Ultrasonic Flow Metering Insertion & Clamp-on Types

(emphasis on Clamp-on UFM's)

Presenter : Izzy Rivera

Flexim Americas Corporation

A Brief History – Significant Milestones

- 1955 – Doppler ultrasonic techniques were first implemented to detect valve heart motions
- 1963 – Tokyo Keiki first introduced Doppler Ultrasonic meters to commercial markets
- 1970’s saw the release of more Doppler meters onto the market, accelerating the pace of research in the industrial field
- 1972 – Controlotron develops first clamp-on transit time meters
- 1976 – Westinghouse LEFM; chordal transit time meters installed on Alaska Pipeline
- 1998 – AGA9 standard published for custody transfer of natural gas

Early Wetted UFM Meter

Installed 1976 – TransAlaska Pipeline

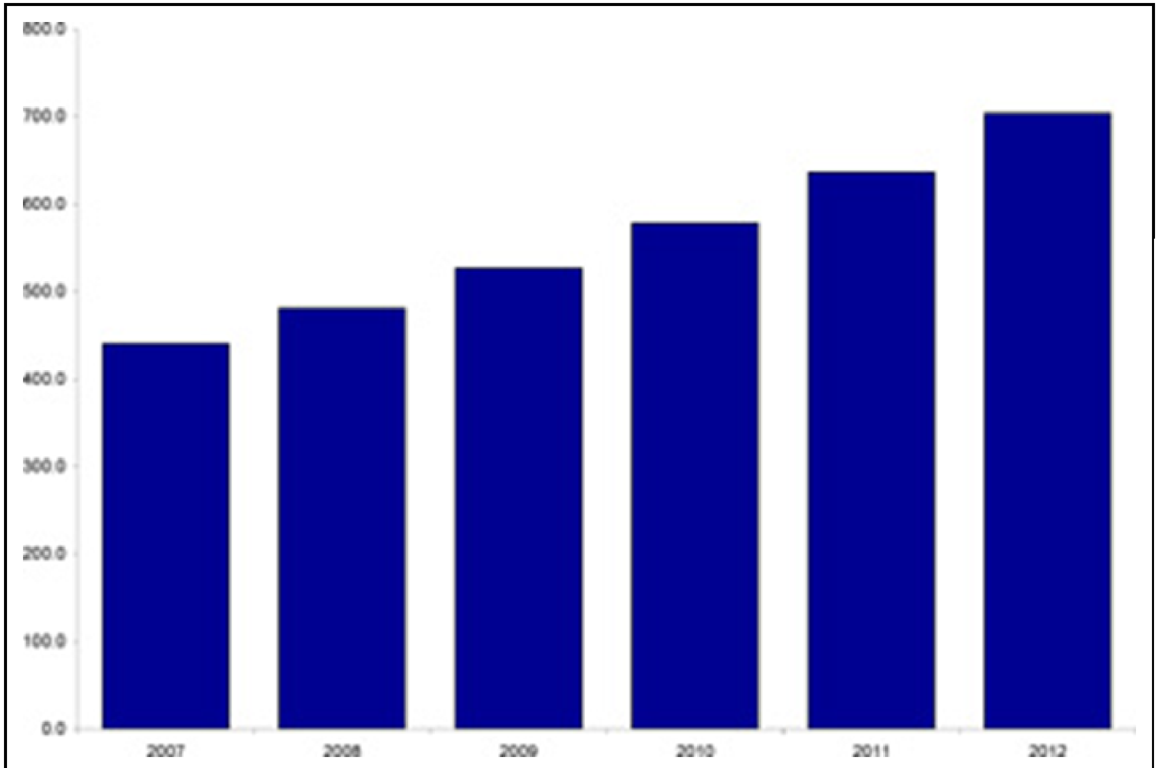
Early Clamp-on UFM Meter

Doppler

Transit-Time

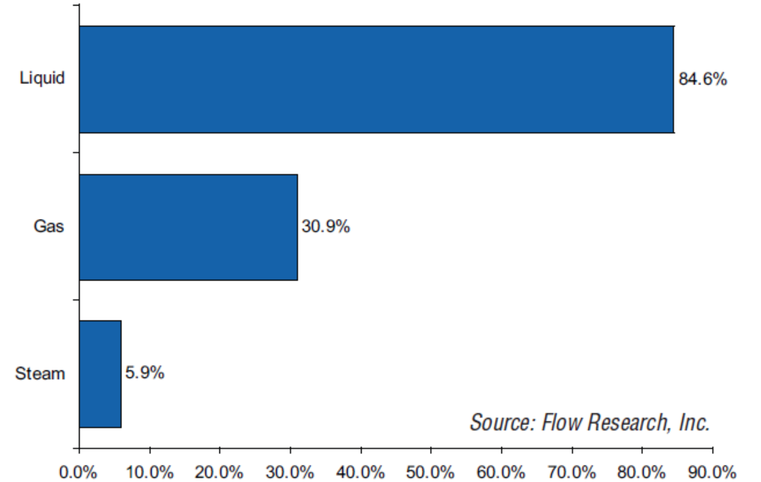
UFM Market Growth

According to Flow Research the Ultrasonic flowmeter market is the fastest growing of any other flowmeter type



Projected Revenue Growth for Ultrasonic Flowmeters Worldwide (Millions of Dollars)

Figure 1
Are or Will the Ultrasonic Flowmeters You Have Purchased or Will Purchase Be Used in Gas, Liquid, or Steam Applications?

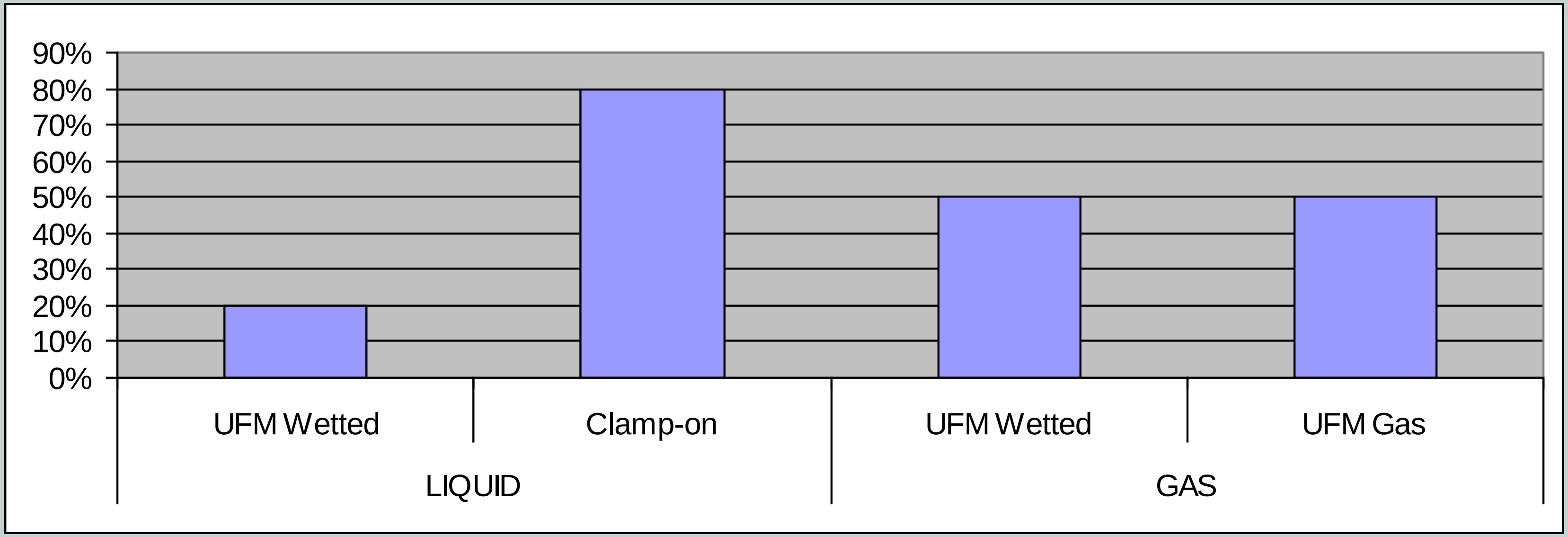


Total respondents = 136
Note: Percentages sum to over 100 due to multiple responses

Flow Co

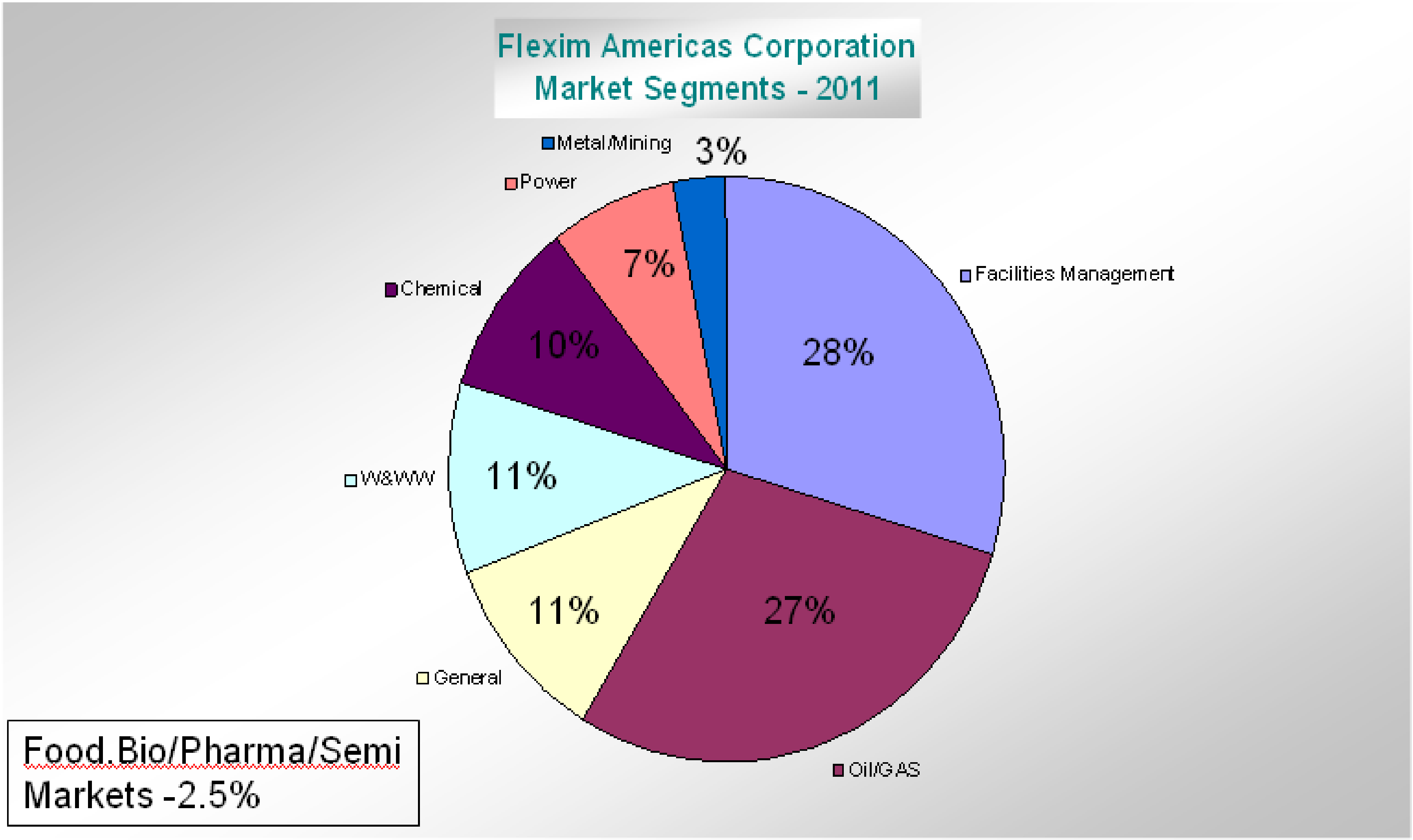
Published by Flow Control – Flow Research Study

Market Share – Wetted versus Clamp-on



% in Units sold 2012 – Izzy's best guess

Flexim 2011 Market Segments



Food.Bio/Pharma/Semi
Markets -2.5%

UFM Transit Time Standards

Liquid Flow

- ASME MFC 5M - 1985 (general purpose)
- API 5.8 – 2005 (custody transfer, hydrocarbon liquids)
- OIML R117 (hydrocarbon liquids)
- ISO 12242 – 2012 (general purpose)

Gas Flow

- AGA-9 1989 (custody transfer gas)
- ISO 17089-1 (custody transfer gas)
- ISO 17089-2 (clamp on gas allocation)

Attributes of Ultrasonic Flowmeters

- Bi-directional flow measurement
- Unlimited turndown
- Very good low flow sensitivity
- Dynamic zero
- High Accuracy
  - 0.15 - .25% custody transfer accuracy
  - 1-2% installed accuracy – Clamp-on
  - Higher accuracy possible with calibration
- Aggressive liquids no problem – Clamp on
- High temperature capability – Clamp on
- No pressure drop
- Retrofit installation – Clamp on

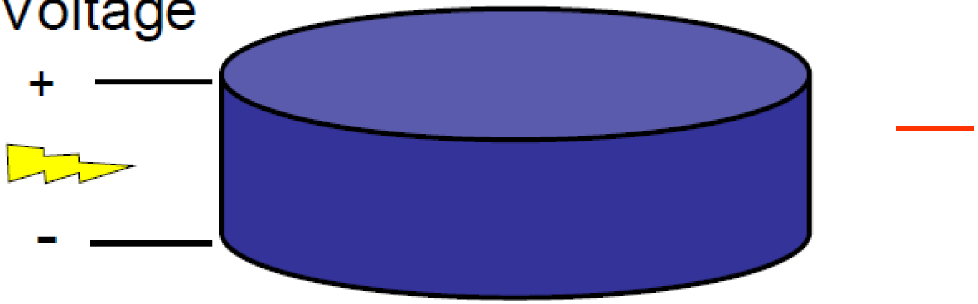
Theory of Operation

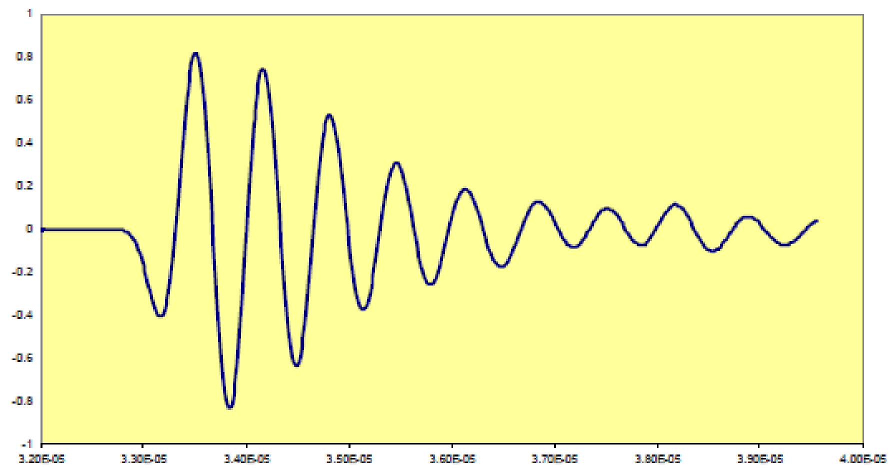
Piezoelectric Crystal

Creating Ultrasonic Sound

Piezoelectric Phenomenon

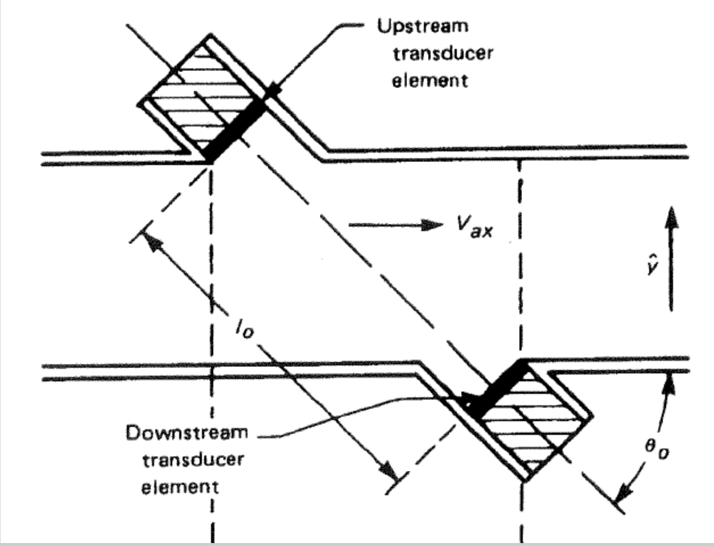
Voltage

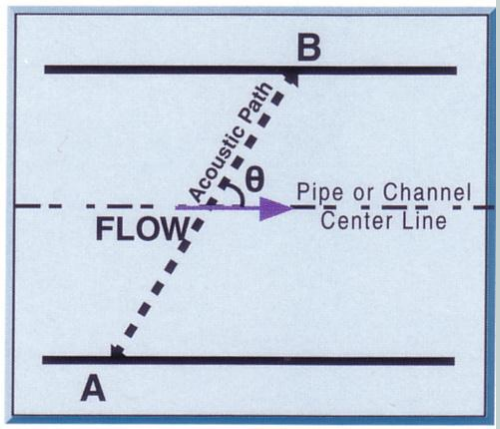




Crystal Rings to Produce Ultrasound – 0.5 to 2 MHz

Transit Time - Wetted Transducer





$$T1 = \frac{L}{C - V \cos Ø} \qquad T2 = \frac{L}{C + V \cos Ø}$$

WHERE:

T1 = Travel time of the acoustic pulse between transducer B and transducer A (Figure 1)

