Flow Measurement and Energy

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TUV NEL

Scope?

- **Relatively easy problems**
  - Because we have worked on them

or

- **Relatively difficult problems**
  - On which we are working

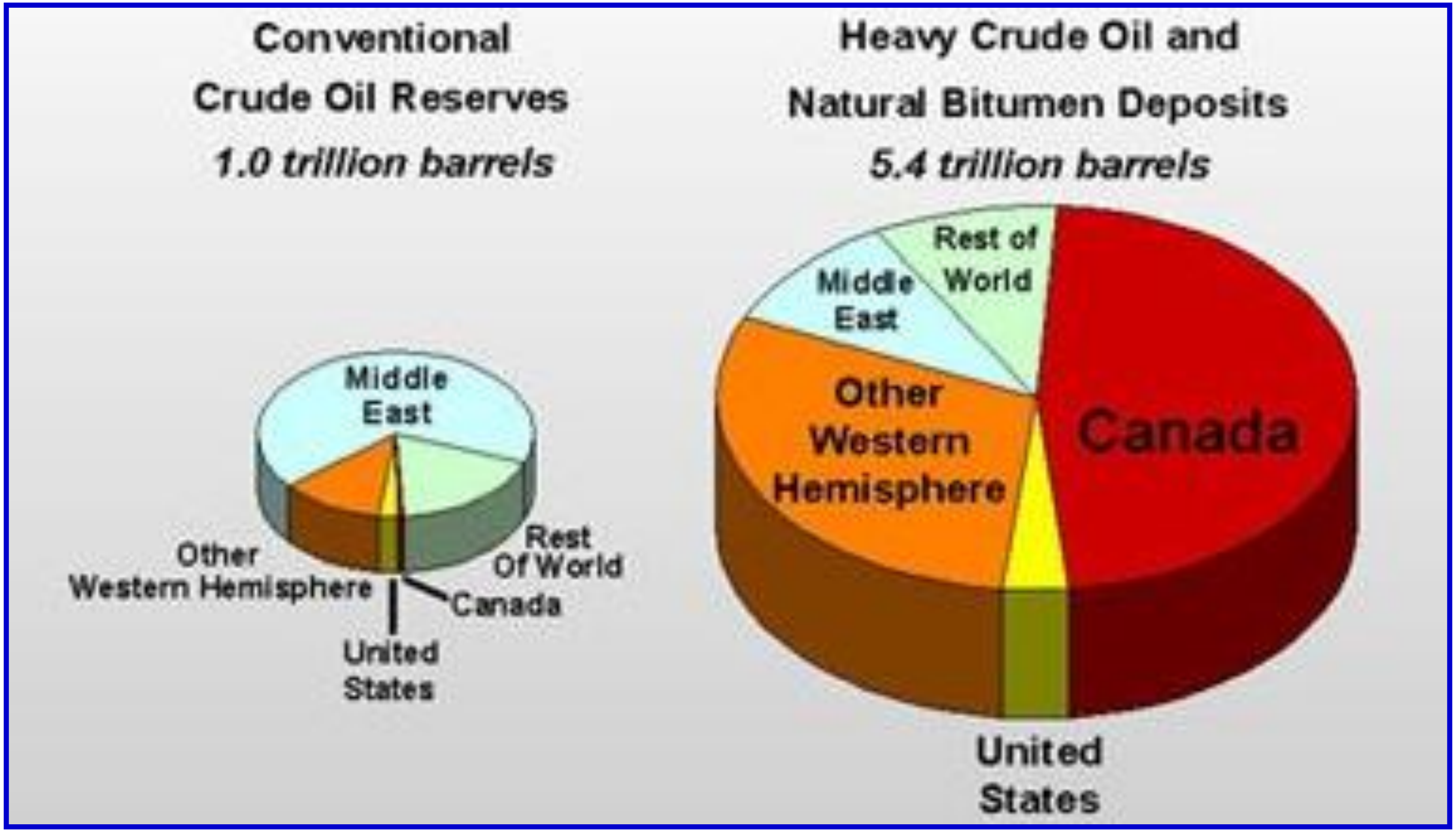
?

Scope

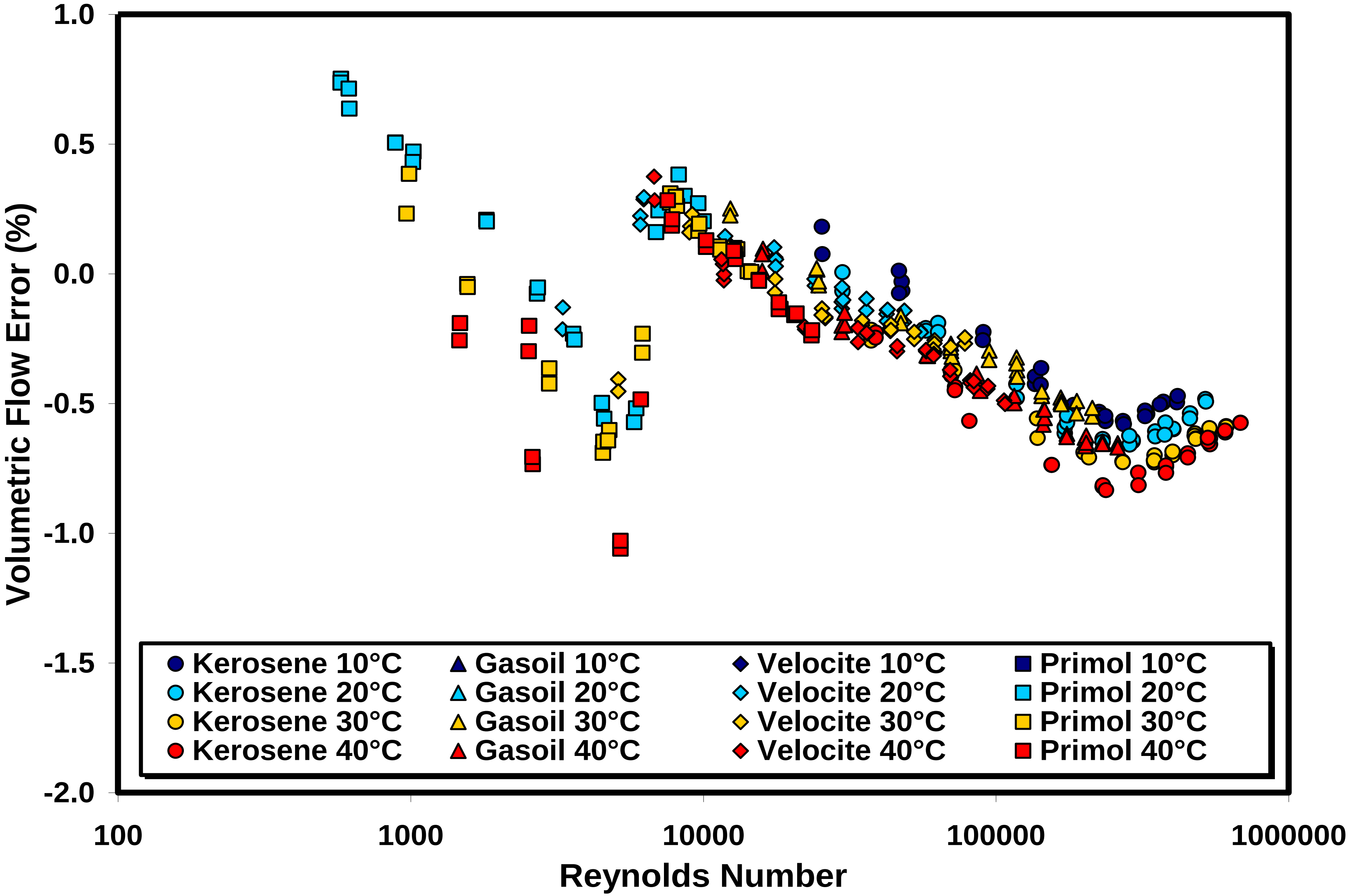
- **1 Difficult Reynolds numbers**
  - 1.1 Heavy oil
  - 1.2 LNG
  - 1.3 Power stations
- **2 Difficult fluids**
  - 2.1 Carbon dioxide
  - 2.2 Wet gas and Multiphase flow
- **3 Difficult installations**
  - 3.1 Emissions
  - 3.2 Flare gas
  - 3.3 Smart meters
  - 3.4 Wind turbines

Difficult Reynolds numbers:
1.1 Heavy oil

- **Worldwide reserves of heavy hydrocarbons now significantly outweigh conventional light crudes.**



