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A Saturated Steam Injection Meter

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DP DIAGNOSTICS
Monitor, Verify and Trust

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MEASUREMATION

A Saturated Steam Injection Meter

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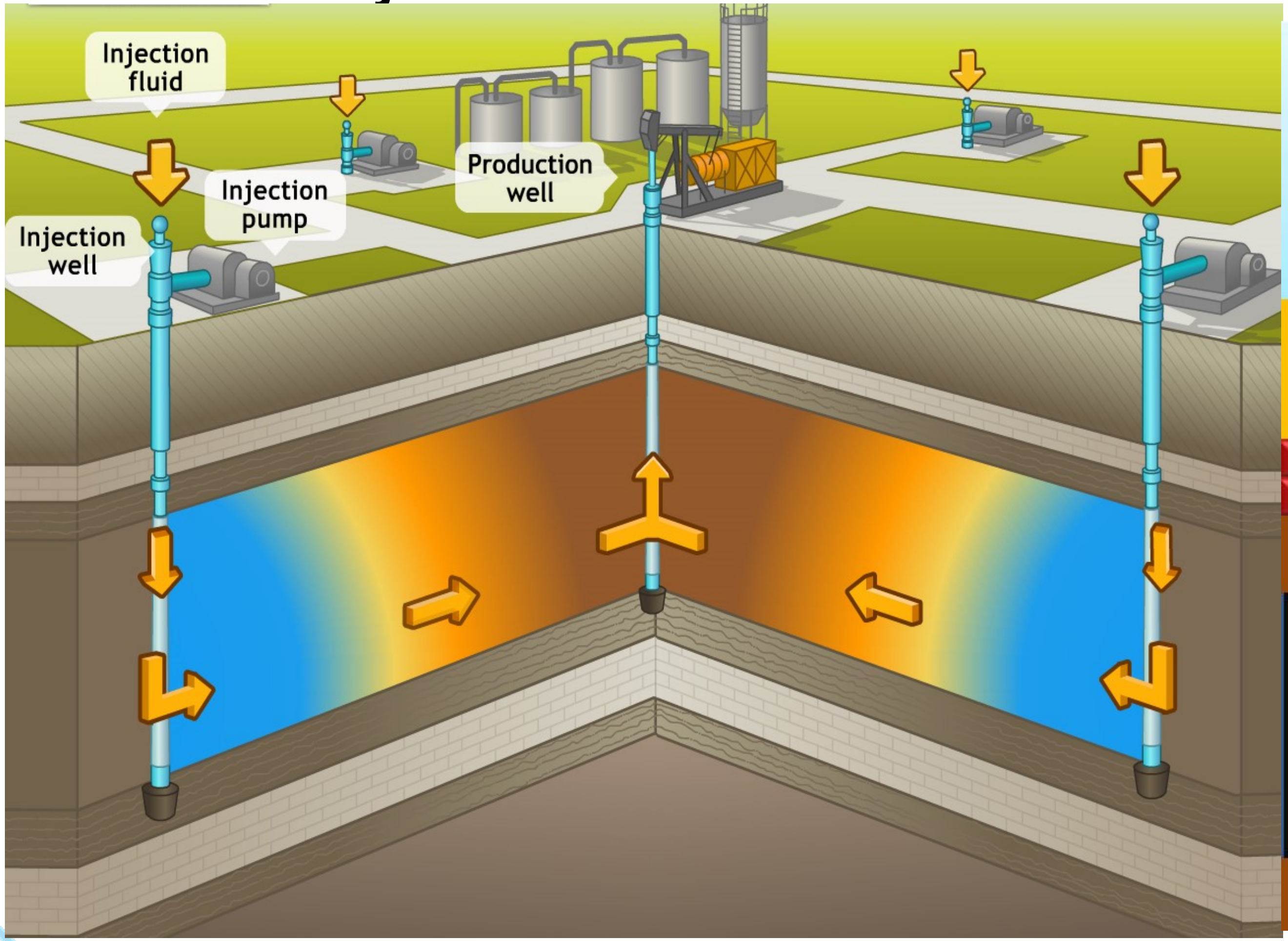
MEASUREMATION

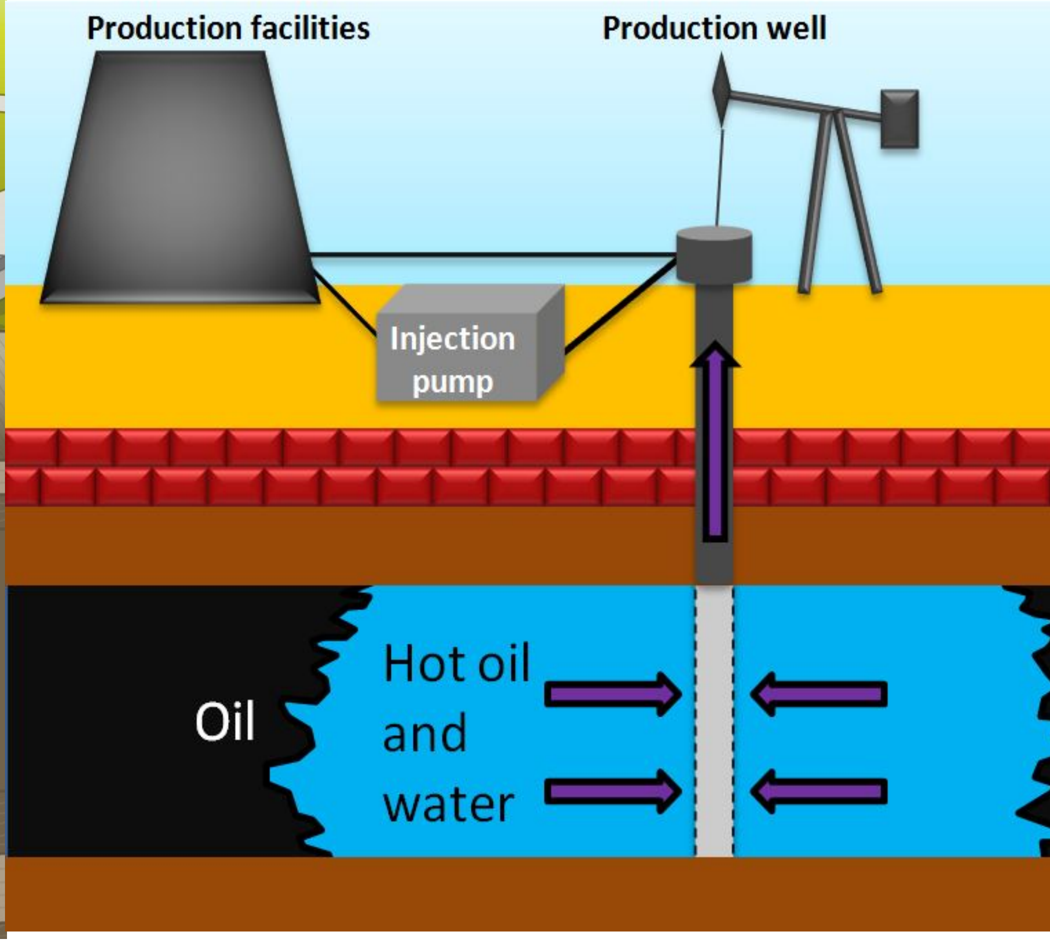
VORTEK INSTRUMENTS

DP DIAGNOSTICS Monitor, Verify and Trust

Introduction

- Steam Injection for EOR





Introduction

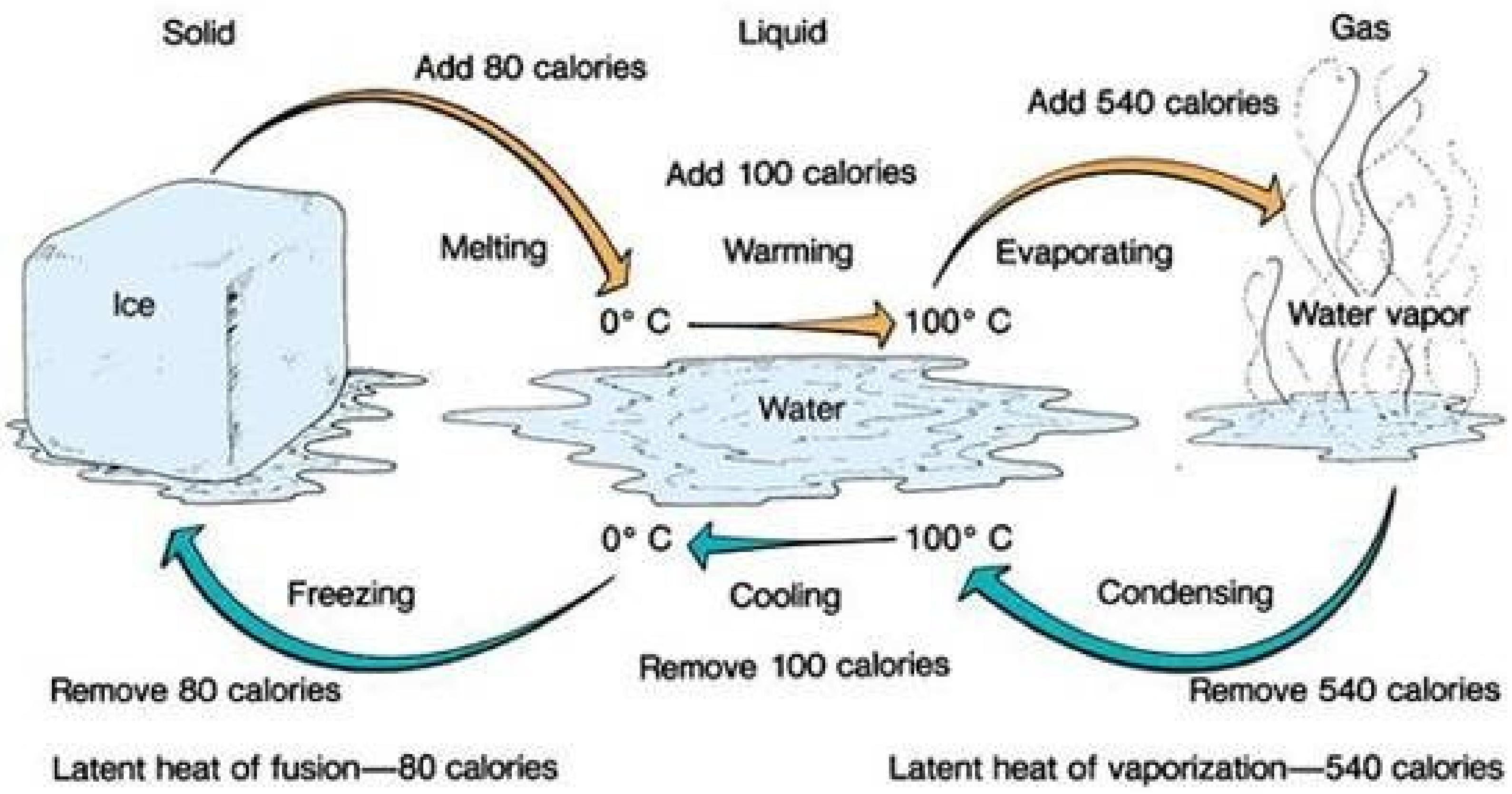
- The design of steam injection projects requires a knowledge of the quality and pressure of steam at the surface before it enters the formation.

