Effects of Flow Conditioning for Liquid Measurement
Class # 2120.1

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Introduction

A dichotomy formed and inadvertently turned into standard practice in the flow measurement engineering business. The present school of thought is that there is a distinction between liquid phase and (gas) vapor phase hydrocarbon flow conditioning, metering businesses, and flow measurement for that matter. The distinction is Reynolds Number, not Phase.

It is the intent of this paper to begin the process of rectifying this misunderstanding. By educating our industry into the commonality and differences between the two. Computational Fluid Dynamics is utilized to explain commonality along with citing flow measurement standards.

"It is common in introductory physics to divide materials into the three classes of solids, liquids, and gases, noting their different behavior when placed in a container. This is a handy classification in thermodynamics, for example, because of the strong differences in state relations among the three. In fluid mechanics, however, there are only two classes of matter; fluids and non fluids (solids)." Copied from Viscous Fluid Flow, Frank M. White, 3rd edition page 15.

That being stated, we will use this as a fresh starting point to look at Fluid Flow conditioning, pipe flow and metering of hydrocarbon fluids. A fluid being either in the vapor or liquid state - the difference is irrelevant. A strong emphasis is placed on the elimination of the need to specify the fluid phase. Certainly there are physical requirements of meter station design dictated by the phase (cavitation and piping losses), but from a fluid flow conditioning standpoint, phase is not in any of the relevant flow equations.

Operation of the meter station in the transitionary region causes severe installation effect behavior. These effects may be interpreted as a meter k factor error and may operationally institute a meter proof, which may not correct the errors.

This paper should be used as a two part explanation in conjunction with ISHM Paper #1330.1 Flow Conditioning for Gas Measurement. This paper being the 1st part addressing the issues of fluid phase, the second paper explaining how a flow conditioner works (regardless of fluid phase).

Once the flow measurement practitioner takes off his or her thermodynamic "cap" where phase is all important, and replaces it with a fluid dynamic "cap" the reasons for some of the challenges related to the liquid hydrocarbon measurement manifest. The fundamentals of good pipe flow still apply to both sciences.

Pay special attention to the fact that no where in this paper are there terms in any of the equations or concepts which relate to phase. This should be a good indicator that there are no differences – with respect to pipe flow.

Flow Metering Standards

Table 1 – Applicable Flow Metering Standards indicates a review of some of the more relevant North American metering flow measurement standards and the state of the committee or organization. In some cases the standards apply to both liquid and gas phase as in the orifice meter standard. In other cases where there is a liquid and gas phase metering standard, the fluid dynamic flowing conditions – or flow conditioning requirements will be identical even though the fluid states are liquid verses gas.

Table 1 – Flow Metering Standards and Status

Meter type	Fluid	Standard(s)	Comments
Orifice	Natural Gas – Vapor	AGA-3, (API 14.3), ISO 5167	*Orifice metering fundamentals do not distinguish between phases.*
	Hydrocarbon - Liquid	AGA-3, (API 14.3), ISO 5167	
Turbine	Natural Gas – Vapor	AGA-7	*Differences in meters due to shaft bearing operation rather than, phase. Differences in meter run design not fluid dynamically based.*
	Hydrocarbon - Liquid	API 5.3 *under construction*	
Corriolis	Natural Gas – Vapor		
	Hydrocarbon - Liquid	API 5.6	
Ultrasonic	Natural Gas – Vapor	AGA 9, ISO 17089 (1,2,3)	*Differences in meters due to fluid sound attenuation values rather than, phase. Differences in meter run design not fluid dynamically based.*
	Hydrocarbon - Liquid	API 5.8 *under construction* , OIML R11 7, ISO 12242, ANSI MFC-5M	
PD- Rotary		API 5.2	

Back to Pipe Flow Basics

Definition of Reynolds Number. In fluid dynamics it is impossible to describe and communicate pipe flow conditions with out the use of the dimensionless parameter – Reynolds Number. It is the measuring tape, or micrometer for fluid flow measurement. S.I. units utilized for simplicity.

$$Re = \frac{\rho \emptyset \bar{U}}{\mu} = \frac{\phi \bar{U}}{\nu} \qquad (1)$$

Where:				
	ρ	=	Density	kg/m^3
	Φ	=	Pipe Diameter	m
	$\bar{U}$	=	Mean pipe velocity	m/s^2
	μ	=	"Coefficient of" or "absolute" Viscosity	kg/ms
	ν	=	Kinematic Viscosity	m^2/s

(how to convert between the S.I. units of viscosity for equation to more recognizable units used in industry)

$$\nu = \frac{\mu}{\rho}$$

cP or Centi-poise – unit of coefficient of viscosity or absolute viscosity

μ = 10 P = 1000 cP = 1 Pas = 1 kg/ms

cSt or centi-stokes – unit of kinematic viscosity

ν = 1,000,000 cSt = 1 m^2/s

Saybolt universal second – unit of kinematic viscosity

Centistokes = $0.226\, v_{SSU} - 195 / v_{SSU}$ *where* $v_{SSU} < 100$

Centistokes = $0.220\, v_{SSU} - 135 / v_{SSU}$ *where* $v_{SSU} > 100$

Sanity Check:

centiStokes *(cSt)*	Saybolt Second Universal *(SSU, SUS)*	Typical liquid
1	31	Water (20^{o}C)
4.3	40	Milk SAE 20 Crankcase Oil SAE 75 Gear Oil
15.7	80	No. 4 fuel oil
20.6	100	Cream
43.2	200	Vegetable oil
110	500	SAE 30 Crankcase Oil SAE 85 Gear Oil
220	1000	Tomato Juice SAE 50 Crankcase Oil SAE 90 Gear Oil
440	2000	SAE 140 Gear Oil
1100	5000	Glycerine (20^{o}C) SAE 250 Gear Oil
2200	10,000	Honey
6250	28,000	Mayonnaise
19,000	86,000	Sour cream

Example: 350 cSt oil, at 47° F, 1000 kg/m3, 8 ft/s, 24 Sch 40 pipe.

Re = 2.43 m/s x 0.574 m / 3.5 x 10^{-4} = 4,000

Now that we can calculate Re what do we do with it.

We can Use Re to determine pressure drop in a section of pipe, of a flow conditioner.

Pipe and flow conditioner Pressure Drop

$$\Delta P = \frac{k \rho \bar{U}^2}{2}$$

Where:				
	ρ	=	Density	kg/m^3
	$\bar{U}$	=	Mean pipe velocity	m/s^2
	k	=	Pressure Drop coefficient	unitless
	ΔP	=	Pressure Loss	Pa (.006895 psi)

<table>
<tr><th>k, If Re less than 2000 Laminar</th><th>k, If Re more than 2000 Turbulent</th><th>k, For a Flow Conditioner Re based</th></tr>
<tr>
<td>

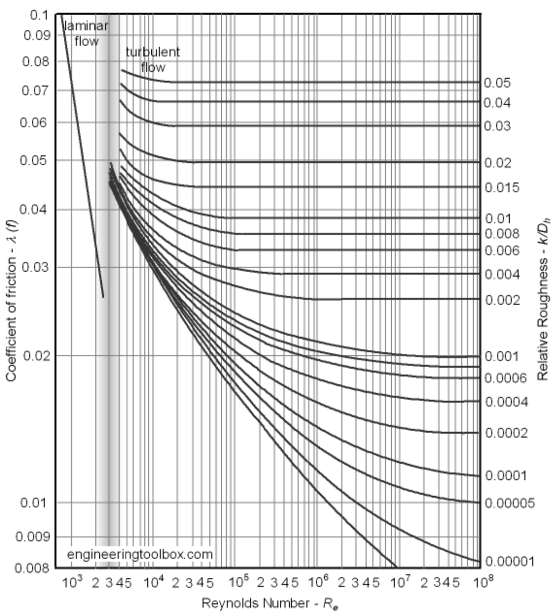
$$k = \frac{fL}{\emptyset}$$

$$f = \frac{64}{Re}$$

</td>
<td>

$$k = \frac{fL}{\emptyset}$$

$\frac{1}{f} = -2\log\left(\frac{\frac{\epsilon}{\emptyset}}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$ Colebrook Equation