Ultrasonic 4” Multipath



TÜV SÜD

nel technology for life

Ultrasonic 4” Multipath

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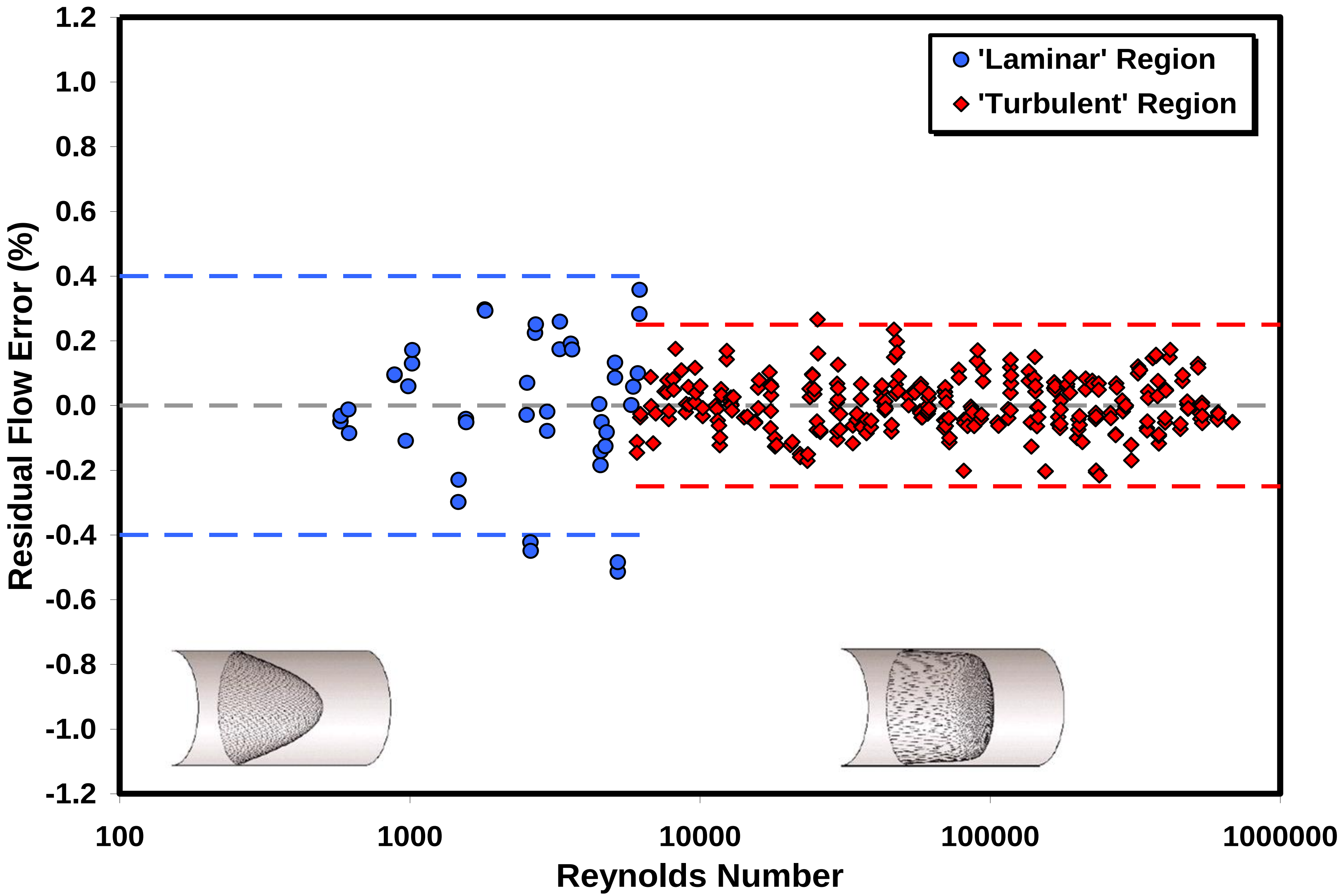
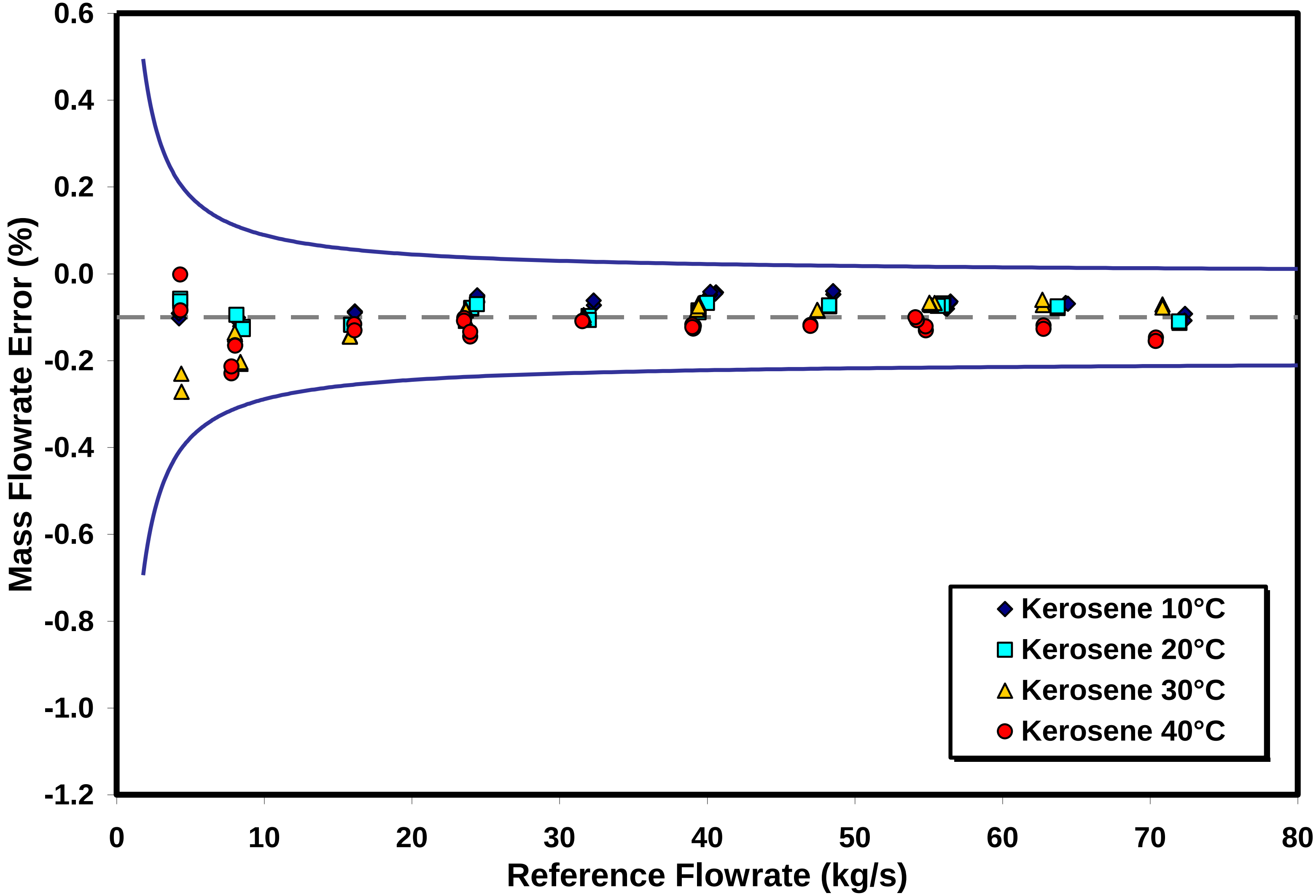
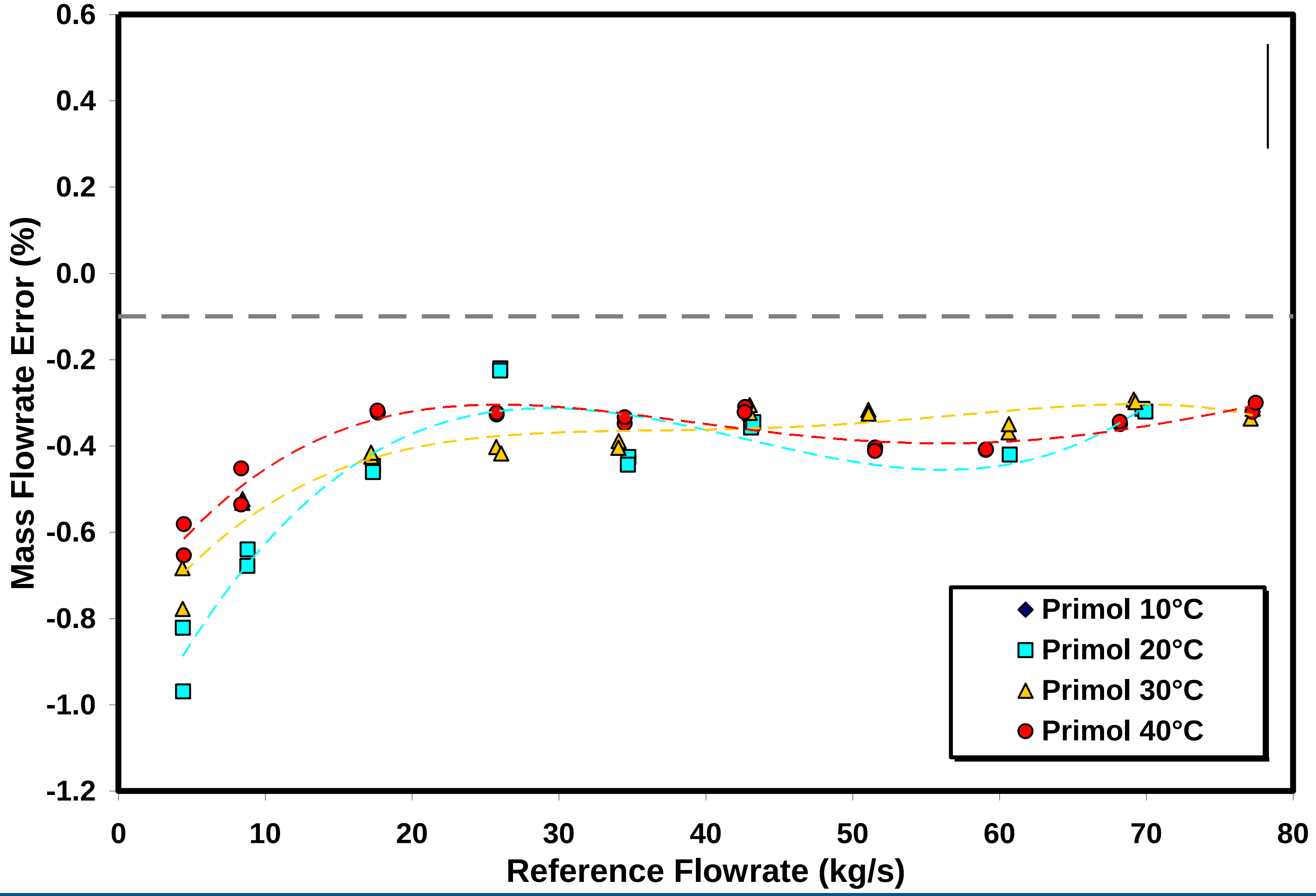


Coriolis: 1- 3 cSt



Coriolis: 40 - 300 cSt



1 Reynolds number issues

- **1.1 Heavy oil**
  - Performance may be difficult through transition (ultrasonic)
  - Performance may be different below transition (Coriolis)
  - Air entrainment
  - Extension to 1500 cSt

- **1.2 LNG**
- **1.3 Power stations**
  - The Reynolds number in LNG or pressurized hot water is much higher than in cold water