- Why is Quality Important? *The great difference in density between steam and liquid during wet steam injection always results in steam override, that is, steam gathers on the top of the pay zone.*

- In order to make such predictions, the multiphase flow and mass & energy balance equations must be solved simultaneously- this requires good measurement data of the homogenous mass/energy injection, Pressure/Temperature and steam quality.

- Further more Poor Steam Quality can compound operational issues with higher erosional velocities and premature equipment failure…

Phase Changes

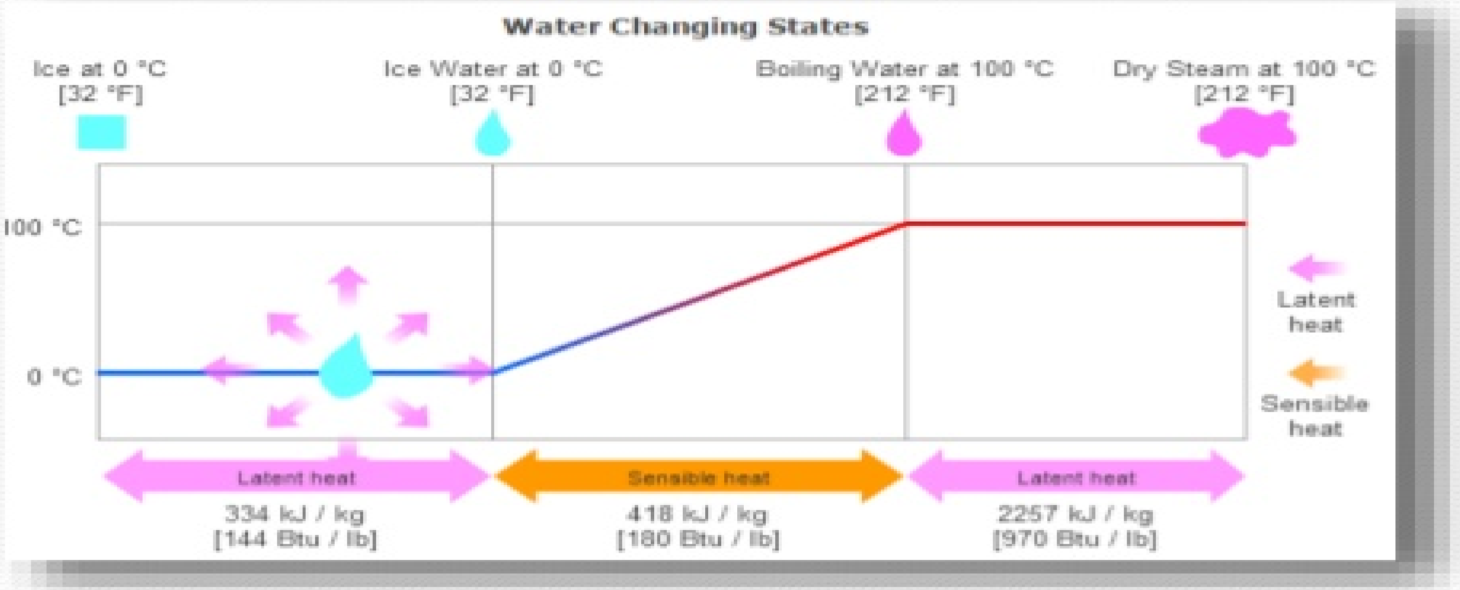


Latent / Sensible Heat

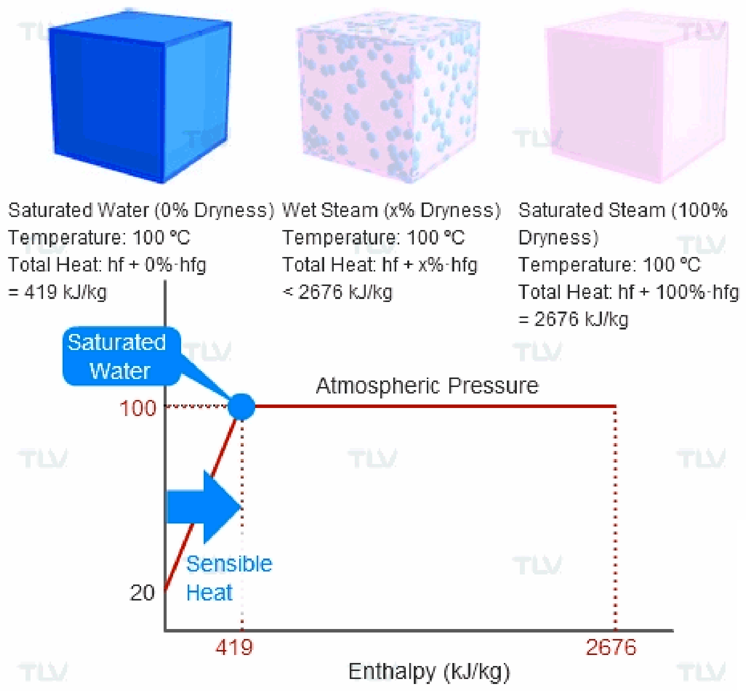
THERMODYNE
Enhancing Energy Efficiency

LATENT HEAT Vs SENSIBLE HEAT

- A change in the temperature of a solid, liquid or gas represents an increase/decrease in sensible heat. A change in state, such as ice turning into water or water into steam, represents an increase/decrease in latent heat.



Steam Primer : Steam Quality?

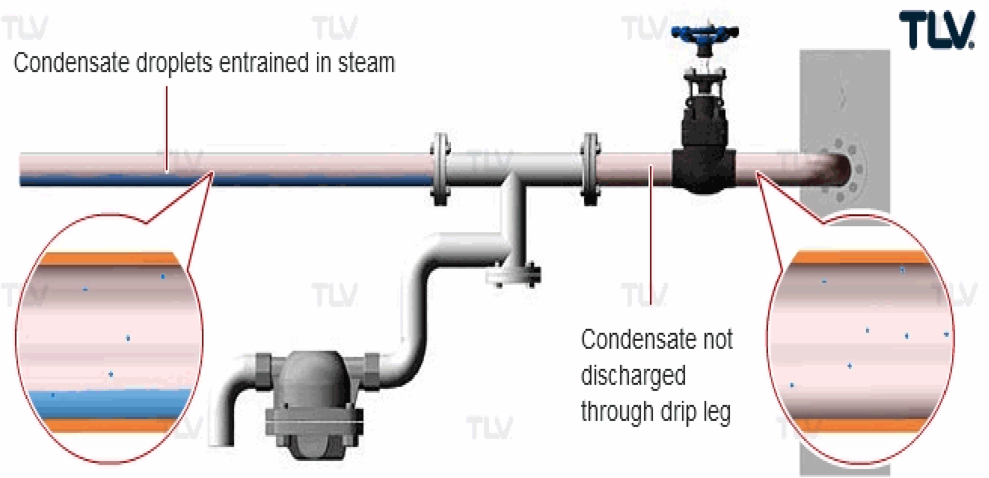


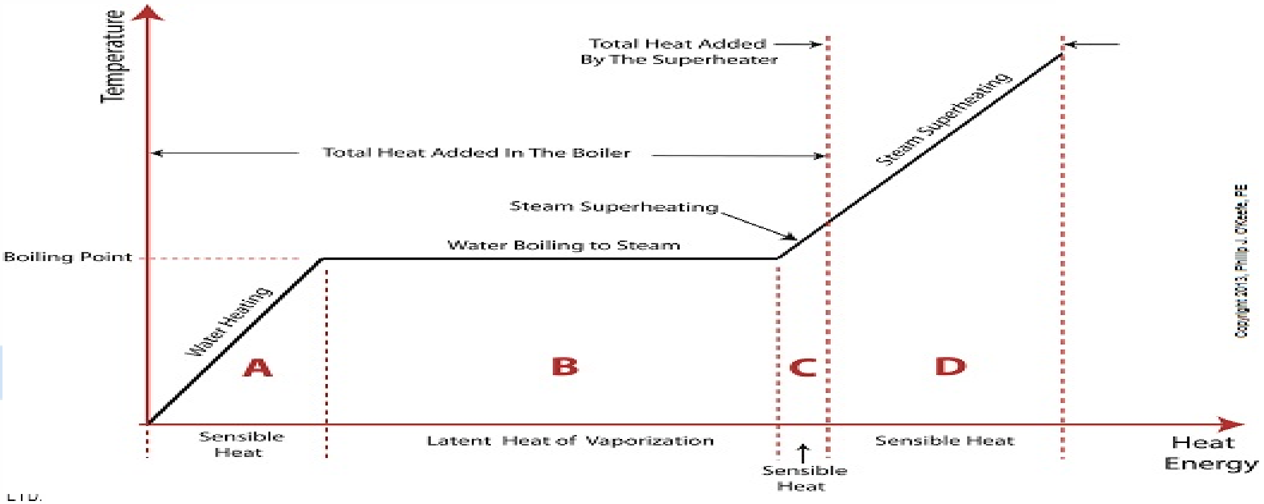
Steam Table (abs)