T2 = Travel time of the acoustic pulse between transducer A and transducer B

C = Speed of sound in water

V = Velocity of the water

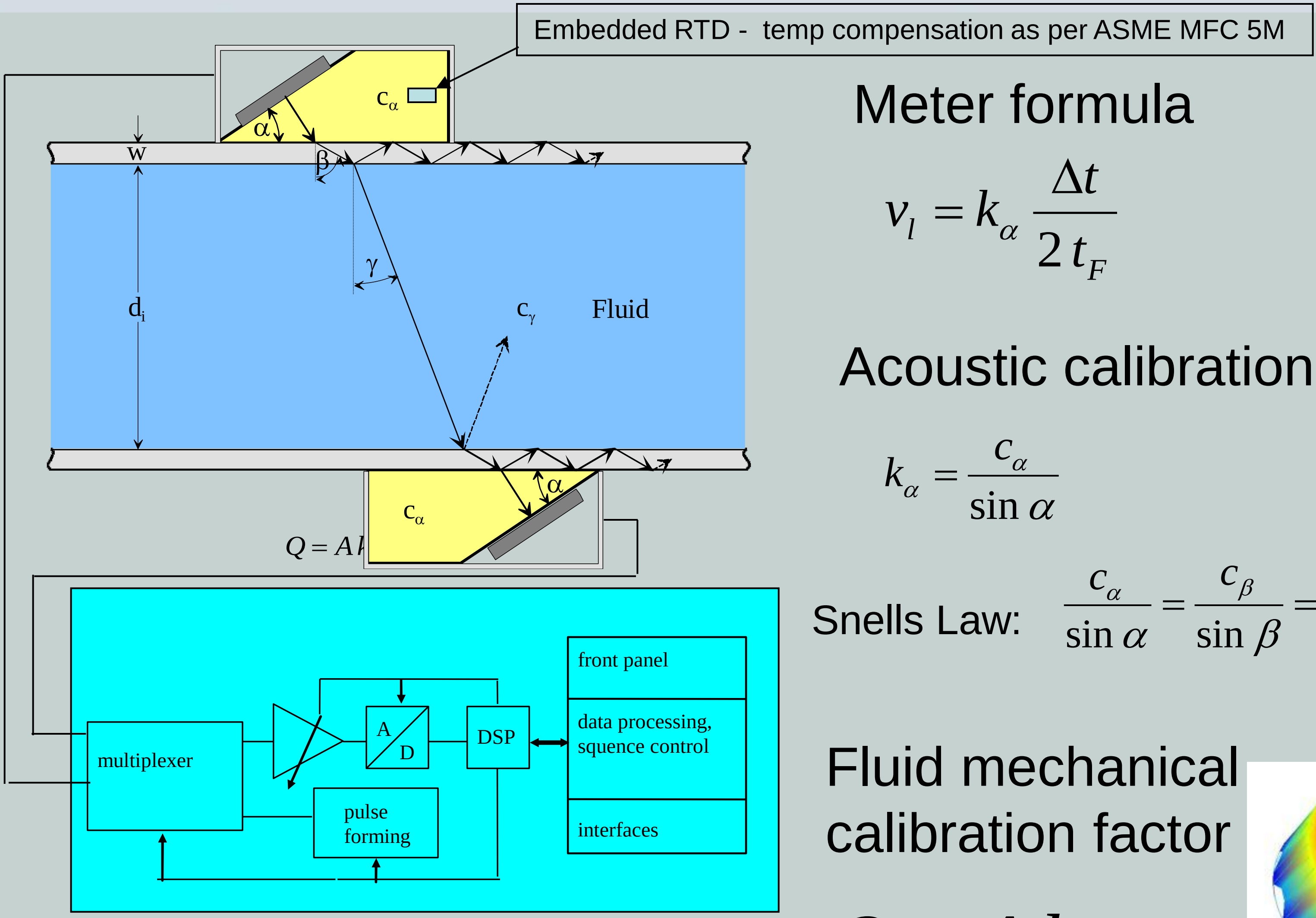
Ø = Angle between the acoustic path and the direction of water flow

L = Path length between transducers

The above equations are solved for V, independent of C, yielding:

$$V = \frac{(T1 - T2)}{(T1 \times T2)} \quad x \quad \frac{L}{2 \cos Ø}$$

Transit Time - Clamp on



Meter formula

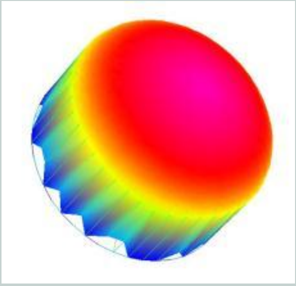
$$v_l = k_\alpha \frac{\Delta t}{2\, t_F}$$

Acoustic calibration factor

$$k_\alpha = \frac{c_\alpha}{\sin\alpha}$$

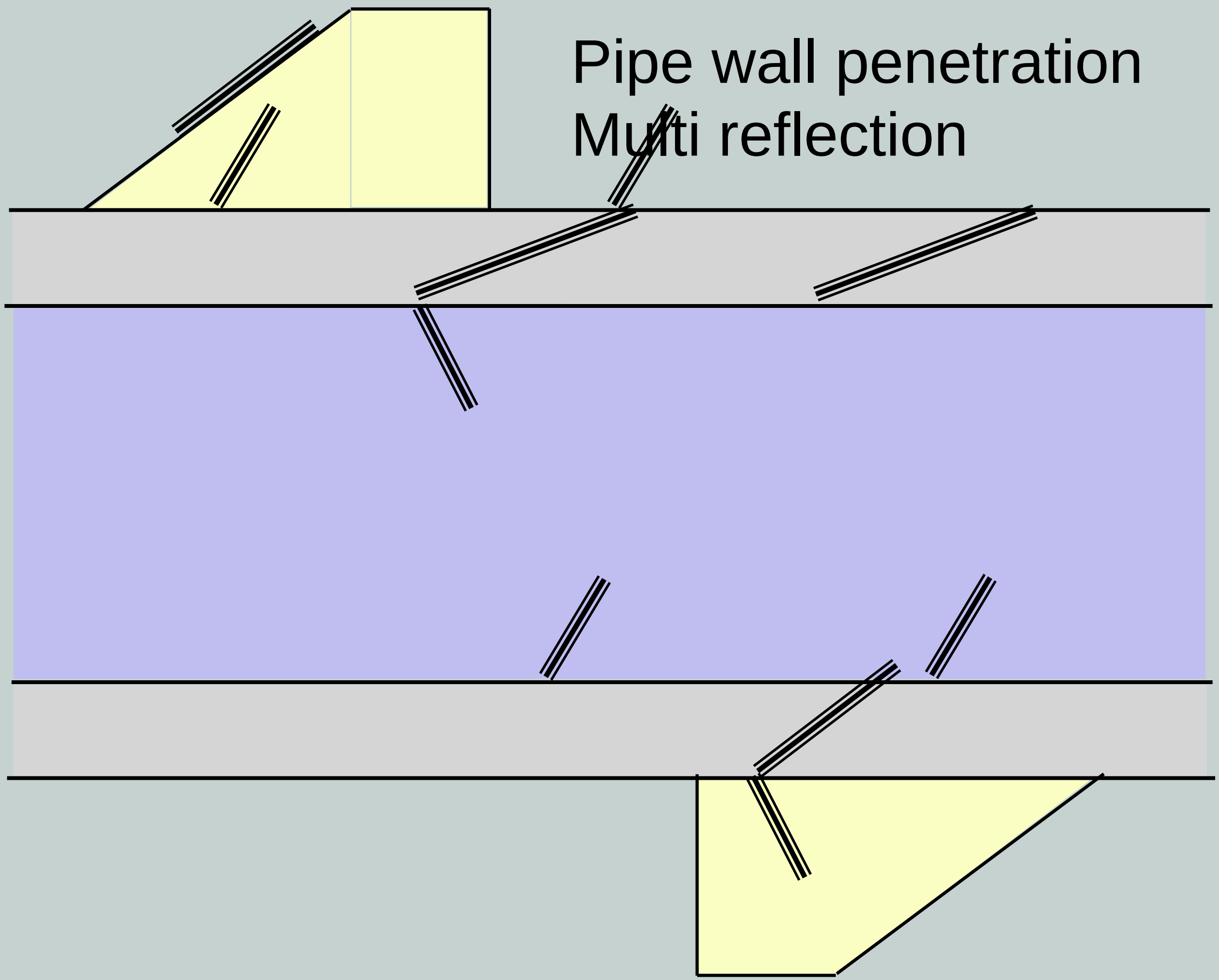
Snells Law: $$\frac{c_\alpha}{\sin\alpha} = \frac{c_\beta}{\sin\beta} = \frac{c_\gamma}{\sin\gamma}$$

Fluid mechanical calibration factor



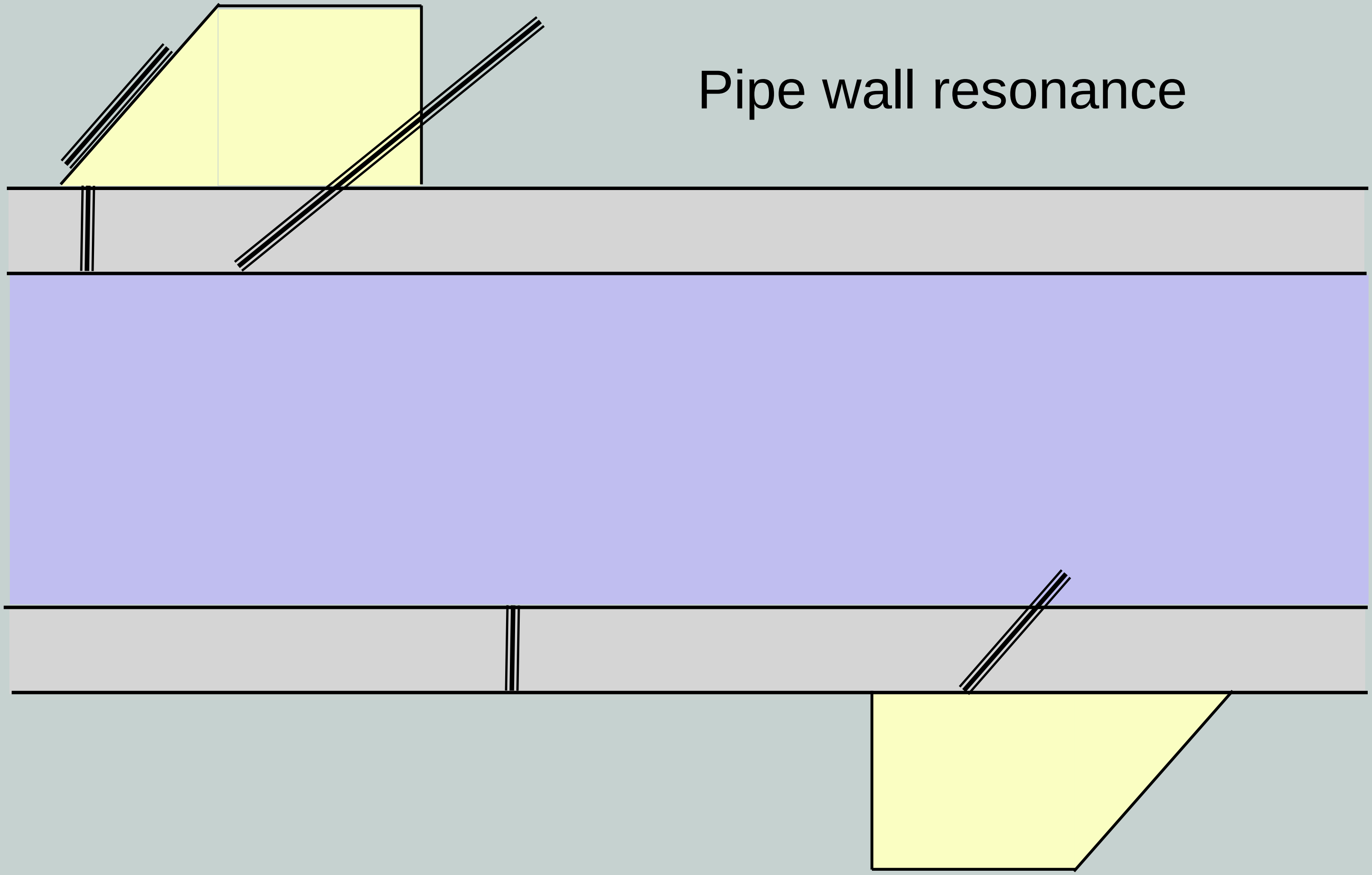
$$Q = A\, k_{\mathrm{Re}}\, v_l$$

Shear Wave sound transmission

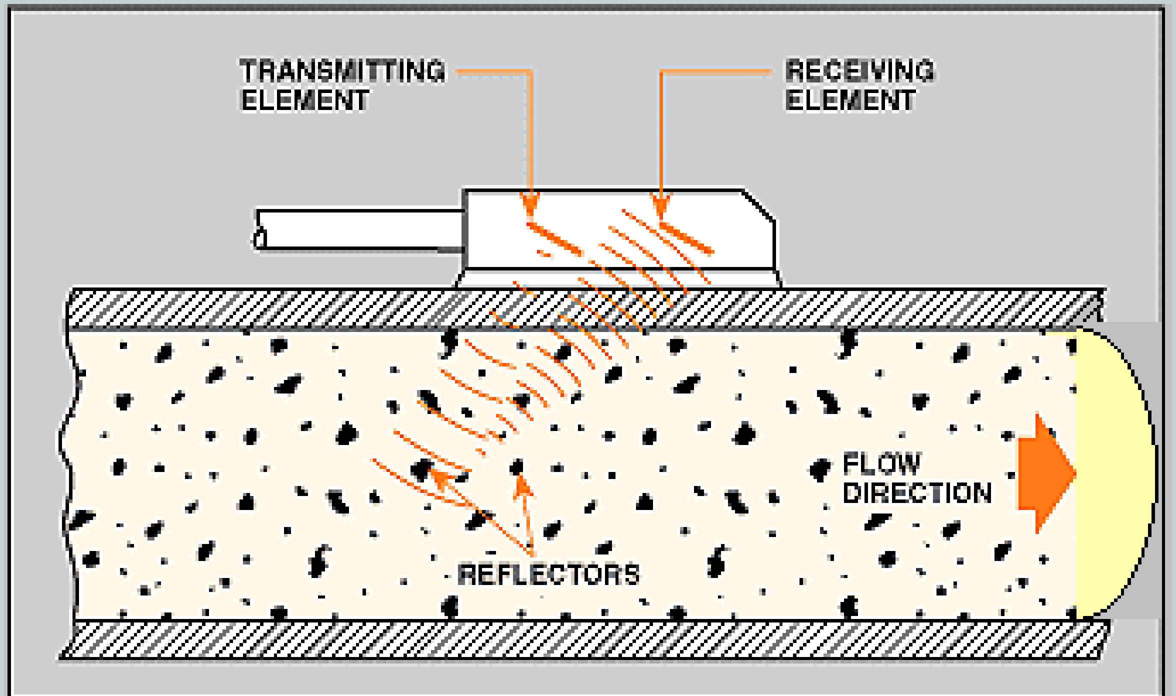


Pipe wall penetration
Multi reflection

Lamb Wave principle

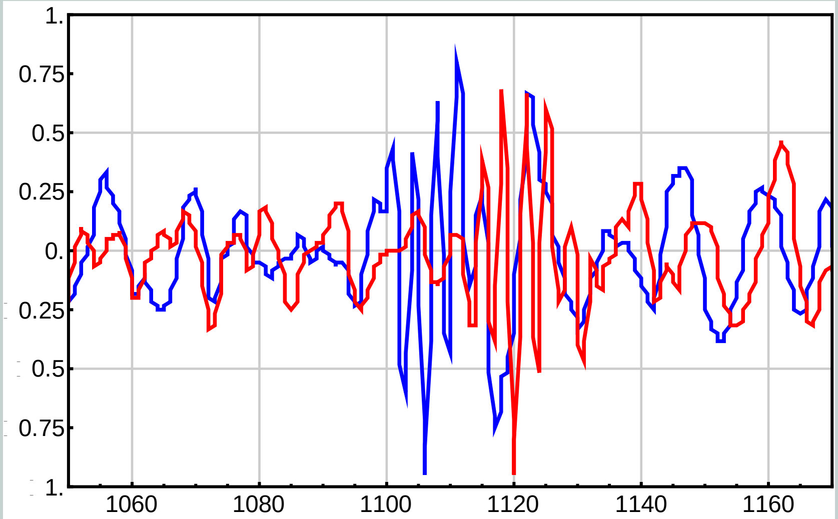


Doppler in Flow Measurement

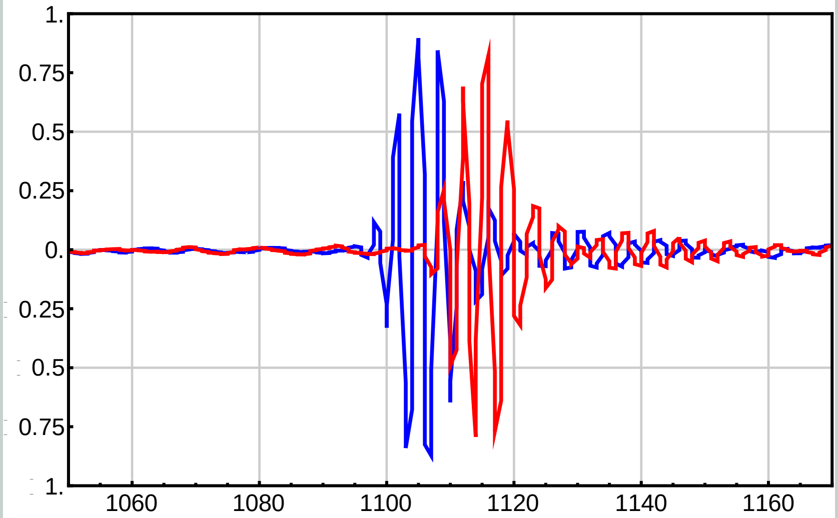


Doppler meters use sound pulse reflection principle to measure liquid flow rate, solids or bubbles in suspension in the liquid reflect the sound back to the receiving transducer. Assumption - Reflected particle representative of average flow

Digital Signal Processing



Digital Signal Processing



- High random noise suppression
- SNR measures amount of random noise relative to fluid signal

Uncertainties of Measurement

Meter Formula

$$Q = K_{\mathrm{Re}} \cdot A \cdot K_{\alpha} \frac{\Delta t}{2t_{fl}}$$

Error contributions:

- fluid mechanics
- geometry
- acoustics
- electronics and time measurement

Meaurement uncertainty - Flexim
1-2% +-0.03ft/s
NIST wet flow calibrated 1% of reading
Repeatability < 0.15% +-0.03ft/s

Volume flow of an ultrasonic flow meter

$$Q = A \cdot v_A = A \cdot \mathrm{Re} \cdot v_l$$

$$\mathrm{Re} = \frac{v_A \cdot d}{\eta}$$

(Kinematic Viscosity)