Moody Diagram

Where: ϵ = Wall Roughness m
Φ= Pipe Diameter m
f = friction factor from Moody Diagram

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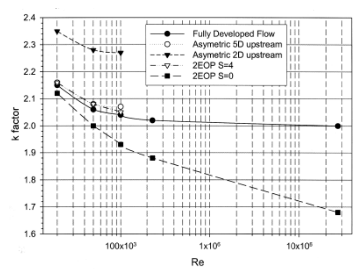
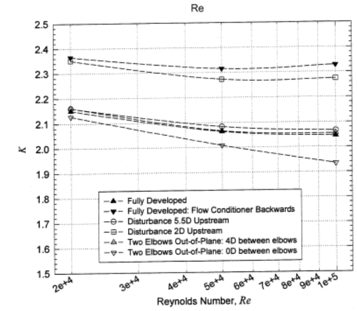
k = empirically determined

<table>
<tr><th>Re</th><th>k</th></tr>
<tr><td>1</td><td>5.2</td></tr>
<tr><td>10</td><td>4.8</td></tr>
<tr><td>100</td><td>4.4</td></tr>
<tr><td>1,000</td><td>4.0</td></tr>
<tr><td>10,000</td><td>3.6</td></tr>
<tr><td>100,000</td><td>3.1</td></tr>
<tr><td>1,000,000</td><td>2.7</td></tr>
<tr><td>10,000,000</td><td>1.8</td></tr>
<tr><td>100,000,000</td><td>1.6</td></tr>
</table>

Experimentally Determined





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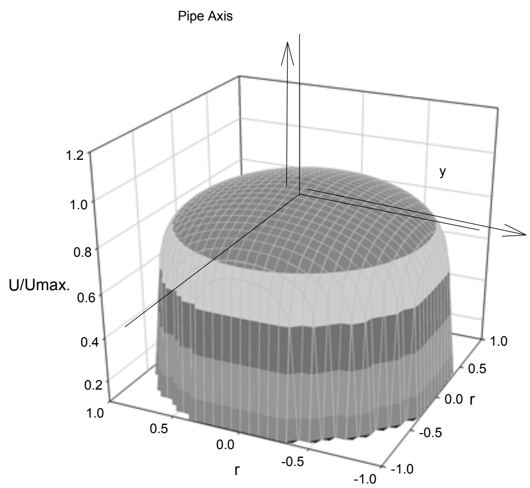
Re can be utilized to calculate the shape of the Normalized Velocity Flow Profile



Plot of: $f(r) = [1-(x^2+y^2)^{1/2}]^{1/10} = U/U_{max.}$

Figure 1, Velocity Flow Profile

Equation 1 – the power law, describes the shape of the velocity flow profile. It is not exact, but it has become the most commonly utilized velocity flow profile equation in the flow measurement business in North America. The value of n determines the shape of the velocity flow profile and is a function of Reynolds Number (Re).

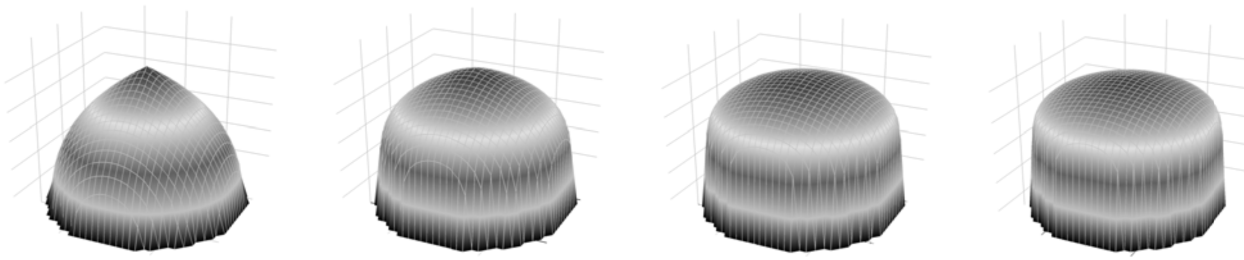
$$\frac{U_y}{U_{\max}} = \left(1 - \frac{y}{R}\right)^{\frac{1}{n}} \qquad (1)$$

A fully developed flow profile is used as the Reference State for meter calibration and determination of Coefficient of Discharge (Cd) for many flow meters. For Reynolds Number 10^5 to 10^6 n is approximately 7.5; for Re of 10^6, n is approximately 10.0 where a fully developed profile in a smooth pipe is assumed.

Since n is a function of Reynolds Number and friction factor, more accurate values of n can be estimated by using

$$n = \frac{1}{\sqrt{f}}, \qquad (3)$$

where f is the friction factor. It is not the intent here to provide detailed instructions for determining friction factors. The Colebrook (1939) equation or Moody (1944) diagram can be utilized as illustrated and detailed by Karnik (1993). **Figure 2 Flow Profile verses Re**, indicates the relative qualitative appearance of various Reynolds Number velocity profiles velocity profiles.



n=2.5, Re=500 n=5, Re=2000 n=7.5, Re=40,000 n=10, Re=2M

Figure 2 Flow Profile verses Re

Note that the shape of the normalized velocity profile from say a heavy oil application Re 40,000 to a natural Gas application Re 2M is negligible.

Computational Analysis of Pipe Installation Effects

Several computational fluid flow analysis were carried out, each having exactly the same Piping configuration(s) (Straight Pipe and 2 Elbows out of Plane) but at various Reynolds Numbers or: 1000, 10,000, 140,000, 40,000,000. This is carried out in order to show that even though theoretically each run could have been in a liquid or vapour phase depending on Reynolds number, the issue of phase is not even entertained entered, looked at, mentioned.

A disturbing phenomenon has been identified and confirmed by a third party which indicates problems may not be phase related but Flow regime related (laminar, transitional, turbulent). This is addressed later in the paper.