P(MPa)	T(℃)	v'	v''	h'	r	h''
0.1	100	0.00104	1.673	419	2257	2676
0.6	159	0.00110	0.3213	671	2085	2756

Saturated Water | Wet Steam | 100% Saturated Steam

Example: Steam at 5 barg [72.5 psig]





Introduction to steam flow meter

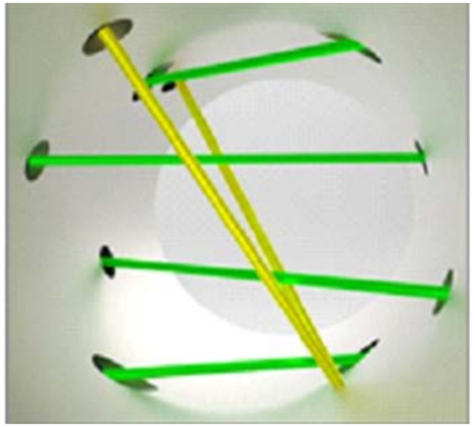
- There are many saturated (wet) steam flow applications throughout industry.
- Most are metered with standard gas meters assuming single phase conditions.
- All steam meters are adversely affected by liquids present within a steam flow.
- This presentation discusses the saturated (wet) steam performance of a hybrid meter, aka ‘VorCone mass meter’ and/or “TekValsys FloMass”.

Doubling Down on Single Phase Meter Principles

Coriolis

DP : Cone/Venturi/
Orifice/Wedge

Multivariable
Vortex



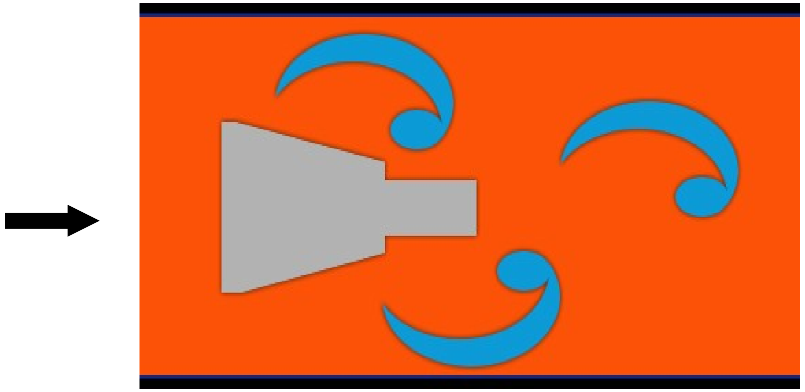
Multipath Ultrasonic

Vortex Shedding Principle

Vortex Shedding Principle

When any liquid, gas or vapor in motion hits a solid body in its path, it flows around it shedding vortices alternately on either side of the body.

Flow

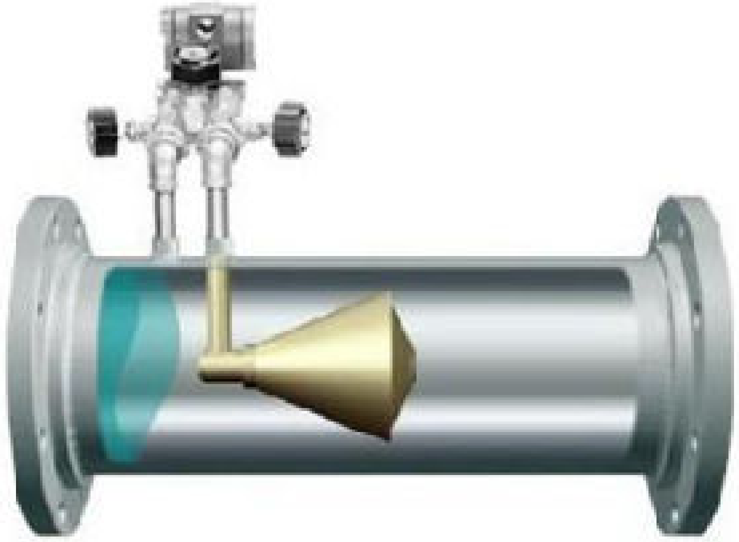


The frequency of the vortices is directly proportional to the velocity of the fluid.

Vortex Meter: $Q_v = f\ (freq)$

$Qv = K(freq)$

Cone Mass Flow Meter Methodology:



Cone meter: $Q_v = f\,(\rho, \Delta P)$

$$Q_{acfs} = \frac{\pi}{4}\sqrt{\frac{2g_c}{\rho}}\,\frac{D_{ft}^{\,2}\beta^2}{\sqrt{1-\beta^4}}\sqrt{\Delta P_{psf}} \times C_f \times Y$$

Volume flowrate

$$Q_{\frac{lb}{s}} = \frac{\pi}{4}\sqrt{2g_c \times \rho}\,\frac{D_{ft}^{\,2}\beta^2}{\sqrt{1-\beta^4}}\sqrt{\Delta P_{psf}} \times C_f \times Y$$

Mass flowrate

Measuring Steam Energy

Measuring Steam Energy

Basic steps for the steam energy calculation

Velocity (ft/s) OR Diff Pressure (DP)

↓ Pipe Cross Area(ft^2)

Volumetric Flow Rate (ft^3/m)

↓ Density (lb/ft^3)

Mass Flow Rate (lb/hr)

↓ Enthalpy (Btu/lb)

Energy Rate (Btu/hr)

Importance of Density

* Steam is a compressible fluid
* Density is a function of both temperature and pressure
* Saturated steam :Process Heating
  - Temperature and pressure are dependent variables .
  - Density can be calculated by measuring one variable P&T.
* Superheated steam: Power- Motive Force
  - Temperature and pressure are independent variables .
  - Need to measure both to calculate density
* Wet Steam: Nuisance Value - Steam Quality !! VV Important

Steam Table

■ Pressure-Based Saturated Steam Table

Press. (Abs.) psi P	Temp. °F T	Specific Volume ft³/lb Vf	Vg	Specific Enthalpy Btu/lb hf	hg	hfg
0.25	59.323	0.016032	1235.5	27.382	1087.4	1060.1
0.50	79.586	0.016071	641.5	47.623	1096.3	1048.6
1.0	101.74	0.016136	333.60	69.73	1105.8	1036.1
5.0	162.24	0.016407	73.532	130.20	1131.1	1000.9
				161.26	1143.3	982.1
20	227.96	0.016834	20.087	196.27	1156.3	960.1
30	250.34	0.017009	13.7436	218.9	1164.1	945.2
40	267.25	0.017151	10.4965	236.1	1169.8	933.6
50	281.02	0.017274	8.5140	250.2	1174.1	923.9
60	292.71	0.017383	7.1736	262.2	1177.6	915.4
70	302.93	0.017482	6.2050	272.7	1180.6	907.8
80	312.04	0.017573	5.4711	282.1	1183.1	900.9
90	320.28	0.017659	4.8953	290.7	1185.3	894.6
100	327.82	0.017740	4.4310	298.5	1187.2	888.6
110	334.79	0.01782	4.0484	305.8	1188.9	883.1

Temperature (°F) at 20 psi

■ Superheated Steam Table

(Excerpt From Japan Society of Mechanical Engineers, 1999)

Pressure psi (Temperature °F)		Steam Temperature (°F) 200	300	350	400	500
10 (193.21)	v	38.84	44.98	48.02	51.03	57.04
	h	1146.6	1193.7	1217.1	1240.6	1287.8
20 (227.96)	v	Data for saturated steam left blank.	22.356	23.900	25.428	28.457
	h		1191.4	1215.4	1239.2	1286.9
30 (250.34)	v		14.810	15.859	16.892	18.929
	h		1189.0	1213.6	1237.8	1286.0
40 (267.25)	v		11.036	11.838	12.624	14.165
	h		1186.6	1211.7	1236.4	1285.0
50 (281.02)	v		8.769	9.424	10.062	11.306
	h		1184.1	1209.9	1234.9	1284.1

Specific Volume (ft³/lb) at 10 psi, 200°F

The Law of the Instrument

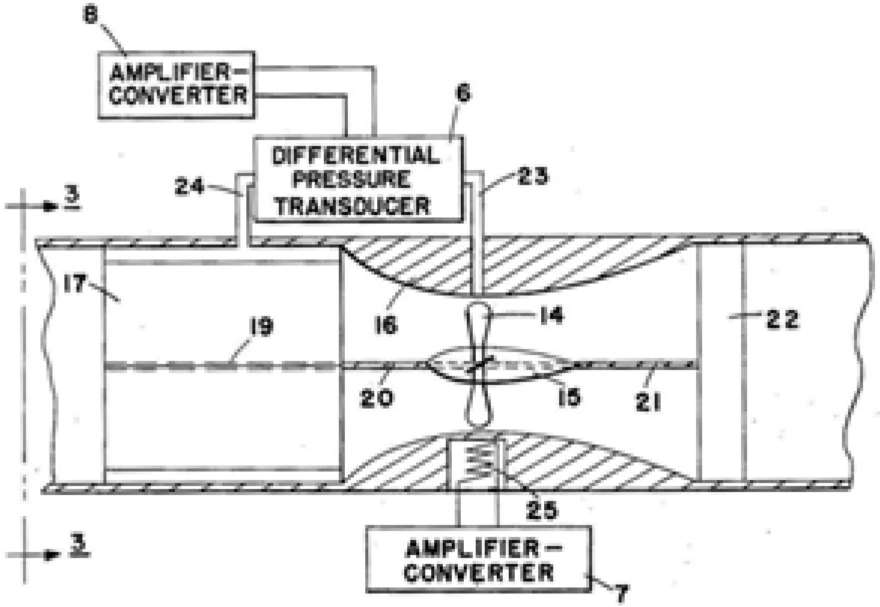
A cognitive bias involving an over-reliance on a familiar tool.

