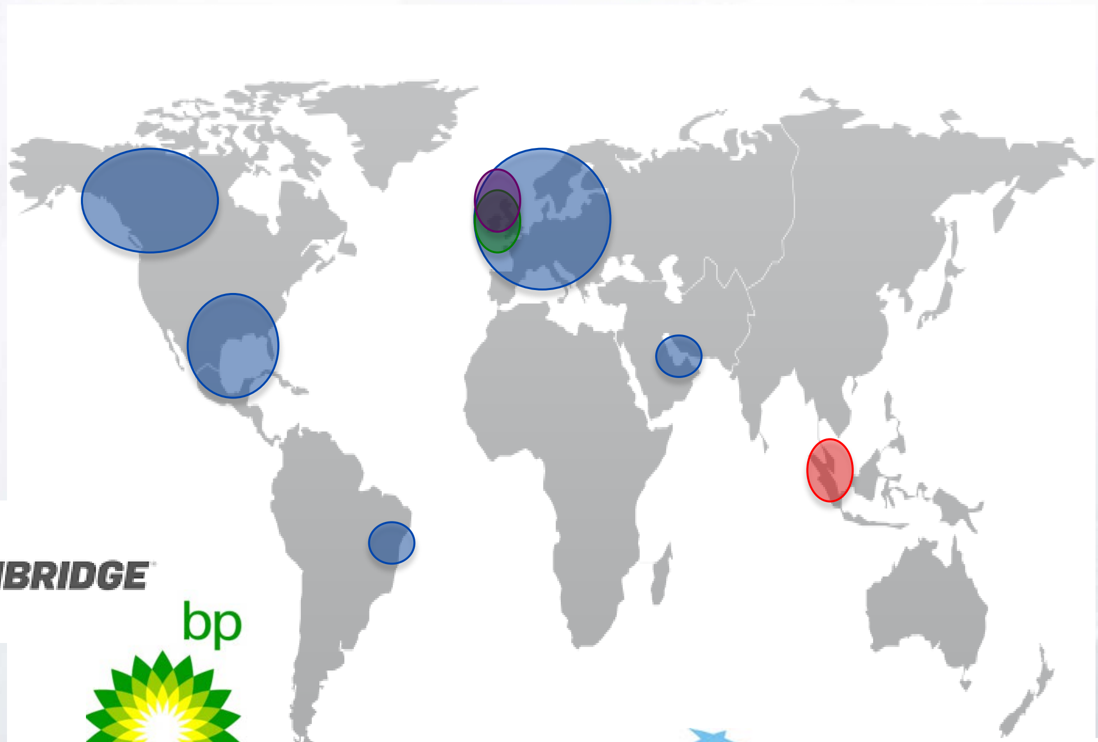
Turbine Performance



Market Study

8 countries visited, another 10 countries contacted, >100 people engaged

>30 end users, >50 manufacturers, >20 stakeholders



Bunker Fuel

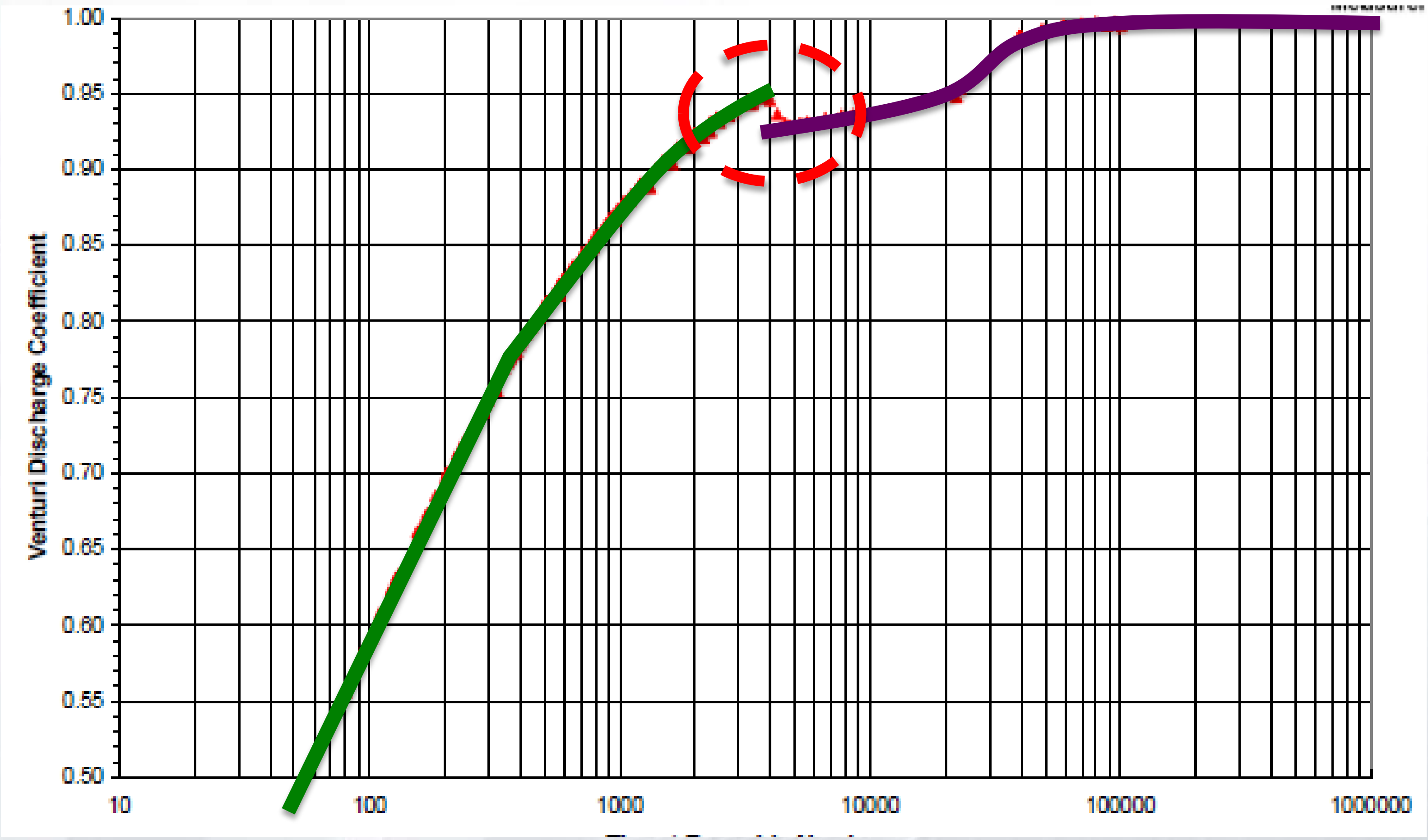
Food & Drink

Chemical

Market Study Outputs

- Better understanding of Fluid Mechanics
- Cost is critical but not the accuracy
- Low cost and 2% accuracy is acceptable
- There a gap in market for the above
- DP meters has a good potential if developed for low Re applications