Straight Pipe - Various Reynolds Numbers

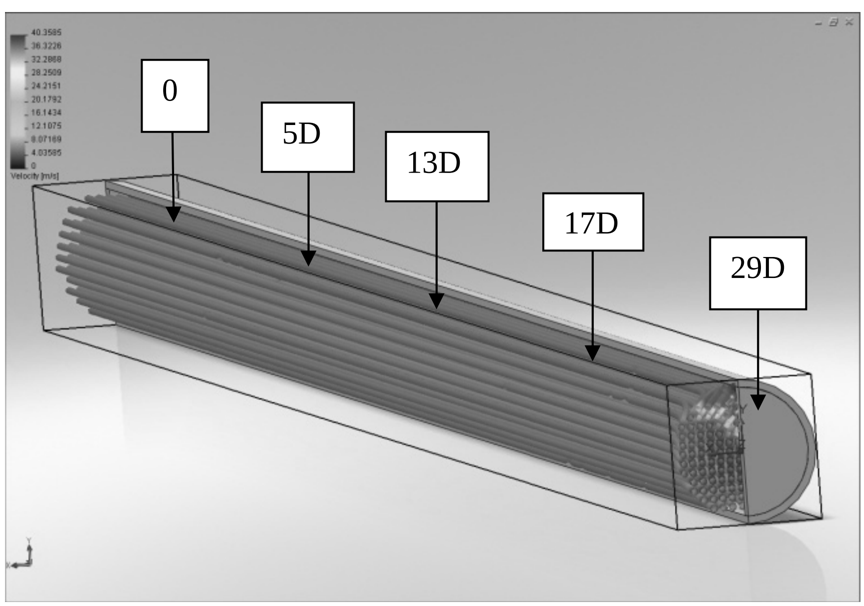


Figure 3- Straight Pipe

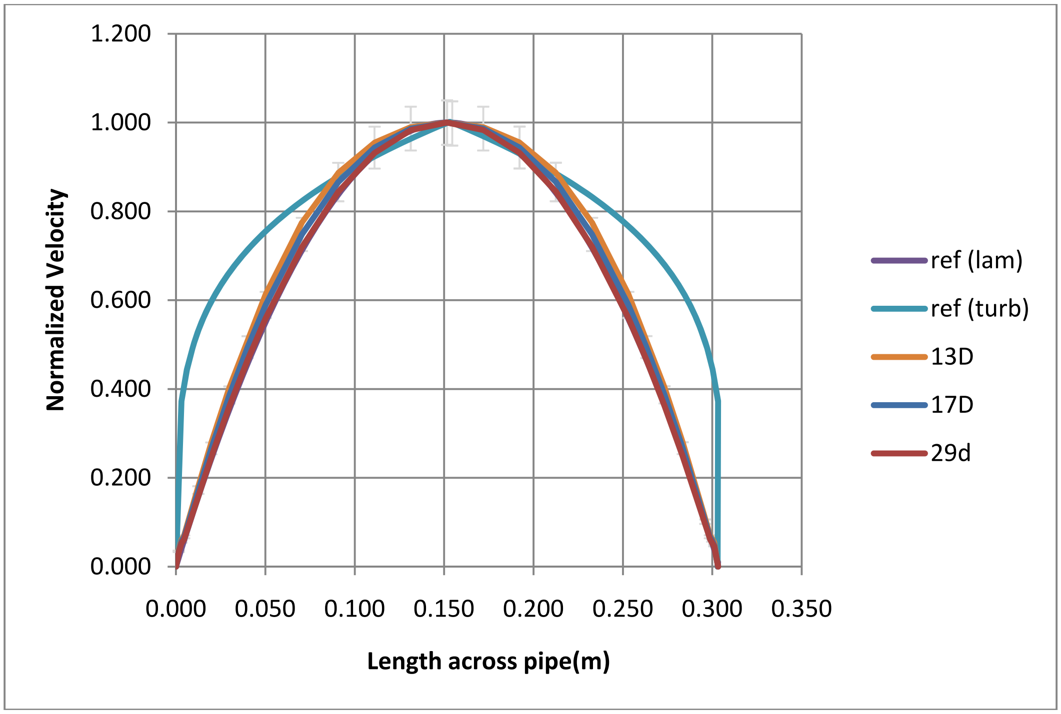


Figure 4 – Straight Pipe, Re = 1000, No Flow Conditioner, Normalized against centre line velocity ± 5% on FDFP.

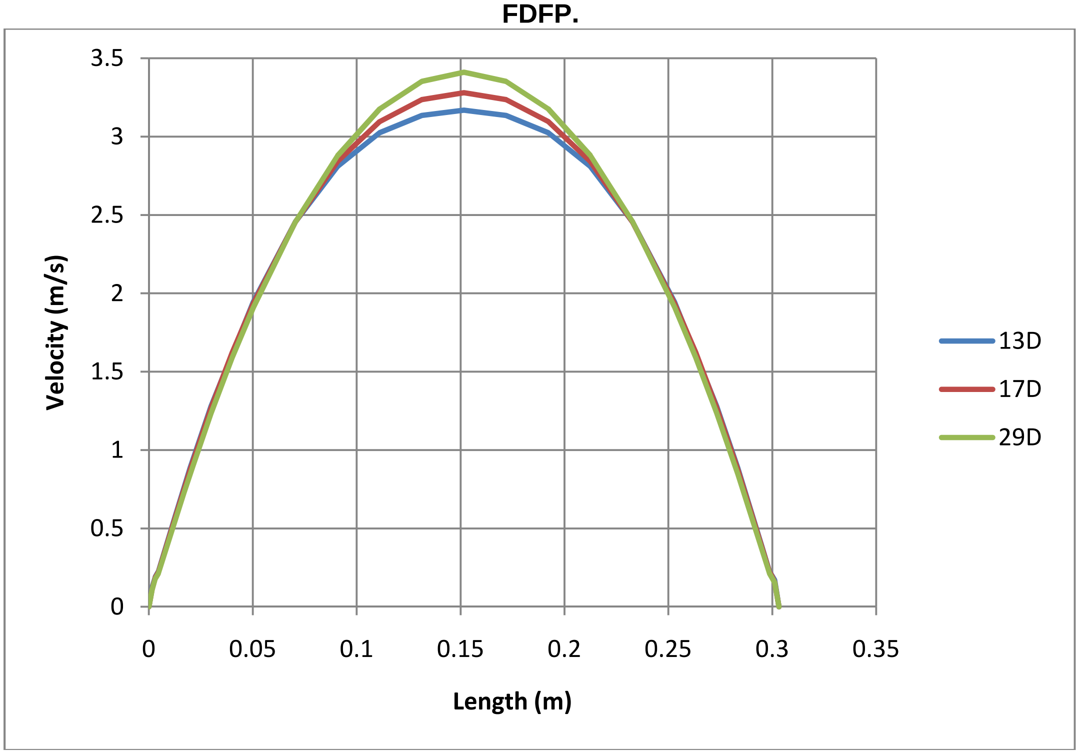


Figure 5 – Straight Pipe, Re = 1000, No Flow Conditioner, Actual velocity

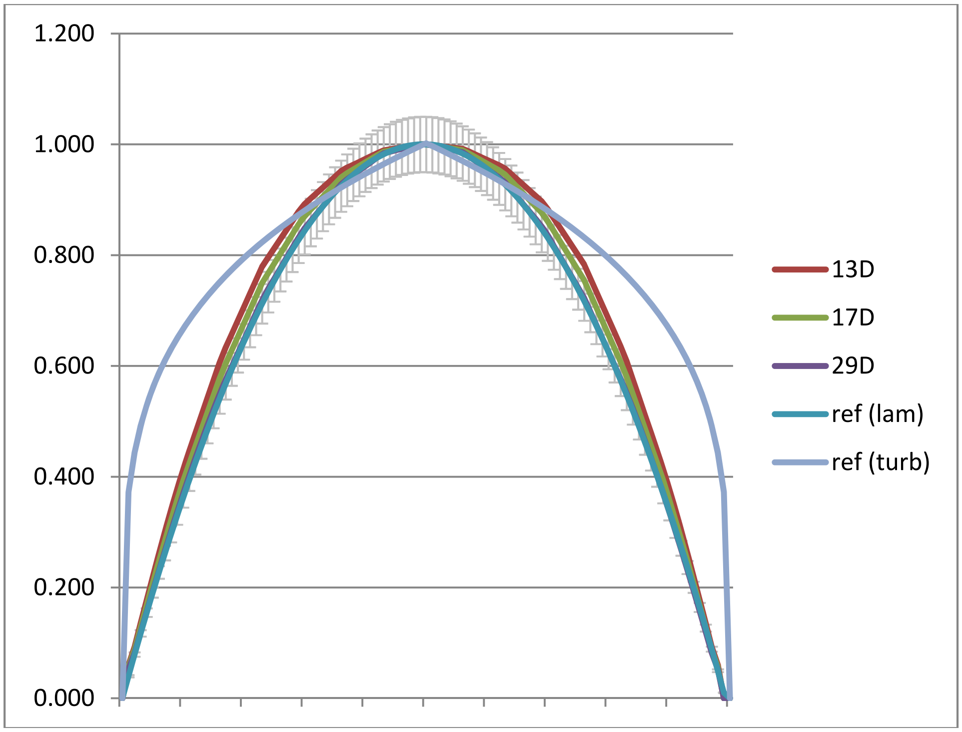


Figure 6 – Straight Pipe, Re 1000, Flow Conditioner, ± 5% on FDFP.