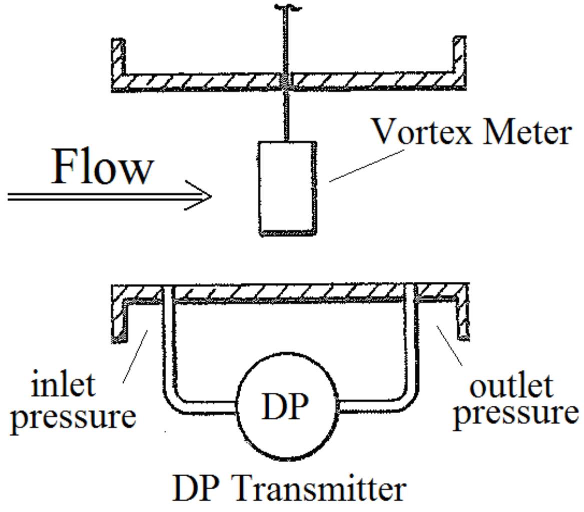
<u>Maslow's Hammer</u>:

"I suppose if you are a proponent of Meter X every flow metering job tends to look like a job for Meter X."

⑩ E.g. trying to make a *specific* flow meter type fit *all* applications, even when it really doesn't.

Early Hybrid Meter Designs





Boden (1956) / Lisi (1973):

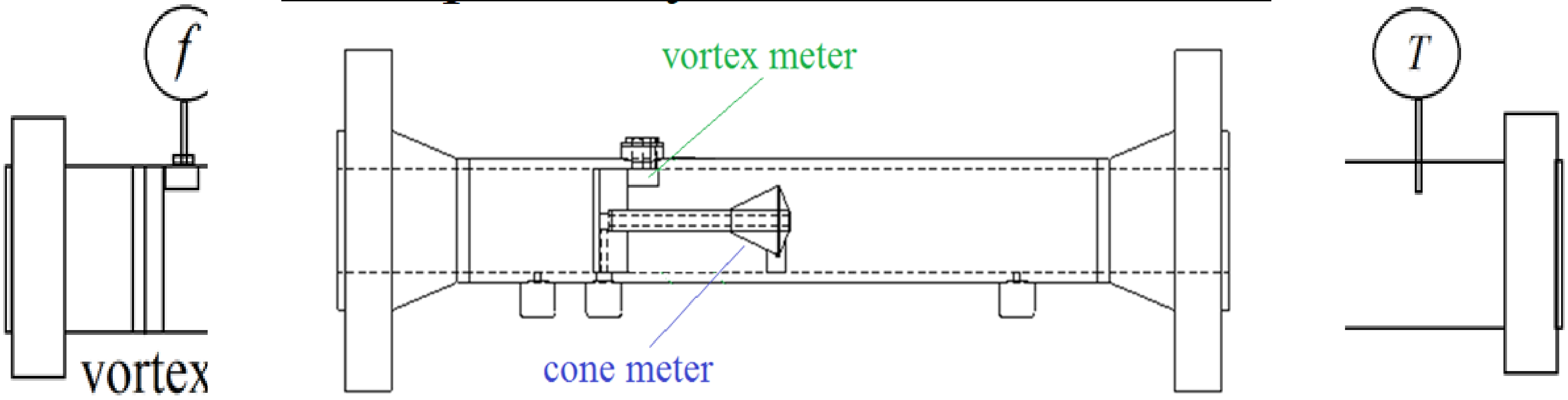
Density Insensitive Q_v meter: $Q_v = f\,(frequency)$

Density Sensitive Q_v meter: $Q_v = f\,(\rho, \Delta P)$

Density: $\rho = f\,(Q_v, \Delta P)$

Mass: $Q_m = \rho Q_v$

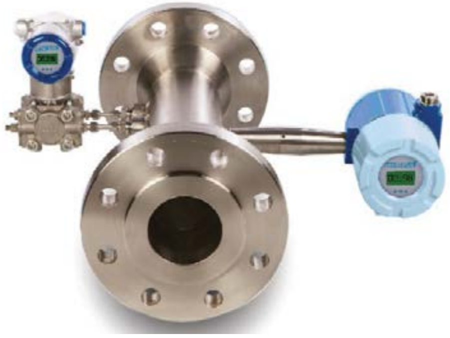
Example 1: Hybrid VorCone Meter

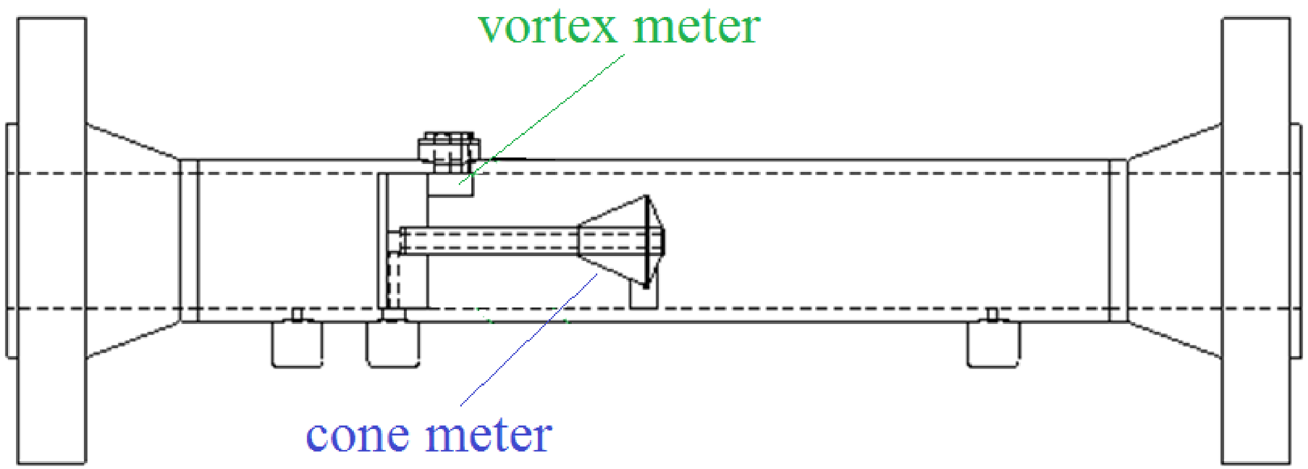


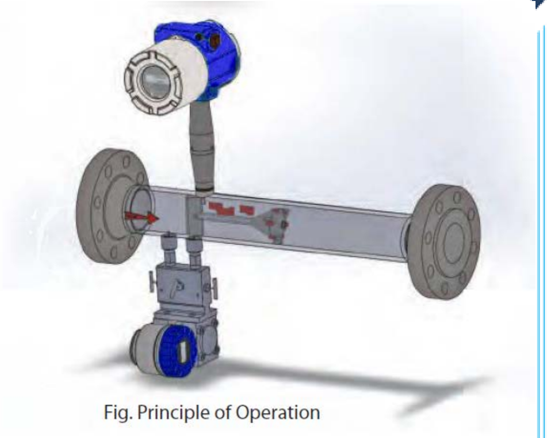
Three Hybrid Meter Design Rules:

1. Give each meter enough consideration to operate.
2. Paired meters must operate over similar ranges.
3. Paired meters must not interfere with each other.

Modern Day Hybrid Meter Design: VorCone™







Vortex + Cone aka VorCone Hybrid Mass Flow Meter Methodology:

Vortex meter meter: $Q_v = f\,(frequency)$ << *density independent*

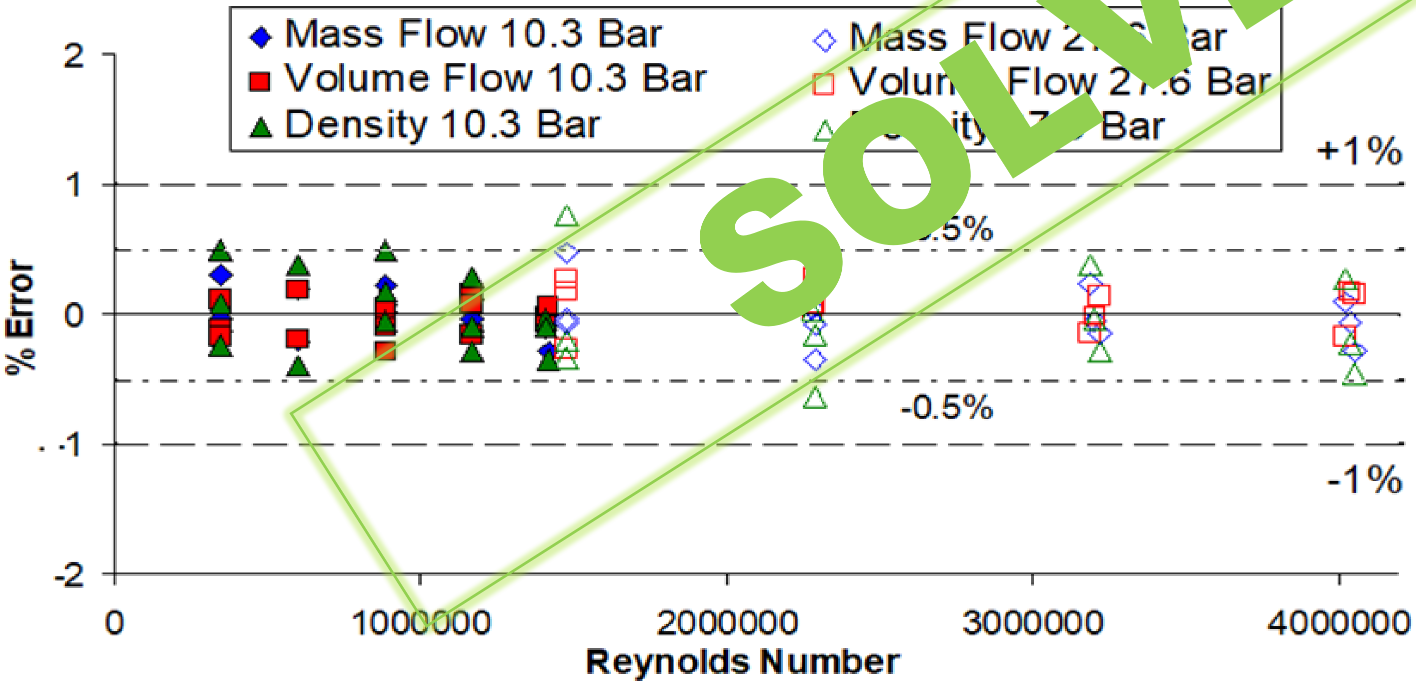
Cone meter: $Q_v = f\,(\rho, \Delta P)$ <<<<< *density dependent*