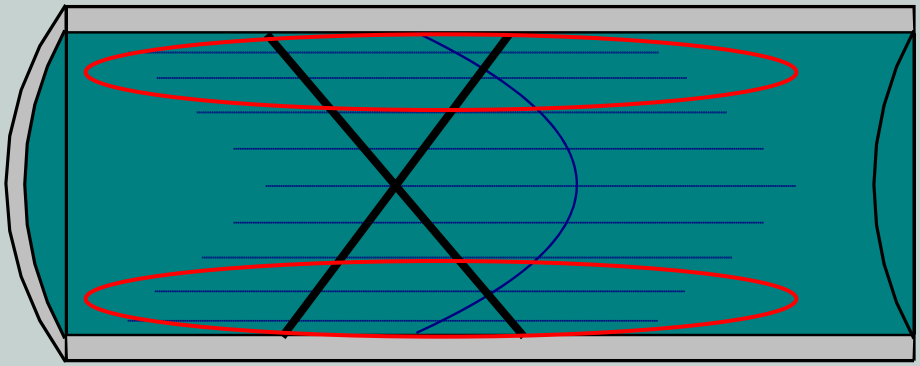
Laminar: *K*=0,75

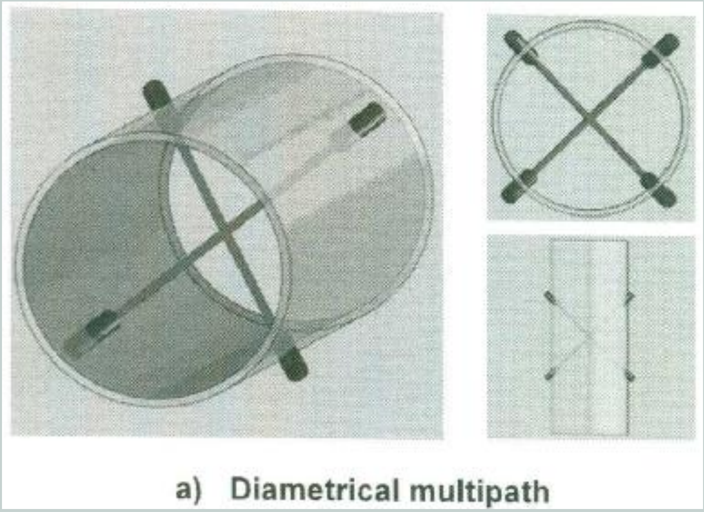
Turbulent: *K*=0,91 ... 0,97

Assumptions: undisturbed flow

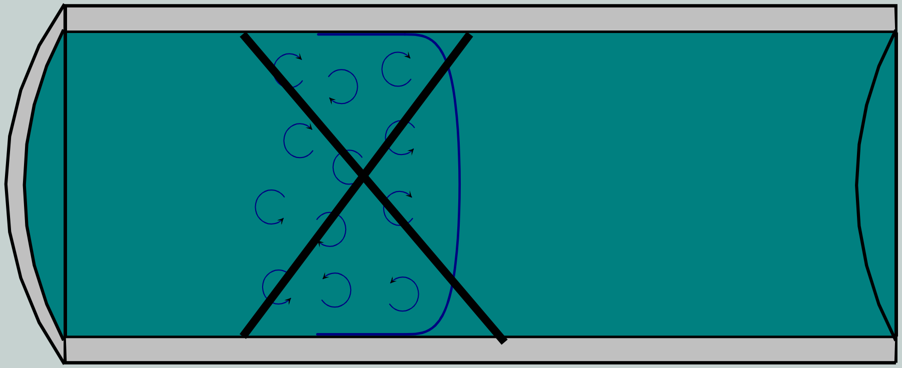
Flow Profile effects – Diametral Path

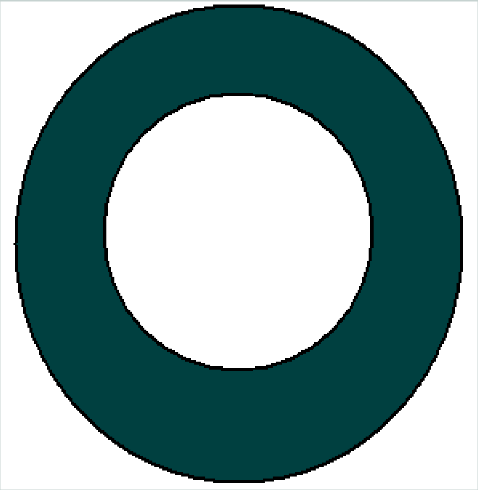
Laminar Flow   Re < 2700



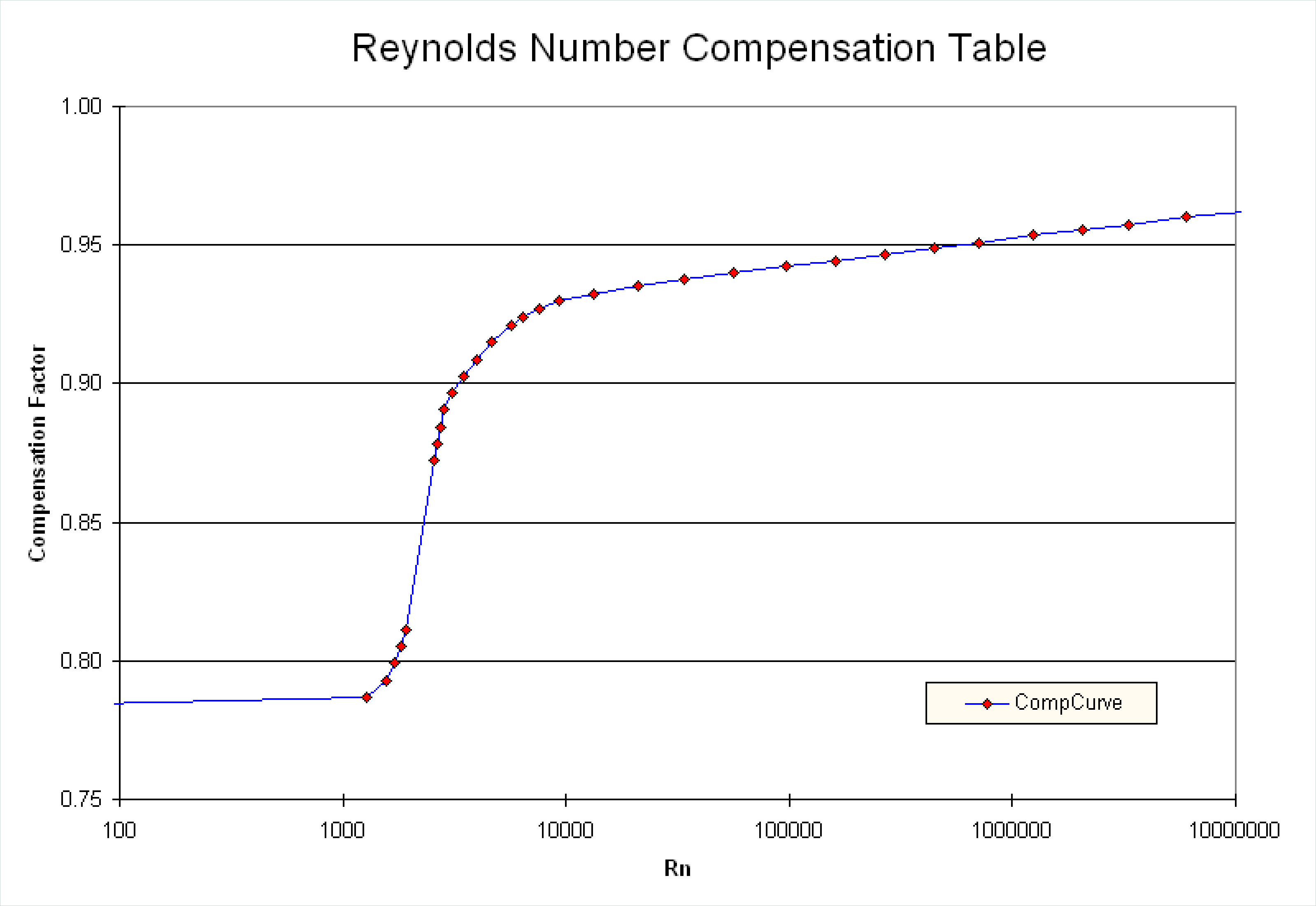


Turbulent Flow   Re > 6000 (>10.000)





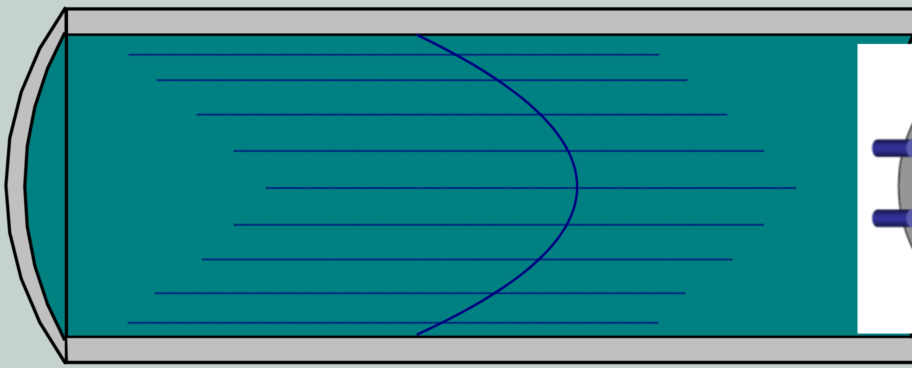
Re Compensation

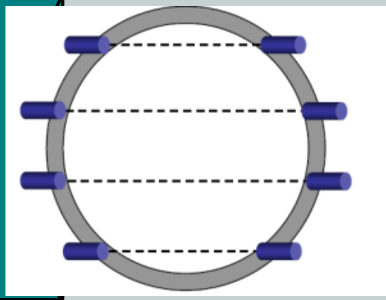


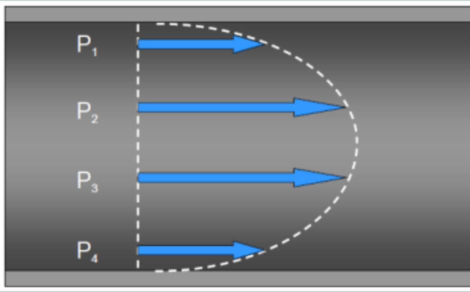
Flow Profile effects – Chordal Paths

Chordal paths are strategically located to average the velocity profile

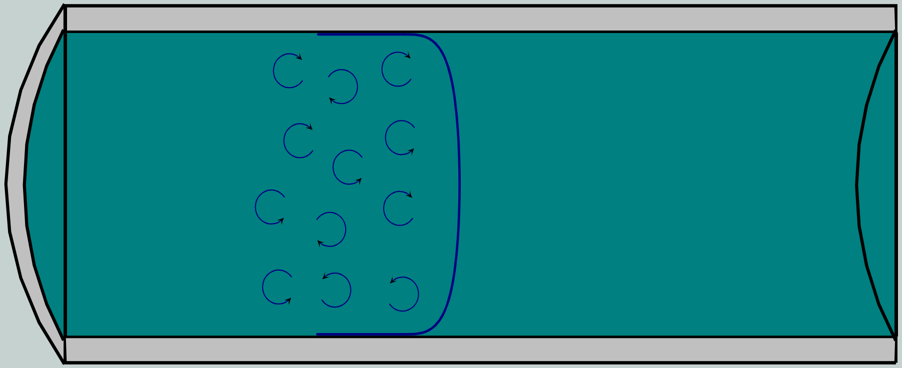
Laminar Flow Re < 2700





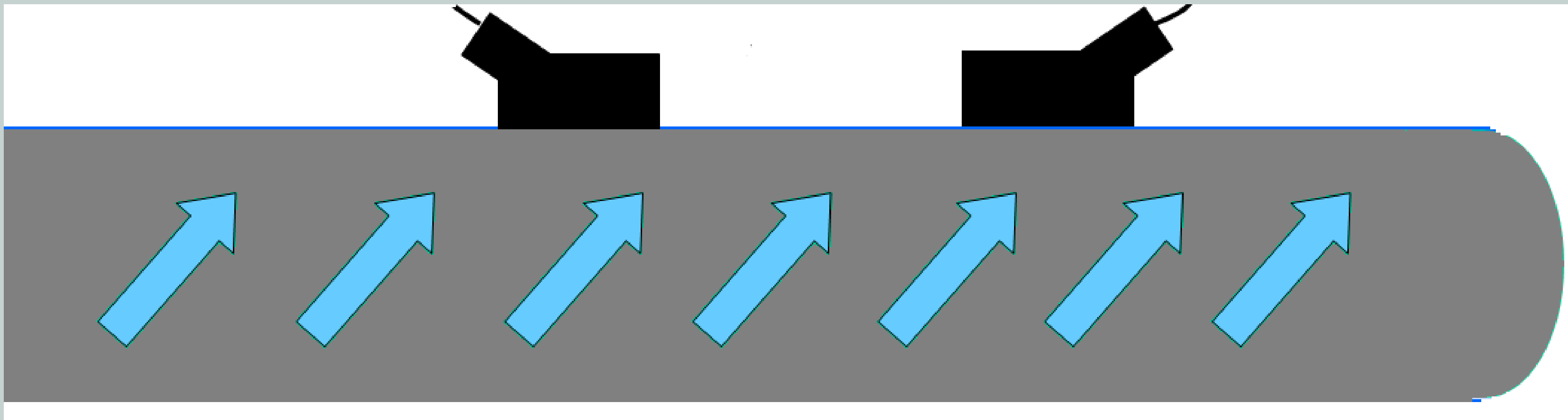


Turbulent Flow Re > 6000 (>10.000)

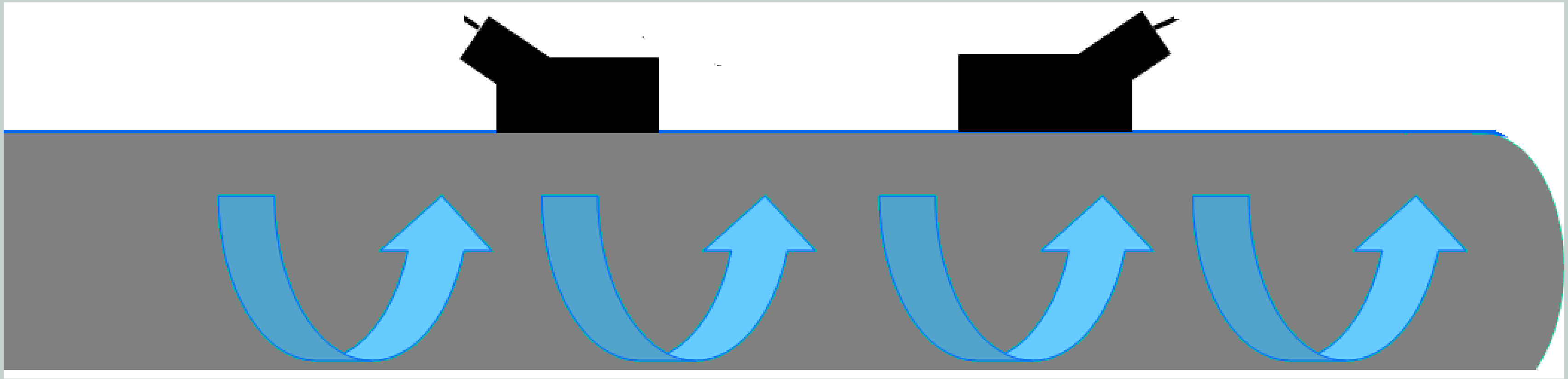


Undeveloped Flow Profiles

Cross Flow

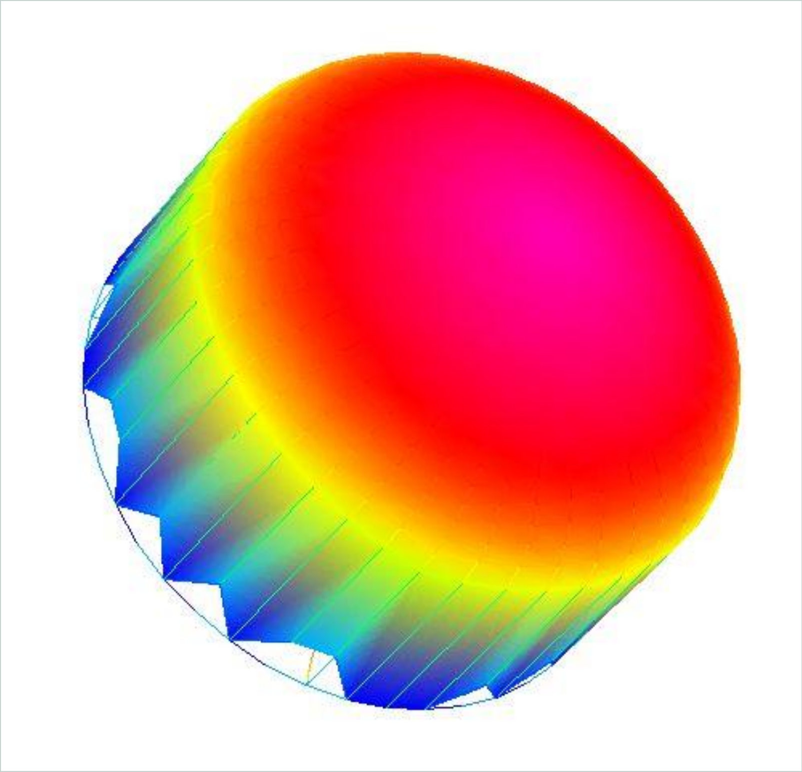


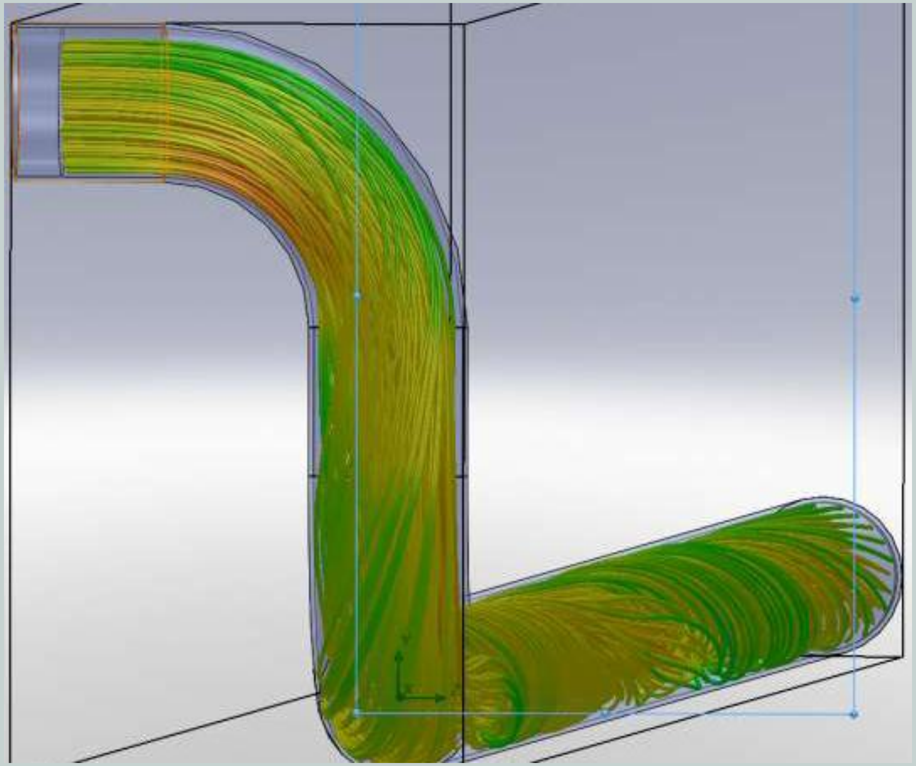
Swirl Flow



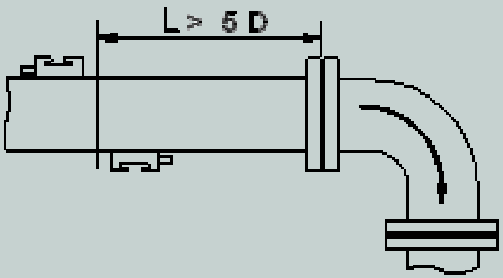
Other Profile effects

- Most flowmeters will be affected by the flow profile in a pipe
- Piping configuration, amount of straight run of pipe must be considered