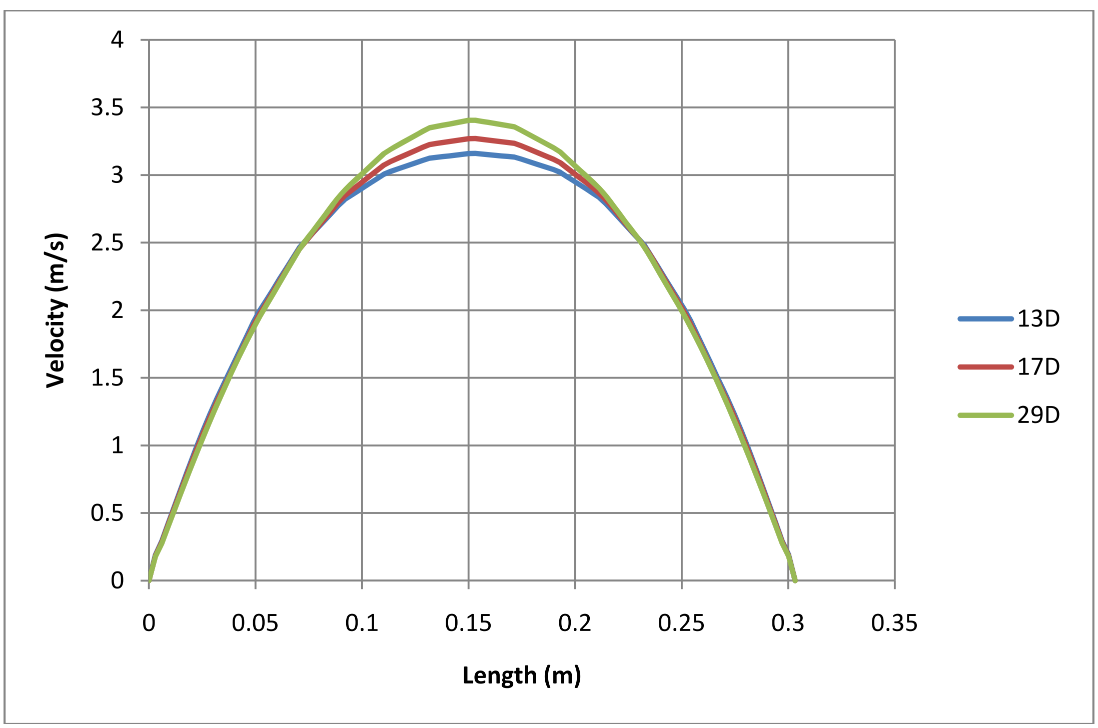


Figure 7 – Straight Pipe, Re 1000, Flow Conditioner, Actual Velocity

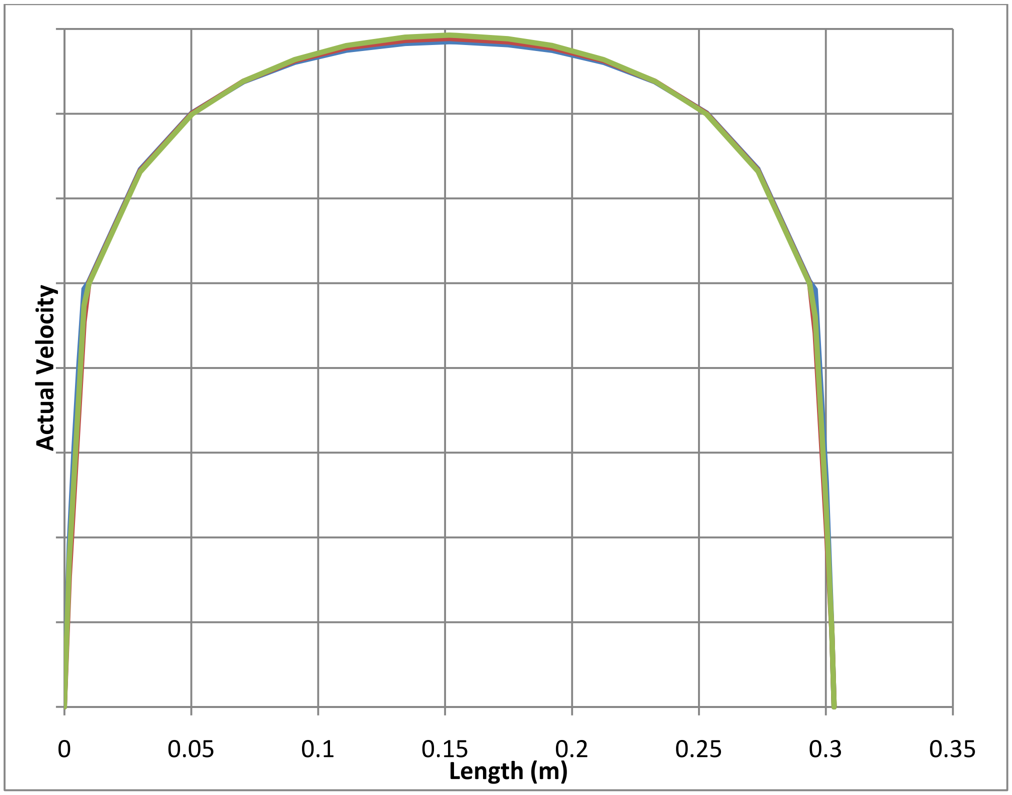


Figure 8 – Straight Pipe, Re 10,000, No Flow Conditioner, Actual Velocity.

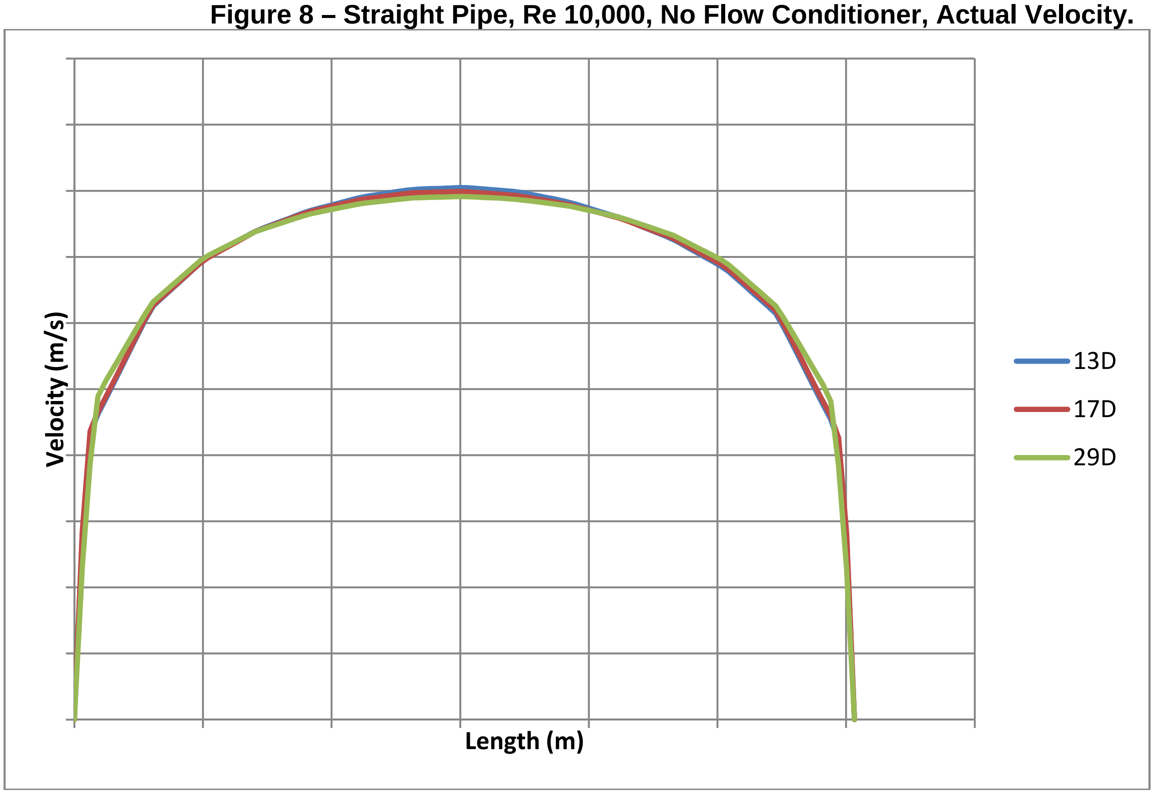


Figure 9 – Straight Pipe, Re 10,000, Flow Conditioner, Actual Velocity.