Density: $\rho = f\,(Q_v, \Delta P)$ << *solve for density (1st unknown)*

Mass: $Q_m = \rho Q_v$ << *solve for mass (2nd unknown)*

3”, 0.68β VorCone Meter

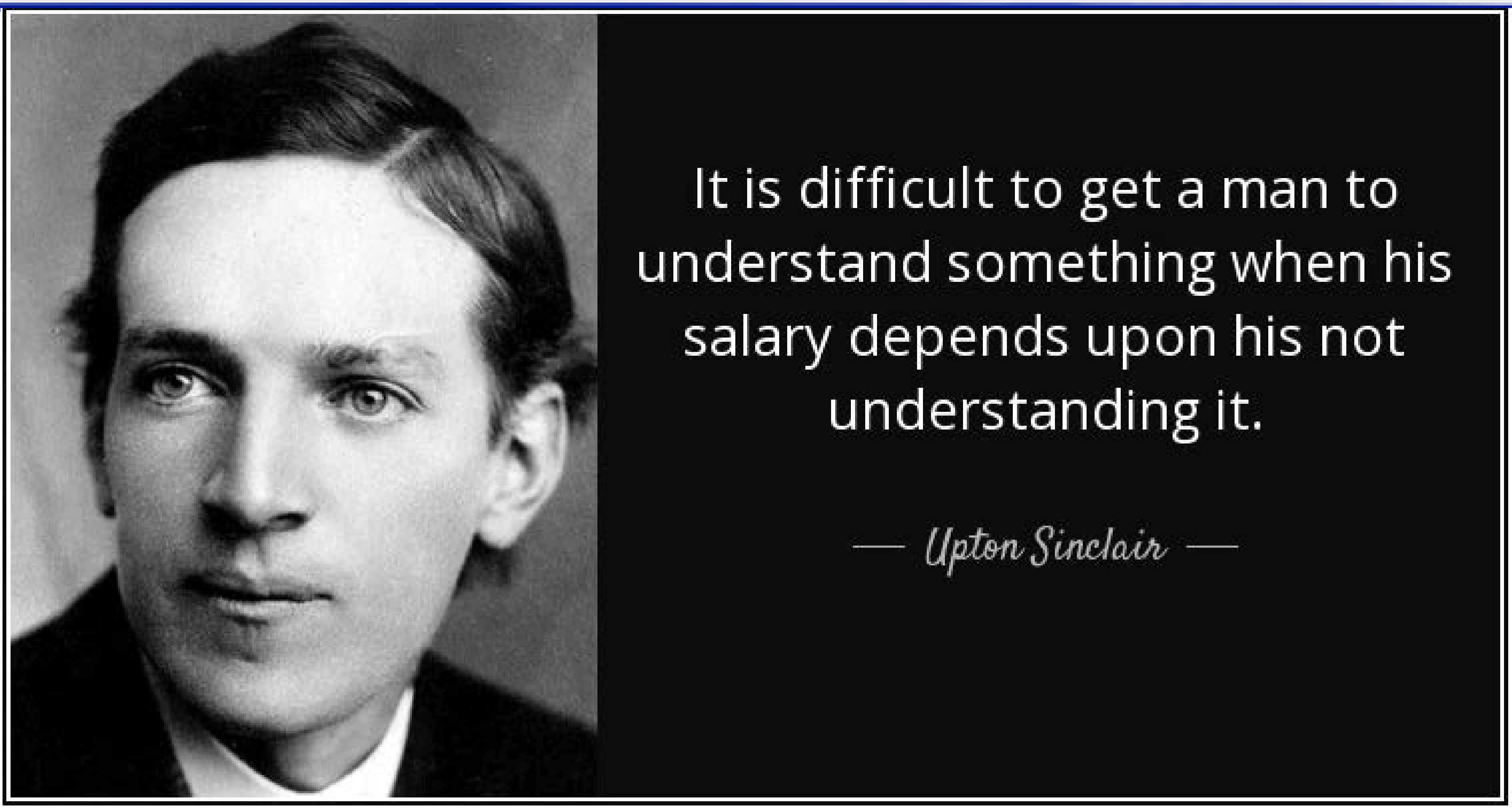
- Air calibrated at CEESI
- Volume & mass flow 0.5%**
- Density ± 0.2 kg/m3



SOLVED

**Without P&T

A Somewhat Balkanized Flow Meter Community



- *This doesn't facilitate the R&D of newer technologies/ Hybrid meters!*

VorCone Meter and Saturated (Wet) Steam

- For known densities, wet gas flow metering has two unknowns: mg & ml,

  i.e.: M_L & the quality ‘x’

$$x = \frac{\dot{m}_g}{\dot{m}_l + \dot{m}_g}$$

- Known: M_H = Mgas + M liquid= Mass Vapor (wet/sat. steam),

Standard Practice / Standard Problem- Wet Steam

- Find the steam flow *for a known x,* using some correction factor '*f*':

$$\dot{m}_g = \frac{\dot{m}_{g,app}}{f(x)}$$

- ISO gives a cone meter wet gas correction (*f*).
- Problem for Standard Vortex meters : if *x* not known, two unknowns and one equation. *Can't be solved!*
- You need two equations to solve for two unknowns dynamically !
- Hence fall back to the conventional P&T compensation and Saturated Steam Tables
- Steam tables give steam and water densities for known P & / or T conditions (Saturated conditions).

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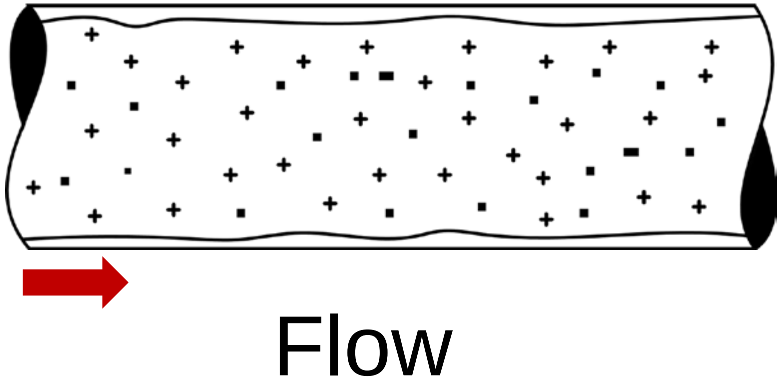
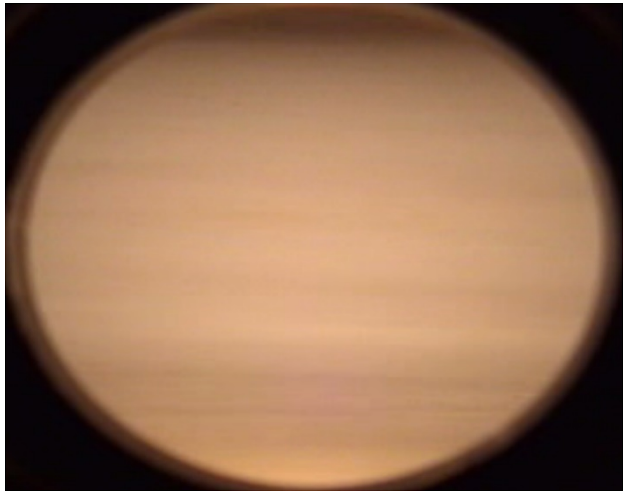
VorCone Meter with Saturated Steam





- Steam injection flows are relatively high pressure velocity flows, i.e. mist / homogenous mix flows.
- Vortex meter predicts homogenous mixture volume.
- VorCone meter then predicts homogenous density.
- Phase densities known from steam tables…