Performance



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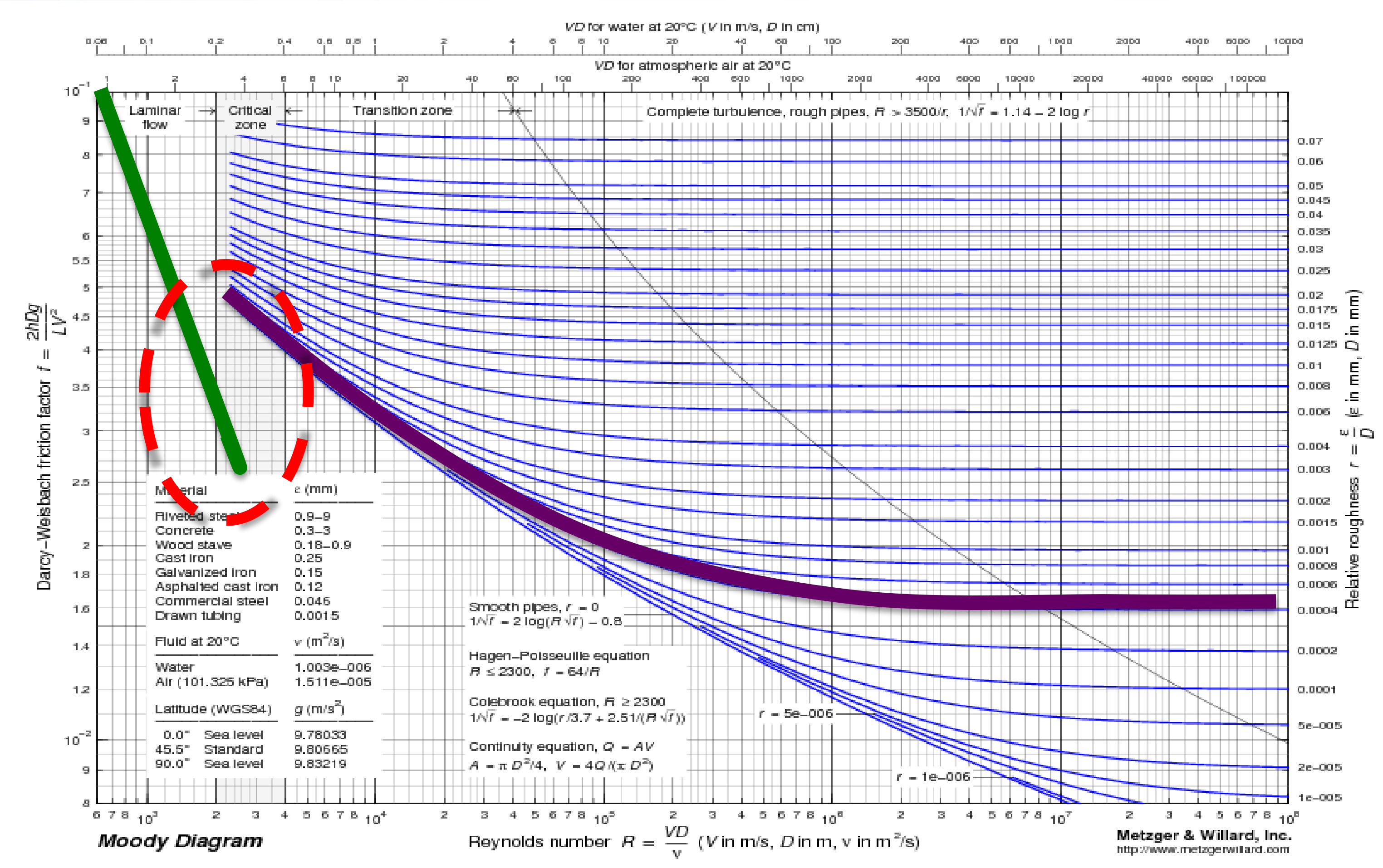
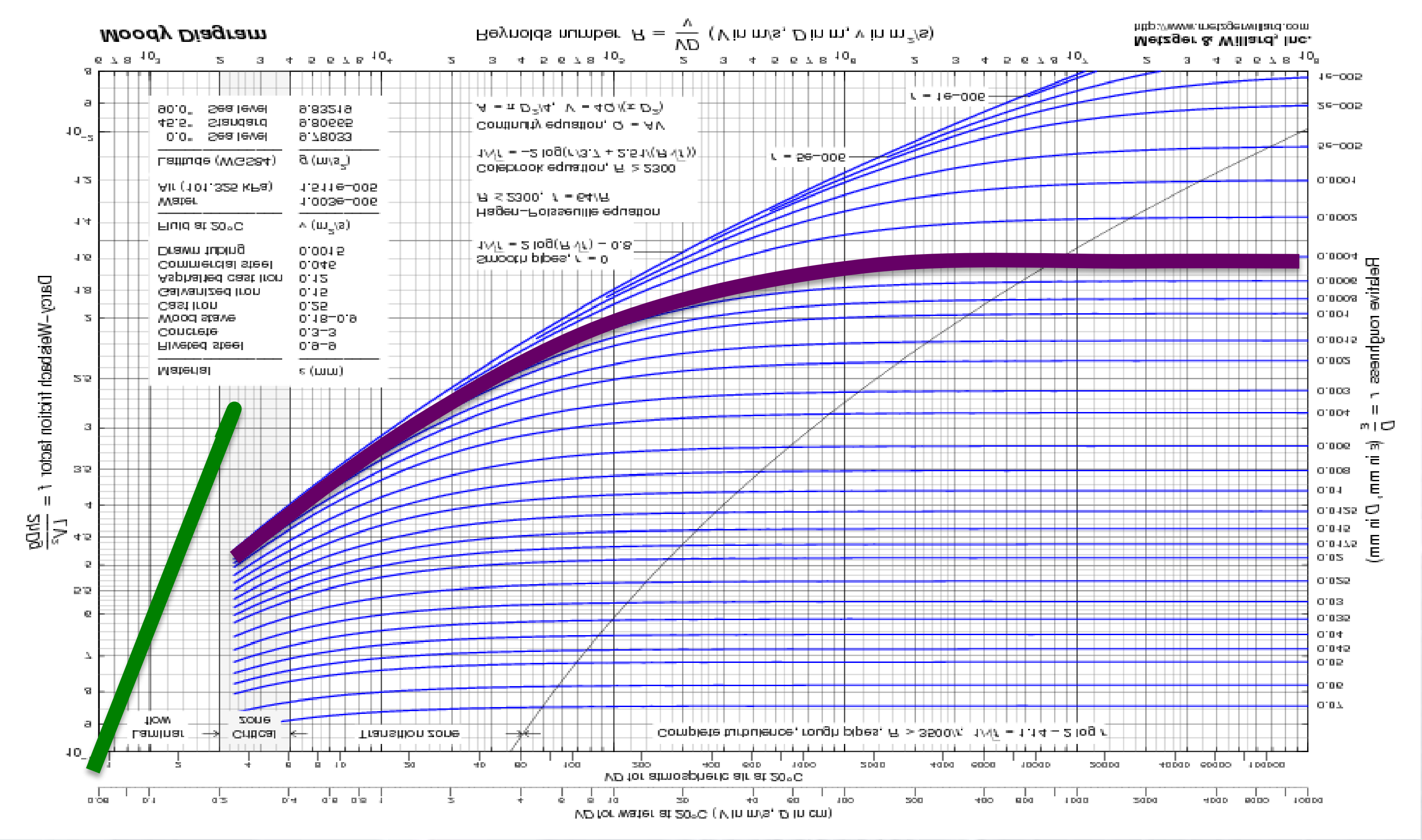
Moody Plot



Invert



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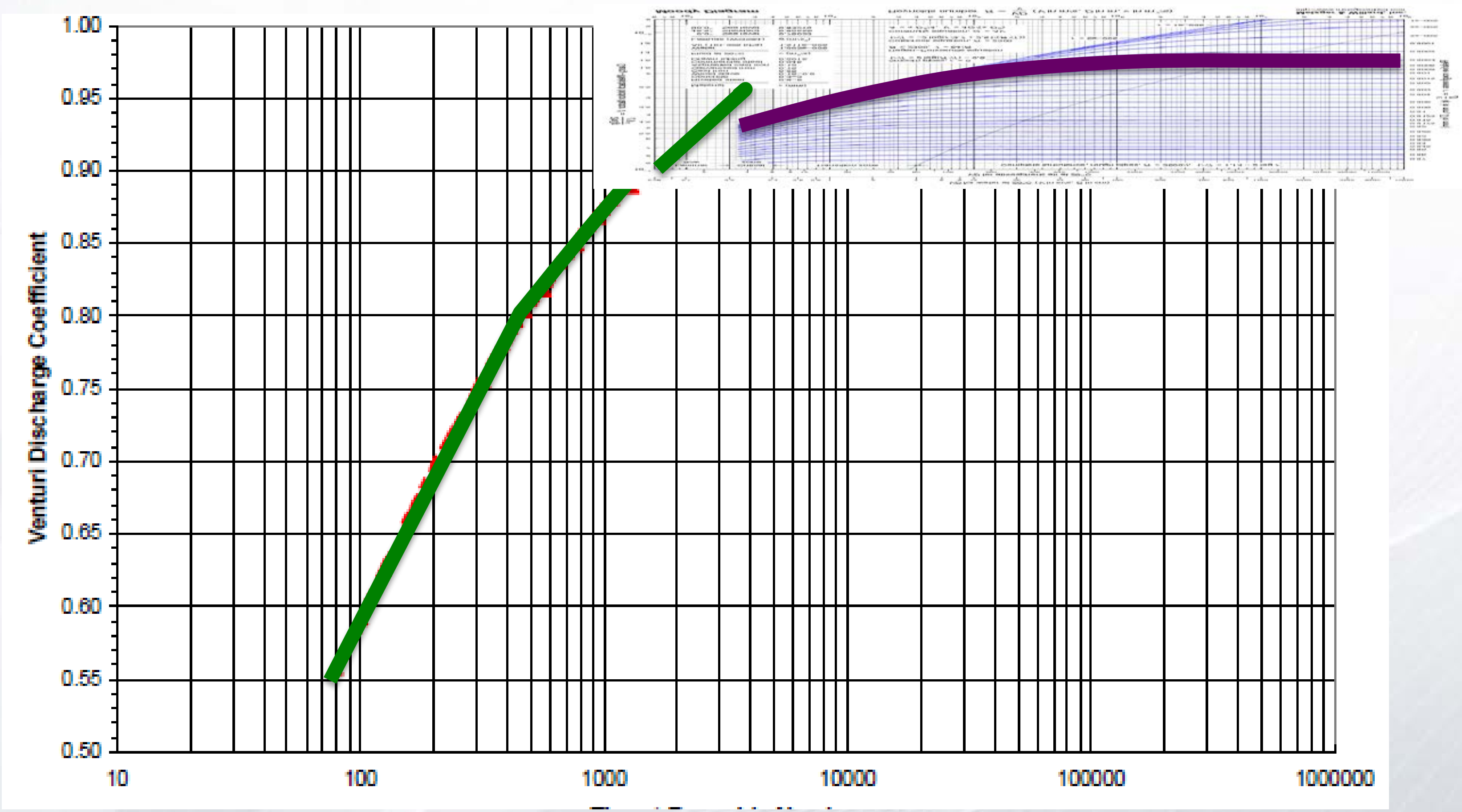
Overlap



Venturi Discharge Coefficient
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
10
100
1000
10000
100000
1000000

Theory (1)

Consider the fundamental theories used in fluid mechanics:

$$\frac{p_1}{\rho g}+\frac{u_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{u_2^2}{2g}+z_2$$

Bernoulli- inviscid fluid

$$Q_v=C_d\cdot\frac{\pi\cdot d^2}{4}\cdot\frac{1}{\sqrt{\left(1-\beta^4\right)}}\cdot\sqrt{\frac{2\cdot(P_1-P_2)}{\rho}}$$

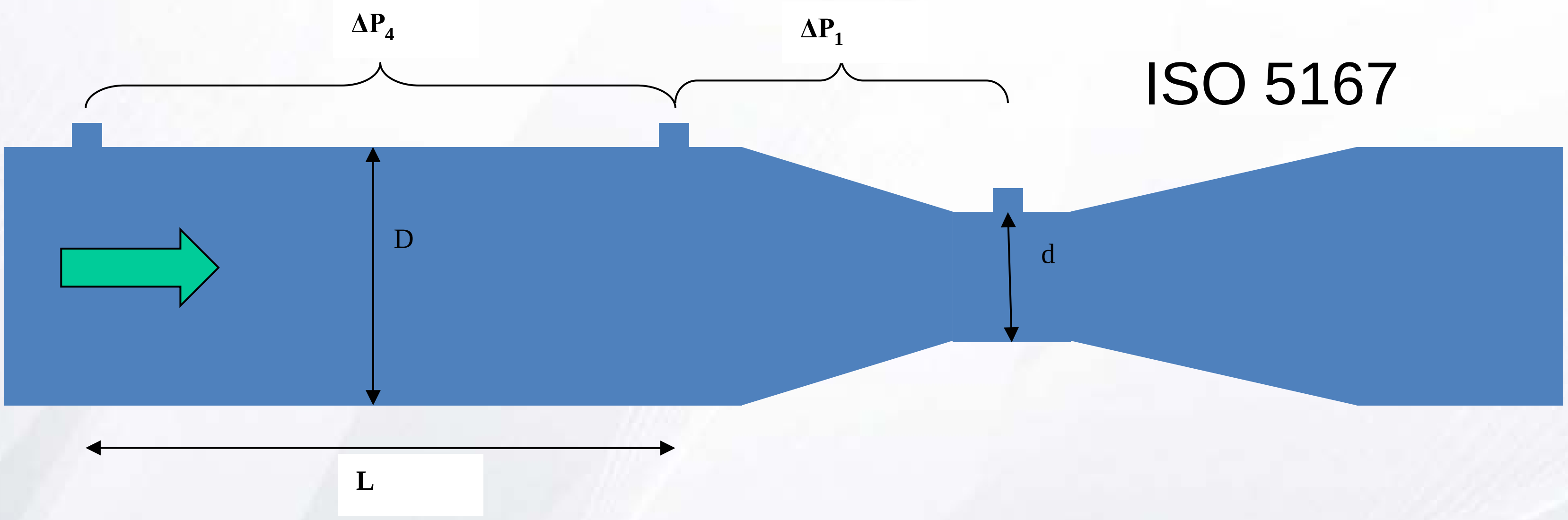
DP meter equation

$$\lambda=\frac{2\Delta P_4\cdot D}{\rho\cdot L\cdot u_D^{2}}$$

Darcy-Weisbach

Theory (2)