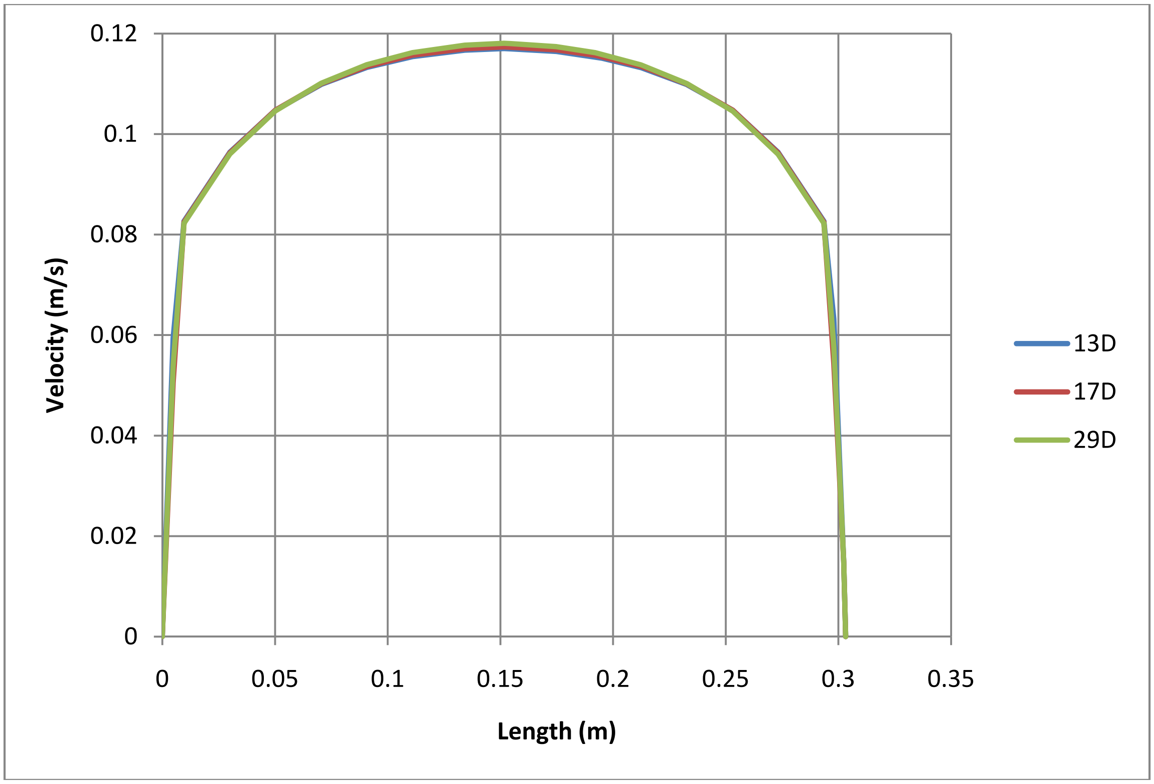


Figure 10 – Straight Pipe, Re 50,000, No Flow Conditioner, Actual Velocity

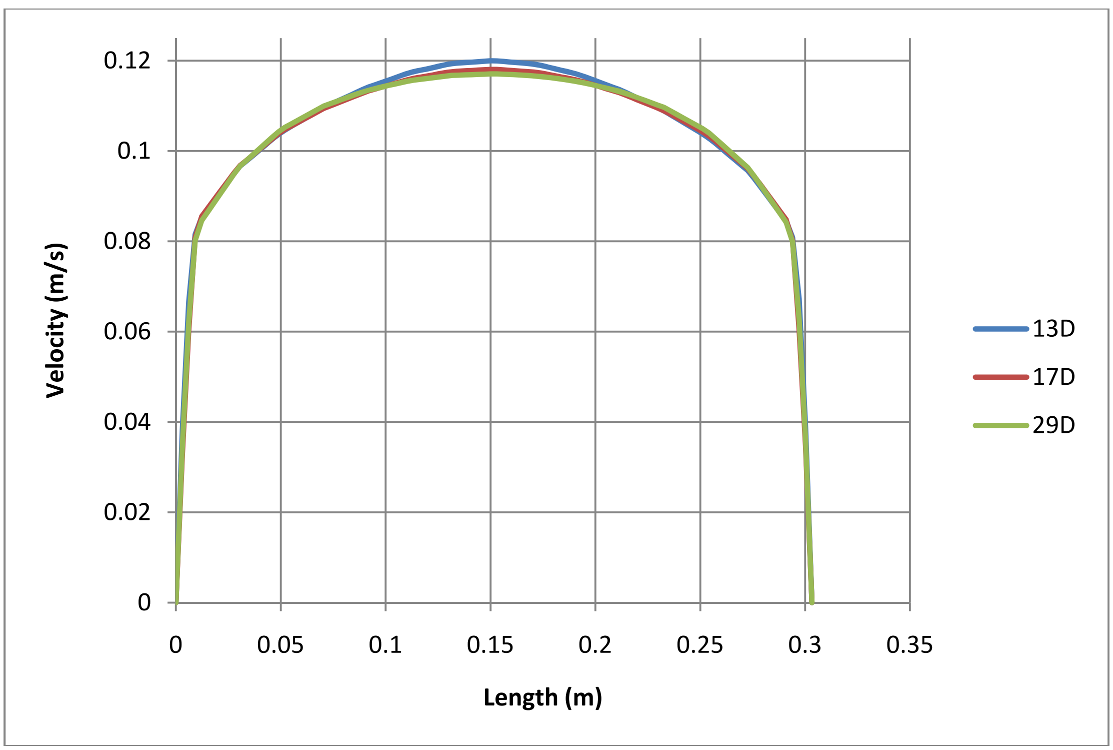


Figure 11 – Straight Pipe, Re 50,000, Flow Conditioner, Actual Velocity

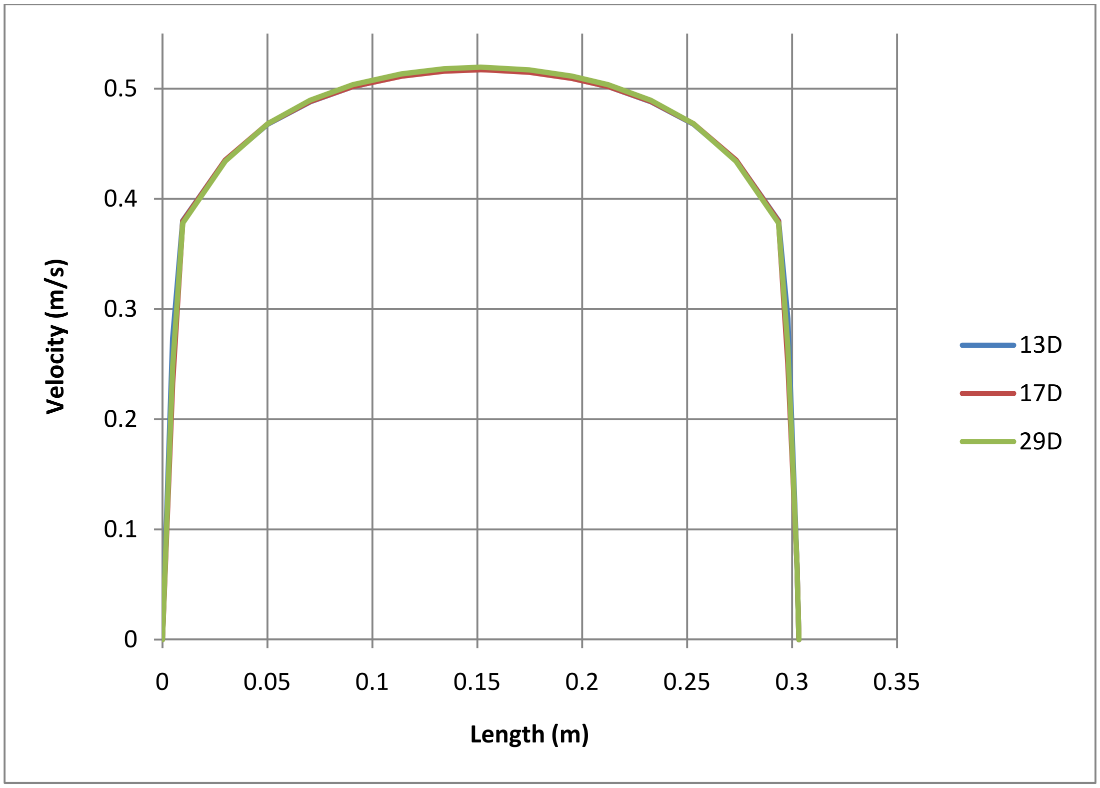


Figure 12 – Straight Pipe, Re 140,000, No Flow Conditioner, Actual Velocity