**Steam Quality "X"

from vortex meter

$$\rho_{hom} = f\left(Q_{hom}, \Delta P_{hom}\right)$$

from steam tables

from combined meter

found

$$x = \frac{\rho_g\left(\rho_l - \rho_{hom}\right)}{\rho_{hom}\left(\rho_l - \rho_g\right)}$$

from combined meter

from steam tables

SOLVED

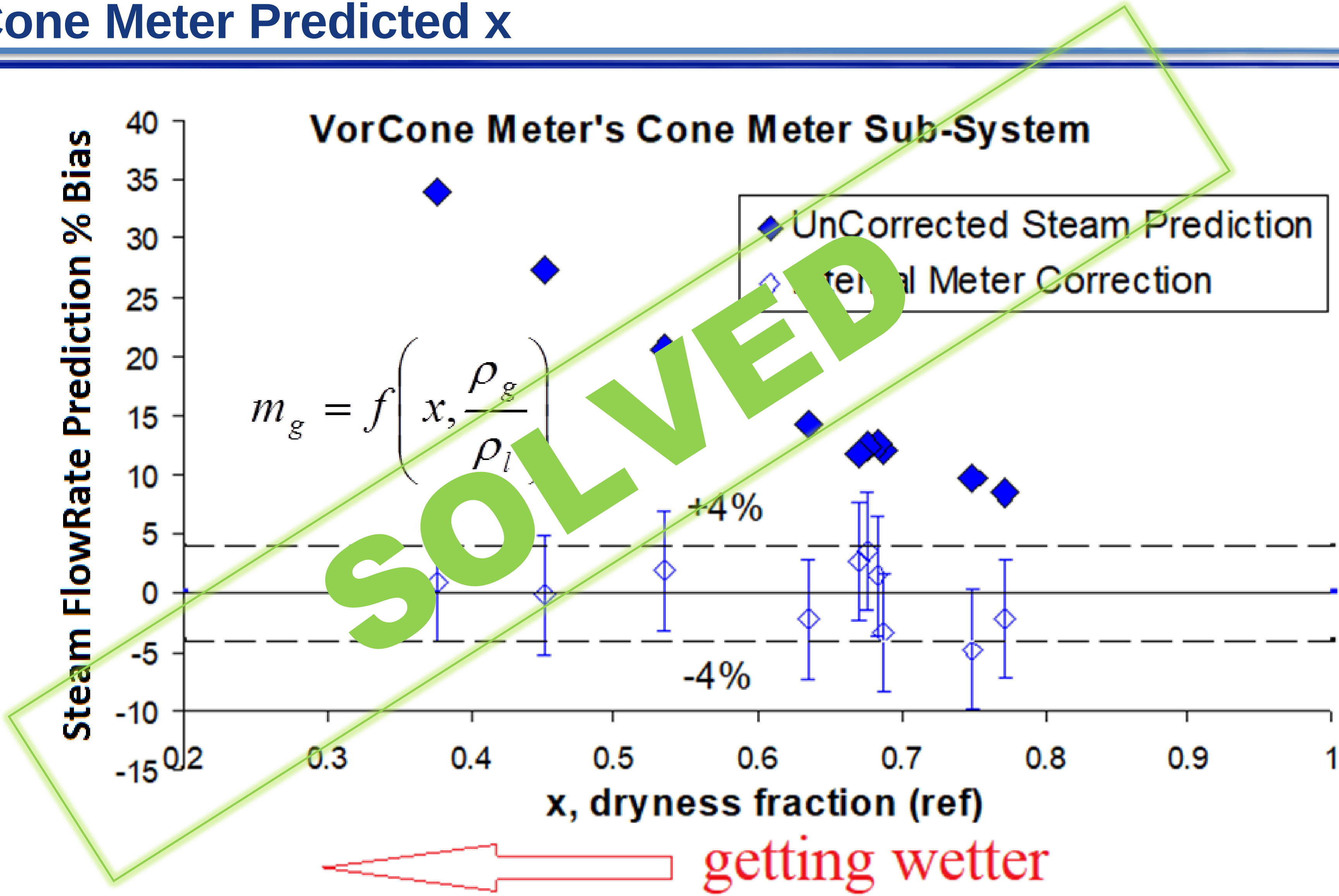
Field Testing: Oil Truck Unloading

⑩ Portable truck compact separator with Coriolis gas and liquid reference system: 5% reference system uncertainty!

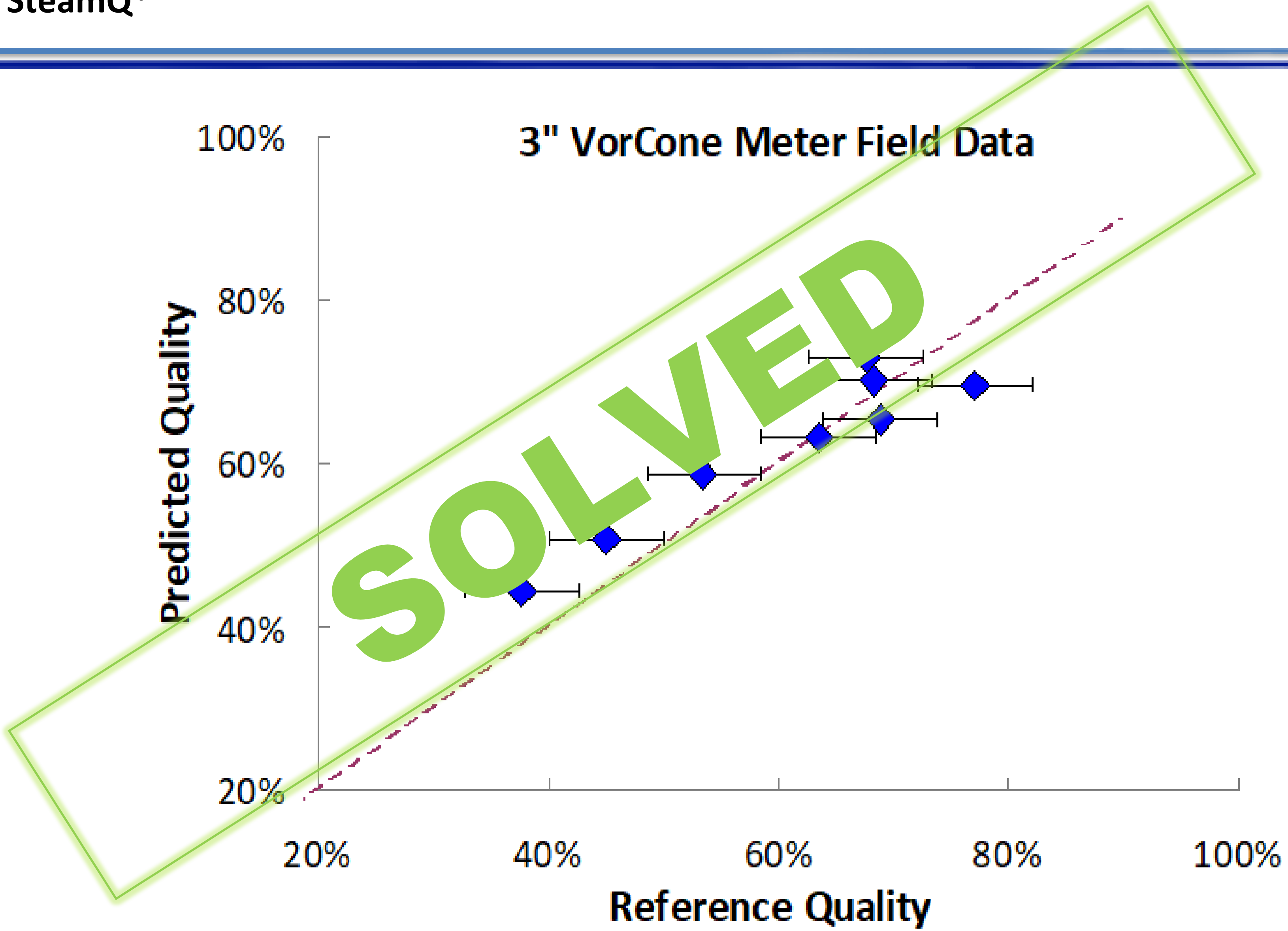
Field Testing: SteamQ*

⑩ 2” VorCone Meter installed at saturated steam oil well injection point.

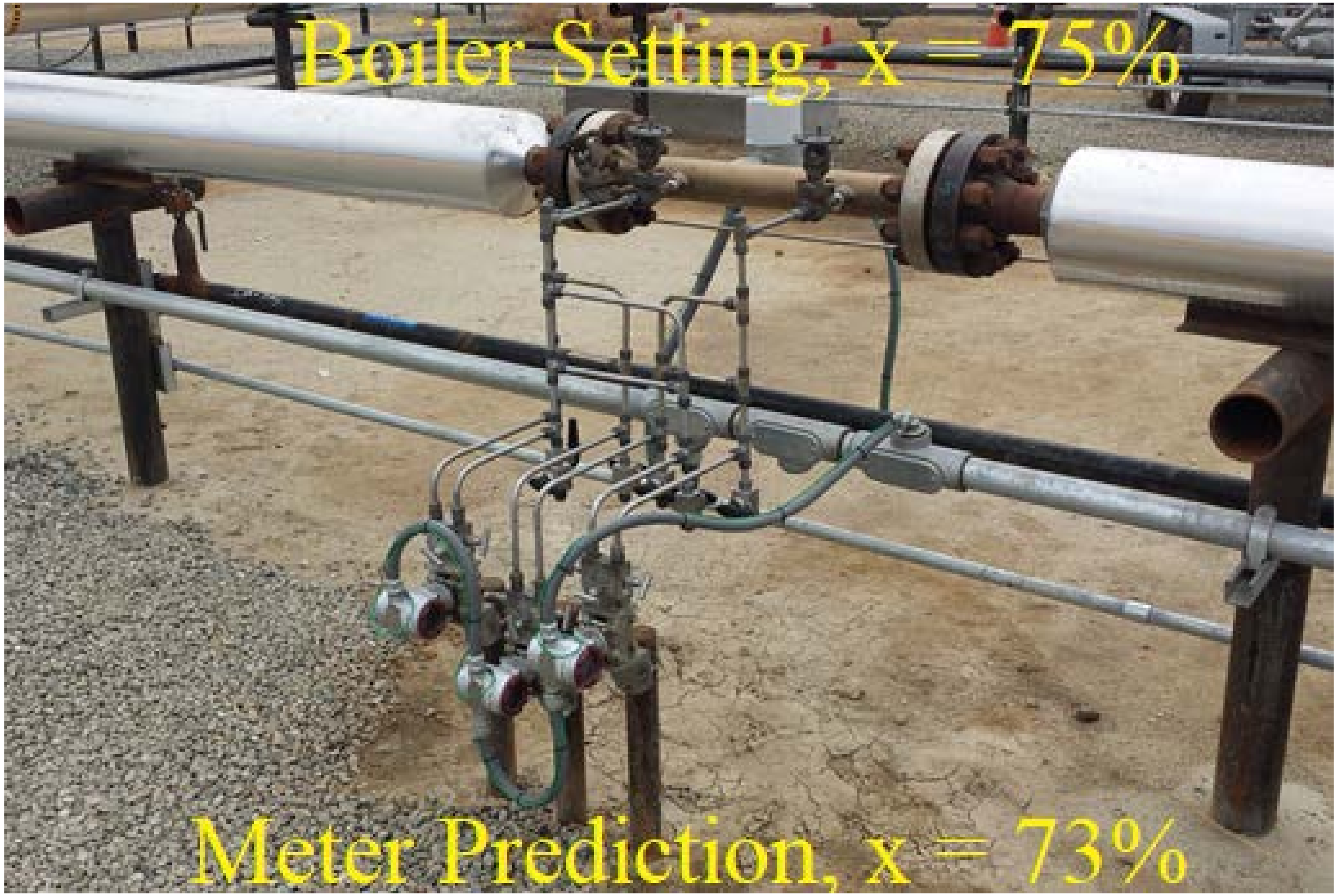
Applying ISO TR 12748 Cone Meter Wet Gas Correction with VorCone Meter Predicted x