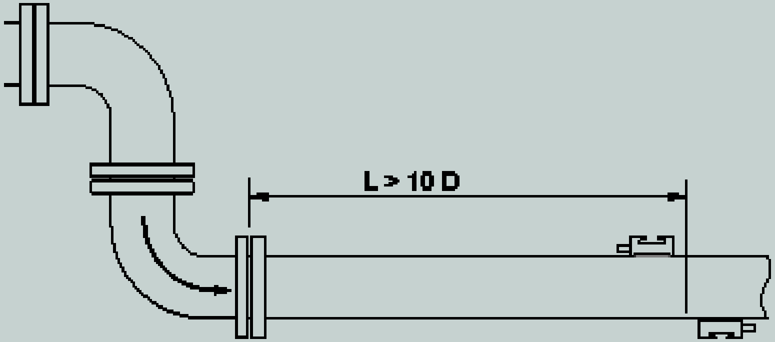




Flow profile disturbance



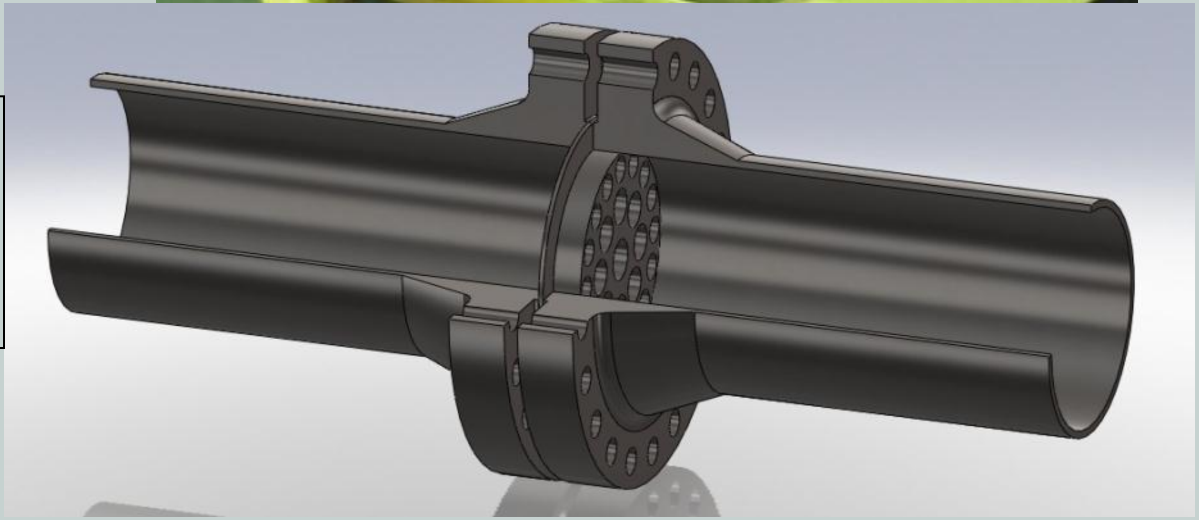
Bends, valves, elbows, diffusers, reducers, pumps etc. change the profile of the flow.



Certain distances to such flow elements are necessary for an undisturbed flow profile.

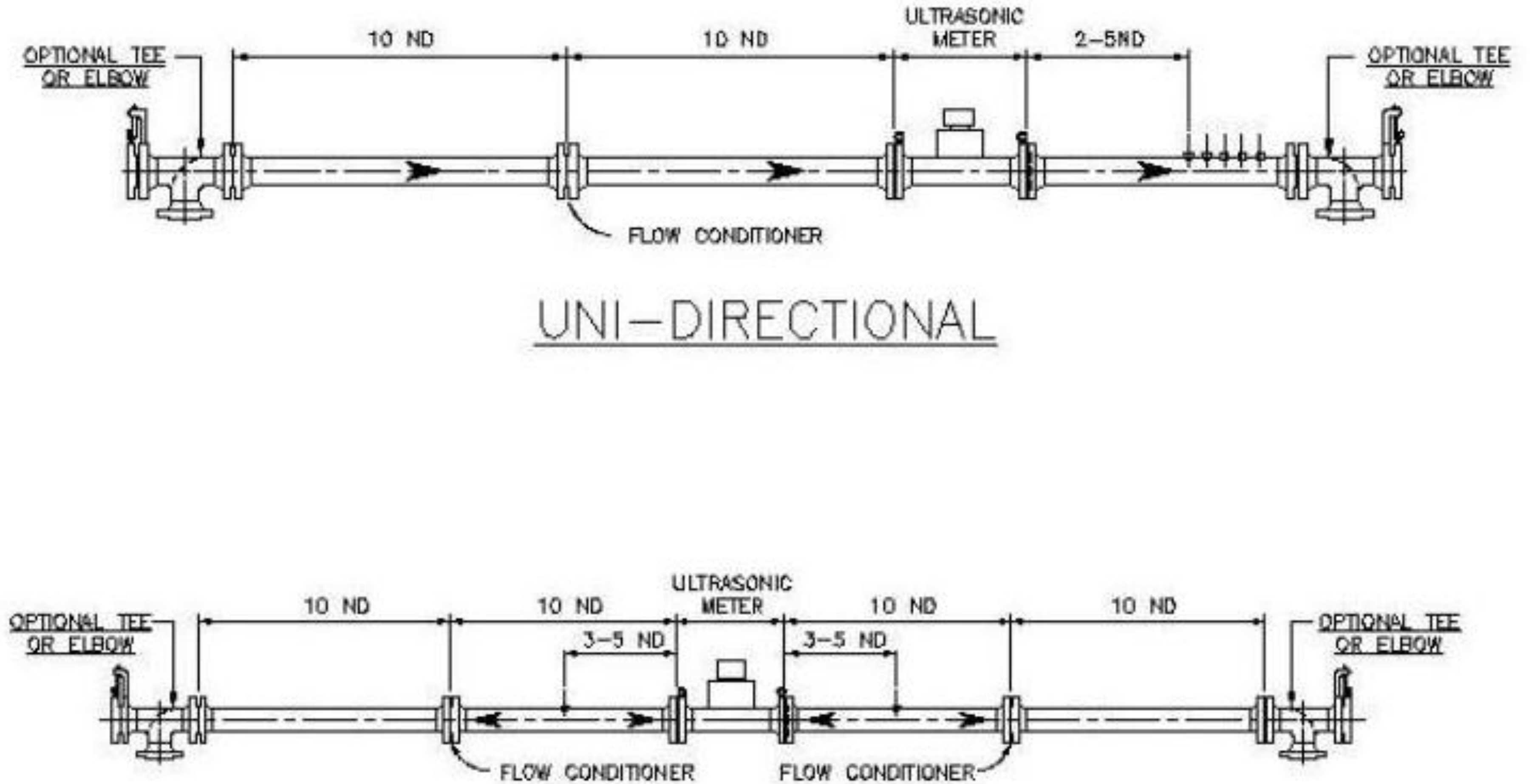
Flow Conditioners

Tube Bundle: Used typically for turbines and orifice meters



CPA Plate: Used for UFM Gas and beginning to replace tube bundle type

AGA-9 Gas Standard requires metering section



Inflow requirements

methods of compensation for flow profile deviations

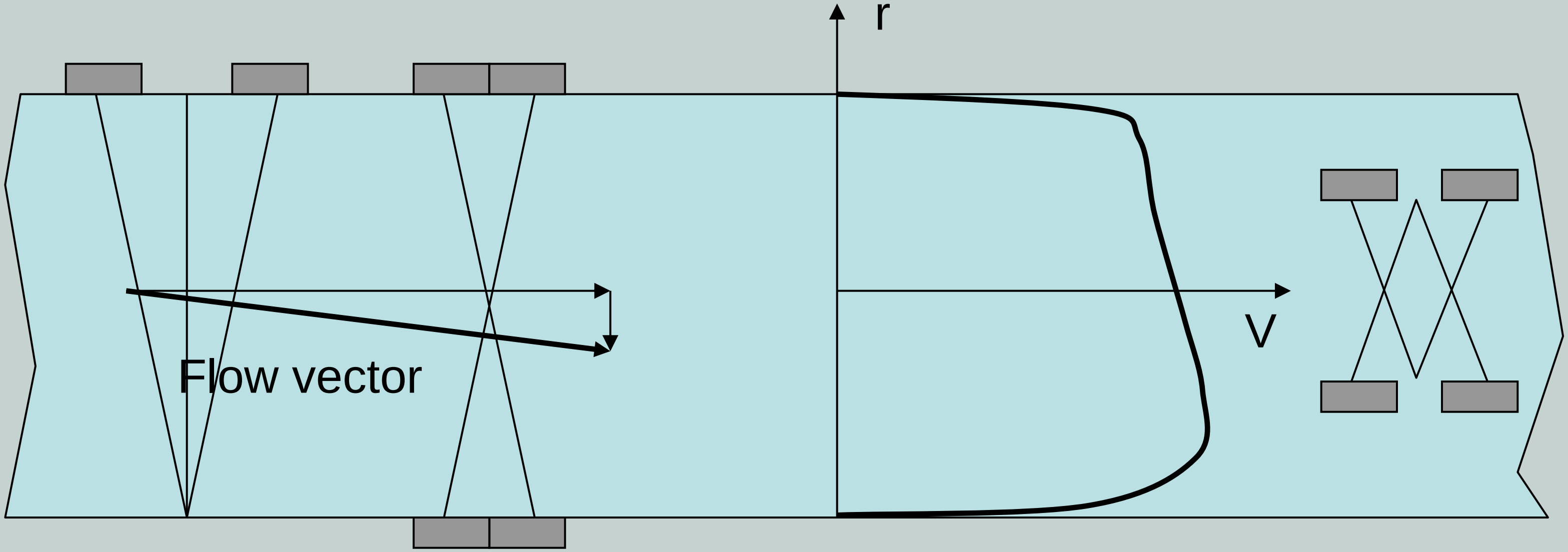
Cross flow compensation:

•Reflect mode or

•Two beam Direct mode

Compensation of profile distortions:

•Two beam reflect mode

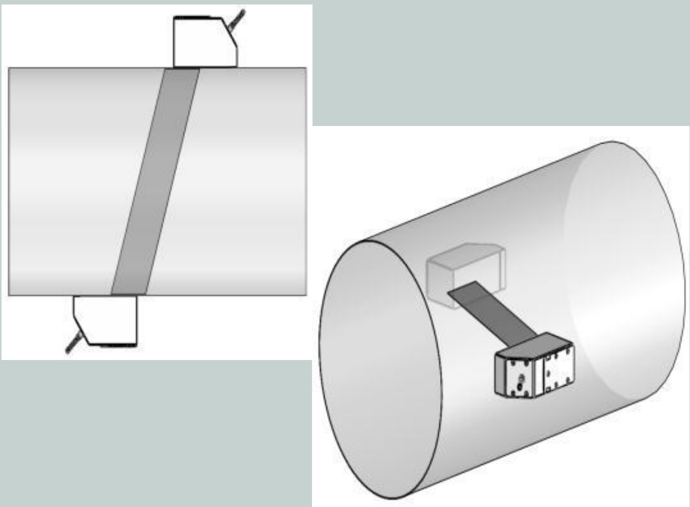


Unsymmetry of

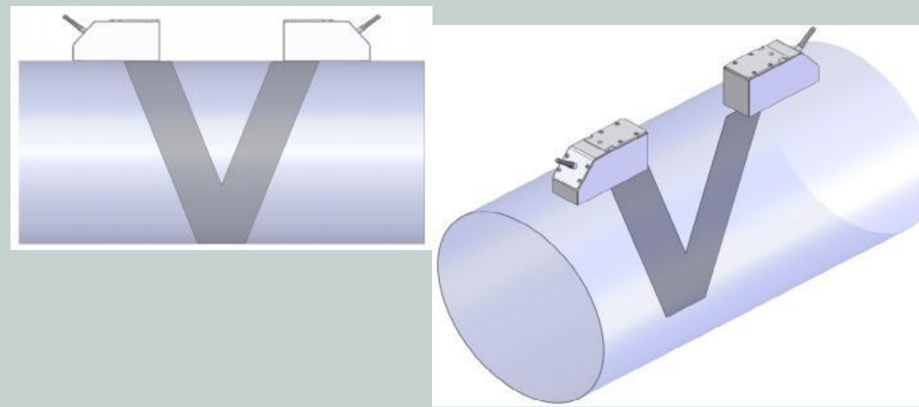
flow profile

Mounting Configurations

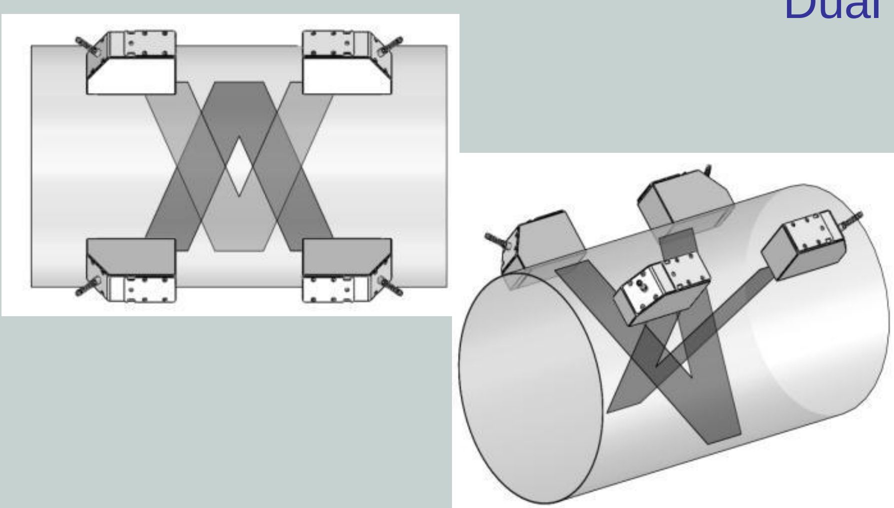
Direct Mount

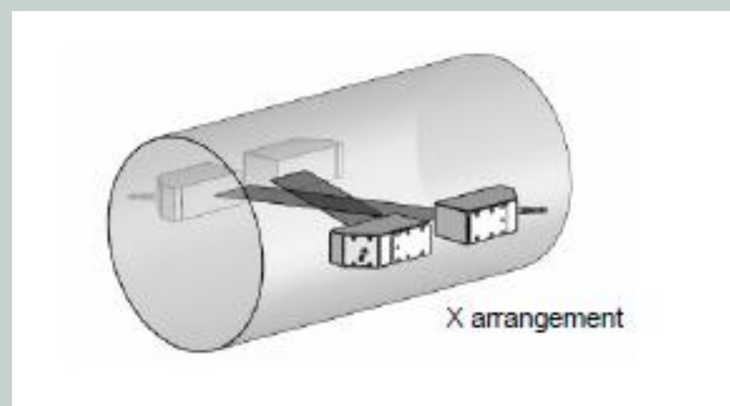


Reflect Mount



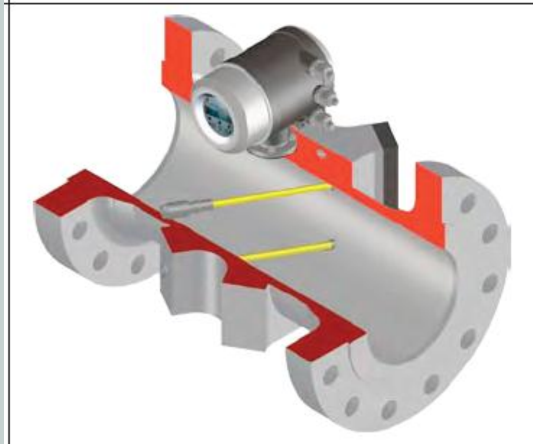
Dual Beam

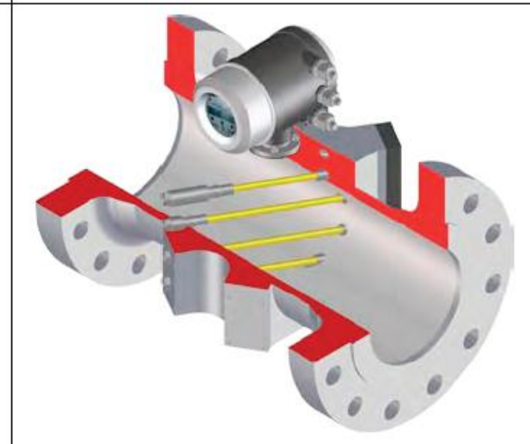


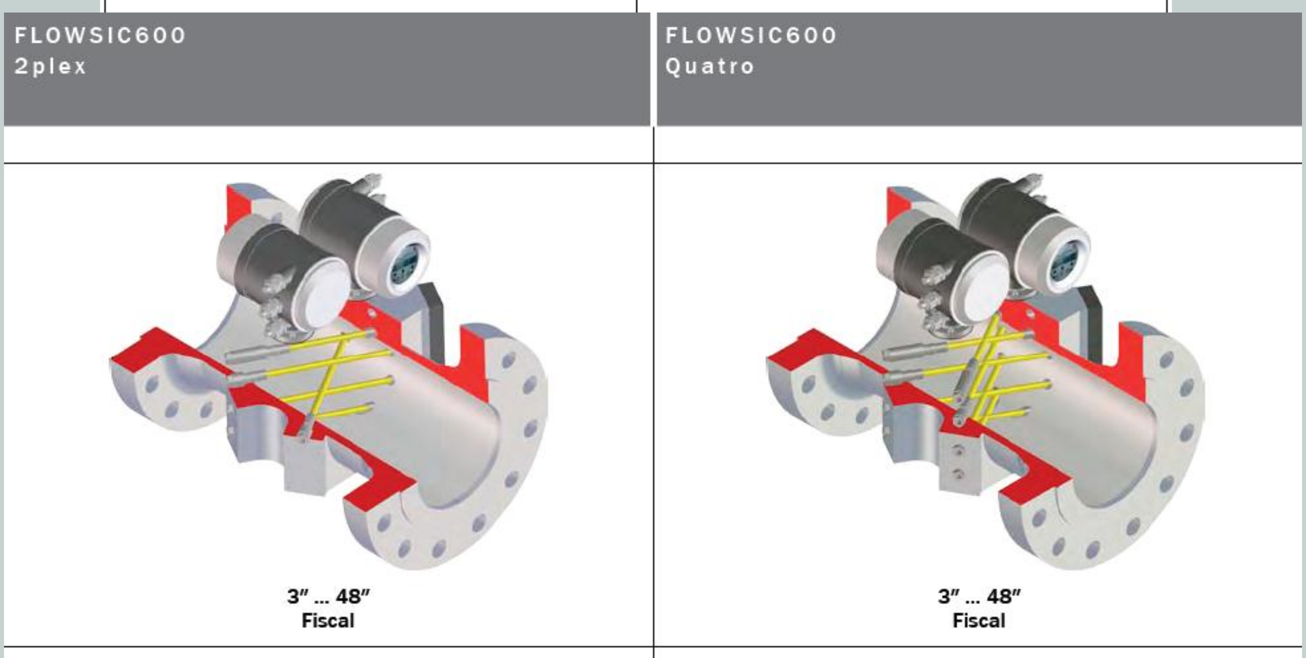


Profile Compensation through multiple chords

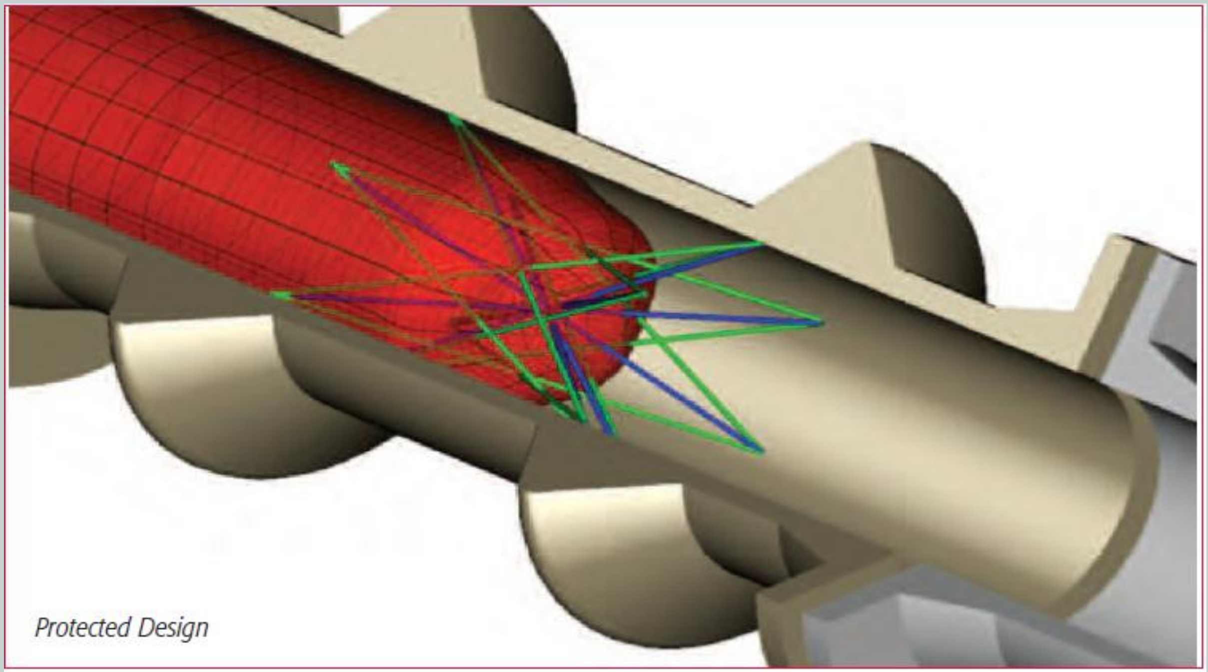
Wetted UFM's Typically Chordal Type
Mostly seen in Gas Applications







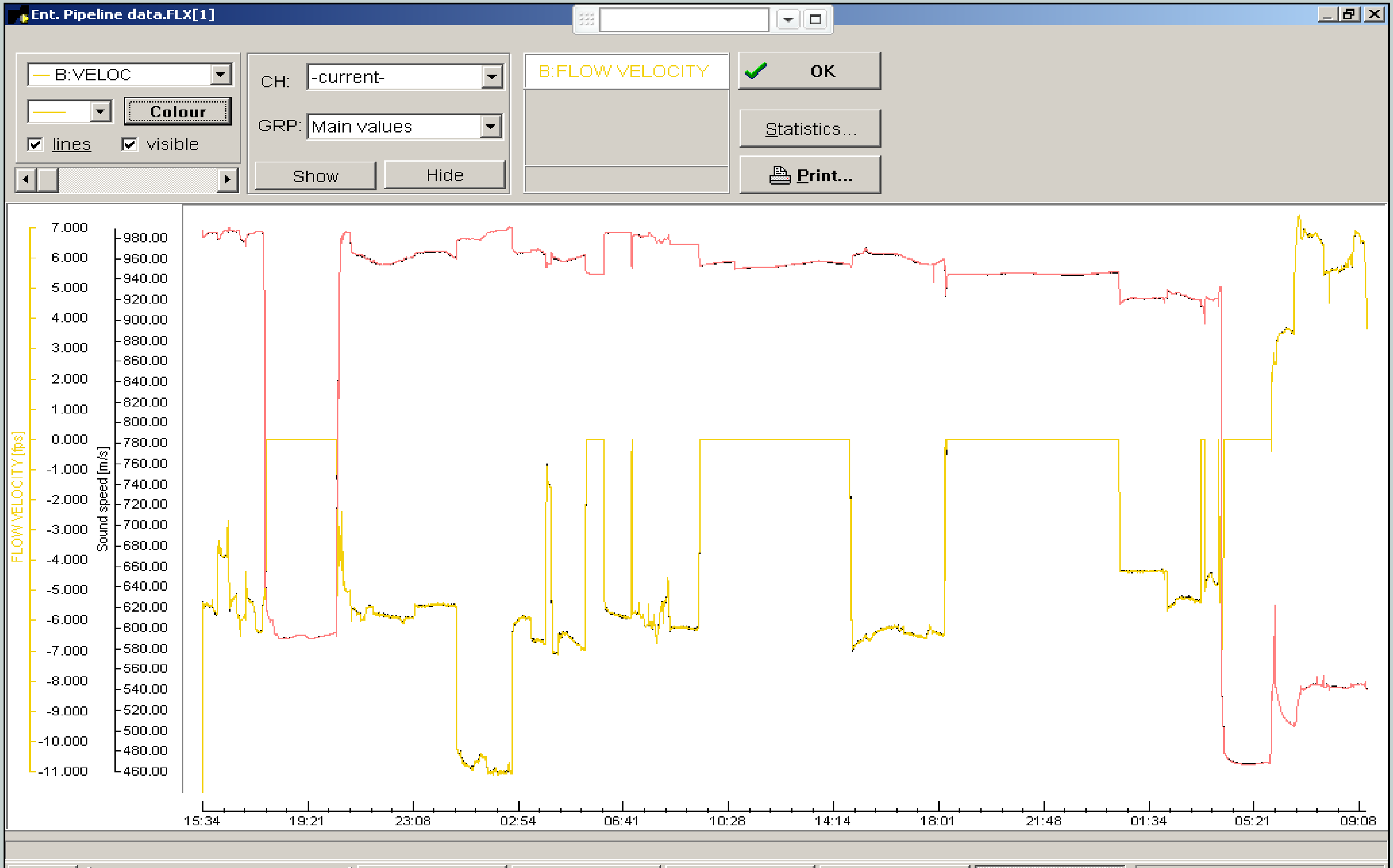
UFM
Utilized primarily for viscous liquids



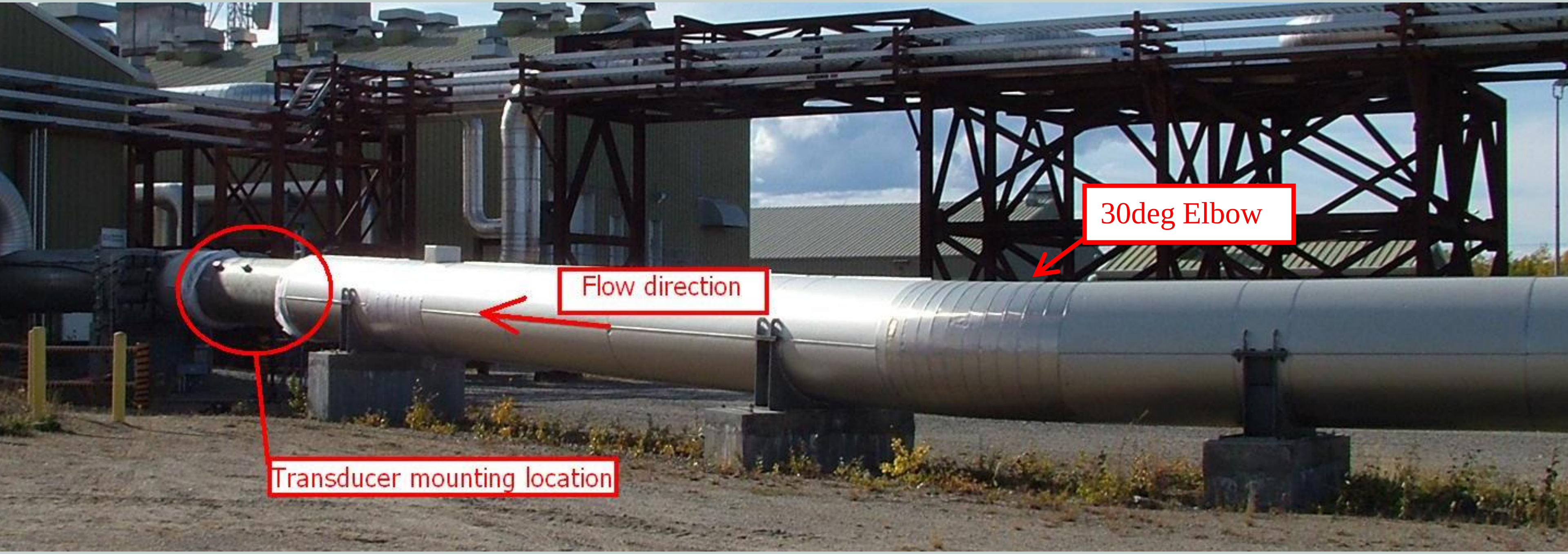
The FH8500 multi-path ultrasonic flowmeter is the only flowmeter that integrates 36 transducers generating 18 ultrasonic beams, providing a complete 3D view of the flow velocity profile.

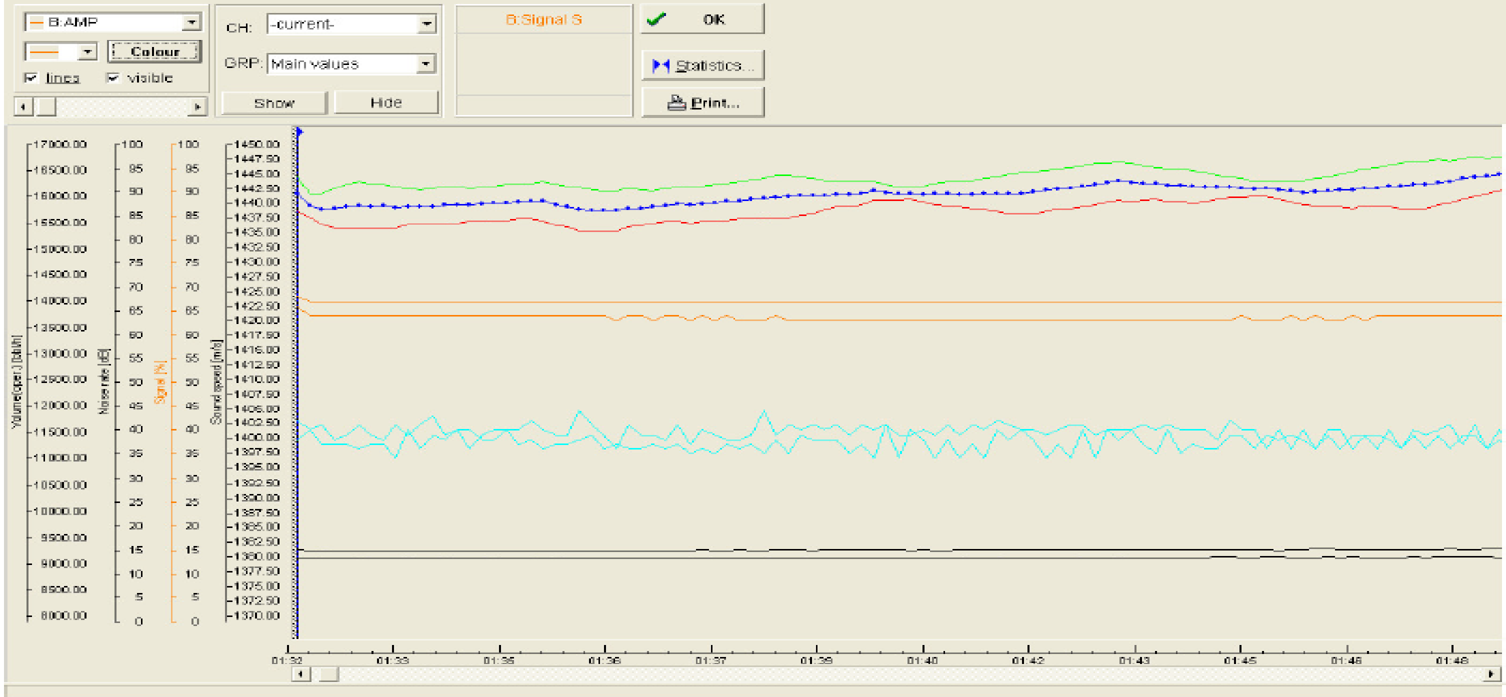
Profile Effect

Diametral Paths yeilding perfect flow symmetry



Dual Channel meter on 48" Pipe





GREEN: Channel A volumetric flow (actual bbl/h)

BLUE: Average volumetric flow (actual bbl/h)

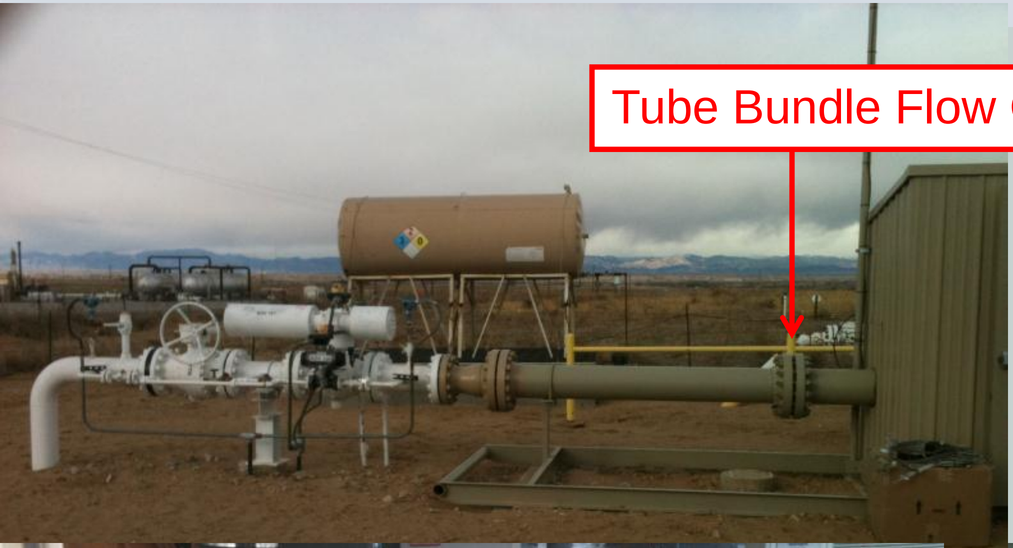
RED: Channel B volumetric flow (actual bbl/h)

ORANGE: Channel A and B signal amplitude (%)

LIGHT BLUE: Signal to correlated noise ratio for channels A and B (dB)

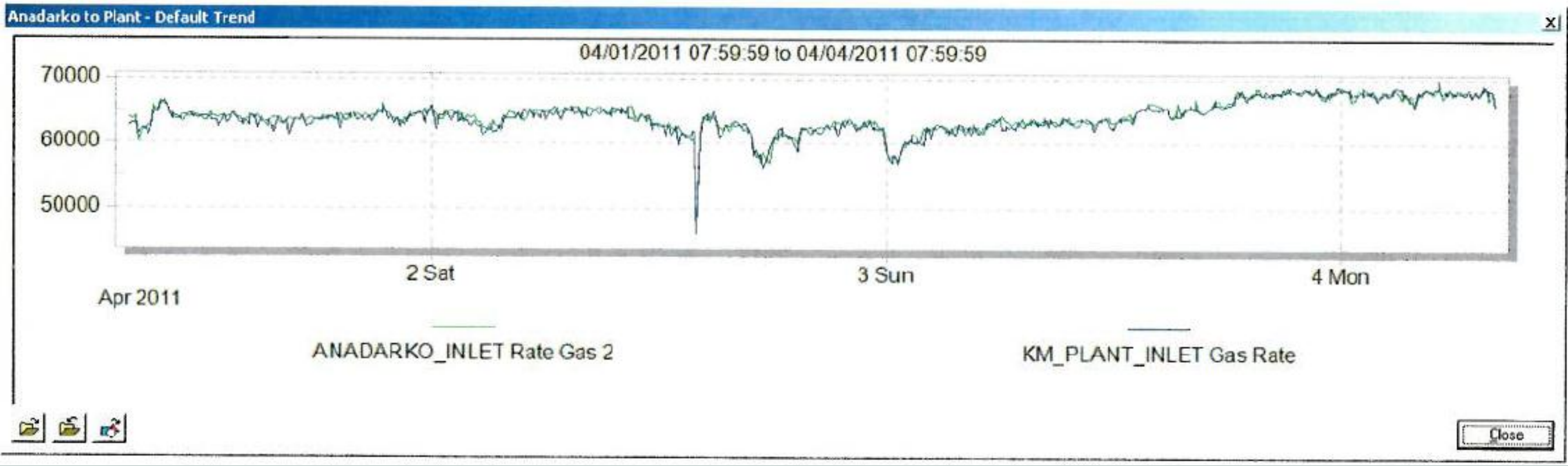
BLACK: Sound speed of both channels as measured by flow meter (m/s)