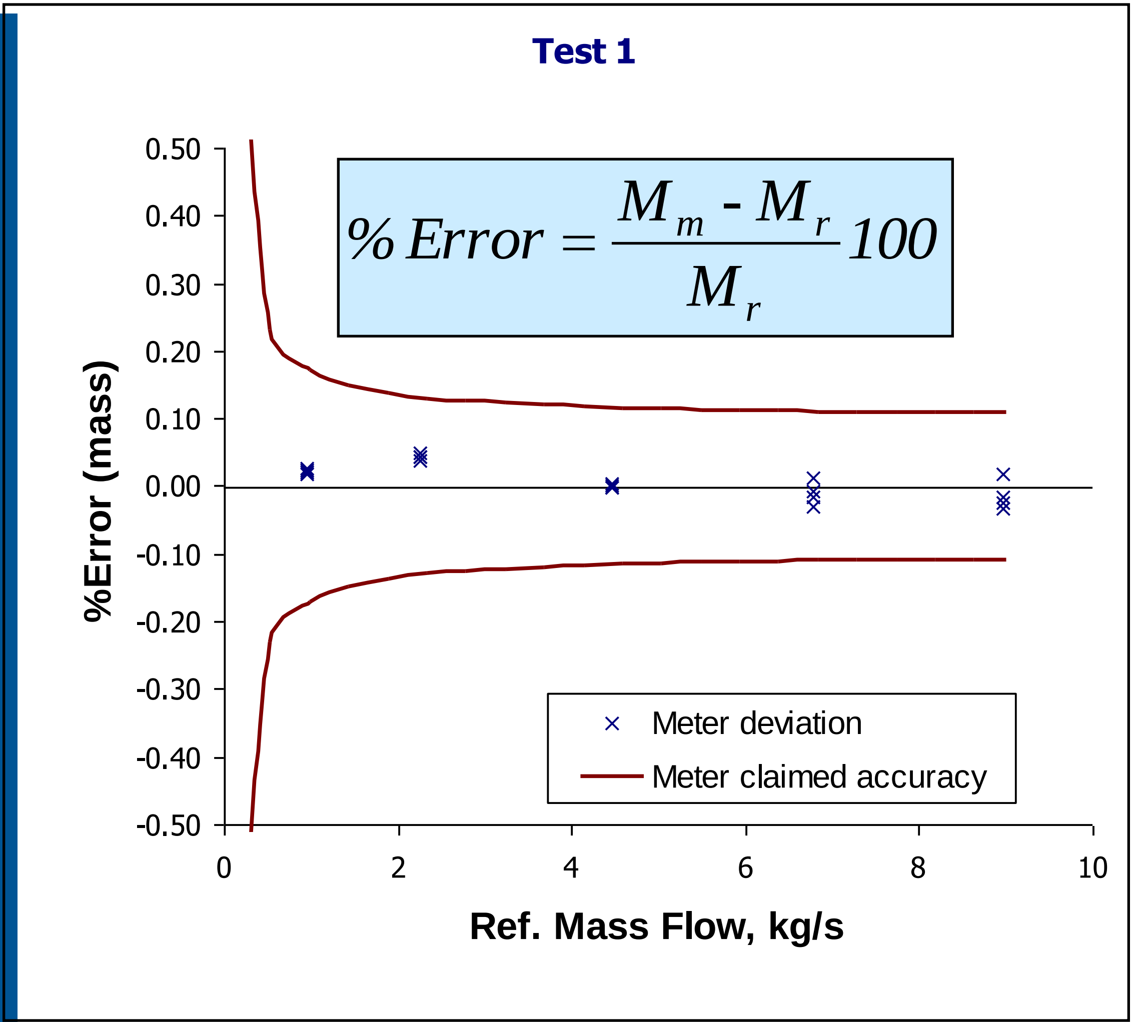
Difficult Reynolds numbers:
1.2 LNG

Most measurement is on board ship, but it would be good to use a flowmeter

Test Programme

- **Flow meters:**
  - Coriolis
  - Ultrasonic
- **Test plan- performance evaluation:**
  - Water (20^{o}C) at TUV NEL
  - Liquid N_2 (-193^{o}C) at NIST
  - Retest with Water

Coriolis – Water - Mass

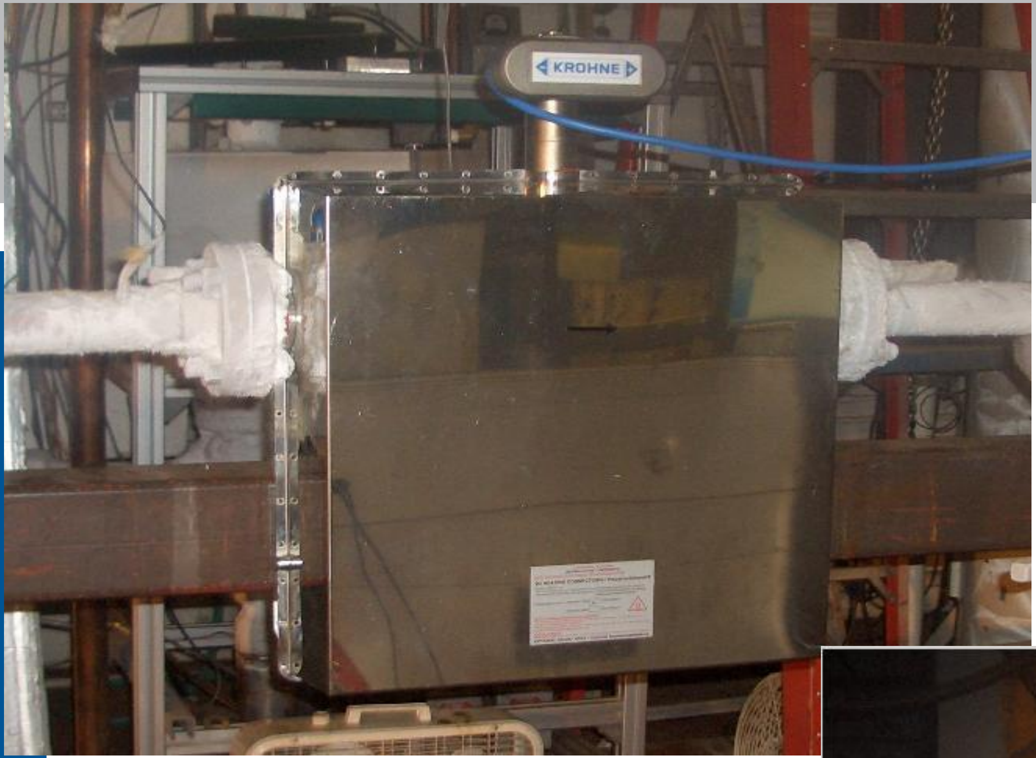


Measurements:-

- 5 points over test range
- Each point repeated 4 times
- Tests repeated 4 times

Results:

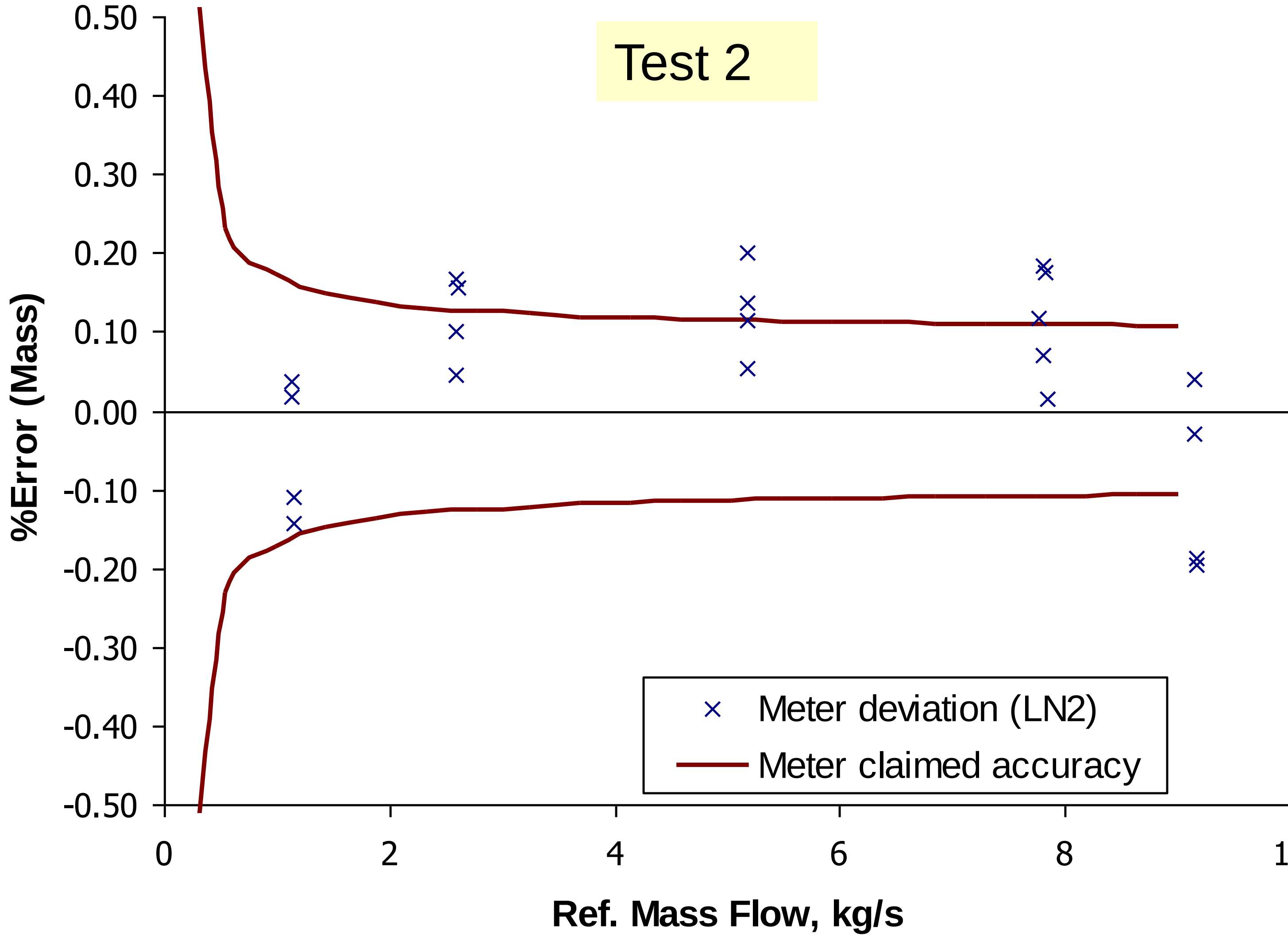
- Good repeatability
- Good reproducibility
- All measurements are within claimed accuracy



4 tests were taken with insulation jacket

One test was taken with no insulation jacket

Liquid N_2 Calibration Results- Mass



Results

- Coriolis:
  - Good results: within 0.2%
  - Water calibration can be successfully transferred to cryogenic conditions if allowance is made for the non-linear temperature dependence of the Young’s Modulus of elasticity of stainless steel.
- Ultrasonic
  - Ambient heat leak in to the flowmeter section (vacuum was not sufficient)