ISO 5167

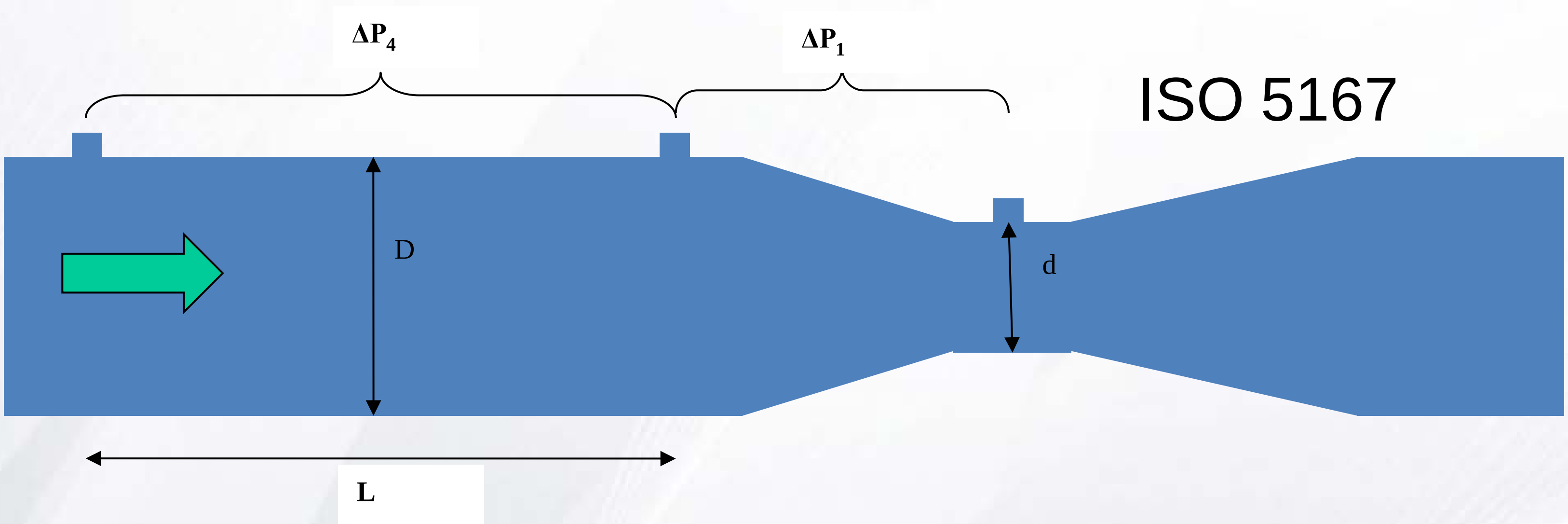


$$u_D^{\ 2} = \frac{2 \cdot C_d^{\ 2} \cdot \beta^4 \cdot \Delta P_1}{\rho\left(1-\beta^4\right)}$$

Substitute into

$$\lambda = \frac{2\Delta P_4 \cdot D}{\rho \cdot L \cdot u_D^{\ 2}}$$

Theory (3)



ISO 5167

$$\lambda = \frac{\Delta P_4}{\Delta P_1} \cdot \frac{C_g}{C_d^{\,2}} \quad \text{where} \quad C_g = \frac{D\left(1-\beta^4\right)}{L \cdot \beta^4}$$

Independent of ρ and μ

Theory (4)

Convert λ to Reynolds number from theory

$$\mathrm{Re} = \frac{64}{\lambda} \qquad \text{Or} \qquad \frac{1}{\sqrt{\lambda}} = -2\log\left(\frac{\varepsilon}{3.7D} + \frac{2.51}{\mathrm{Re}\sqrt{\lambda}}\right)$$

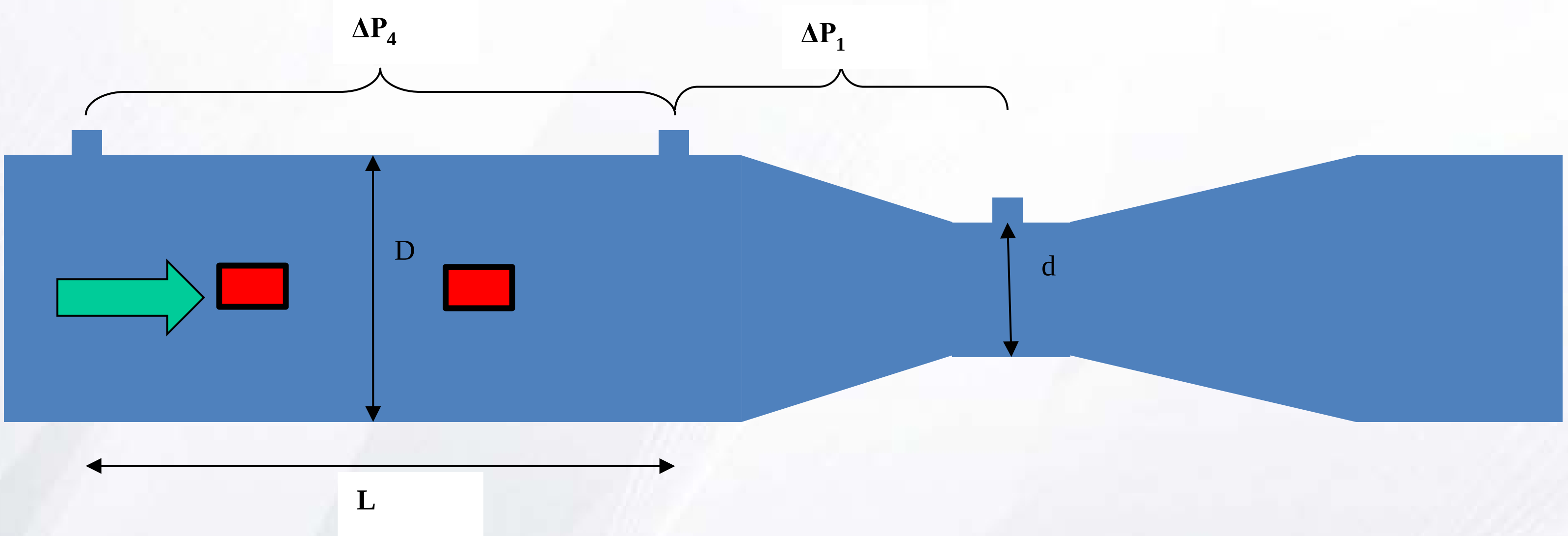
Since C_d as a function of Re is well known. We can iterate to find solution for C_d, λ and Re starting with a guessed C_d.

To calculate the flowrate, we still need ρ. Is there someway to calculate ρ in line? Yes, from the friction factor Eqn

$$\lambda = \frac{2\Delta P_4 \cdot D}{\rho \cdot L \cdot u_D^{\,2}}$$

But u_D is unknown…

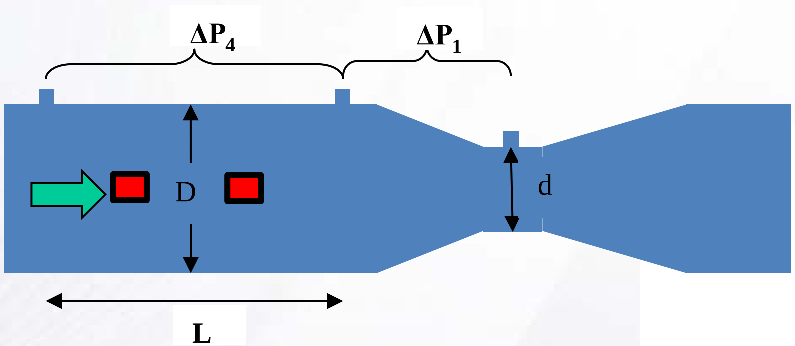
Theory (5)



u_D can be obtained by adding secondary technology such as Clamp-on USM

$$\rho = \frac{2\Delta P_4 \cdot D}{\lambda \cdot L \cdot u_D^{\ 2}} \qquad \mu = \frac{\rho \cdot u_D \cdot D}{\text{Re}}$$