2 Channel on Orifice meter run

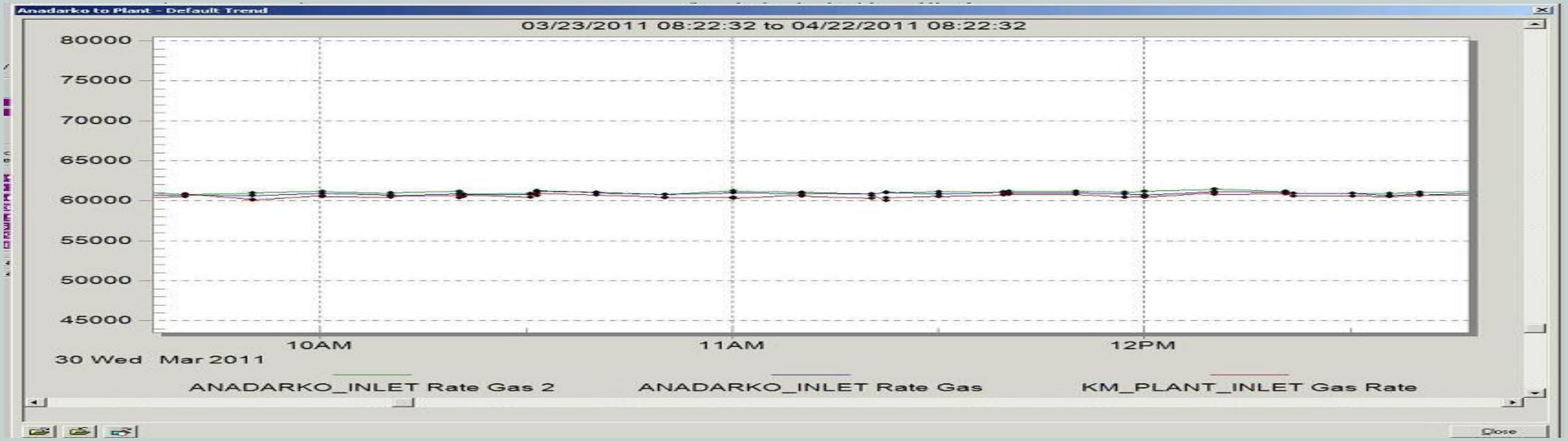


Downstream of tube bundle (less than 10d)
Results show either profile or dimensional effect

Encana Test



2 Orifice Meters at Fiscal point Anadarko & Encana – Flexim meter installed next to Encana meter



Profile effected by product change

Summary of profile effects

- Diametral systems – profile effects are minimized through mounting and multiple beams
- Chordal systems – profile effects are minimized by aligning the paths to mathematically achieve average velocity
- For highest accuracy flow profile conditioners are recommended

UFM Types

Wetted Meters - Gas

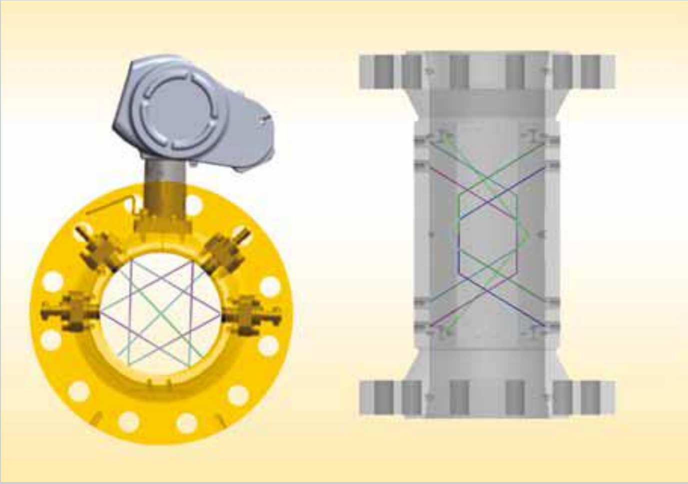
Daniels – 4 Path

Sick - 4 path

Elster American Meter - 6 path

Junior Sonic

Sick - 4 + 4



Wetted UFM arriving at the CEESI Cal Lab

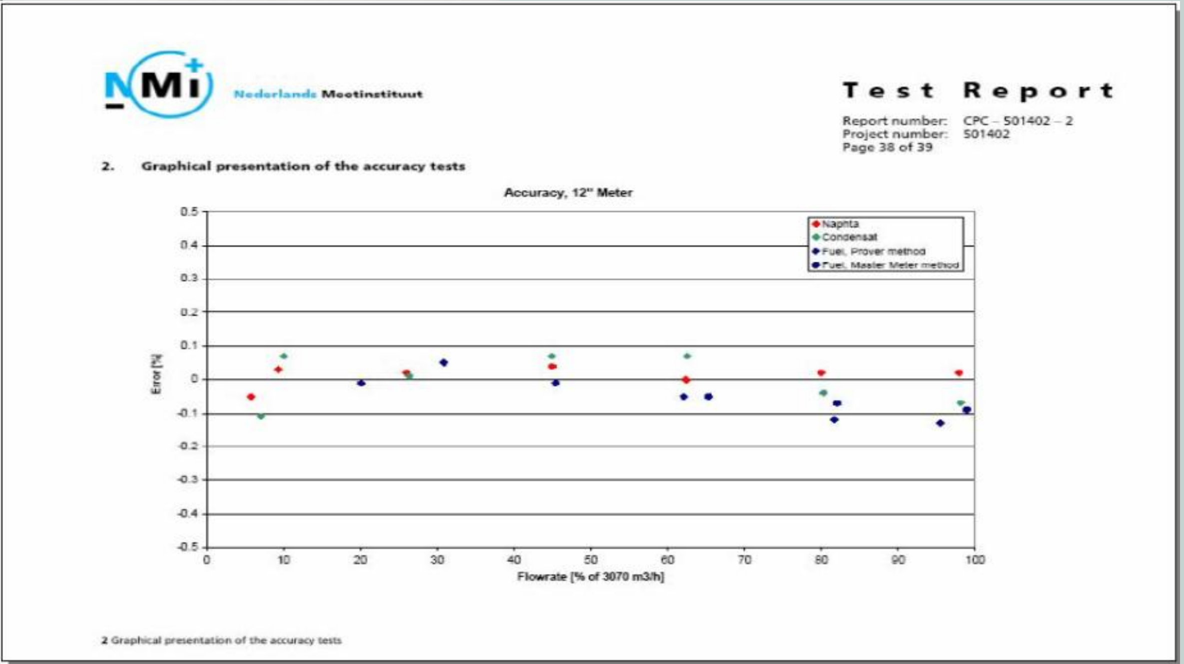
Wetted Meters - Liquids

Hydrocarbon Meters

Cameron 2,4,8 path

Krohne 3,5 path

FMC Technologies 4,6 path



Nederlands Meetinstituut

Test Report

Report number: CPC – 501402 – 2
Project number: 501402
Page 38 of 39

2. Graphical presentation of the accuracy tests

2 Graphical presentation of the accuracy tests

Wetted Meters - Liquids

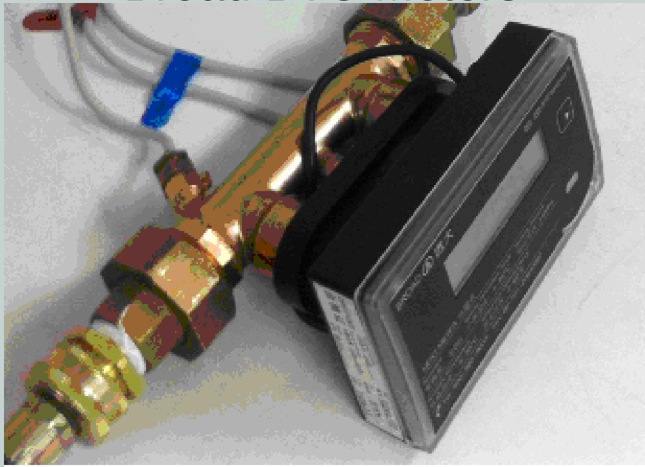
Water and General Purpose Meters

Siemens (Danfoss)

Master Meter

Kamstrup BTU Meters

Broad BTU Meters



Wetted Meters - Steam

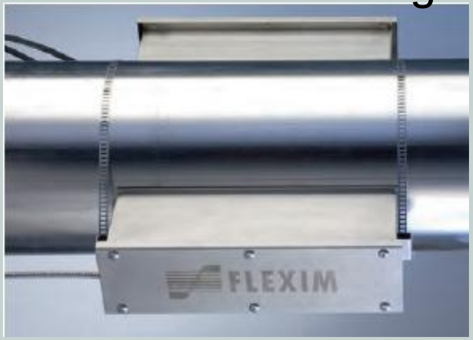
GE – saturated and superheated

Krohne – superheated

Clamp-On Meters – Gas and Liquid

- Flexim
- Siemens (Controlotron)
- GE (Panametrics)
- E&H
- Dynasonics

PermaLok mounting



Ex Housing

Nema 4x (also C1D2)

Flexim - Class 1 Div 2 Portable

Ex Stainless Steel

Where's the Grease?

No more maintenance associated with dry-out of coupling grease

Permanent Couplant Pads

FLEXIM's PermaLok Track Mount System

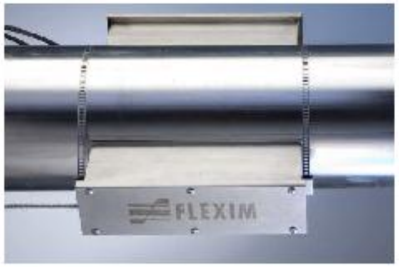
FLEXIM

PermaLok®

PermaLok® Track Mounting System for the FLEXIM Ultrasonic Transducers

RUGGED COST EFECTIVE MOUNTING

FLEXIM recognizes the need for a track mounting system that provides complete protection for the transducer – not only for extreme environments like offshore platforms but for all applications. The protection provided by the PermaLok track system eliminates the maintenance and reliability issues associated with Clamp-on meters. The PermaLok track contains all of the mounting elements to lock in the transducer, effectively securing the transducer coupling in place. Used with the FLEXIM permanent coupling pads the transducer mount becomes permanent. It's as solid as a spool meter without the inconvenience and cost of the spool, and with no internal liquid contact – hence "maintenance free". The cover and pipe mating surfaces are equipped with gaskets to make the track water tight. Used with recommended backfill grease the PermaLok enclosure can be made completely water resistant for underground direct burial applications.



FEATURES

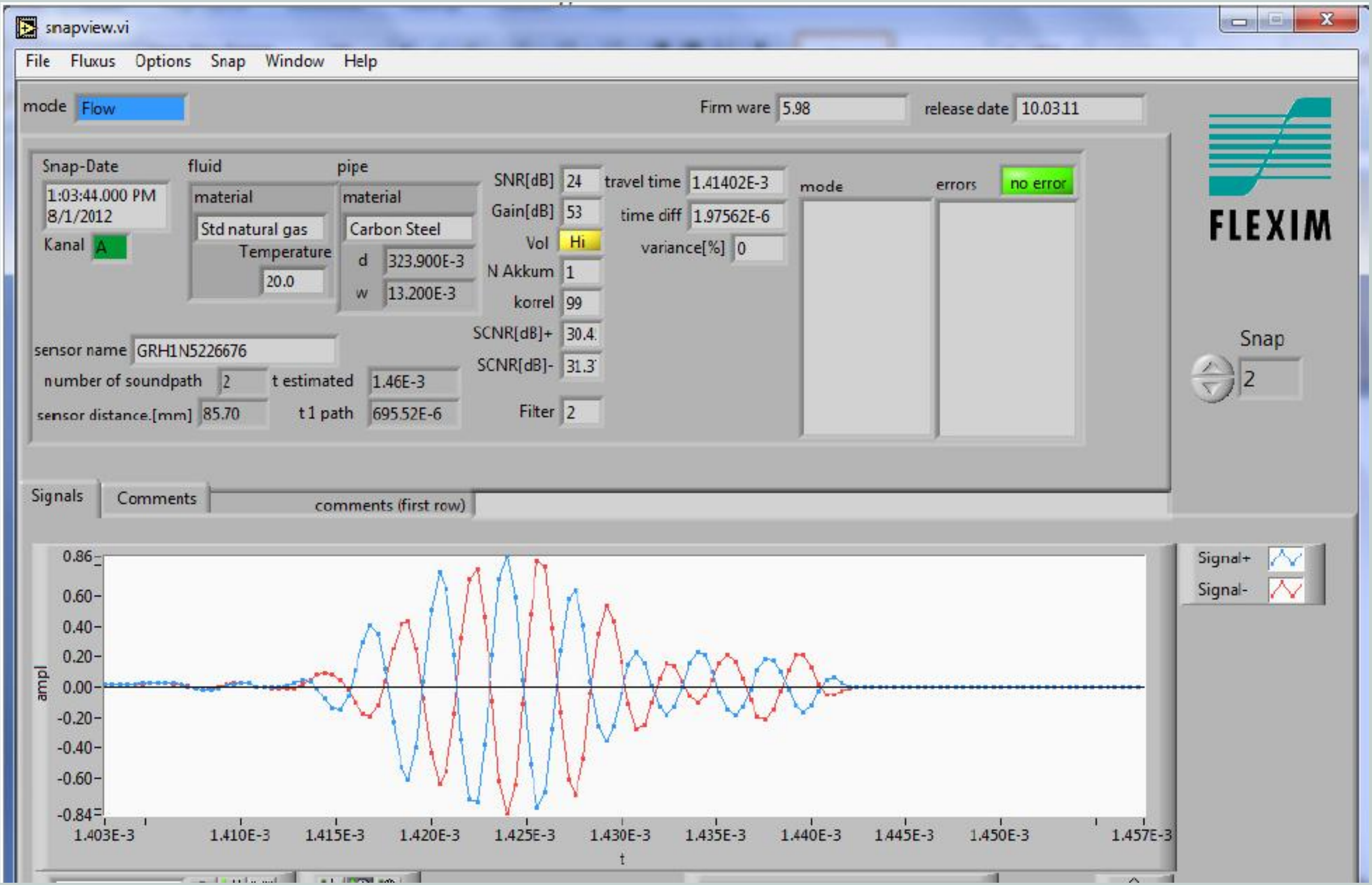
- 304 stainless steel material including strap bands
- CCS Neoprene/EPDM/SBR Blend gasket material
- O-ring gasket for transducer cable
- Single and dual track types to support different mounting requirements
- Optional Feature – Brackets epoxy welded to the pipe eliminates the need for straps.

… external measurement of internal flow

Ultrasonic Metering Diagnostics

A window to the process

Signal Waveforms



Data Set

Measuring data set from C:\Documents and Settings\IzzyR\My Documents\Flexim\Trips\2011\MS Hub\Trip 5-23-11\5-10-11 data\5-10-1...

MEASURING DATA SET: 01 date stamp:
5/5/2011 11:26:26 AM

Channel A:

	DATE_TIME	DATE	TIME	VELOC	MEASURE	Q_POS	Q_NEG	I1	I2	SSPEED	AMP	SCNR	SNR	VARIAMP	VARITIME	ERRBITS
				[fps]	[MCFD]	[Mcft]	[Mcft]	[°F]	[psi]	[m/s]	[%]	[dB]	[dB]	[%]	[%]	[bits]
957	5/8/2011 7:06:26 PM	5/8/2011	7:06:26 PM	3.051	58.19	+36.77		67.10	1016.20	420.71	49	31	39	1	0	0
958	5/8/2011 7:11:26 PM	5/8/2011	7:11:26 PM	3.025	57.65	+36.97		67.10	1016.20	420.78	49	33	39	2	0	0
959	5/8/2011 7:16:26 PM	5/8/2011	7:16:26 PM	3.058	58.34	+37.17		67.10	1016.30	420.62	49	30	39	2	0	0
960	5/8/2011 7:21:26 PM	5/8/2011	7:21:26 PM	3.058	58.33	+37.37		67.10	1016.20	420.67	49	32	39	1	0	0
961	5/8/2011 7:26:26 PM	5/8/2011	7:26:26 PM	2.969	56.60	+37.57		67.10	1016.10	420.65	49	32	39	1	0	0
962	5/8/2011 7:31:26 PM	5/8/2011	7:31:26 PM	3.061	58.35	+37.77		67.10	1016.20	420.65	49	32	39	3	0	0
963	5/8/2011 7:36:26 PM	5/8/2011	7:36:26 PM	2.966	56.55	+37.97		67.10	1016.20	420.65	49	33	40	3	0	0
964	5/8/2011 7:41:26 PM	5/8/2011	7:41:26 PM	3.018	57.57	+38.17		67.10	1016.20	420.66	49	32	39	2	0	0
965	5/8/2011 7:46:26 PM	5/8/2011	7:46:26 PM	3.051	58.17	+38.37		67.10	1016.10	420.67	49	32	39	1	0	0
966	5/8/2011 7:51:26 PM	5/8/2011	7:51:26 PM	3.028	57.76	+38.57		67.10	1016.30	420.63	49	31	39	1	0	0
967	5/8/2011 7:56:26 PM	5/8/2011	7:56:26 PM	3.045	58.05	+38.78		67.10	1016.10	420.60	49	33	40	2	0	0
968	5/8/2011 8:01:26 PM	5/8/2011	8:01:26 PM	2.920	55.66	+38.98		67.10	1016.20	420.60	49	33	40	1	0	0
969	5/8/2011 8:06:26 PM	5/8/2011	8:06:26 PM	3.107	59.27	+39.18		67.10	1016.10	420.61	49	33	40	2	0	0
970	5/8/2011 8:11:26 PM	5/8/2011	8:11:26 PM	3.104	59.18	+39.39		67.10	1016.20	420.58	49	34	39	2	0	0
971	5/8/2011 8:16:26 PM	5/8/2011	8:16:26 PM	3.051	58.23	+39.59		66.92	1016.20	420.59	49	34	40	1	0	0
972	5/8/2011 8:21:26 PM	5/8/2011	8:21:26 PM	3.048	58.15	+39.80		66.92	1016.10	420.55	48	35	40	1	0	0
973	5/8/2011 8:26:26 PM	5/8/2011	8:26:26 PM	3.058	58.35	+40.00		66.92	1016.20	420.53	48	35	39	3	0	0
974	5/8/2011 8:31:26 PM	5/8/2011	8:31:26 PM	2.904	55.41	+40.20		66.92	1016.20	420.54	48	34	40	1	0	0
975	5/8/2011 8:36:26 PM	5/8/2011	8:36:26 PM	3.048	58.15	+40.40		66.74	1016.10	420.48	48	34	38	2	0	0
976	5/8/2011 8:41:26 PM	5/8/2011	8:41:26 PM	3.107	59.30	+40.60		66.74	1016.20	420.54	48	36	39	2	0	0
977	5/8/2011 8:46:26 PM	5/8/2011	8:46:26 PM	3.031	57.83	+40.81		66.74	1016.00	420.48	48	33	40	2	0	0
978	5/8/2011 8:51:26 PM	5/8/2011	8:51:26 PM	3.081	58.84	+41.01		66.74	1016.10	420.47	48	34	38	2	0	0
979	5/8/2011 8:56:26 PM	5/8/2011	8:56:26 PM	3.074	58.70	+41.21		66.56	1016.10	420.46	48	35	39	2	0	0
980	5/8/2011 9:01:26 PM	5/8/2011	9:01:26 PM	3.104	59.29	+41.41		66.56	1016.00	420.45	48	35	39	3	0	0
981	5/8/2011 9:06:26 PM	5/8/2011	9:06:26 PM	3.120	59.61	+41.61		66.56	1016.10	420.42	48	35	39	1	0	0
982	5/8/2011 9:11:26 PM	5/8/2011	9:11:26 PM	3.051	58.28	+41.82		66.56	1016.10	420.38	48	34	39	1	0	0
983	5/8/2011 9:16:26 PM	5/8/2011	9:16:26 PM	3.081	58.87	+42.02		66.56	1016.00	420.37	48	34	39	2	0	0