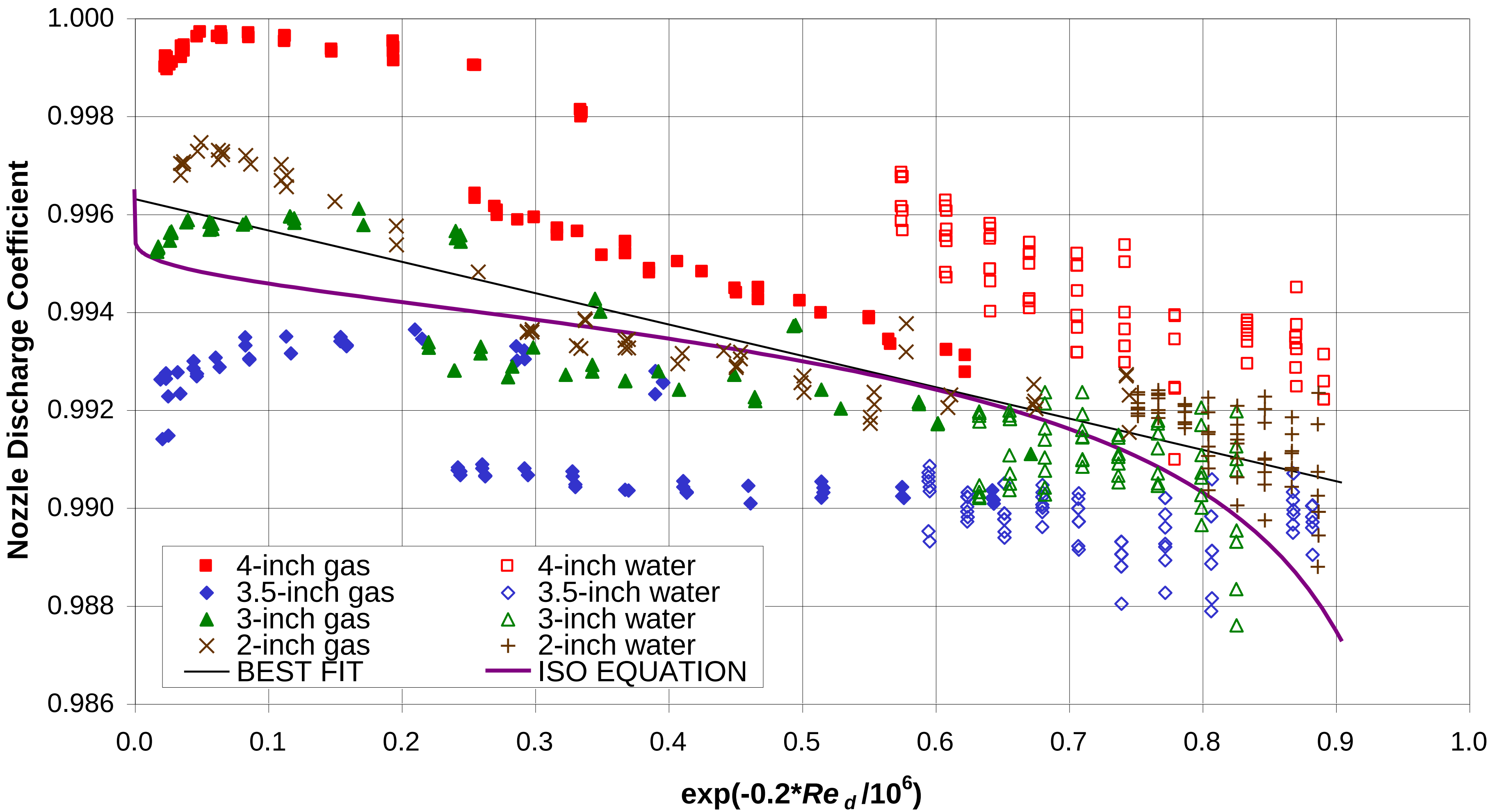
Difficult Reynolds numbers: 1.3 Power stations

- Reynolds numbers in pressurized hot water can be up to 2×10^7.
- Since this is roughly 10 times the value that can be obtained in cold water flow measurements have high uncertainty.
- Reducing the uncertainty by 1.5% enables the thermal output of a nuclear power station to be increased by 1.5%.
- New NMIJ flow facility uses water at 70 °C to give Reynolds number up to 1.8×10^7 to calibrate ultrasonic meters for nuclear power stations.

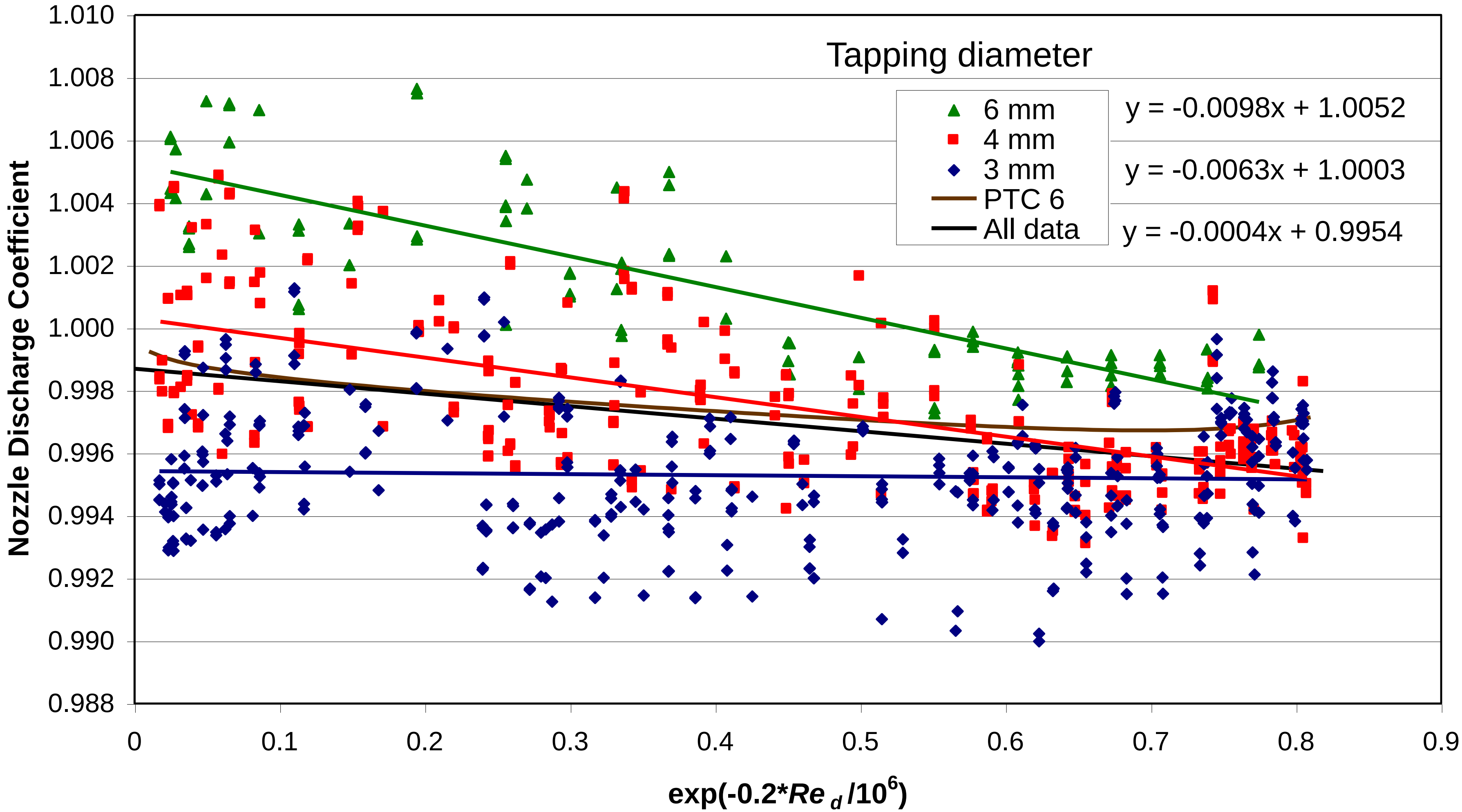
Difficult Reynolds numbers: 1.3 Power stations

- **Nozzles are commonly used for efficiency tests**
- **Traditionally they are calibrated in water and the calibration is extrapolated**
- **So nozzles were manufactured to meet ASME PTC 6 (and nearly ISO 5167)**
  - spark erosion for tappings
  - 2”, 3”, 3½” and 4” nozzles
  - 6” and 8” pipework

Nozzles: wall tappings



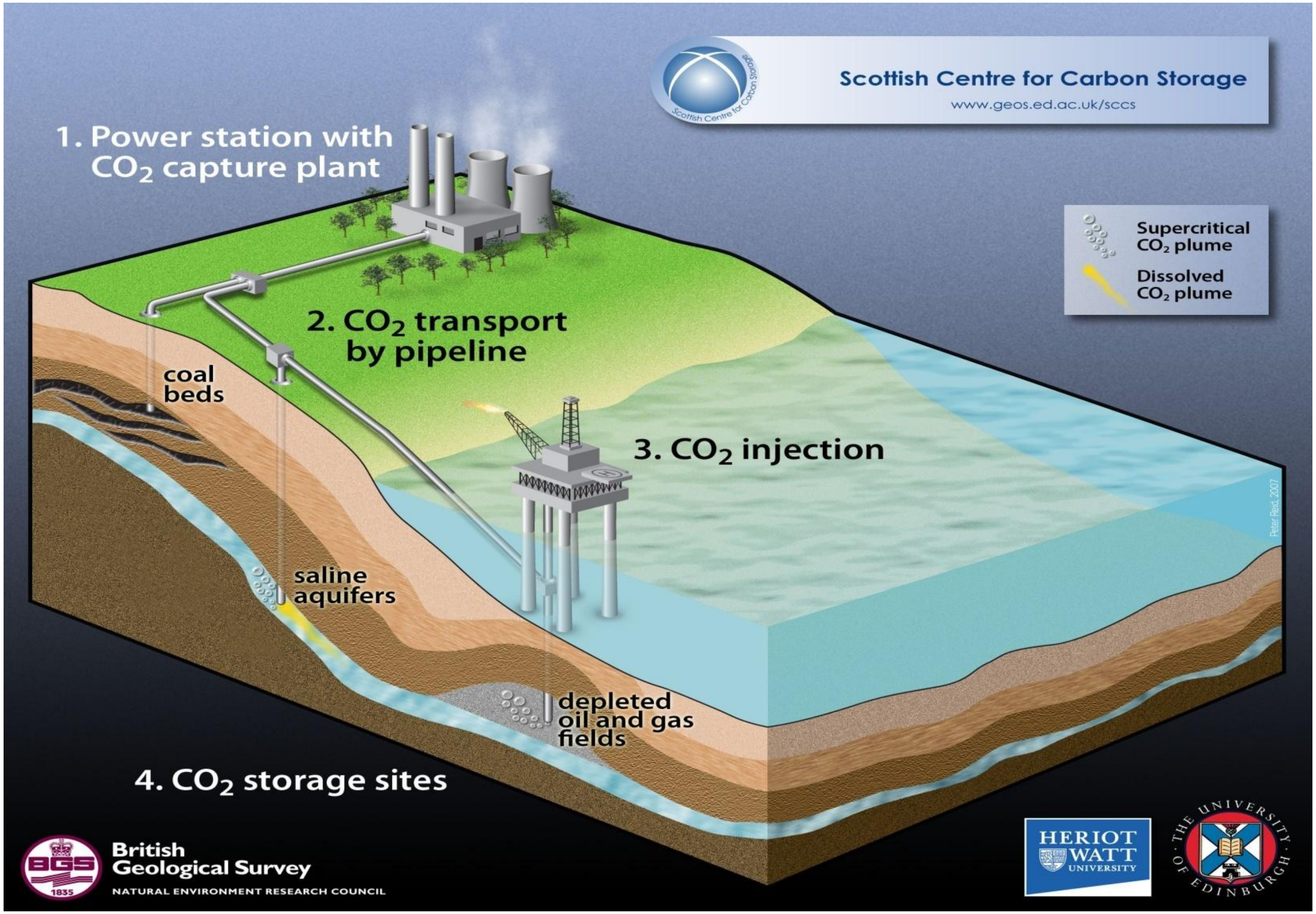
Nozzles: throat tappings



Nozzles: conclusions

- Wall tappings are superior and give better extrapolation
- Static hole error problems affect throat-tapped nozzles in gas just as they affect Venturi tubes.
- What about throat-tapped devices at high Reynolds number in liquids? This is the type of problem that can be solved using the new NMIJ flow facility.