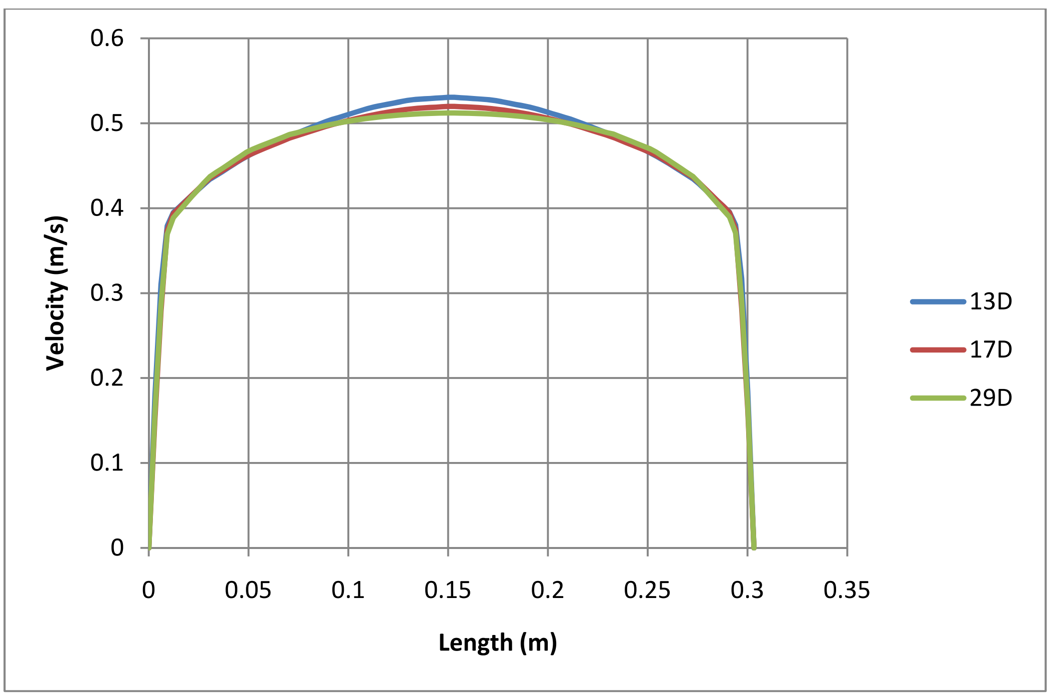


Figure 13 – Straight Pipe, Re 140,000, Flow Conditioner, Actual Velocity

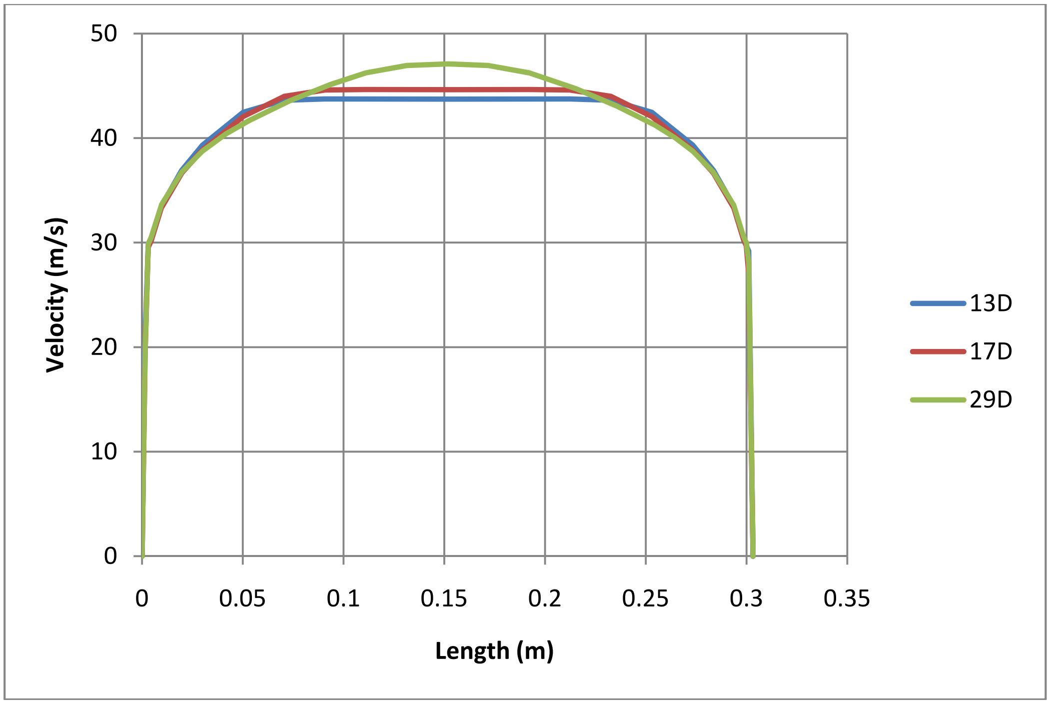


Figure 14 – Straight Pipe, Re 40,000,000, No Flow Conditioner, Actual Velocity

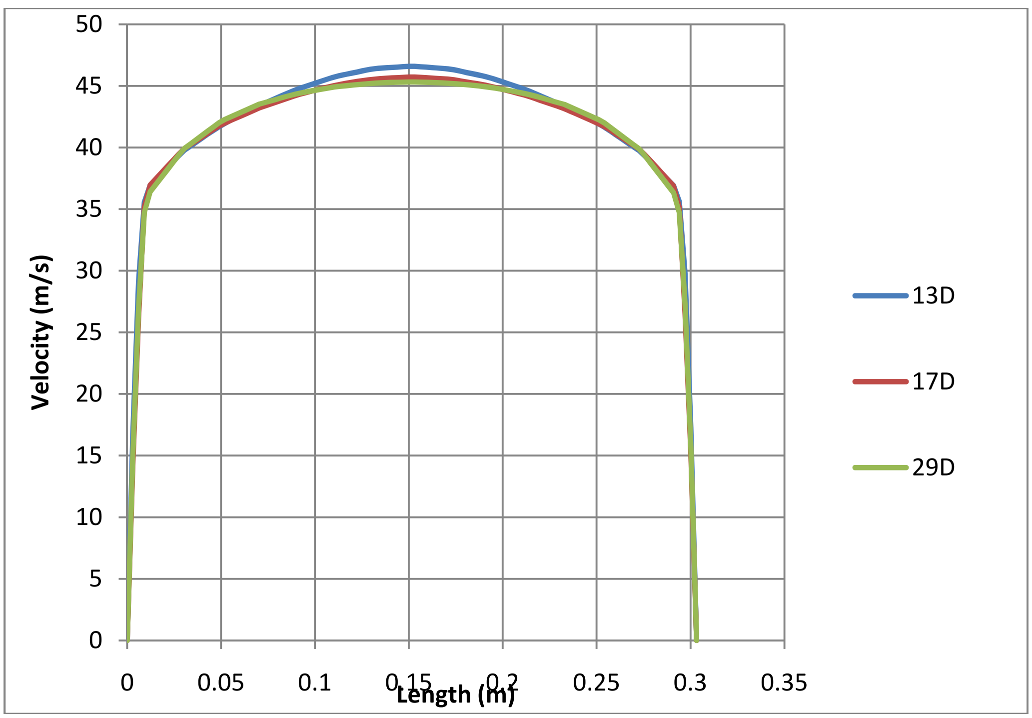


Figure 15 – Straight Pipe, Re 40,000,000, Flow Conditioner, Actual Velocity

Straight Pipe Interpretation.