Diagnostic Statistics and Quality Indicators

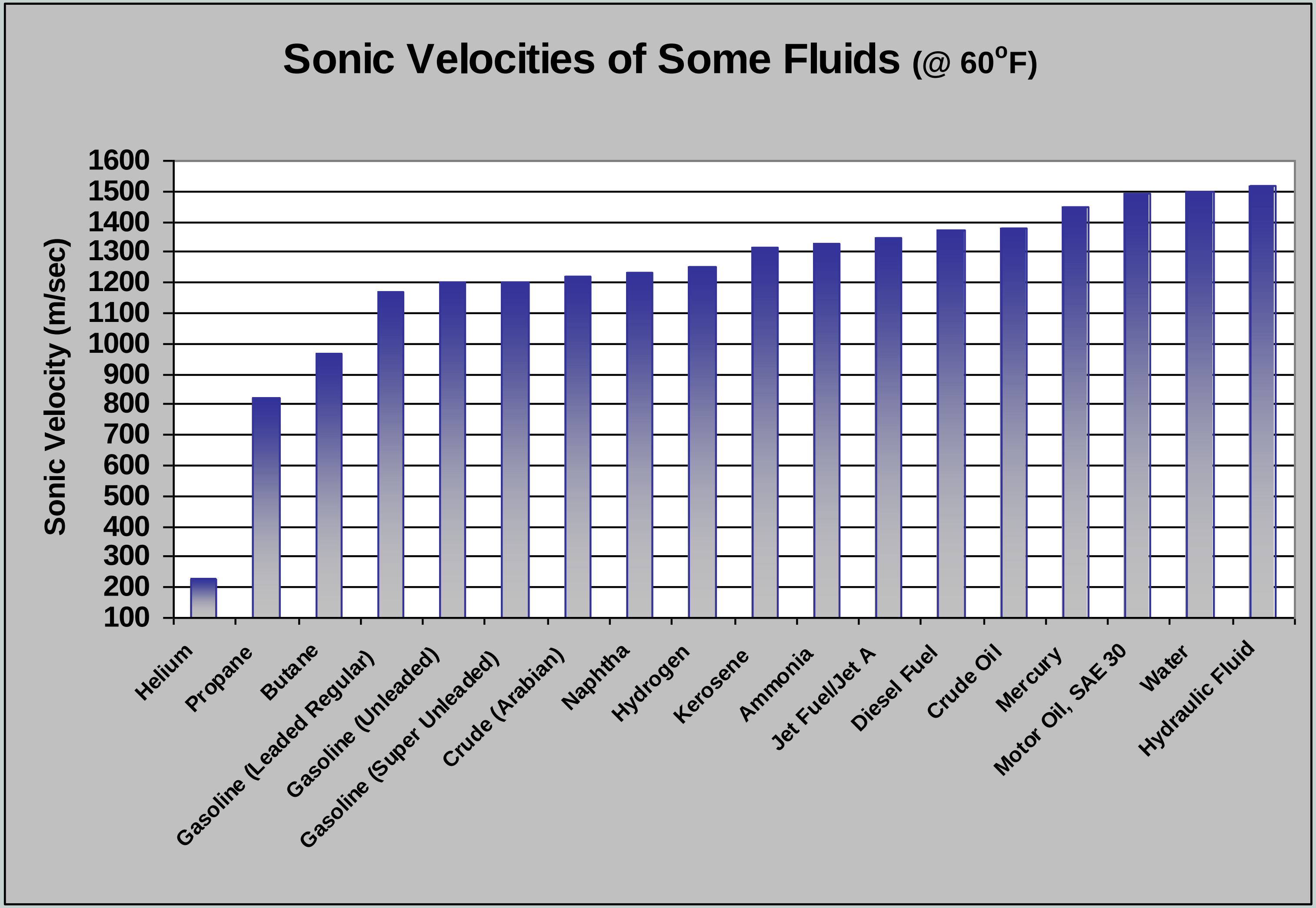
Encana 3-8.FLX[1]

BEGIN: 3/2/2011 3:33:20 AM from first point
END: 3/8/2011 6:43:20 PM to last point

☐ Show flow ranges ☐ Quality view only ☑ Show Min/Max

	Flow [m/s]	Ch	Curve	Quality	MEAN	Std.Dev	Unit	Points	Valid	MIN	MAX	MAX-MIN	MinValue@	MaxValue@
1	ALL	A:	VELOC		17.796	0.8991	fps	1911	1911	15.413	19.626	4.213	3/5/2011 1:38:20 AM	3/6/2011 4:08:20 PM
2	ALL	A:	MEASURE		35189.66	1777.878	CFH	1911	1911	30478.96	38809.10	8330.14	3/5/2011 1:38:20 AM	3/6/2011 4:08:20 PM
3	ALL	A:	SSPEED		346.33	1.849	m/s	1911	1911	341.99	353.15	11.16	3/6/2011 5:33:20 PM	3/6/2011 12:53:20 PM
4	ALL	A:	AMP		53	0.8	%	1911	1911	52	54	2	3/2/2011 3:38:20 AM	3/2/2011 10:53:20 AM
5	ALL	A:	SCNR		42	1.4	dB	1911	1911	34	48	14	3/3/2011 2:08:20 AM	3/4/2011 11:08:20 AM
6	ALL	A:	SNR		27	3.0	dB	1911	1911	18	32	14	3/3/2011 1:38:20 AM	3/3/2011 1:58:20 PM
7	ALL	A:	VARIAMP		6	1.5	%	1911	1911	2	12	10	3/4/2011 1:28:20 PM	3/5/2011 6:53:20 AM
8	ALL	A:	VARITIME		0	0.2	%	1911	1911	0	4	4	3/2/2011 3:33:20 AM	3/3/2011 11:38:20 PM
9	ALL	B:	VELOC		17.508	0.8780	fps	1912	1912	15.161	19.341	4.180	3/5/2011 1:43:20 AM	3/6/2011 4:13:20 PM
10	ALL	B:	MEASURE		34621.21	1736.178	CFH	1912	1912	29979.41	38244.67	8265.26	3/5/2011 1:43:20 AM	3/6/2011 4:13:20 PM
11	ALL	B:	SSPEED		345.57	1.839	m/s	1912	1912	341.28	352.35	11.08	3/6/2011 5:38:20 PM	3/6/2011 12:58:20 PM
12	ALL	B:	AMP		52	0.7	%	1912	1912	50	54	4	3/4/2011 8:33:20 PM	3/6/2011 6:03:20 AM
13	ALL	B:	SCNR		41	1.4	dB	1912	1912	37	46	9	3/3/2011 12:03:20 AM	3/3/2011 12:08:20 AM
14	ALL	B:	SNR		26	3.0	dB	1912	1912	18	32	14	3/3/2011 1:48:20 AM	3/2/2011 4:58:20 AM
15	ALL	B:	VARIAMP		5	1.2	%	1912	1912	2	11	9	3/2/2011 11:38:20 PM	3/5/2011 7:13:20 AM
16	ALL	B:	VARITIME		0	0.2	%	1912	1912	0	3	3	3/2/2011 3:33:20 AM	3/6/2011 12:18:20 AM
17	ALL	Y:	MEASURE		34905.22	1756.607	CFH	1912	1912	30201.19	38532.66	8331.47	3/5/2011 1:43:20 AM	3/6/2011 4:13:20 PM
18	ALL	S:	PDR_VELOC		1.63	13.646	%	1911	1911	-12.69	5.97	18.65	3/3/2011 1:03:20 AM	3/5/2011 5:33:20 AM
19	ALL	S:	PDR_SSPEED		0.22	25.536	%	1911	1911	-1.23	1.68	2.91	3/6/2011 1:18:20 PM	3/6/2011 1:33:20 PM
20	ALL	S:	PDA_AMP		0.6	0.52	dB	1911	1911	0.0	2.0	2.0	3/2/2011 3:38:20 AM	3/2/2011 11:08:20 PM
21	ALL	S:	PDA_SNR		0.1	1.95	dB	1911	1911	-7.0	7.0	14.0	3/6/2011 1:08:20 AM	3/8/2011 5:53:20 AM
22	ALL	S:	PDA_SCNR		1.6	1.97	dB	1911	1911	-7.0	8.0	15.0	3/3/2011 2:08:20 AM	3/4/2011 11:08:20 AM

Sound Velocity used for Fluid Identity



Special HPI Variables

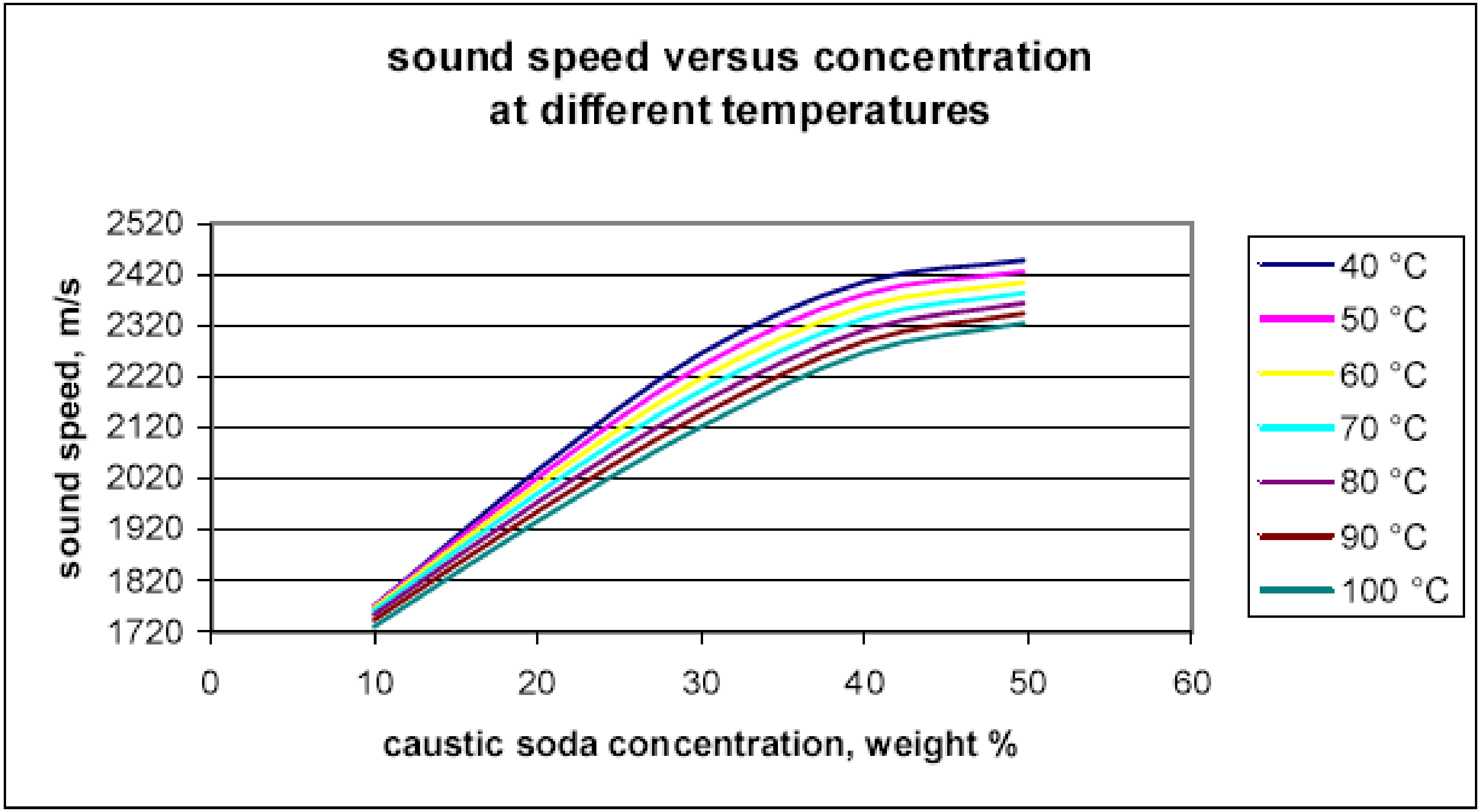
- A number of new variables that are unique to the HPI meter are available to the user:
  - SonicID: Temperature corrected speed of sound of the liquid. This variable allows the meter to know which liquid is being sensed for Multi-Liquid systems.
  - DBC (density @ base conditions), S.G. (specific gravity) and API gravity: These are all expressions of the same basic parameter (mass per unit volume of the liquid being sensed).
  - VCF & VCP: Temperature and Pressure Volume correction factors used to publish standard volumetric rate and totals.
  - Liquid: If enabled, the meter publishes which of a series of liquids is currently being sensed based on SonicID.

Special HPI Variables

- VSC: Computed Liquid Viscosity based on currently sensed liquid and measured temperature.
- Normalized Volumetric Flowrate and Totals (+ and -)
  - These are derived by multiplying the actual rate and totals by the temperature and pressure volume correction factors. The volume correction factors are computed in accordance with industry standard algorithms such as TP-25, ASTM1250 and D4311.
  - The meter ‘knows’ which algorithm to apply since it knows the liquid currently being sensed by means of its SonicID variable.

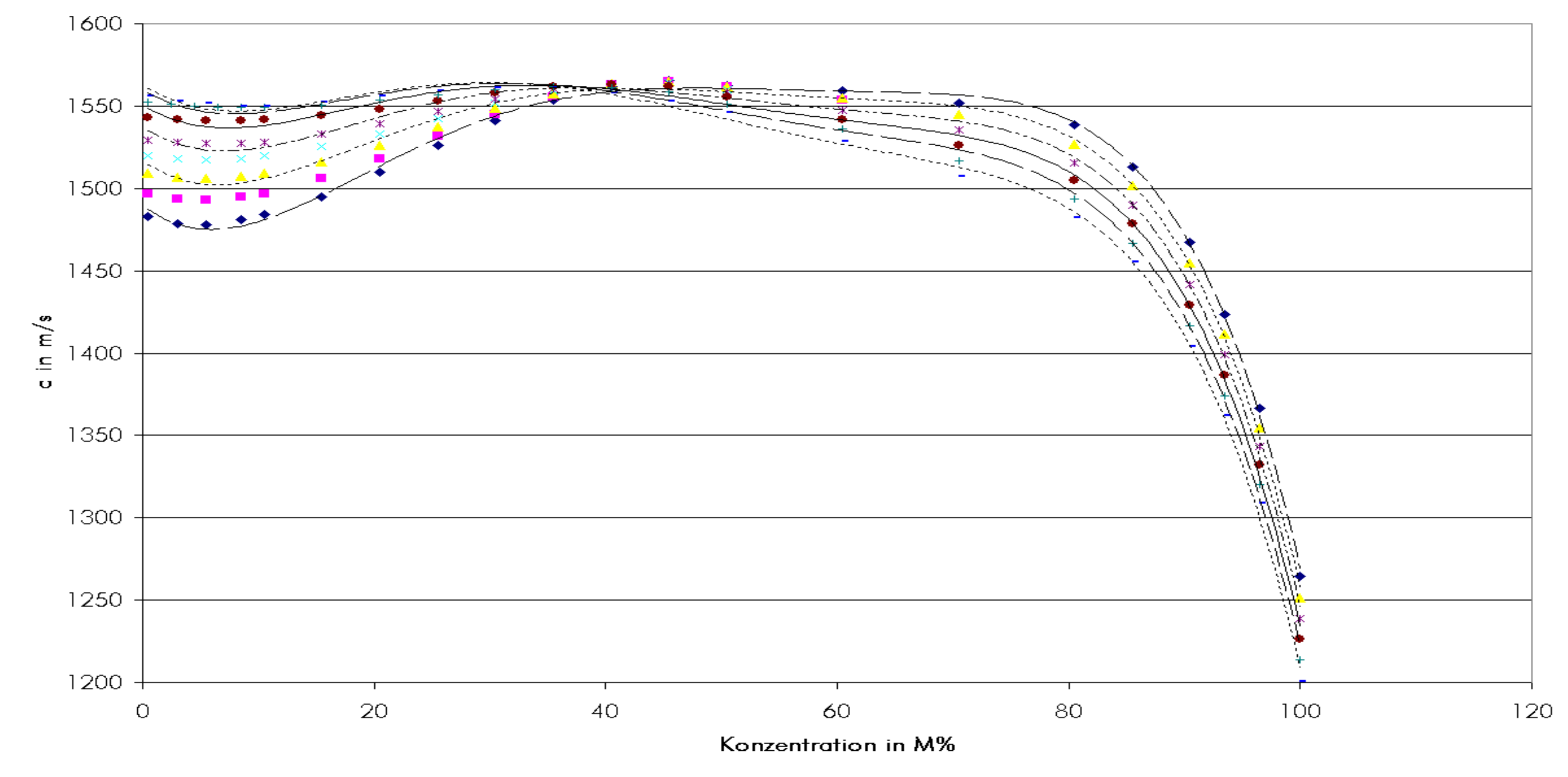
Concentration Measurement

NaOH



Concentration Measurement

H2SO4 between temperatures 60 … 180°F



case study

By Jack Sine & Izzy Rivera

Running Hot

Ultrasonic flowmeter reveals reason for tube failure in high-heat application

A major power generator on the East Coast was having a serious problem with premature tube failure in the feed-water heater in one of its 400-megawatt pulverized coal plants. The company has asked not to be identified, but says it thinks the nature of the problem may be widespread and would like to share the solution with the rest of the industry.