Theory Recap

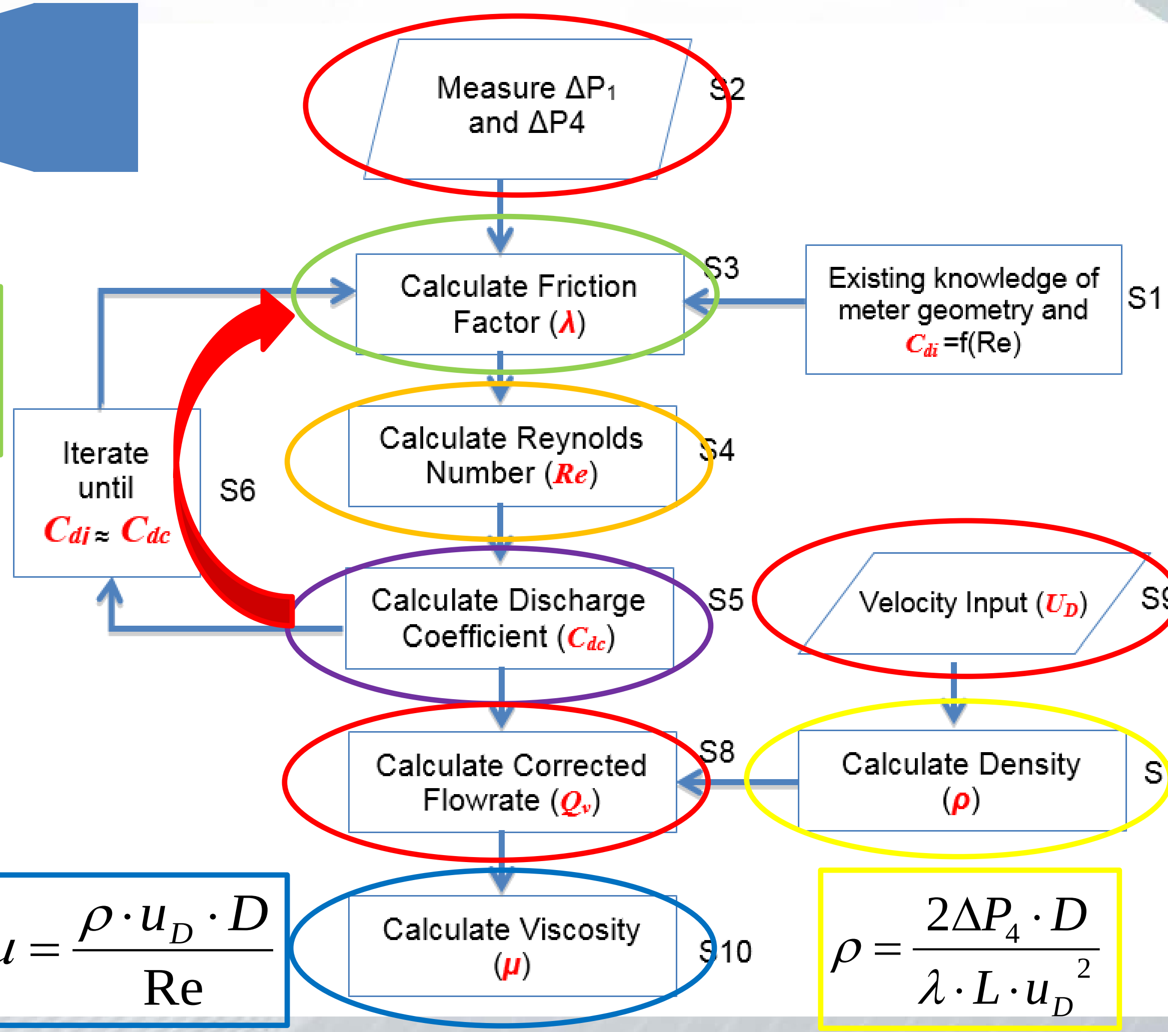


$$\lambda = \frac{\Delta P_4}{\Delta P_1} \cdot \frac{C_g}{C_d^{\ 2}} \quad \text{where} \quad C_g = \frac{D(1-\beta^4)}{L \cdot \beta^4}$$

$$Re = \frac{64}{\lambda} \quad \text{or from}$$

$$\frac{1}{\sqrt{\lambda}} = -2\log\left(\frac{\varepsilon}{3.7D} + \frac{2.51}{Re\sqrt{\lambda}}\right)$$

$$C_d = f\,(Re)$$



$$\mu = \frac{\rho \cdot u_D \cdot D}{Re}$$

$$\rho = \frac{2\Delta P_4 \cdot D}{\lambda \cdot L \cdot u_D^{\ 2}}$$

NEL Heavy Oil Facility

UK National Standard Oil facility:

Flow up to 200 l/s

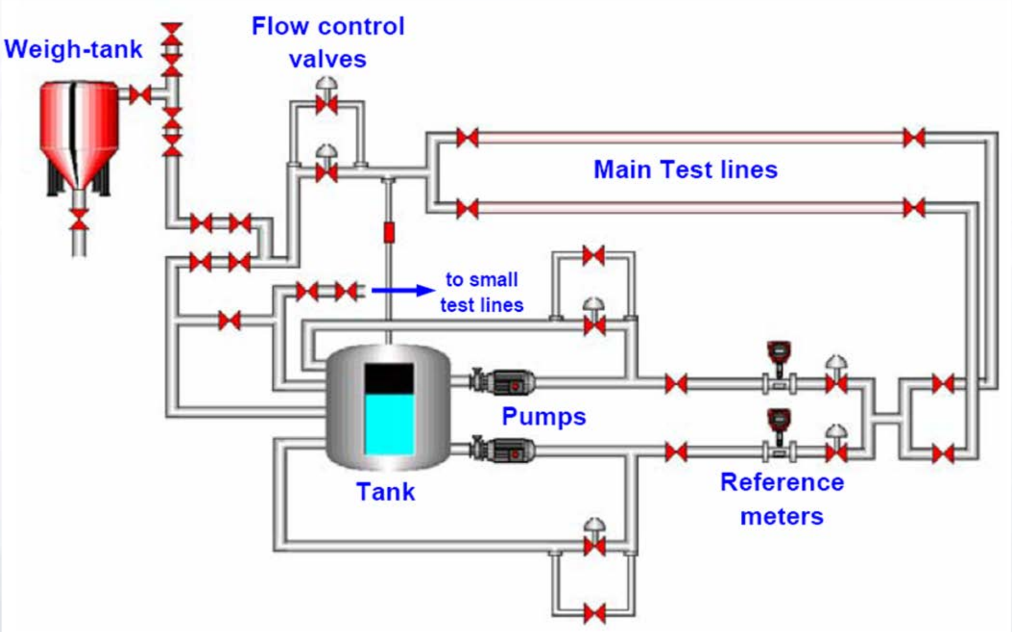
Oil viscosity from 1.5 to 1500 cSt

Test temperature up to 60^{o}C

Temp control with ± 1^{o}C

Test pressure up 10 bar

Pipe sizes 0.5” to 8”



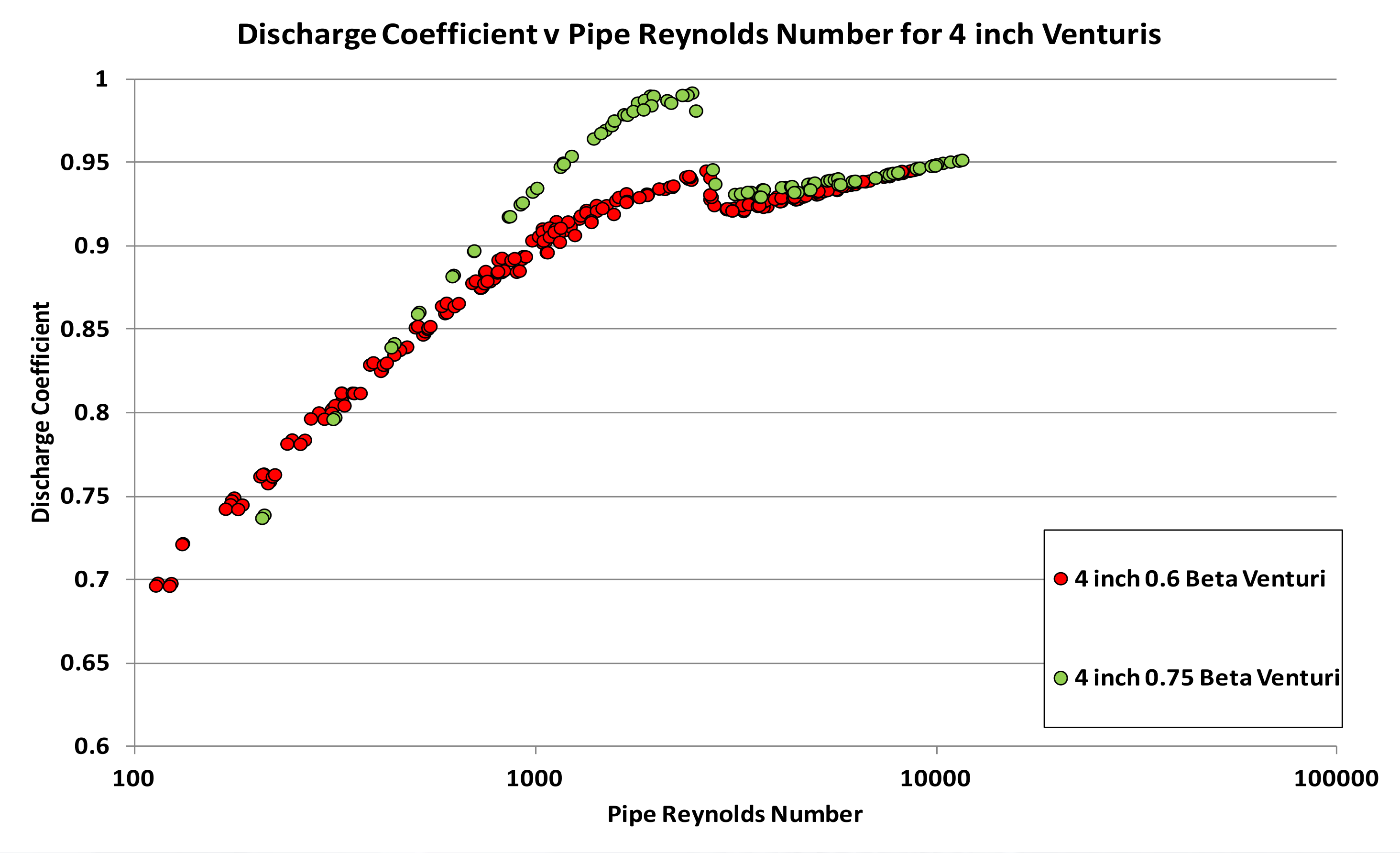
Overall uncertainty in ref flow ± 0.03% (Gravimetric)