Computationally, a simple straight pipe run is a difficult task, and is a good test for your computational tools.

The straight pipe computational runs verify the power law approximation and also indicate the relative changes in flow profile (both normalized and actual) between Reynolds Number flow ranges. i.e. as the Re becomes larger, the flow profiles become flatter.

The pipe roughness is not changed through out this analysis, but if it were, the shape of the flow profile becomes flatter as the pipe roughness is reduced. This is an additional affect and can complicate the analysis of piping realted installation effects.

Actual flow profiles when compared to each other against Re will appear to be \`pointier\`. For example if one plots the flow profile across the Re range the flow profiles seem to become pointy. This is what you would see with an ultrasonic meter path comparative output. All hope is not lost though, because when these flow profiles are normalized against centre line velocity, the flattening behavior becomes evident.

Also indicated is the fully developed flow profile complimenting performance of a sample flow conditioner to illustrate that the flow conditioner should not affect a fully developed flow profile as seen in a long straight piece of pipe. What goes in should also exit, if it does not, then the flow conditioner may be an installation effect upon itself.

2 Elbows out of Plane

The most severe piping installation one can assemble is the close coupled double elbows out of plane. In some instances made even worse by utilizing tees rather than elbows. The reader is cautioned that some the flow profiles indicated are graphically offensive and be troubling to some readers.

Elbow separation has a large impact on the magnitude of the installation effect.

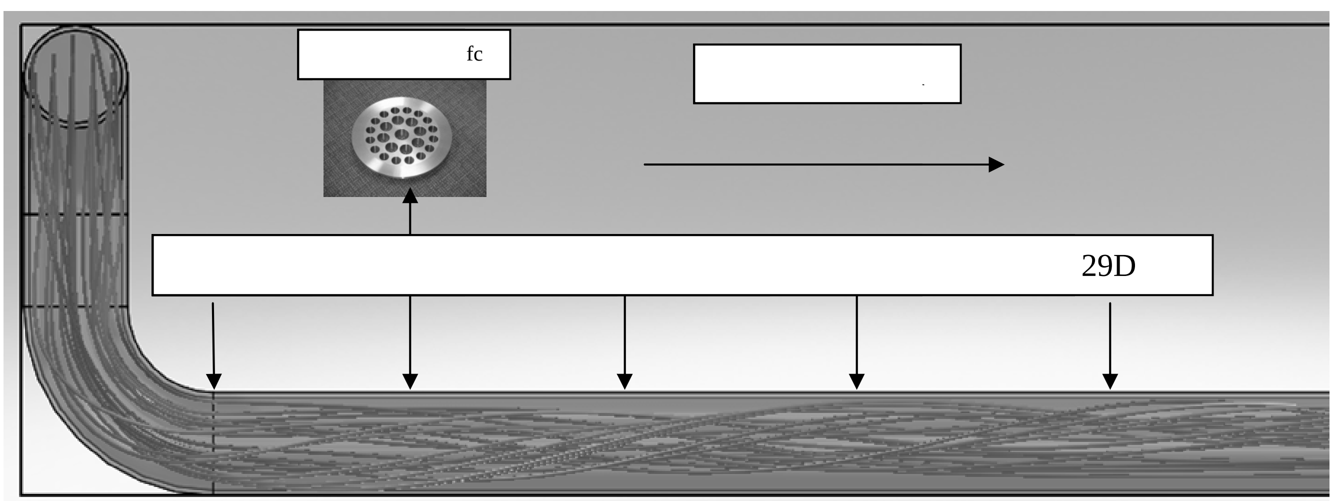


Figure 16 – Piping Layout for two elbows out of plane.

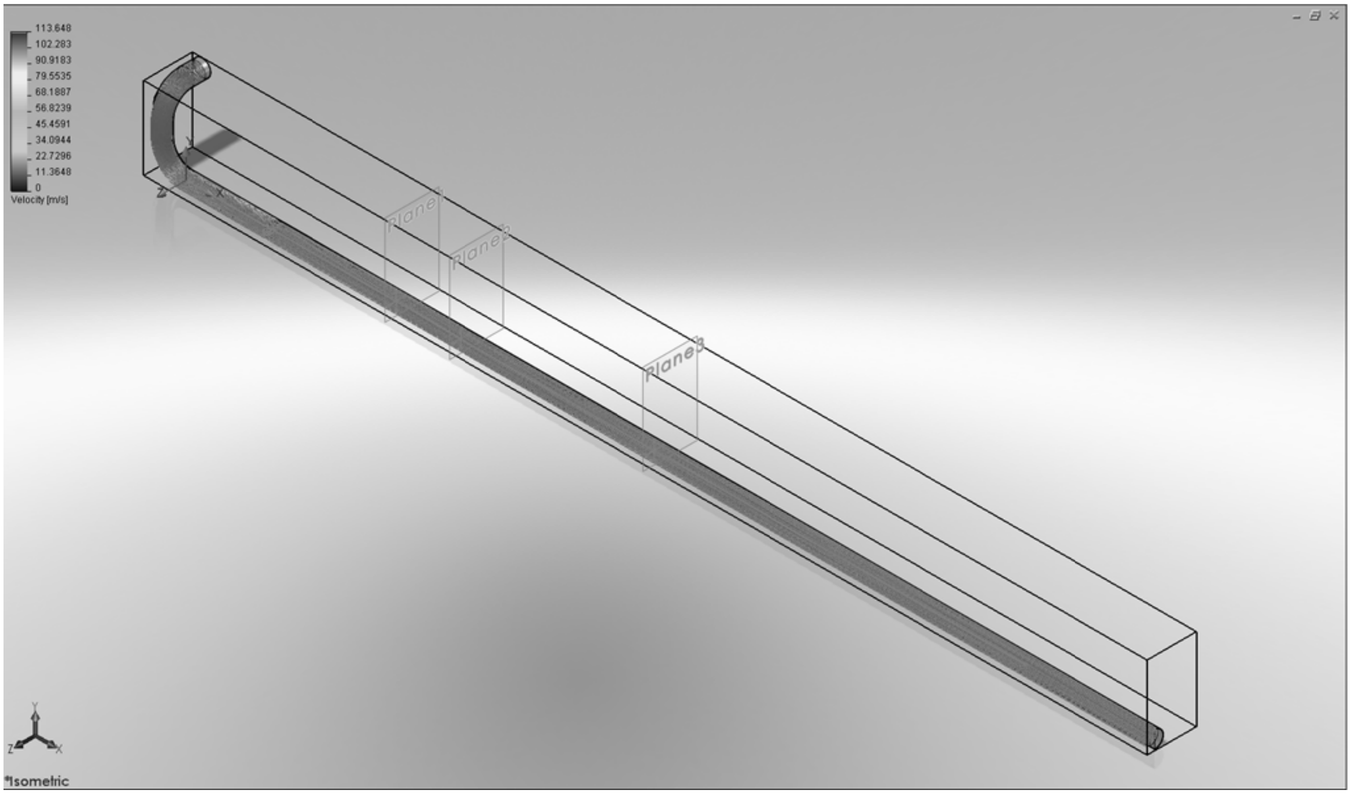


Figure 17 – Isometric view of piping layout.