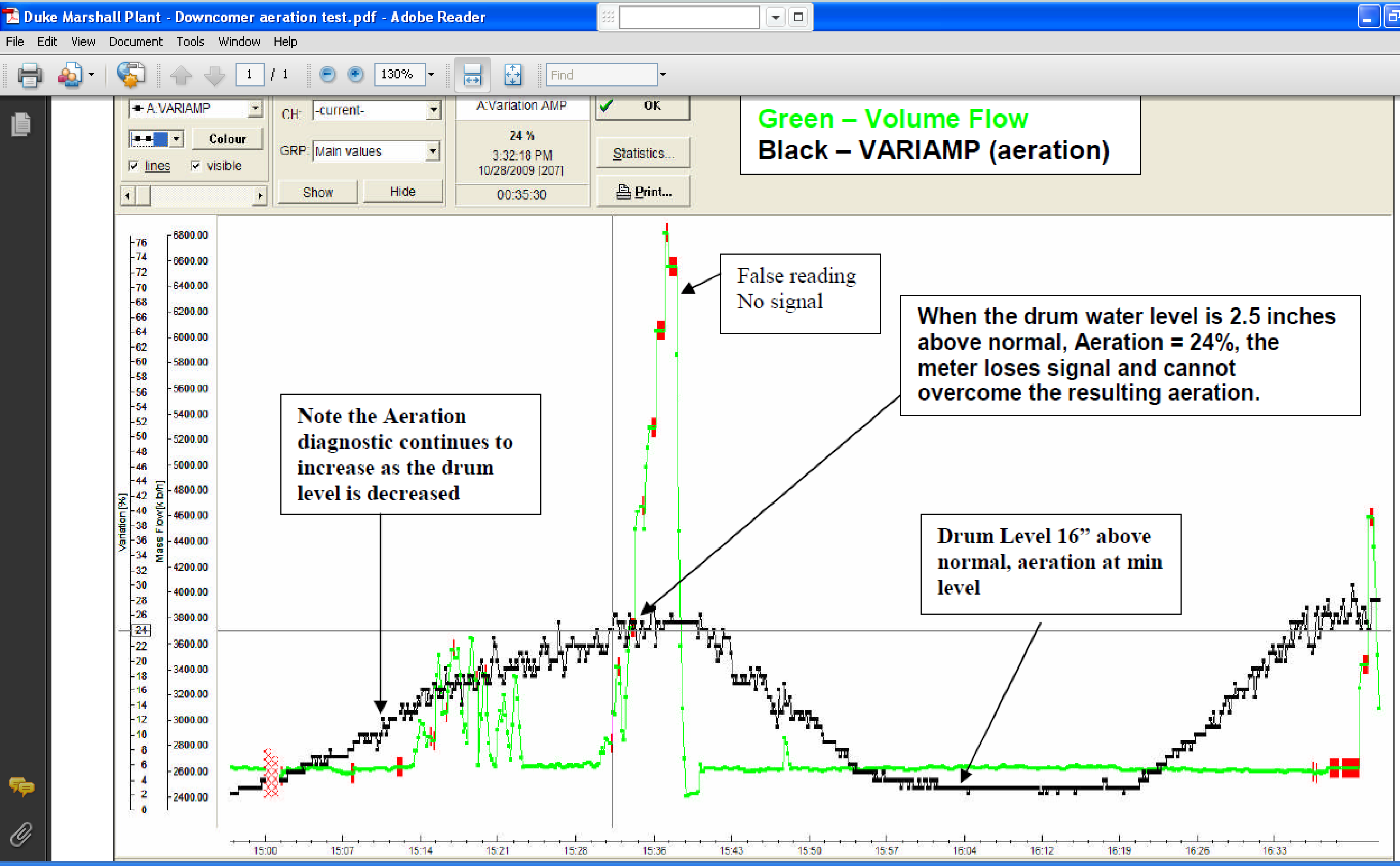
"We were getting hot spots in the water wall," says Tim, the plant's chief engineer. "We were pretty sure this was contributing to the tube failure, and maybe the only cause. We could measure the temperature at various spots on the water wall easily enough, but we thought the problem might be caused by inconsistent water flow, so what we needed was to find a way to measure the flow of the return water.

However, there were two problems with measuring the water flow. The first was that the company didn't want to cut into the pipe to generate the flow measurement. The second was that the return water was condensed from steam and under pressure, so the pipe temperature was around 650 F.

ing accurate readings. A clamp-on transducer mounted directly on the pipe can only operate up to around 400 F. The WaveInjector utilizes a mounting structure that removes the transducer from the pipe and positions it on waveguide plates. It also enables a set of standard transducers to operate accurately at temperature ranges from -256 F up to 750 F.

Duke Energy – Feedwater Downcomers

Aeration Diagnostic



Lab Calibrations of Clamp-on

CEESI Calibration Lab - Iowa

Gas Accuracy Testing on Multiple Pipe Sizes

FLEXIM

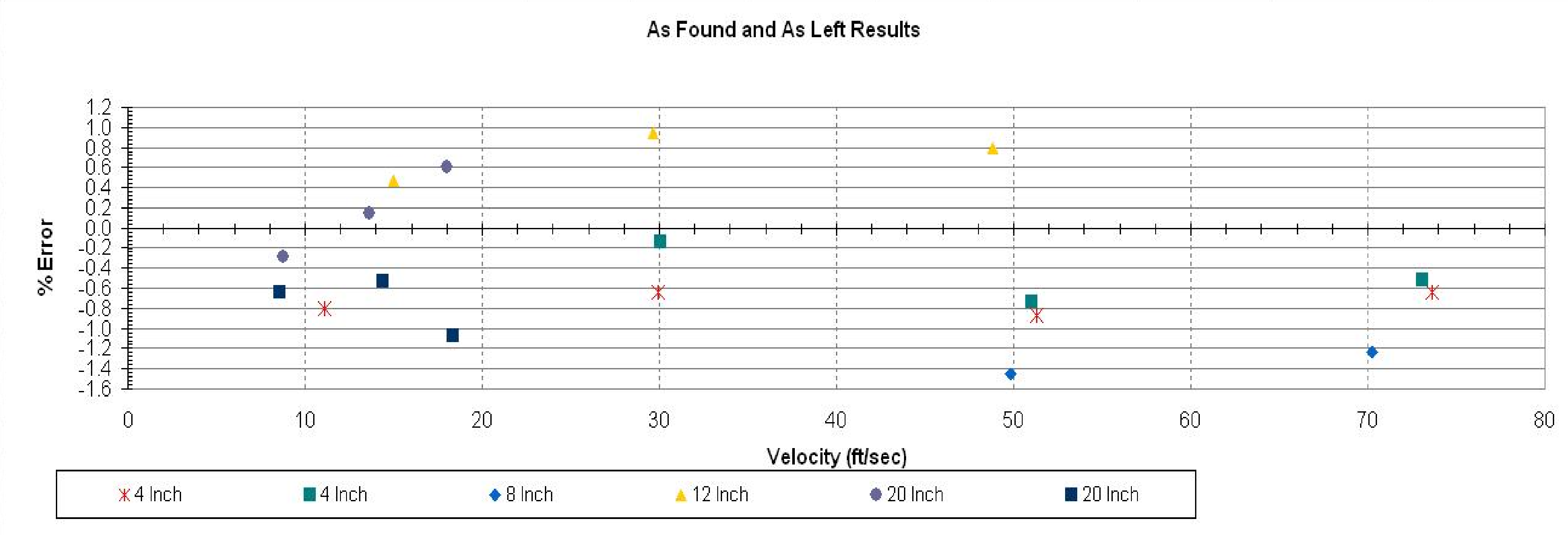
CEESI Iowa Flow Calibration

CALIBRATION RESULTS

PRELIMINARY

Customer :	CEESI
Serial Number :	6010285
Purchase Order # :	NA
Sales Order # :	NA
Flow Conditioning :	Profiler
Date :	6-Jan-10
Flow Direction =	Forward

Data Point	4" Pipe - 1/6/10 10CEE-0015		4" Pipe - 1/6/10 10CEE-0020		8" Pipe - 1/7/10 10CEE-0023		12" Pipe - 1/7/10 10CEE-0027		20" Pipe (Reflect Mode) - 1/8/10 10CEE-0042		20" Pipe (Reflect Mode) - 1/18/10 10CEE-0131 (GDK Transducers)	
	ft/sec	% Error	ft/sec	% Error	ft/sec	% Error	ft/sec	% Error	ft/sec	% Error	ft/sec	% Error
1	73.633	-0.641	73.08	-0.524	70.266	-1.241	48.853	0.798	18.045	0.611	26.455	-5.314
2	51.314	-0.871	51.037	-0.733	49.863	-1.458	29.636	0.949	13.597	0.148	18.389	-1.078
3	29.961	-0.644	30.077	-0.136			14.973	0.471	8.765	-0.293	14.359	-0.534
4	11.114	-0.802									8.587	-0.646



… external measurement of internal flow

3rd party calibration results

FLEXIM

CEESI

LABORATORY/OFFICE:
54043 County Rd. 37
Nunn, Colo. 80648
Phone: 970-897-2711
FAX: 970-897-2710

COLORADO ENGINEERING EXPERIMENT STATION INC.

...the primary source for flow measurement solutions...

CEESIowa

IOWA HIGH FLOW FACILITY
2365 240th St.
Garner, IA 50438
Phone: 641-923-3664
FAX: 641-923-3693

Calibration of a Clamp On Flowmeter
Model: FLUXUS ADM 6725 Serial Number: 02501087-2
For: Flexim Order: 1061
Data File: 07FXM-0005 Disc: CE04815 Date: 3 May 2007
Inlet Diameter: 10.094 inches Throat Diameter: 10.094 inches
Test gas: Natural Gas Standard density= 0.04434 lbm/ft³ (* for nominal gas composition)
at standard conditions of 519.67 °R, and 14.696 Psia
Freq: Meter Output, Hertz (pulses/sec)
ACFH: Volumetric flowrate at meter BODY, actual cubic feet per hour
KFactor: Pulses per cubic foot
ReyNo: Pipe Reynolds number
Density: Flowing density at meter BODY, pounds mass per cubic foot
Press: Meter BODY static pressure in psia
Temp: EXIT temperature, degrees Rankine
%Error: Percent difference CEESI k-factor from nominal k-factor

Pt.	Freq	ACFH	KFactor	ReyNo	Density	Press	Temp	%Error
1	766.33	30737	89.754	4954764	3.3335	974.16	521.3	-0.273
2	759.88	30431.1	89.894	4907063	3.3337	974.14	521.3	-0.117
3	733.56	29430.5	89.730	4742328	3.3337	974.16	521.3	-0.299
4	2503.75	100076	90.066	16056042	3.3074	967.02	521.2	0.074
5	2502.11	100167	89.925	16062936	3.3071	966.96	521.2	-0.083
6	2508.83	100373	89.982	16090910	3.3057	966.60	521.2	-0.020
7	3731.71	149155	90.068	23858985	3.2945	963.25	521.0	0.076
8	3703.01	148215	89.943	23706809	3.2938	963.21	521.0	-0.064
9	3717.47	148671	90.017	23767185	3.2930	963.09	521.1	0.019

Average values for above results:
Press: 968.07 Psia Density: 3.3114 lbm/ft³
Temp: 521.17 °R
Compressibility factor: 0.87439

ATMOS builds a 24” Spool Calibrated at CEESI Iowa

CEESI Calibration 8/2012

FLEXIM

CEESI Iowa Flow Calibration

CALIBRATION RESULTS

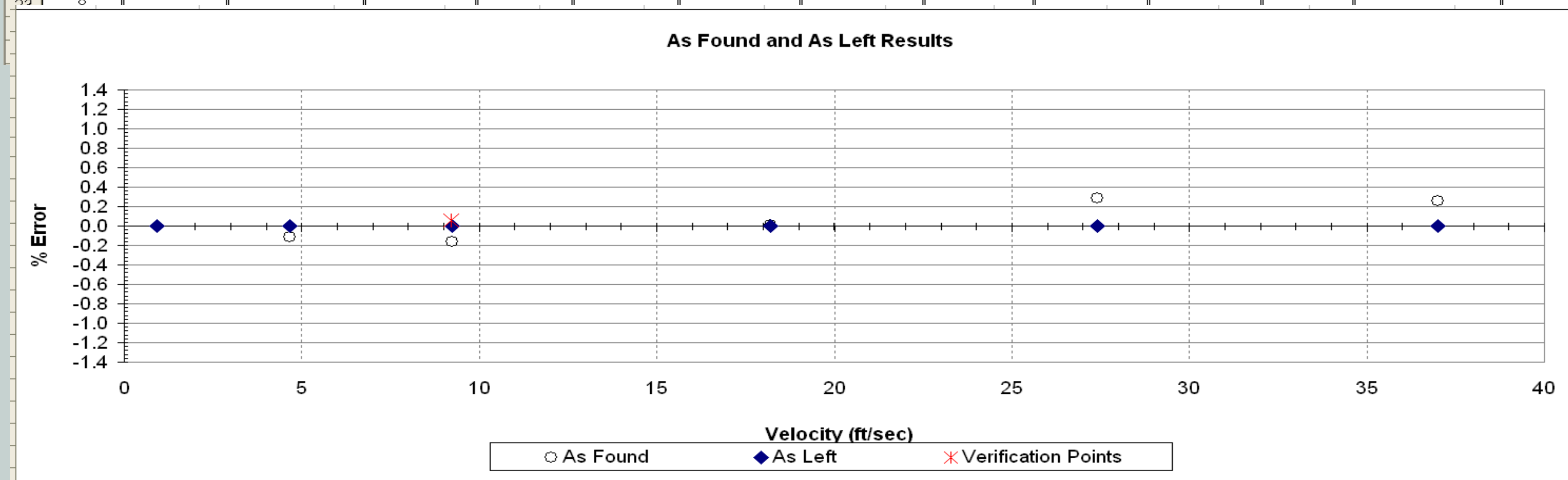
Customer : Flexim
Serial Number : 7408440
Sales Order # : N/A
Purchase Order # : N/A
Flow Conditioning : No F.C.
Date: 21-Aug-12
Flow Direction = Forward

95

PRELIMINARY

Meter I.D. m	Meter I.D. in.
0.6096	24.0000

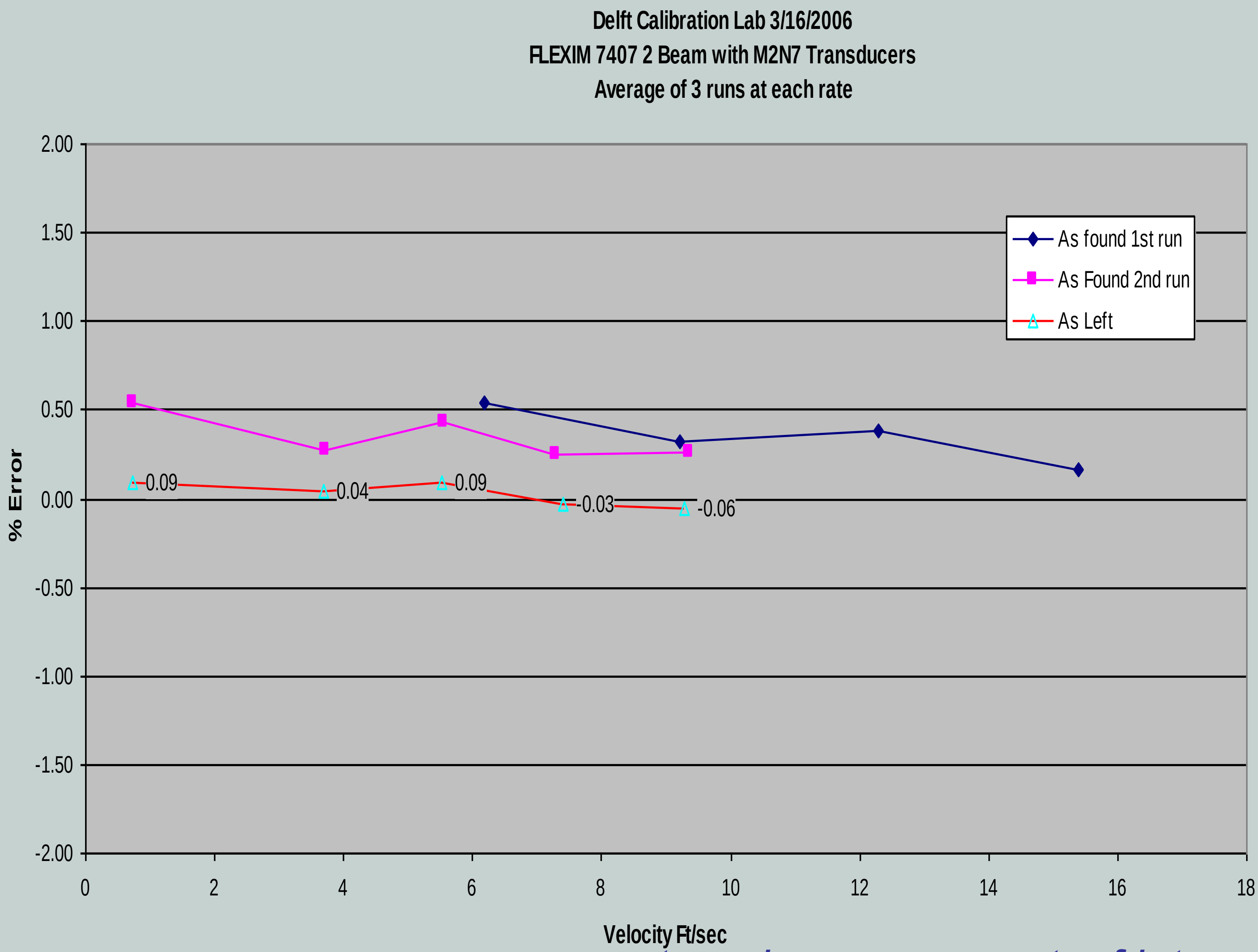
Data Point	Calibration Factor	Flow Rate ft³/hr Prover	Flow Rate ft³/hr Meter	Flow Rate m³/hr Prover	Flow Rate m³/hr Meter	Velocity m/sec V_p	Velocity ft/sec V_p	Velocity m/sec V_m	Velocity of ft/sec V_m	As Found error %	As Left Predicted %	Verification Vel ft/sec	Verifcation Results %
1	0.9974	417333.0	418408	11817.56	11848.01	11.247	36.900	11.276	37.00	0.26	0.000		
2	0.9972	309157.0	310031	8754.35	8779.11	8.332	27.335	8.355	27.41	0.28	0.000		
3	1.0000	205734.0	205744	5825.74	5826.03	5.545	18.191	5.545	18.19	0.01	0.000		
4	1.0016	104579.0	104412	2961.35	2956.62	2.818	9.247	2.814	9.23	-0.16	0.000	9.194	0.059
5	1.0011	52767.1	52709	1494.20	1492.56	1.422	4.666	1.421	4.66	-0.11	0.000		
6	1.0248	10622.1	10365	300.78	293.51	0.286	0.939	0.279	0.92	-2.42	0.000		
7													



DELFT Calibration Lab
Customer Acceptance Testing

… external measurement of internal flow

DELFT Calibration Results



… external measurement of internal flow