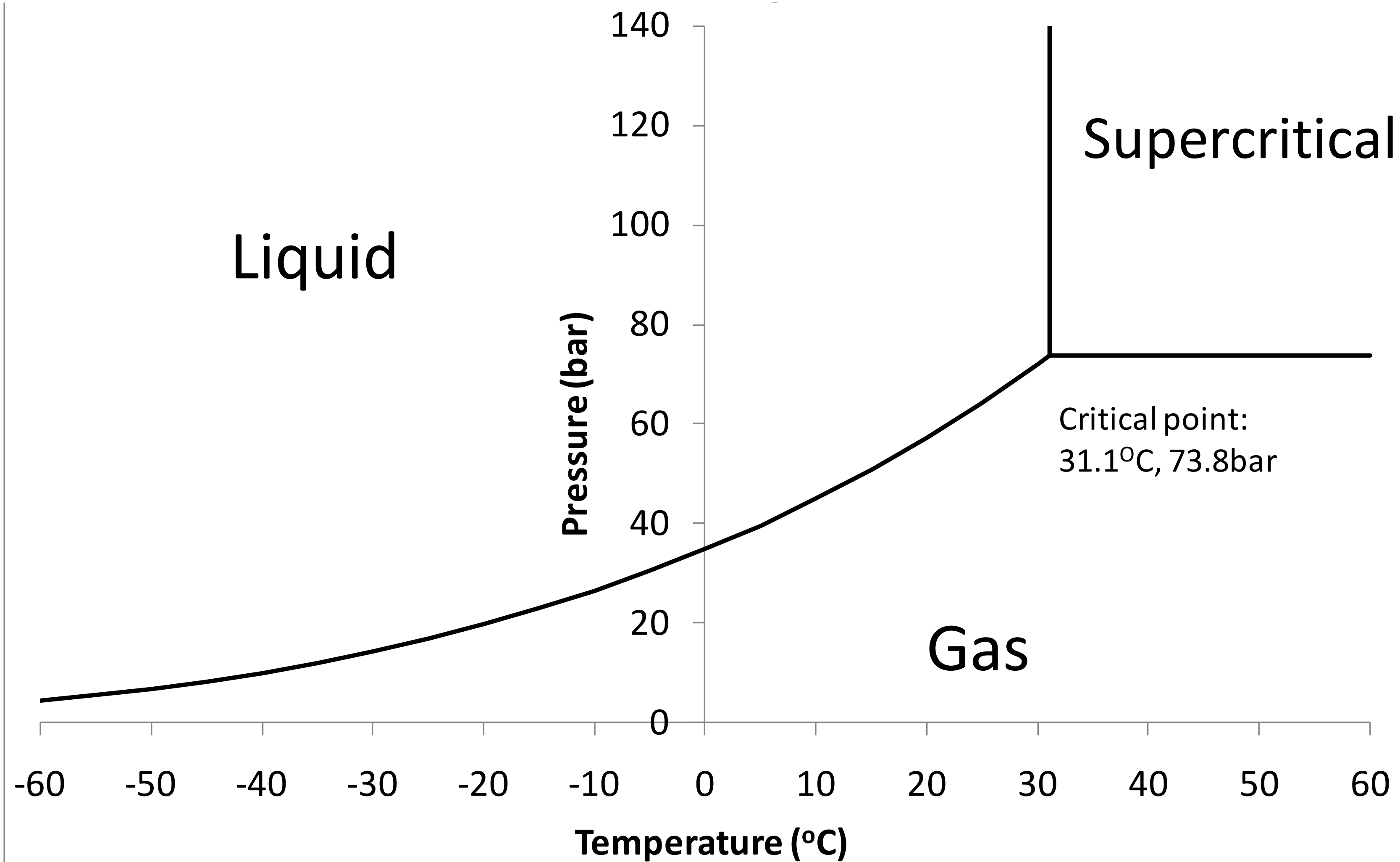
Difficult Fluids:
2.1 Carbon Capture & Storage



The issue

- Kyoto Protocol
- CO_2 could be captured and stored
- It will need to be measured
- Total UK emissions = 548 million tonnes
- Suppose mass flow uncertainty is 1.5%
- If CO_2 price = £30 ($45) per tonne
  uncertainty ≈ £250 million ($375 million)
- But at 5c per tonne uncertainty ≈ $0.4 million

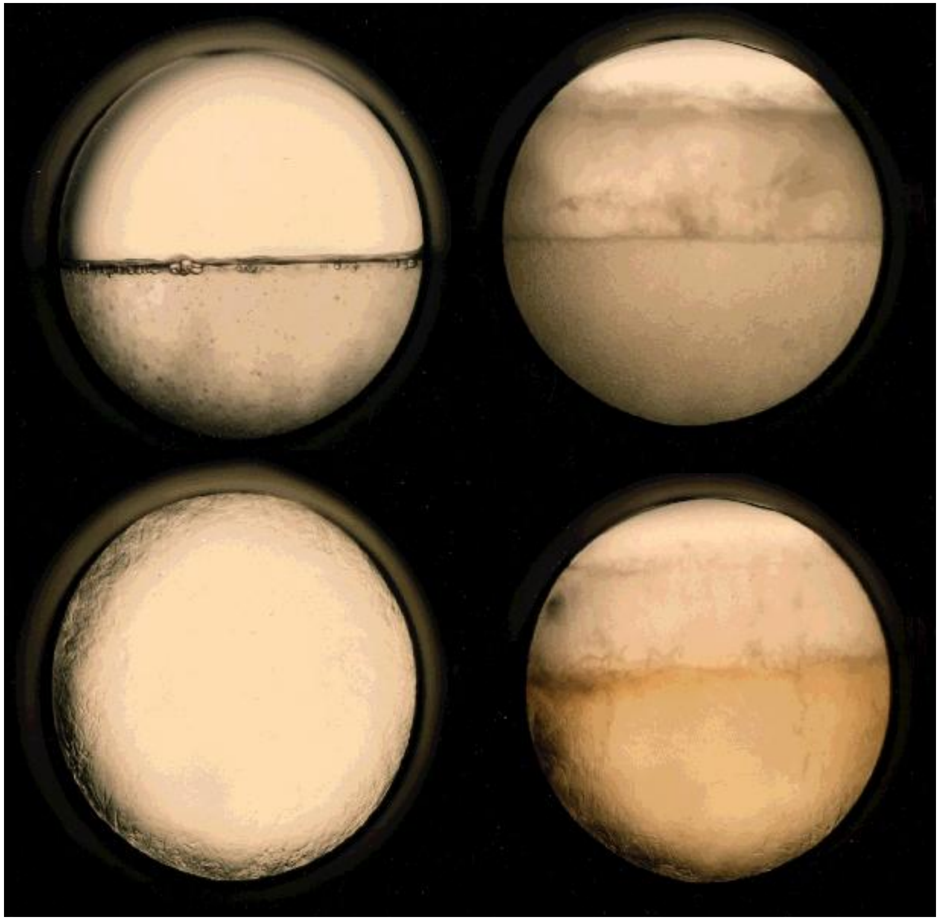
Pure CO_2 Phase Diagram



CO_2 going Supercritical

Liquid and vapour phases in co-existence – distinct meniscus

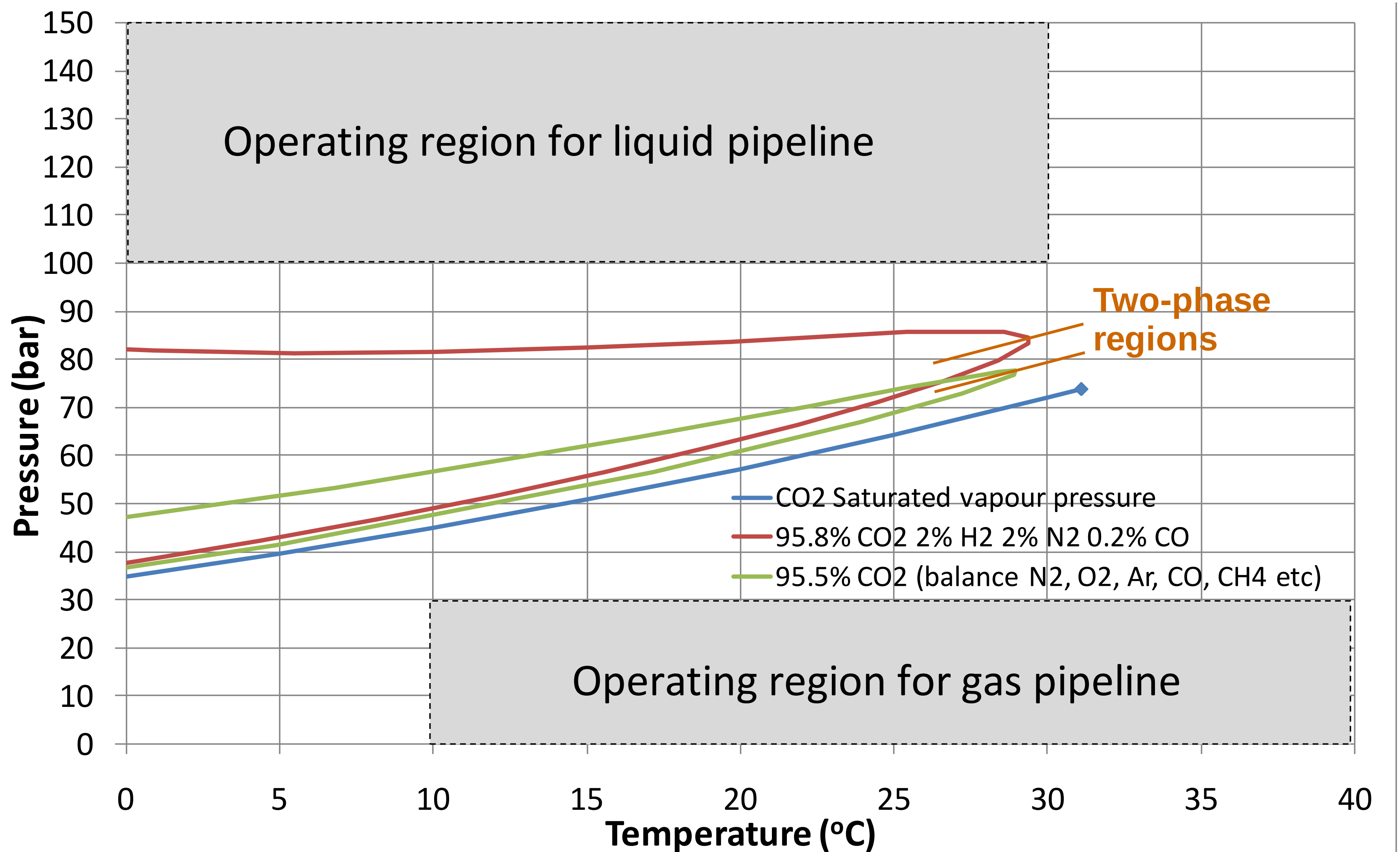
Liquid and vapour phases in co-existence – visible meniscus