Overall uncertainty in ref flow ± 0.08% (Reference meters)

Test Meters

Meter Number	Meter Type	Nominal Size (in)	Nominal Beta	Upstream Length (m)	Min Re	Max Re
1	Venturi	8	0.4	2.027	**94**	8268
2	Venturi	8	0.6	2.027	84	9213
3	Venturi	6	0.4	1.540	285	6081
4	Venturi	6	0.75	1.540	391	9781
6	Venturi	4	0.6	1.022	88	11404
7	Venturi	4	0.75	1.022	208	**14600**
8	QE Orifice	8	0.45	2.393	647	9140
9	QE Orifice	8	0.6	2.393	240	7681

4 inch Venturi Results



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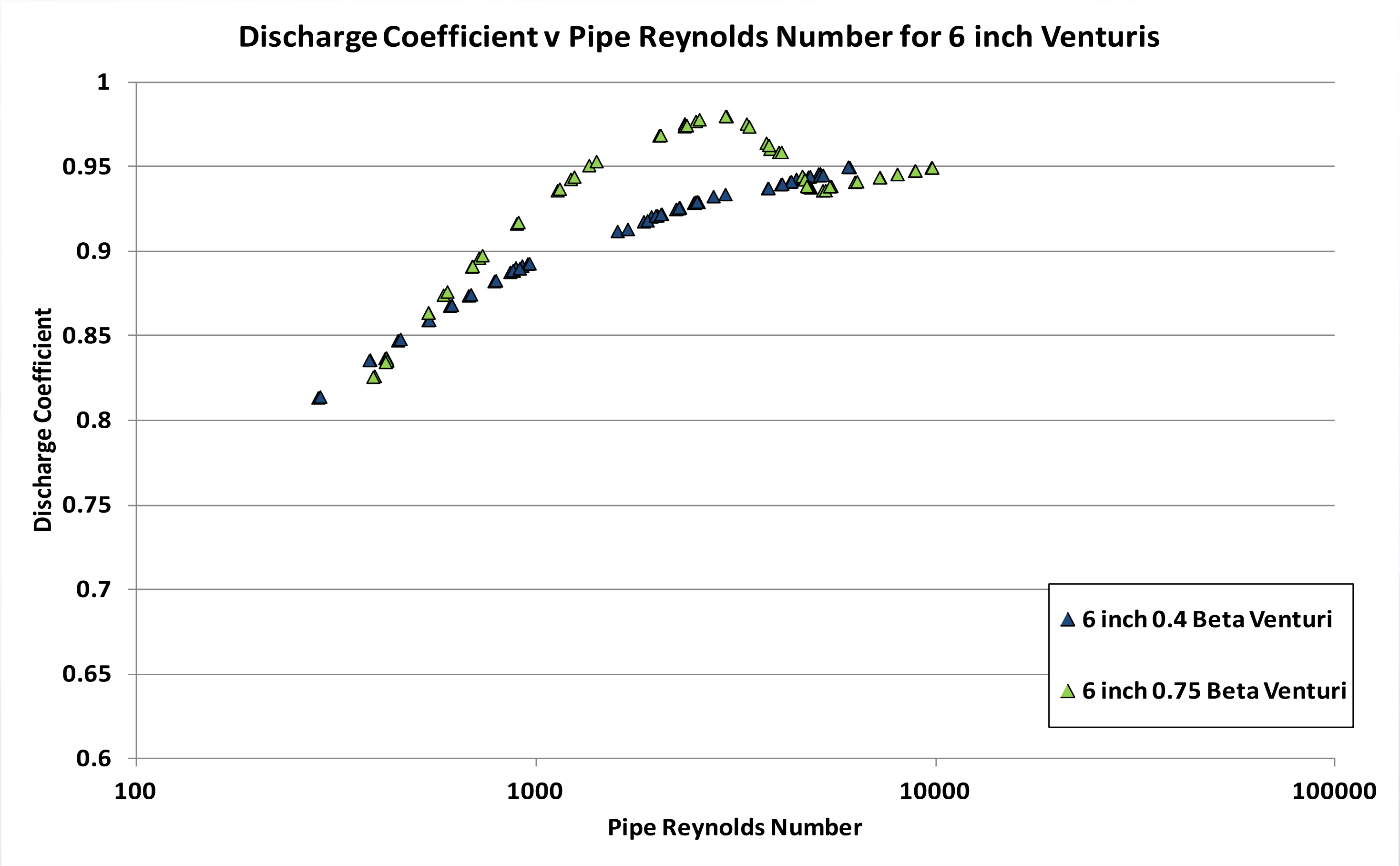
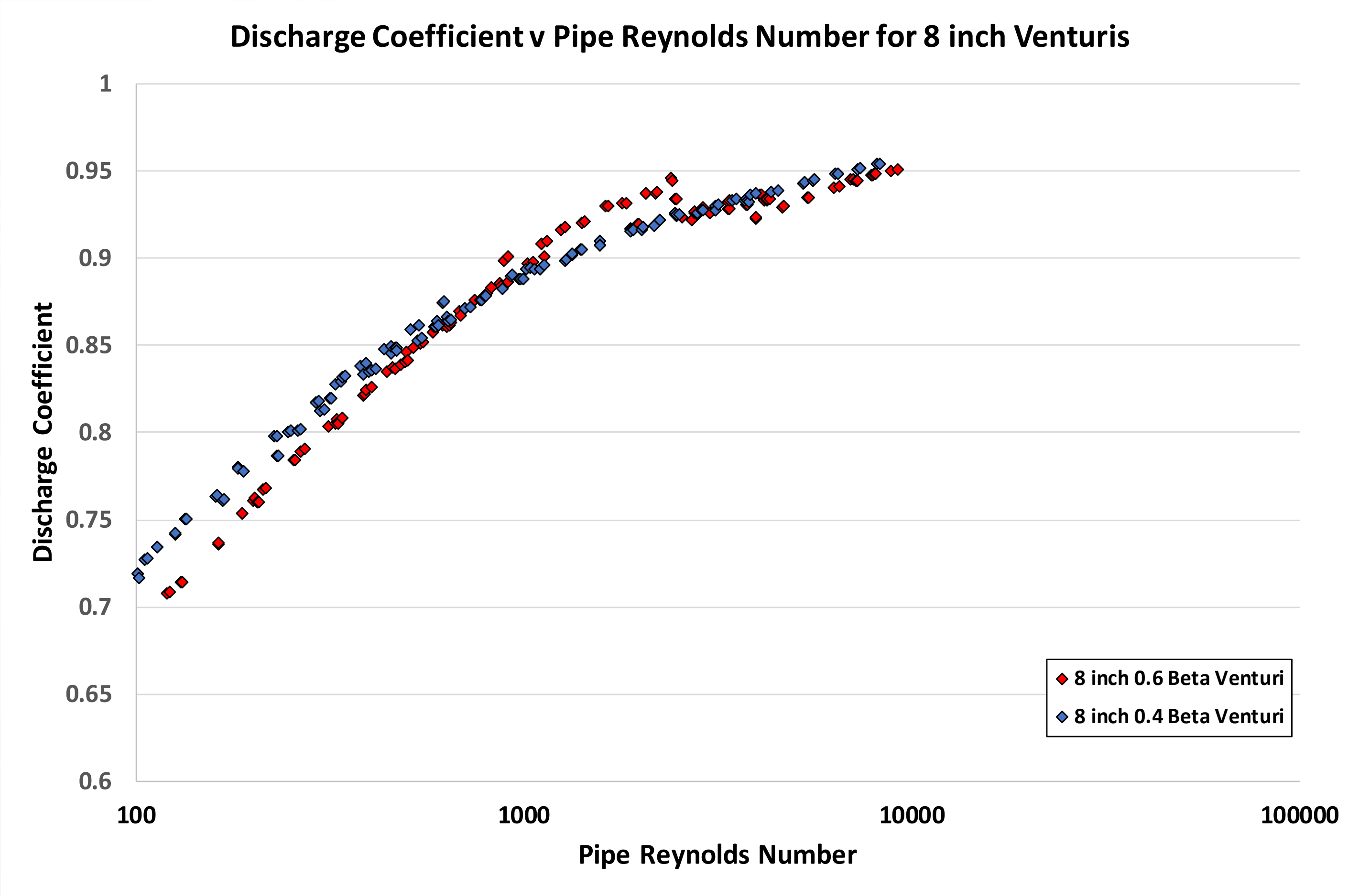
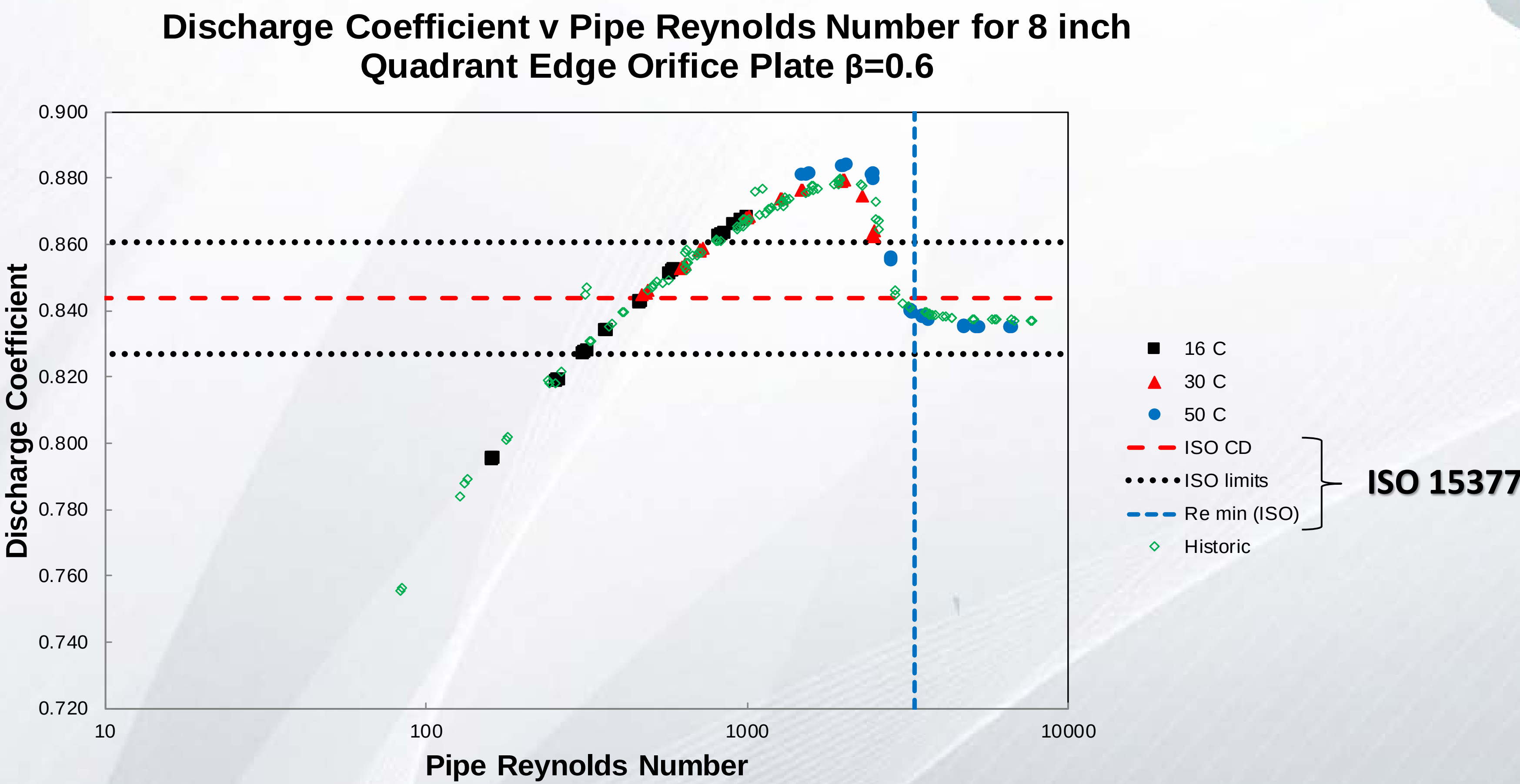
6 inch Venturi Results