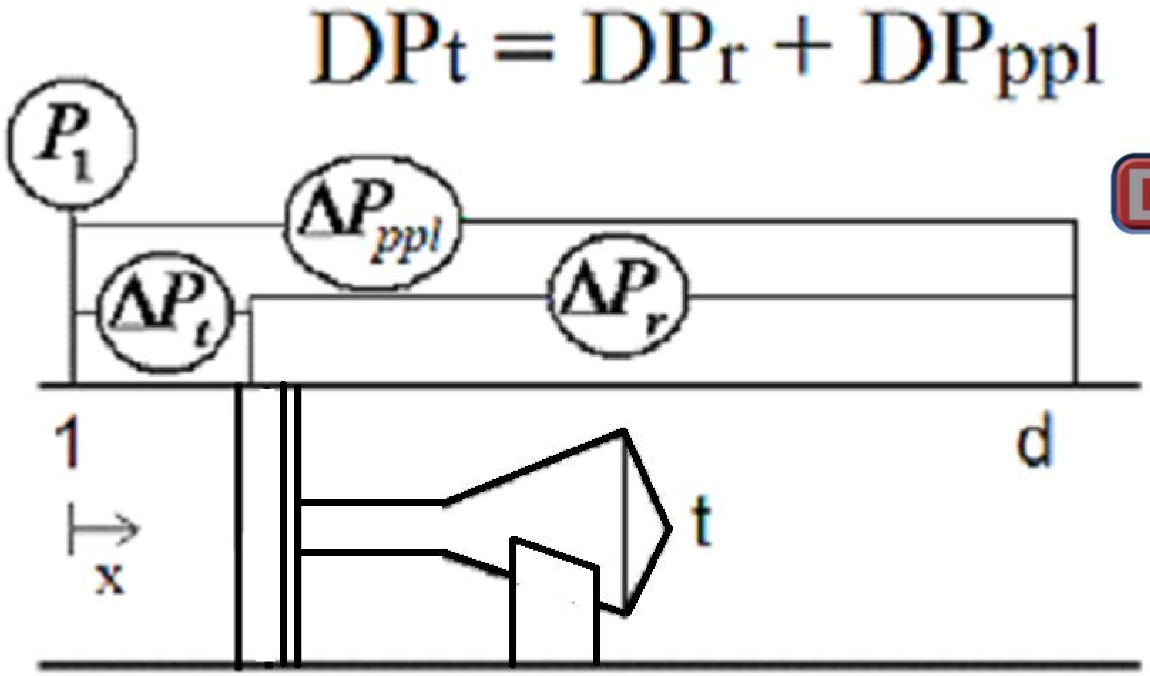
Field Testing: SteamQ*



3” VorCone Meter Boiler Outlet Location



Added Cone DP Meter Verification System

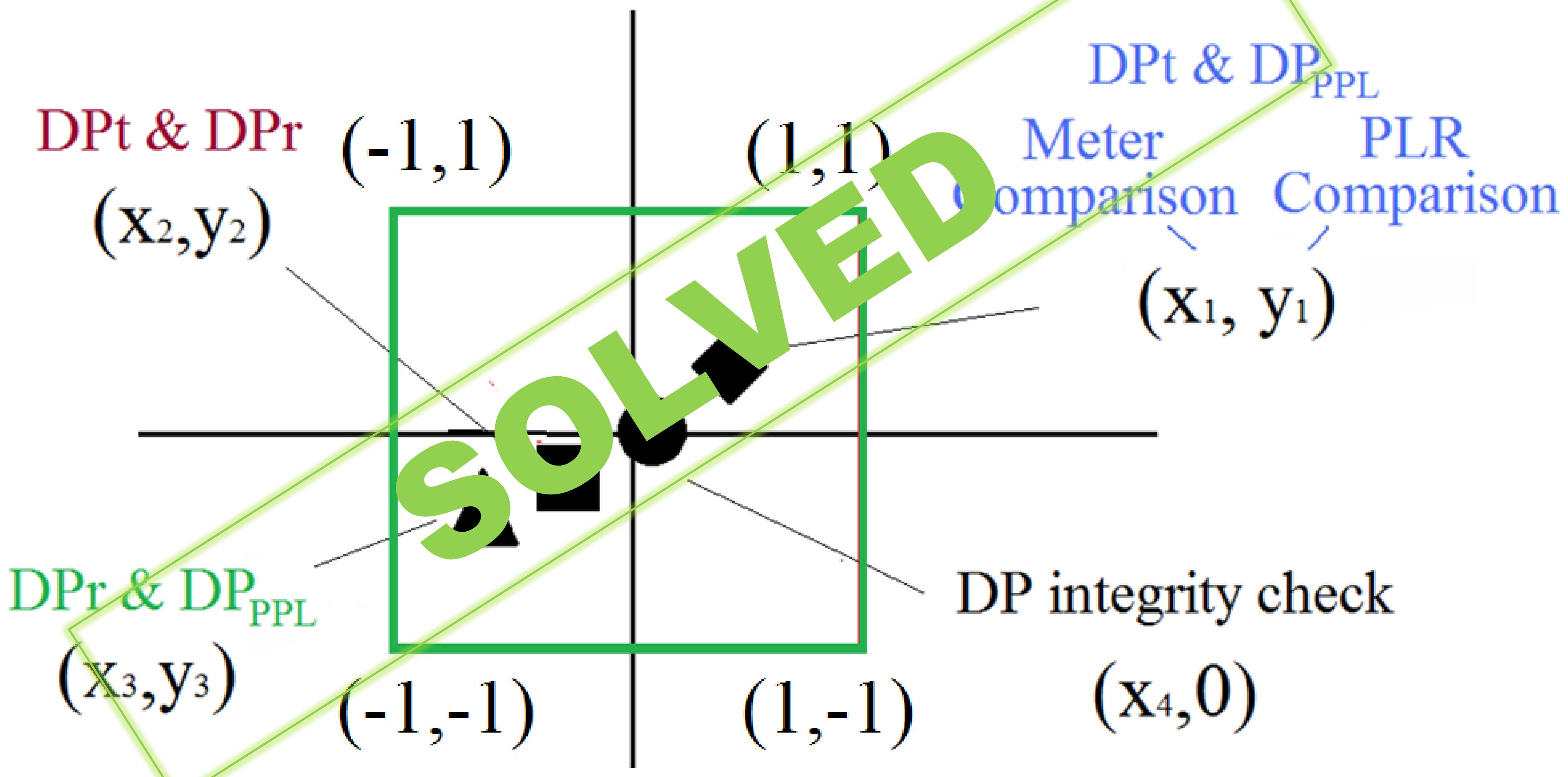


1 DP summation

3 flow meters to compare

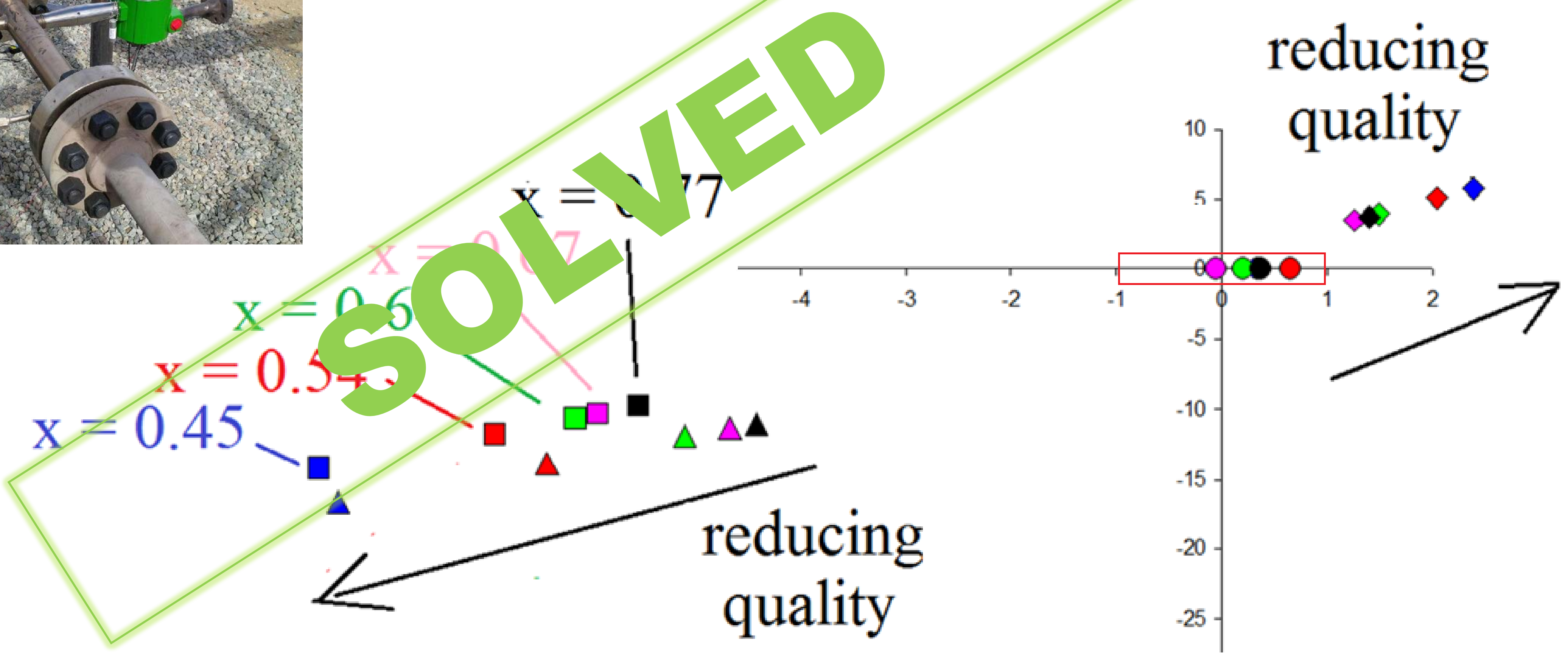
3 DP ratios to check

Normalized Diagnostic Display- Built in Validation



Field Test Varying Steam Quality Validation

❿ X= liquid loading/steam Quality



Conclusions

- For an unknown gas density the VorCone meter predicts dry gas mass flow to < 1% uncertainty (95% confidence!).
- Saturated steam flows are usually metered by gas meters, with liquid induced gas prediction biases.
- Correction factors (if they exist for a given meter) require an externally supplied liquid loading – which is usually not known.
- The VorCone meter can internally predict x (down to 40%), and apply a 2-phase flow correction factor, thereby also predicting a more accurate Wet steam flow along with Steam Quality.

Continue…

Conclusions

- The cone meter diagnostic system DPrognosis offers
  - Two additional DP check meters