Single phase supercritical fluid – no meniscus

Liquid and vapour densities converging – barely visible meniscus

Operating regions

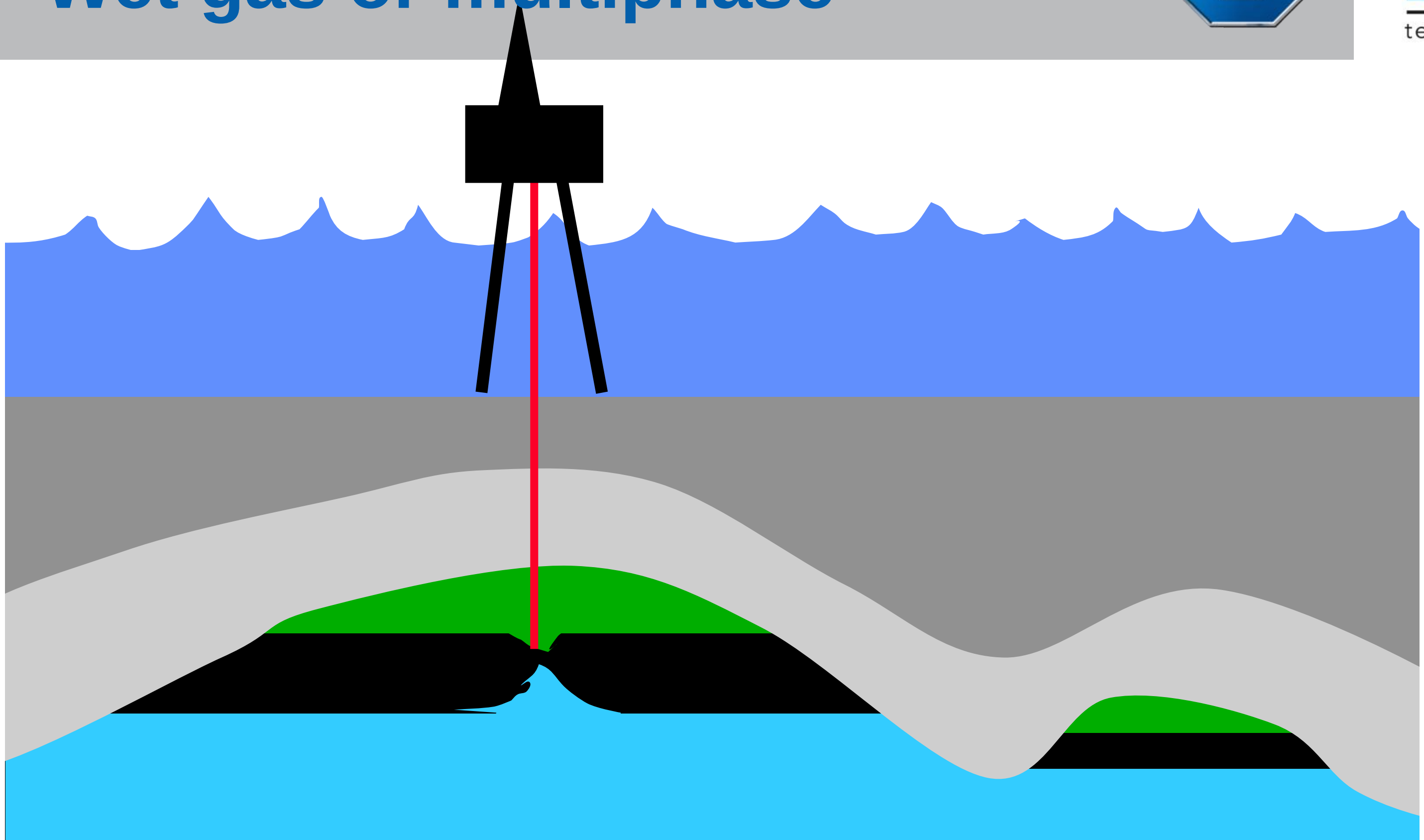


Potential CCS Metering Technologies

- **CO_2 has been metered for 30 years in EOR applications**
  - no legislation on accuracy (sacrificed for cost)
  - not as stringent on impurities
  - shorter pipe distances

- **However, a number of metering technologies could be suitable**
  - DP metering
  - volumetric metering
  - mass metering (Coriolis)
  - non-invasive metering

Difficult Fluids:
2.2 Wet gas or multiphase



- Increasing need to measure wet gas or multiphase
- Separators are very large and expensive

Venturi tubes in wet gas: use of wet-gas correlations

$$q_{m,\text{gas}} = \frac{C}{\sqrt{1-\beta^4}}\,\varepsilon\,\frac{\pi}{4}\,d^2\,\frac{\sqrt{2\Delta p\,\rho_{1,\text{gas}}}}{\phi}$$

$$\phi = \sqrt{1 + C_{\text{Ch}} X + X^2}$$

$$C_{\text{Ch}} = \left(\frac{\rho_{\text{liquid}}}{\rho_{1,\text{gas}}}\right)^n + \left(\frac{\rho_{1,\text{gas}}}{\rho_{\text{liquid}}}\right)^n$$

$$X = \left(\frac{q_{m,\text{liquid}}}{q_{m,\text{gas}}}\right)\sqrt{\frac{\rho_{1,\text{gas}}}{\rho_{\text{liquid}}}}$$

$$Fr_{\text{gas}} = \frac{4 q_{m,\text{gas}}}{\rho_{1,\text{gas}}\,\pi D^2 \sqrt{gD}}\sqrt{\frac{\rho_{1,\text{gas}}}{\rho_{\text{liquid}} - \rho_{1,\text{gas}}}}$$