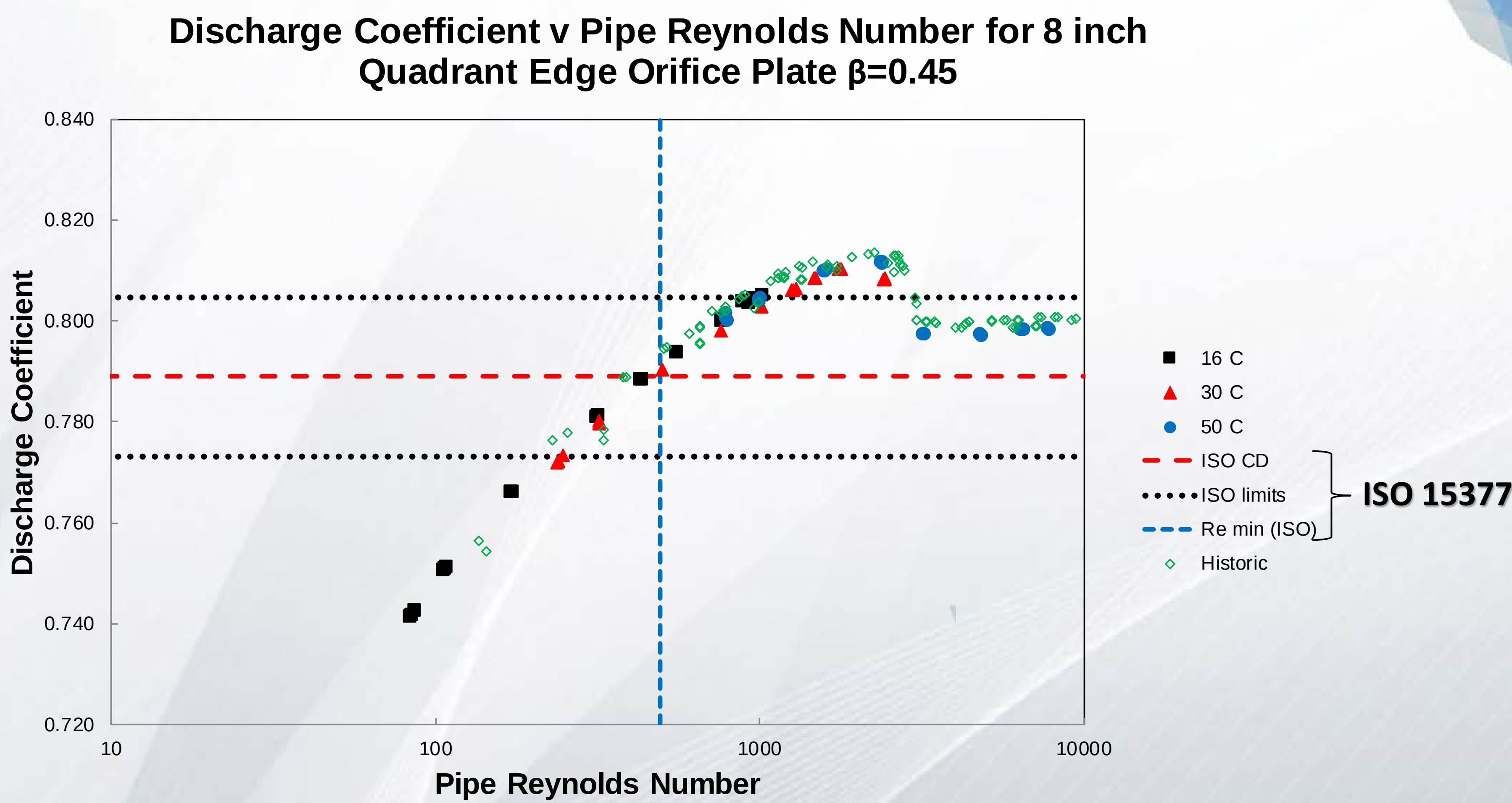
8 inch Venturi Results



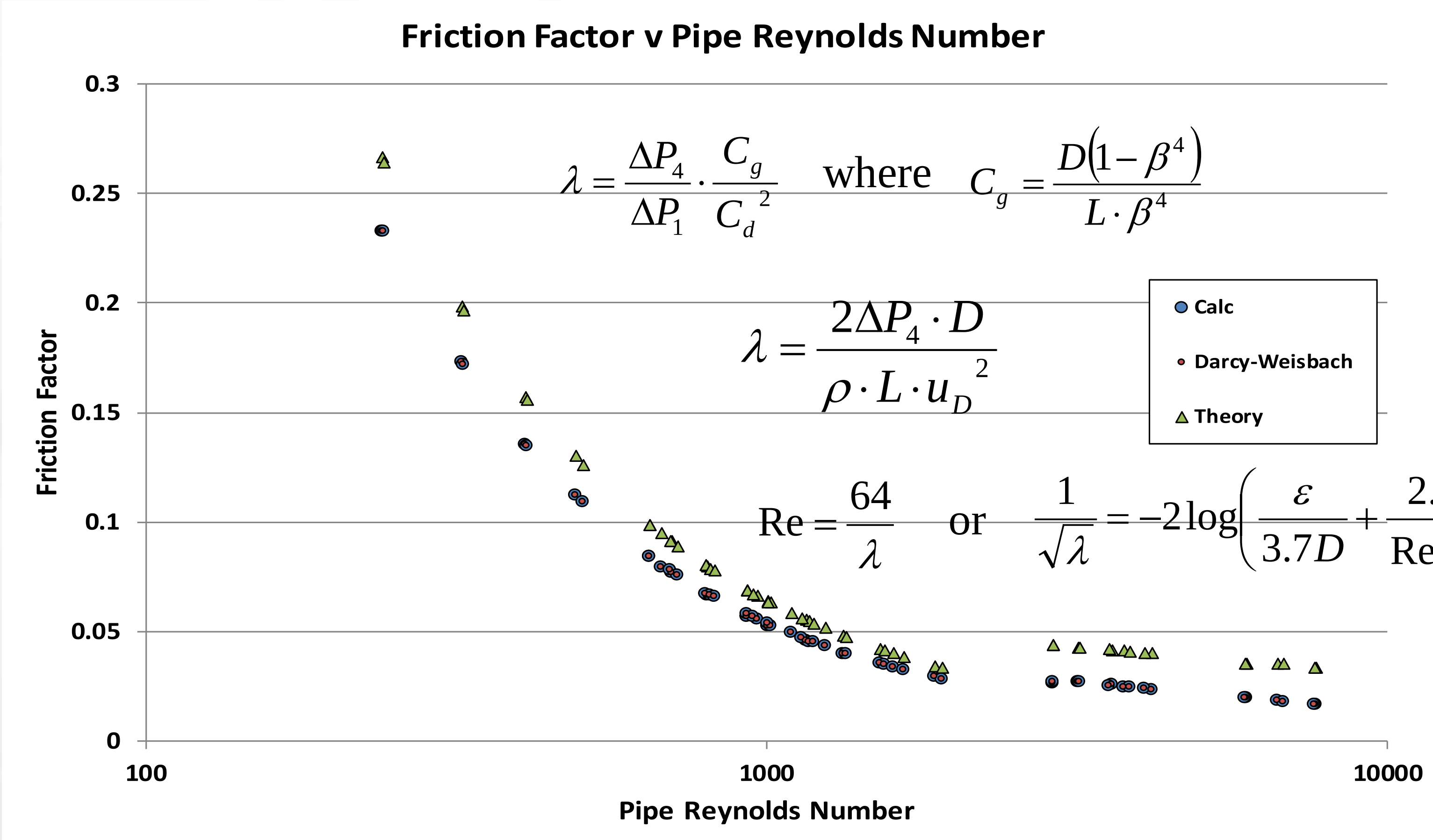
8 inch QE Orifice Results



8 inch QE Orifice Results



Applying New Method

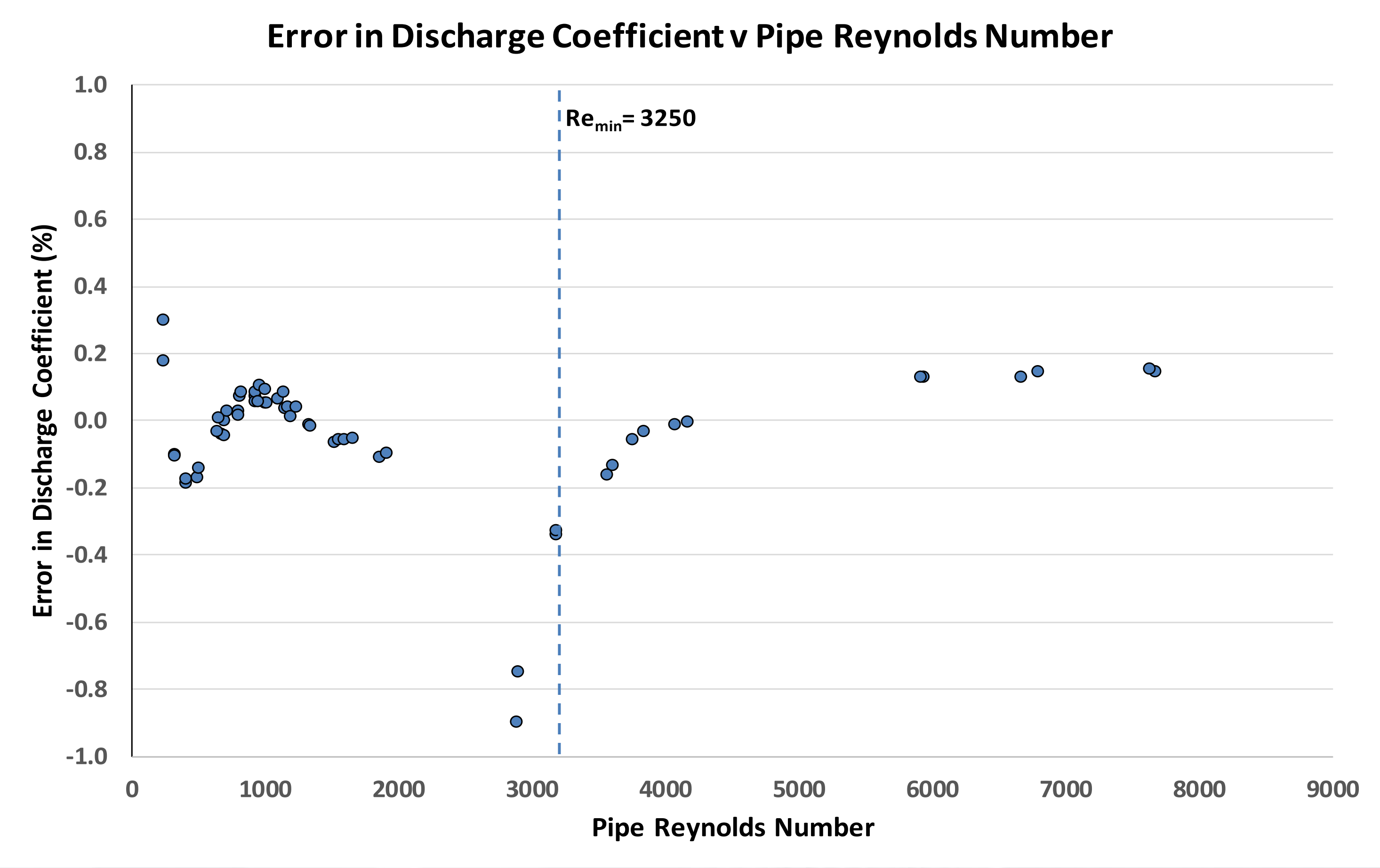


$$\lambda = \frac{\Delta P_4}{\Delta P_1} \cdot \frac{C_g}{C_d^{\,2}} \quad \text{where} \quad C_g = \frac{D\left(1-\beta^4\right)}{L \cdot \beta^4}$$