  - An built in Expanded Hybrid Check meter with a 2nd independent liquid loading validation system.
- Next Project : Wet Gas (Lab Testing on Wet Gas – completed early 2019, awaiting results from Field Trails !!)
- Questions ?

VORTEK INSTRUMENTS

DP DIAGNOSTICS Monitor, Verify and Trust

MONITOR, VERIFY, AND TRUST YOUR DP METER

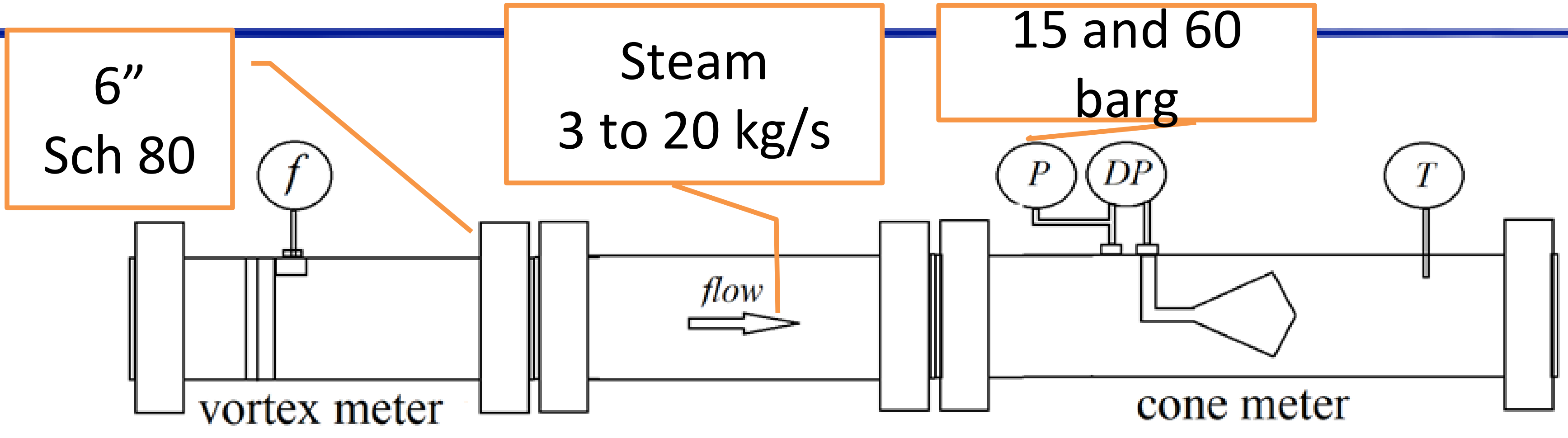
MEASUREMATION

THANK YOU

What I'm Going to Talk About Next

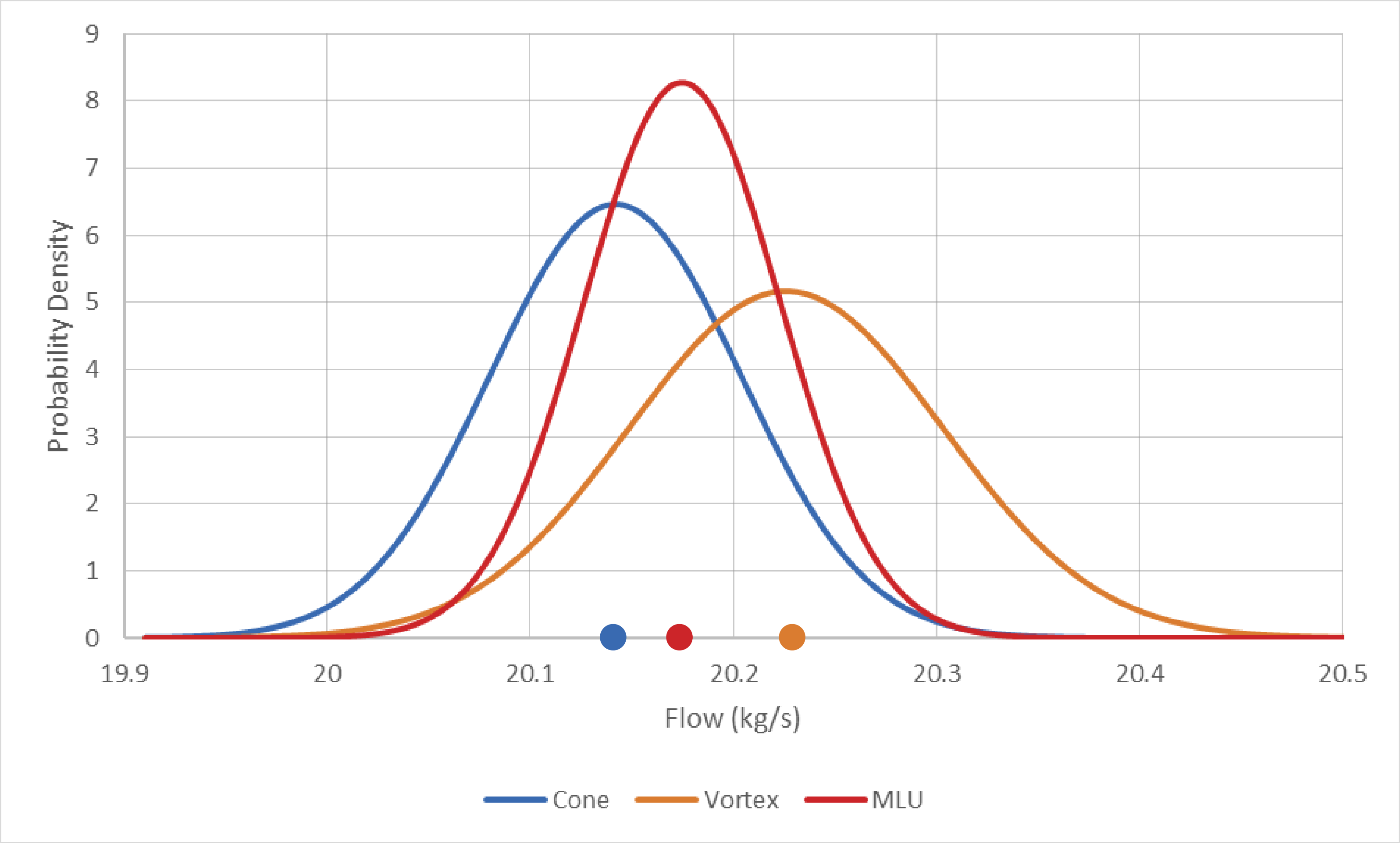
- Uncertainty Certainty
- Two meters combined Reducing uncertainty
- Maximum Likelihood Uncertainty (MLU)
- Independent & Hybrid Meters

Vortex and Cone Meters in Series



±0.6%	±0.47%	±0.75%
Cone	MLU	Vortex

Vortex and Cone Meters in Series



Annual Revenue and Uncertainty Exposure

$76.18 million	$76.30 million	+$127K
Cone 20.142 kg/s ± 0.6% $5.5 / tonne	MLU 20.175 kg/s ± 0.47% $5.5 / tonne	Difference ↓± 0.13%

Annual Revenue and Uncertainty Exposure

Cone	MLU	Difference
±0.457 million	±0.359 million	↓ ± $98K
20.142 kg/s ± 0.6%	20.175 kg/s ± 0.47%	↓± 0.13%
$5.5 / Tonne	$5.5 / Tonne	