Chisholm

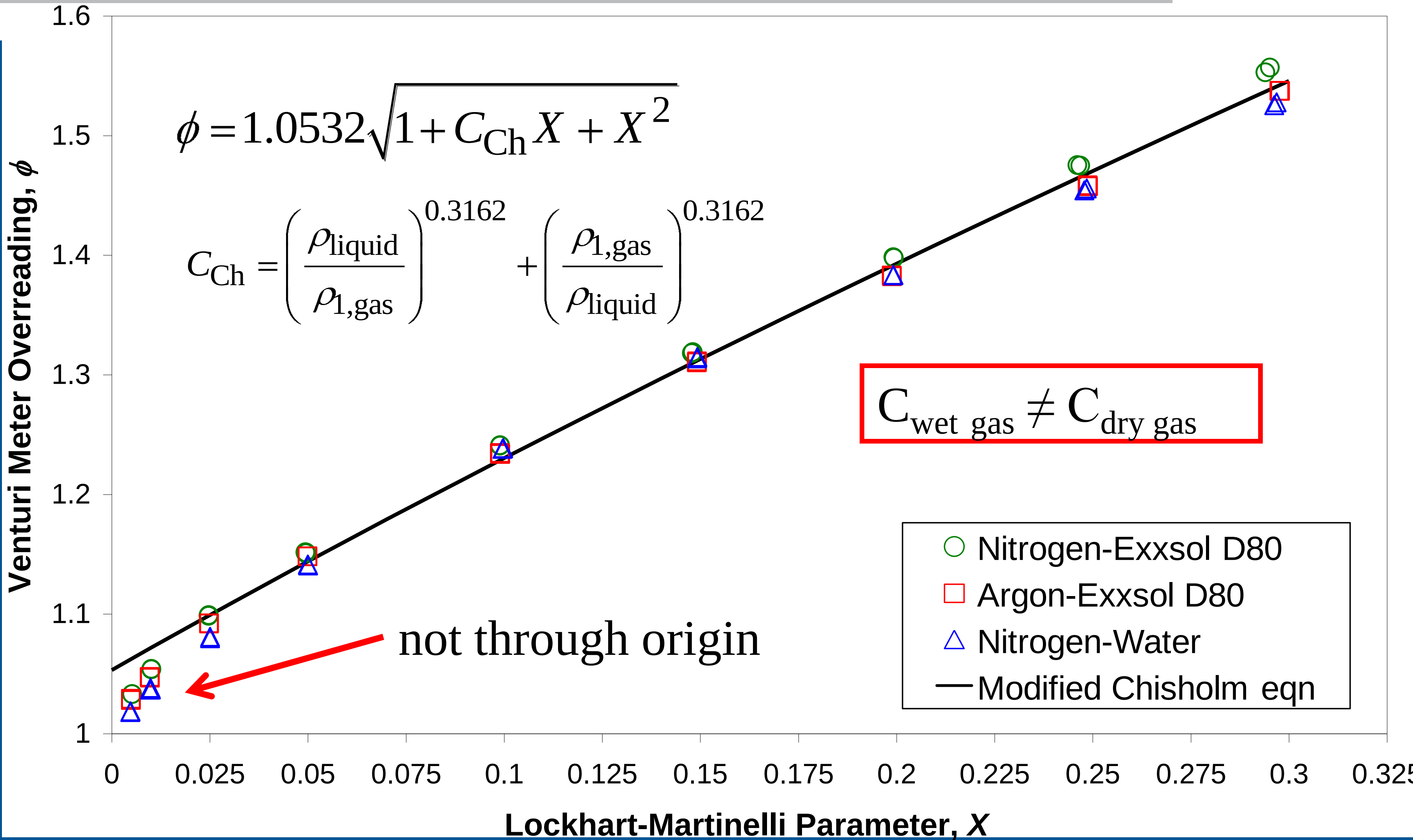
$n=0.25$

de Leeuw

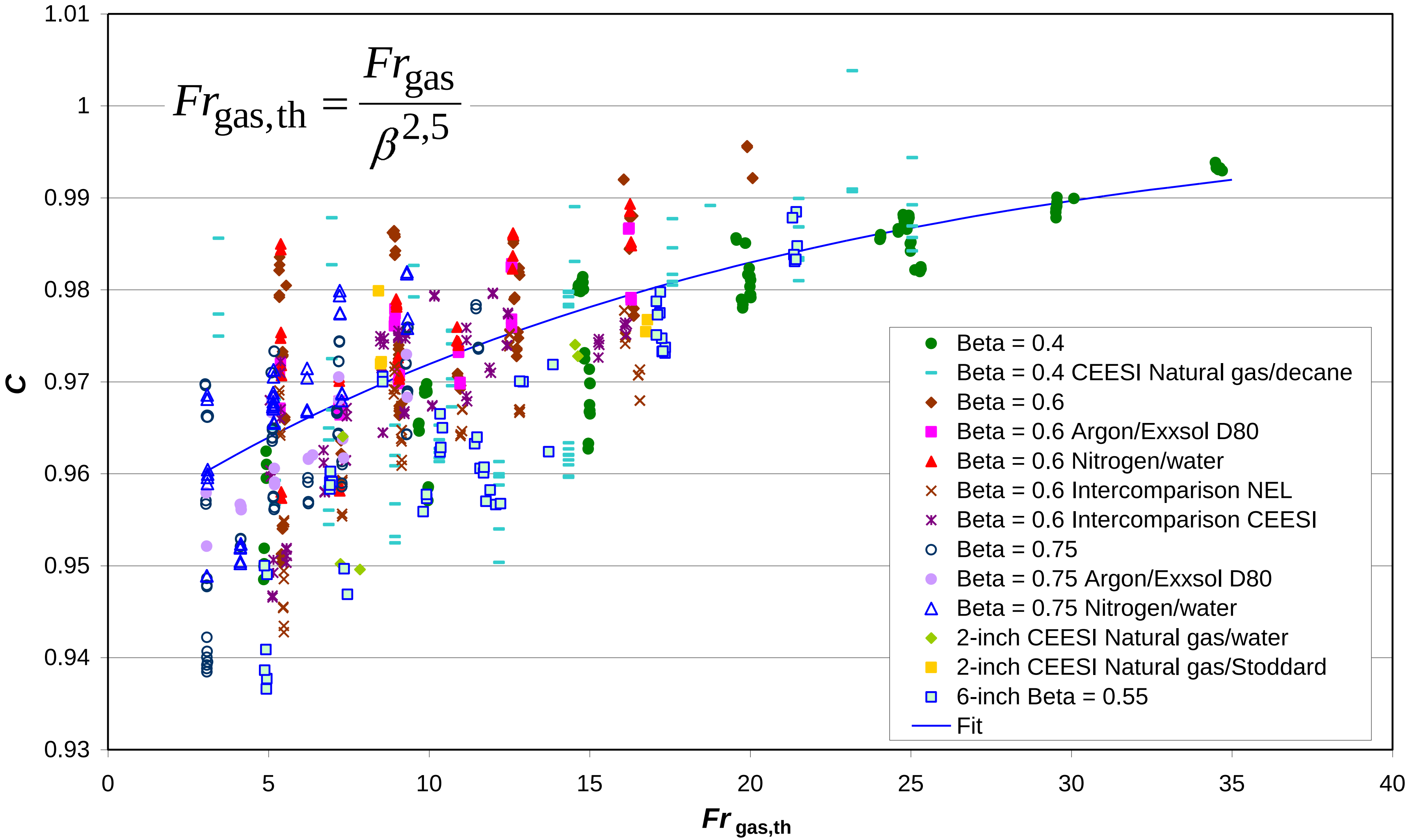
$n = 0.41$ for $0.5 \le Fr_{\text{gas}} < 1.5$

$n = 0.606\,\left(1 - e^{-0.746 Fr_{\text{gas}}}\right)$ for $Fr_{\text{gas}} \ge 1.5$

4” Venturi $\beta = 0.6$, $\rho_{1,gas}/\rho_{liquid} = 0.024$, $Fr_{gas} = 1.5$



C based on 0.02 < *X* < 0.065



Determine new value for n and C using extended data set

$$n = \max(0.583 - 0.18\beta^2 - 0.578e^{-0.8Fr_{gas}/H}, 0.392 - 0.18\beta^2)$$

$$C = 1\text{-}0.0463e^{-0.05Fr_{\text{gas,th}}} \min\left(1, \sqrt{\frac{X}{0.016}}\right)$$

Limits of use

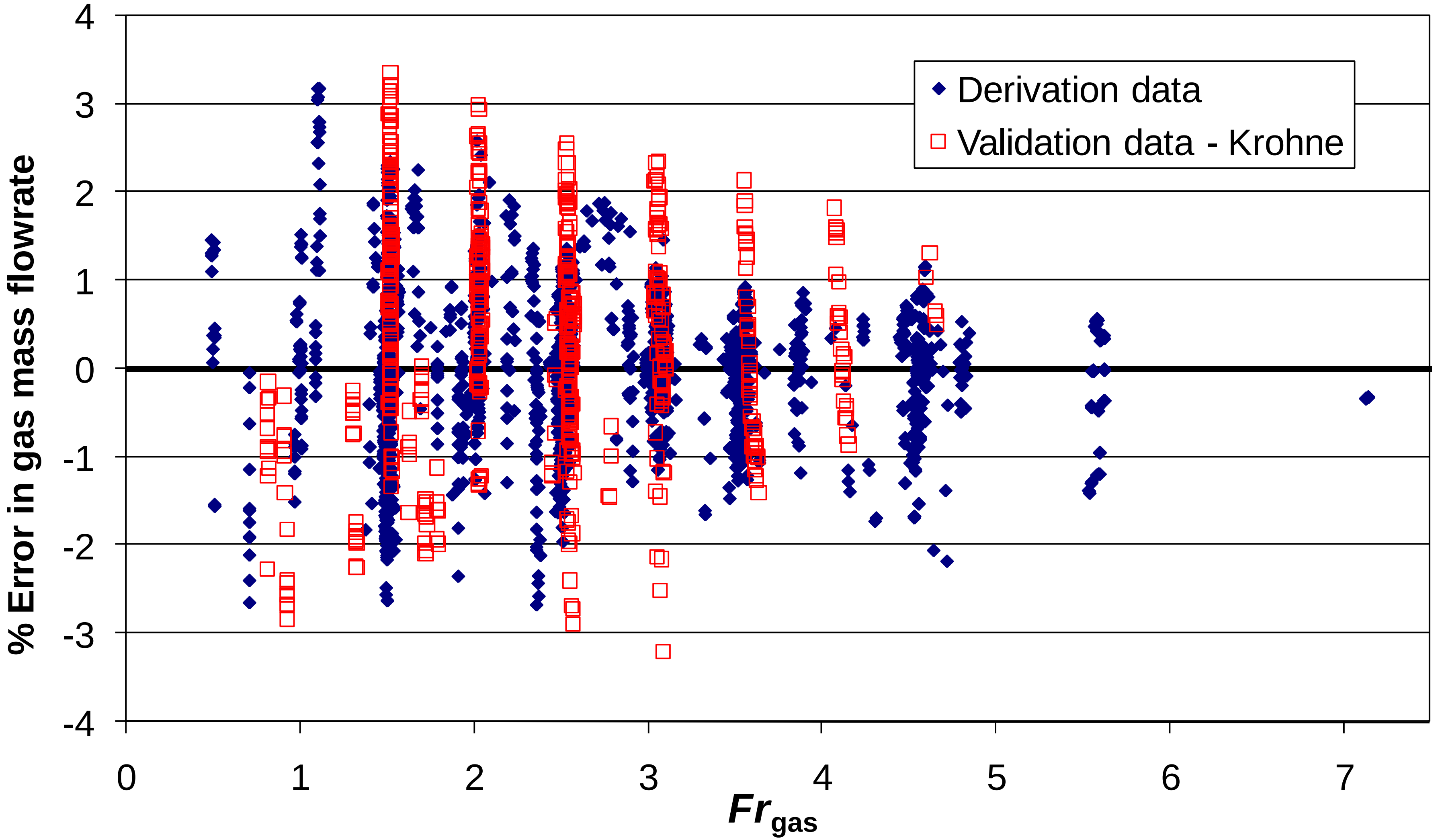
- $0.4 \leq \beta \leq 0.75$
- $0 < X \leq 0.3$
- $3 < Fr_{\text{gas,th}}$
- $0.02 < \rho_{\text{gas}}/\rho_{\text{liquid}}$
- $D \geq 50$ mm