$$\lambda = \frac{2\Delta P_4 \cdot D}{\rho \cdot L \cdot u_D^{\,2}}$$

$$\mathrm{Re} = \frac{64}{\lambda} \quad \text{or} \quad \frac{1}{\sqrt{\lambda}} = -2\log\left(\frac{\varepsilon}{3.7D} + \frac{2.51}{\mathrm{Re}\sqrt{\lambda}}\right)$$

New Method (using input ρ)



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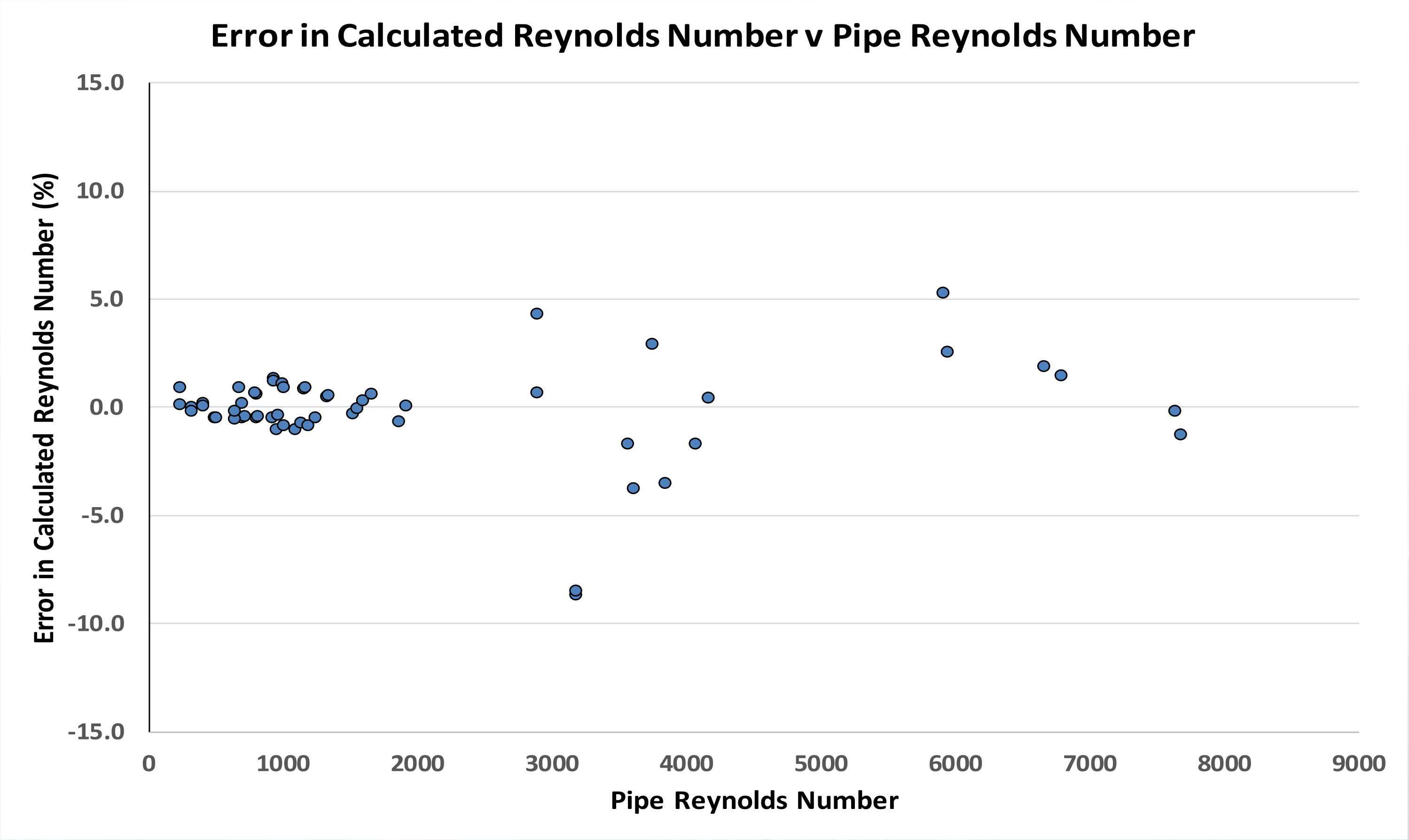
New Method (using input ρ)



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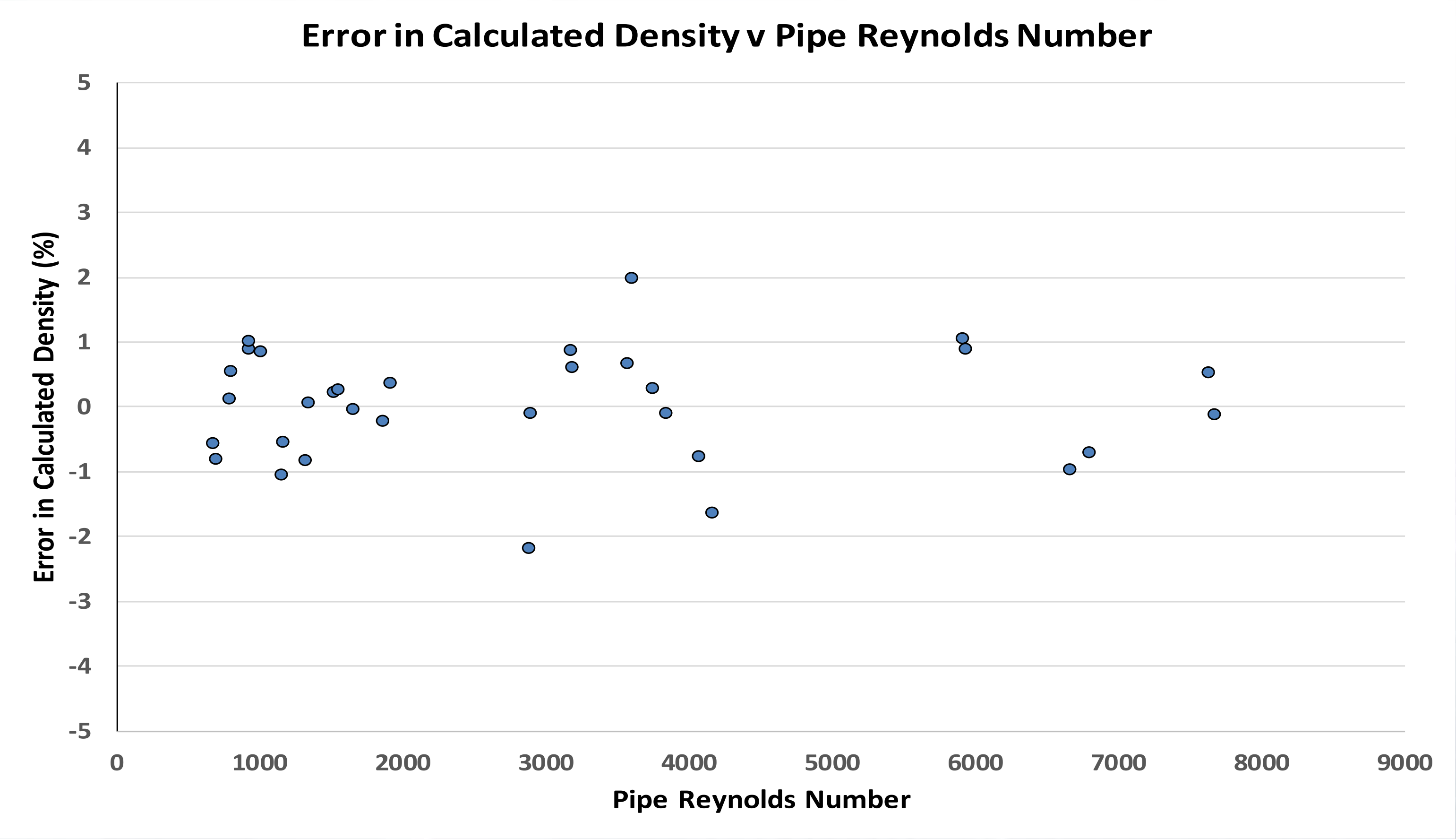
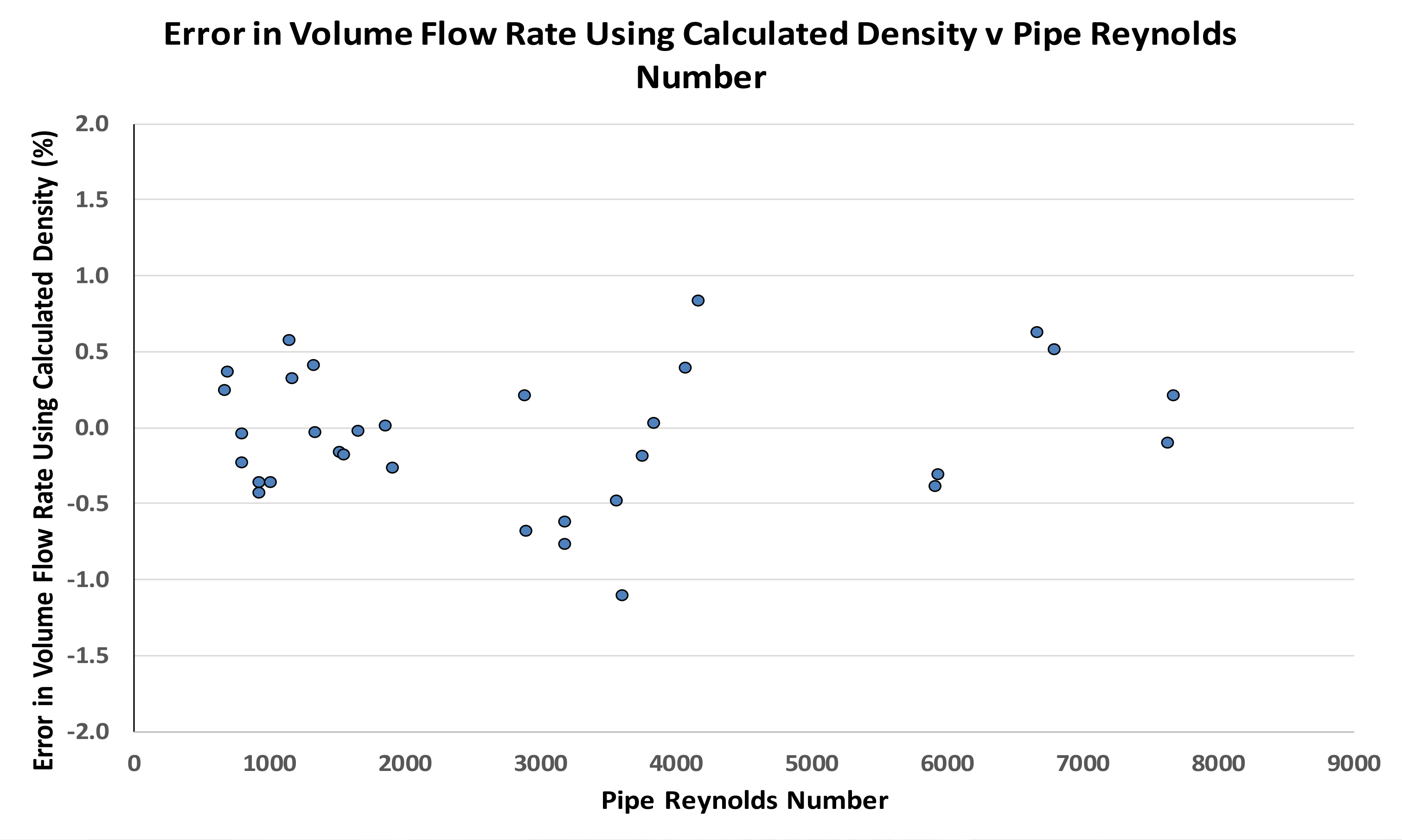
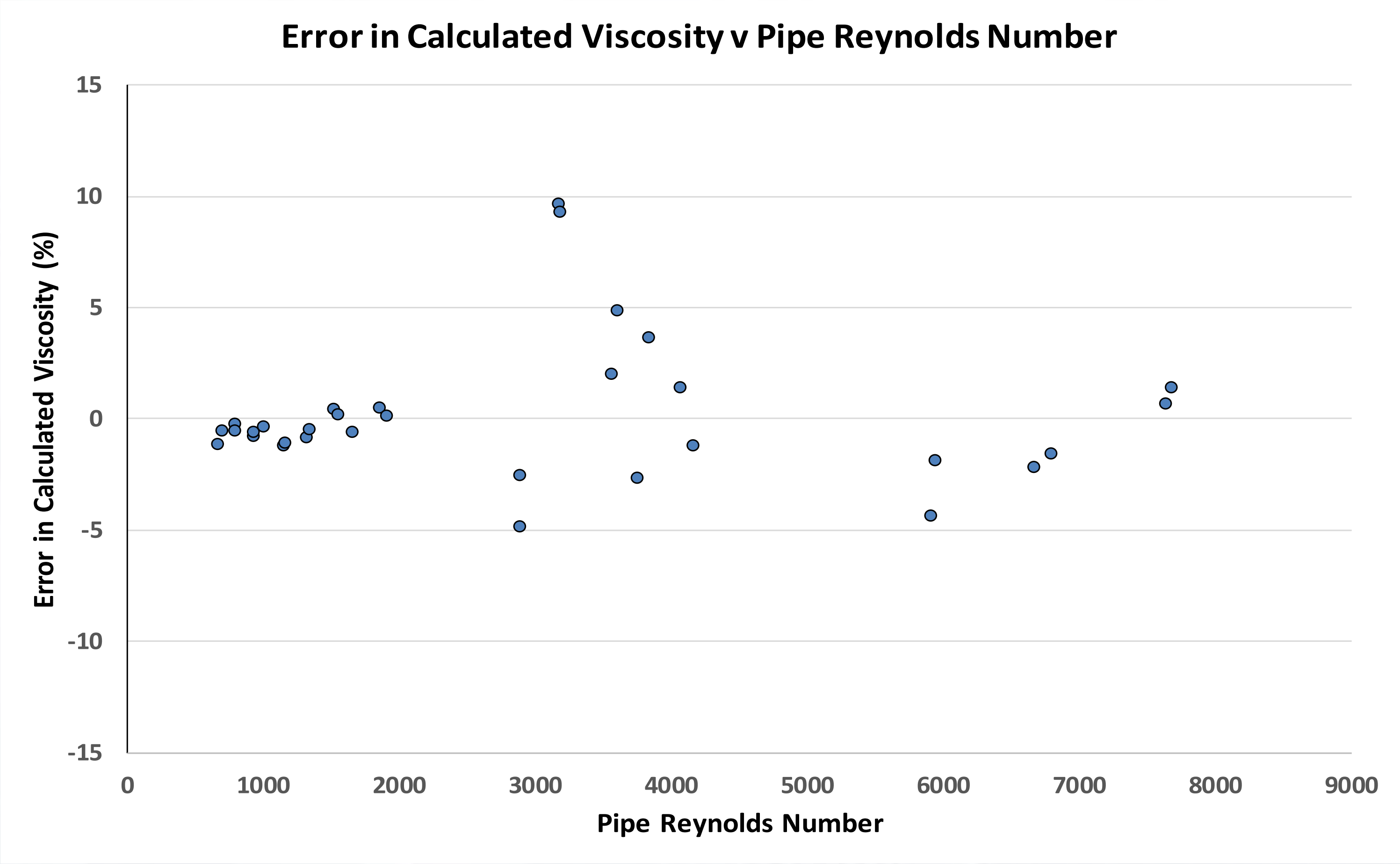
New Method (calculated ρ)



New Method (using calculated ρ)



New Method (using calculated ρ)



Conclusions

- A new method is presented to show the potential of DP meters for measurements in low Re applications.
- Initial limited testing have shown promising results:

Re:	within ±5%
Cd:	within ± 0.2%
Vol flow:	within ± 0.2% (using known density)

- By using additional measurement technology we can get:

Density:	within ±2%
Vol flow:	within ± 1% (using calc density)
Viscosity:	within ±5%

However more work is required to develop this method further and to investigate the influence of several parameters

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Future Work

- Investigate the influence of following parameters:
  - Influence of upstream length and installation effects
  - Influence of fluid properties and fluid condition
  - Influence of meter geometry
- Combine the method with other measurement technologies
- Developing new standard equation for low Re and update relevant standards
- Calculation of uncertainty

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Acknowledgements

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Thanks for Attention