H = 1 for hydrocarbon

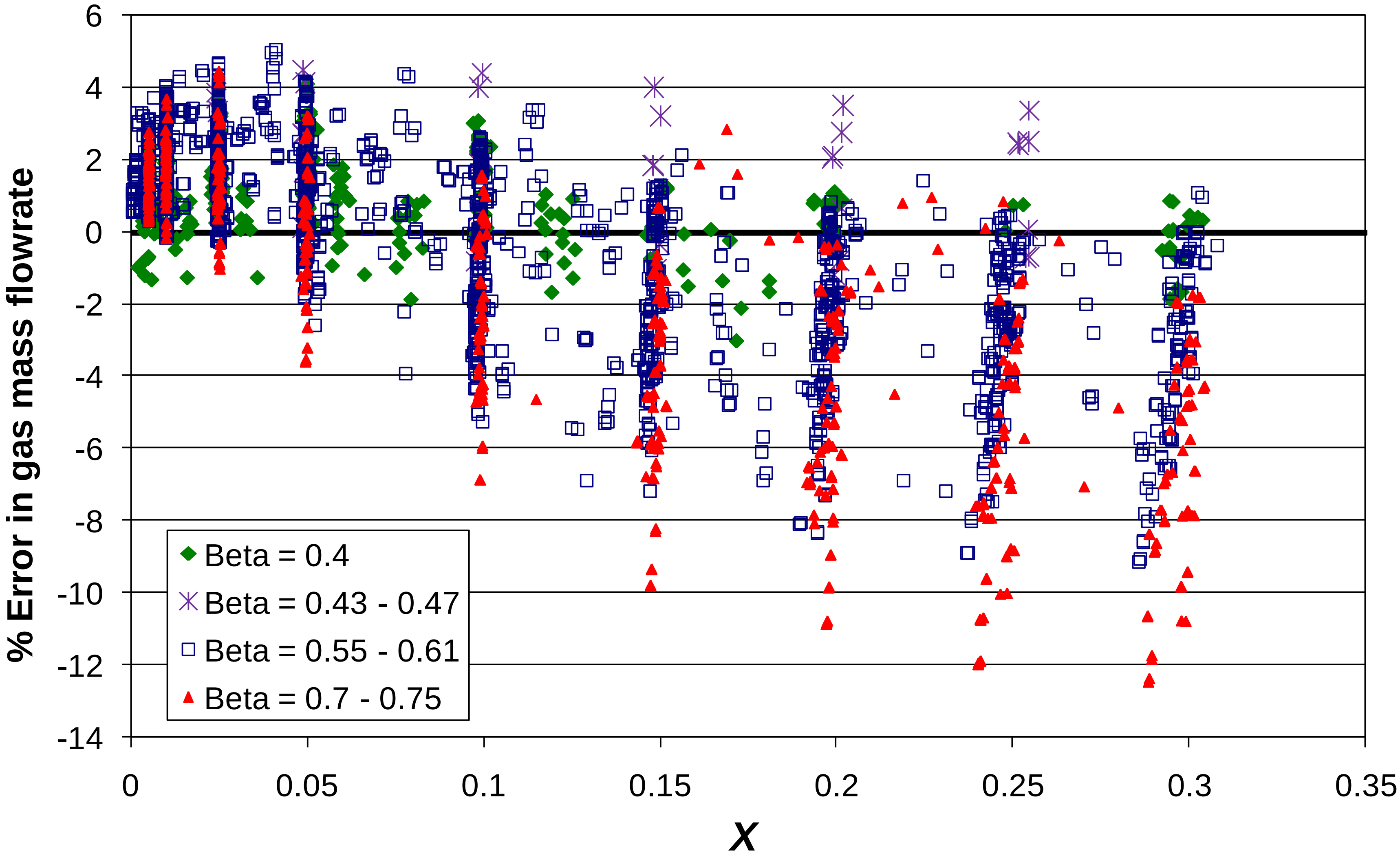
1.35 for water,

0.79 for very hot water

Errors in gas mass flowrate



Errors in gas mass flowrate using de Leeuw correlation



Standards

- **ISO/TR 11583 (Measurement of wet gas by means of Venturi tubes and orifice plates) is being ballotted at present**
- **ISO/TR 15377 still needs more data on orifice plates with drain holes**

Difficult Installations:
3.1 Stack emissions

Stack emissions: are Pitot tubes a good method of flow measurement?

- Significant work was undertaken in the 1960s and 1970s to establish the uncertainty of flowrates measured with pitot tubes.
- Errors of less than 1% were regularly obtained if the utmost care was taken in good flow conditions.
- An uncertainty of not greater than 2% can be achieved by following ISO 3966 (: 4.1). To do this corrections are required and were determined together with the uncertainty.

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The problem: errors using pitots

- Compressibility correction factor
- Head loss
- Transverse velocity gradient
- Reynolds number
- Turbulence
- Static hole error
- Wall proximity
- Blockage
- Misalignment
- Swirl
- Integration scheme
- Asymmetry
- Leakage
- Positioning
- Diameter
- Unsteadiness
- Vibration
- Differential pressure
- Density

Systematic, correctable over-reading

• Transverse velocity gradient	0.4% ± 0.4%
• Turbulence	1.25% ± 0.75%
• Swirl	1.5% ± 1.5%
• Blockage	0.4% ± 0.4%
• Integration scheme (ISO 10780)	1%
• **TOTAL**	**4.5%**

Problem

- **Discarding good flow measurement in the quest for simplicity**
- **The stack emissions standards (e.g. ISO 10780) need to be changed.**

Difficult Installations:
3.2 Flare gas

EU Emissions Trading Scheme

- Phase I (2005 – 2008) – Trial period
- Phase II (2008 – 2012) – Mandatory
  - Sets maximum uncertainty level on activity data (flowrate)
  - UK Offshore = Tier 2 (12.5% on m^3/yr)
  - Highest tier = Tier 1 (7.5% on m^3/yr)
- Phase III (2013 - 2020)
  - Free allocations will reduce to 80%, reducing annually to 0% in 2020
  - No free allowances for electrical power generation
  - Offshore electricity production will be hit hard
  - Direct-drive equipment will get allowances

Functions of a flare system

- **Ultimately a safety relief system**
  - Emergency Blow-Downs
  - Pressure relief
  - Venting of vessels etc. for maintenance

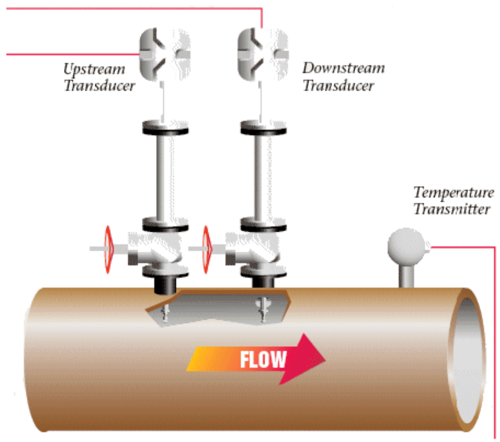
- **c 30% of UK offshore CO_2 emissions**

Flare metering - issues

- Typically no calibration = no traceability to Standards
- Very wide velocity range (> 1 000:1)
- Minimal pressure drop required
- Large line sizes
- Liquids, solids, low temperatures
- Winds causing pulsations, noise
- Installation errors can be large

Ultrasonic Flare Gas Meters

- Most widely adopted technology for flare
- Very wide range (> 2 000:1 is quoted)
- Wide turndown, negligible pressure loss
- Can calculate Density = f(SOS, T, p) using proprietary correlations



Difficult Installations:
3.3 Smart meters

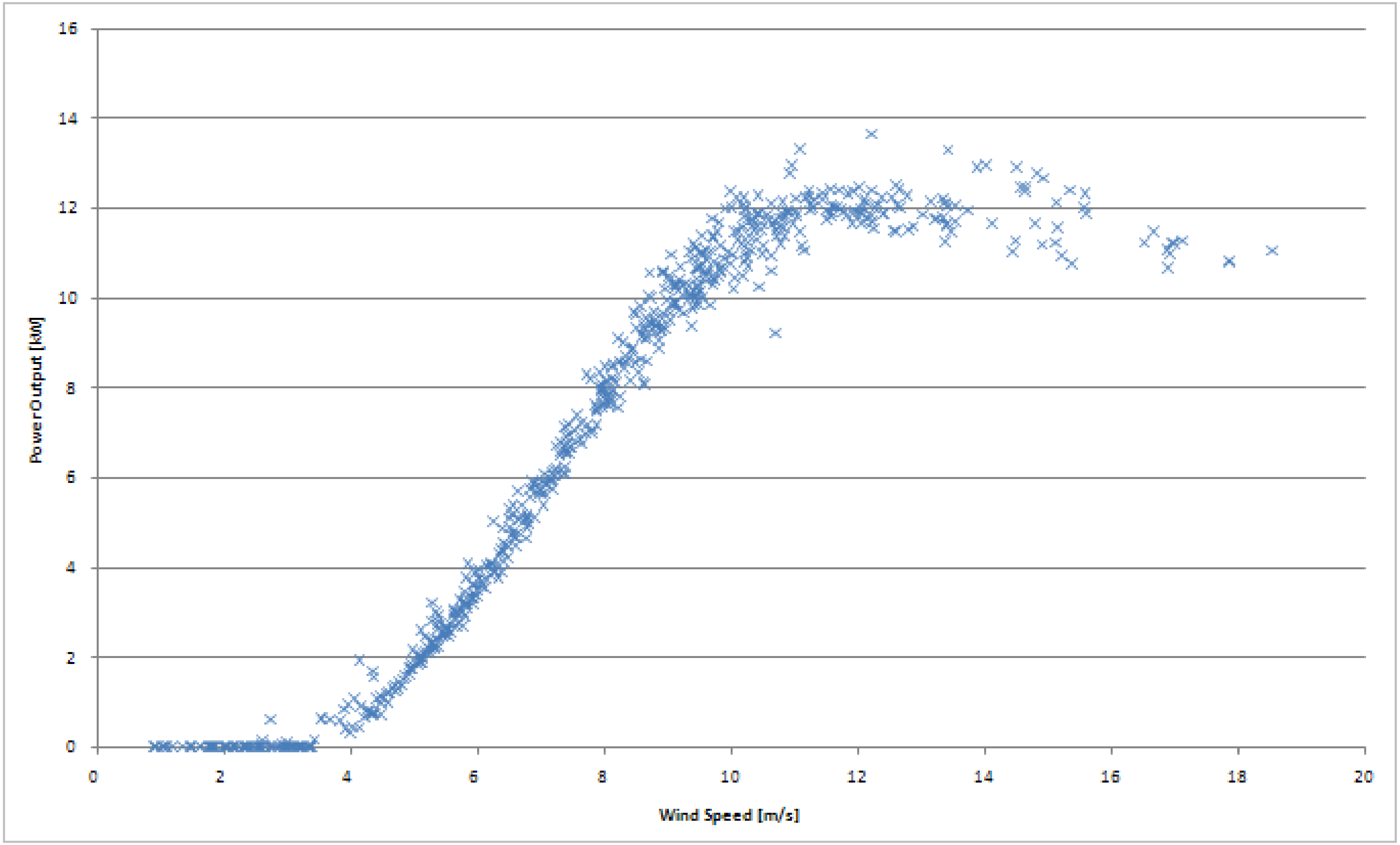
- **Consumer:**
  - Information on costs available in the house (or more widely)
- **Utility:**
  - Remote reading
  - Different prices at different times of day

- **Environment:**
  - Spreading the load might save a power station or a reservoir
- **Legal metrology issues:**
  - How can consumer's bills be checked?

Difficult Installations:
3.3 Wind turbines

- Myres Hill test site, near East Kilbride, Scotland

Typical power curve



Wind turbines

- **Velocity measurement**
- **Most tests are in situ**
  - Terrain
- **Tests are dependent on the weather**
  - Wind velocity
  - Wind direction

Scope of this talk

- **1 Difficult Reynolds numbers**
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It is encouraging that much has been achieved but there is still plenty to do

Thank you – any questions