Flow Profiles Re at 1000

If only to convey the unimportance of phase, Figure XX, indicates the flow conditions in a pipe carrying water (in the liquid phase) having an artificially adjusted viscosity of 1000 cSt (at least twice that of Alberta Heavy Oil).

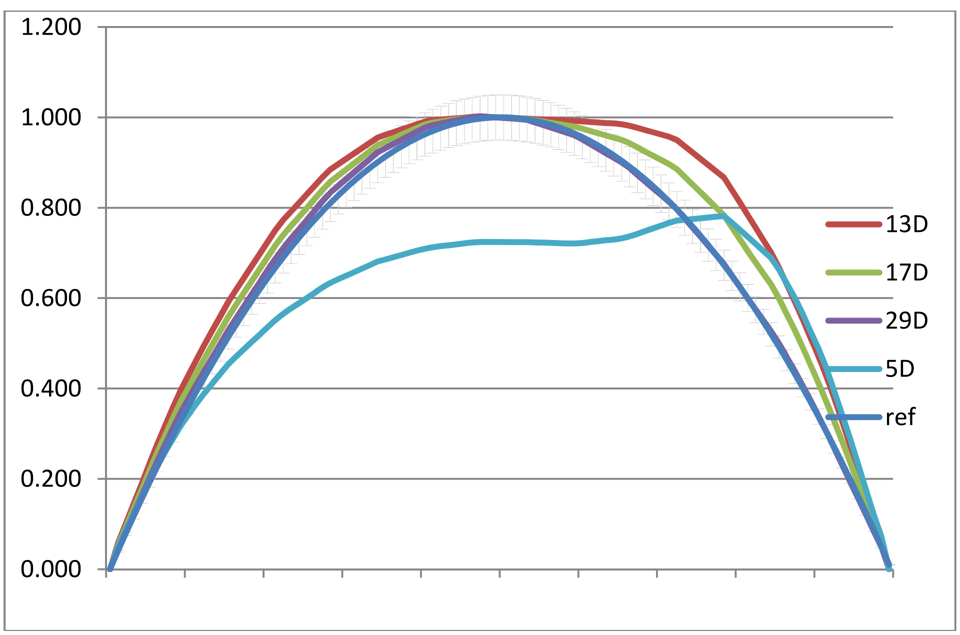


Figure 18 – 2 Elbows out of Plane, Re 1000, No Flow Conditioner, Normalized Velocity, ± 5% on FDFP.

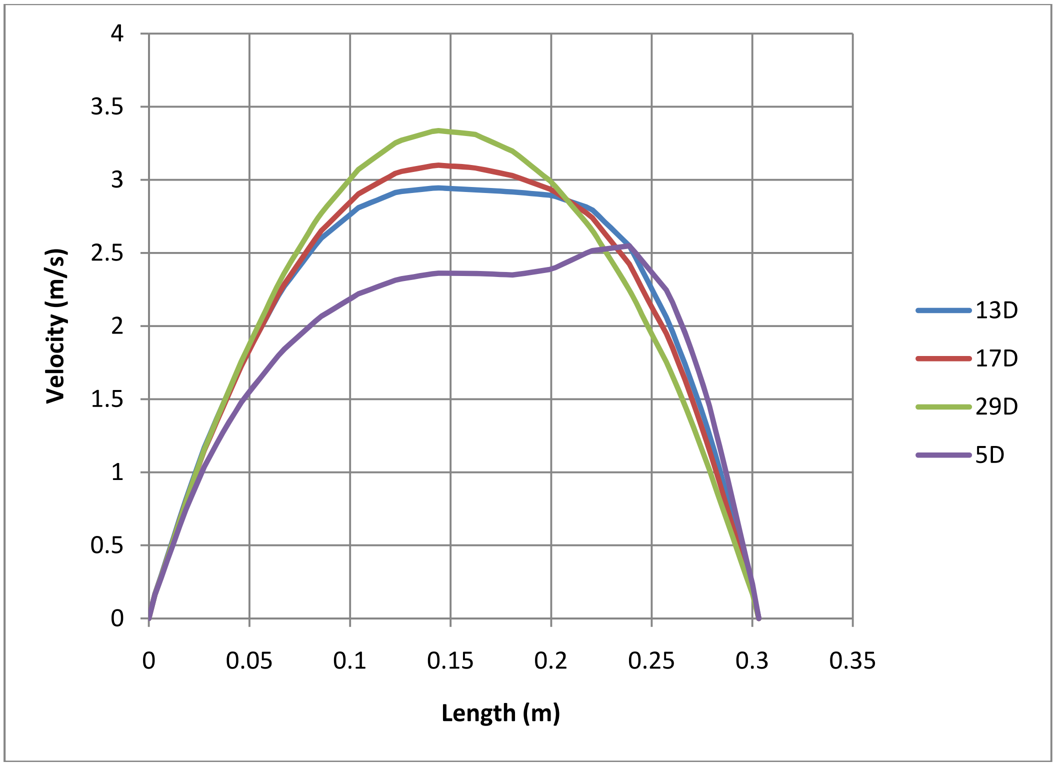


Figure 19 – 2 Elbows out of Plane, Re 1000, No Flow Conditioner, Actual Velocity

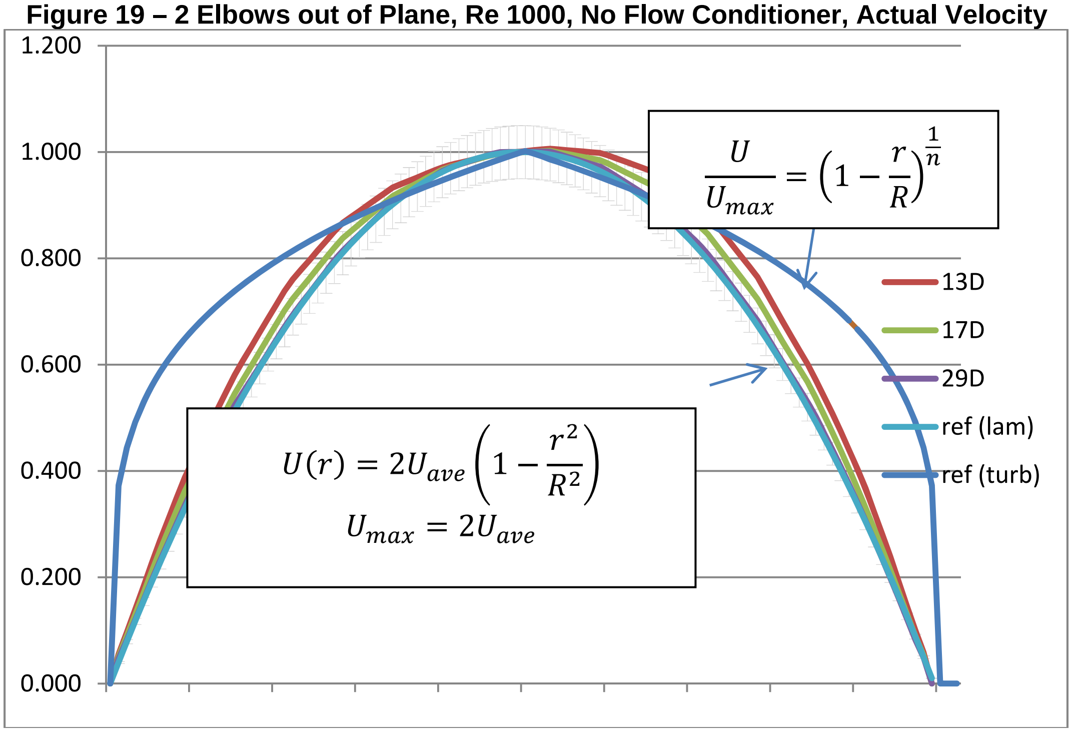


Figure 20 – 2 Elbows out of Plane, Re 1000, Flow Conditioner, ± 5% on FDFP

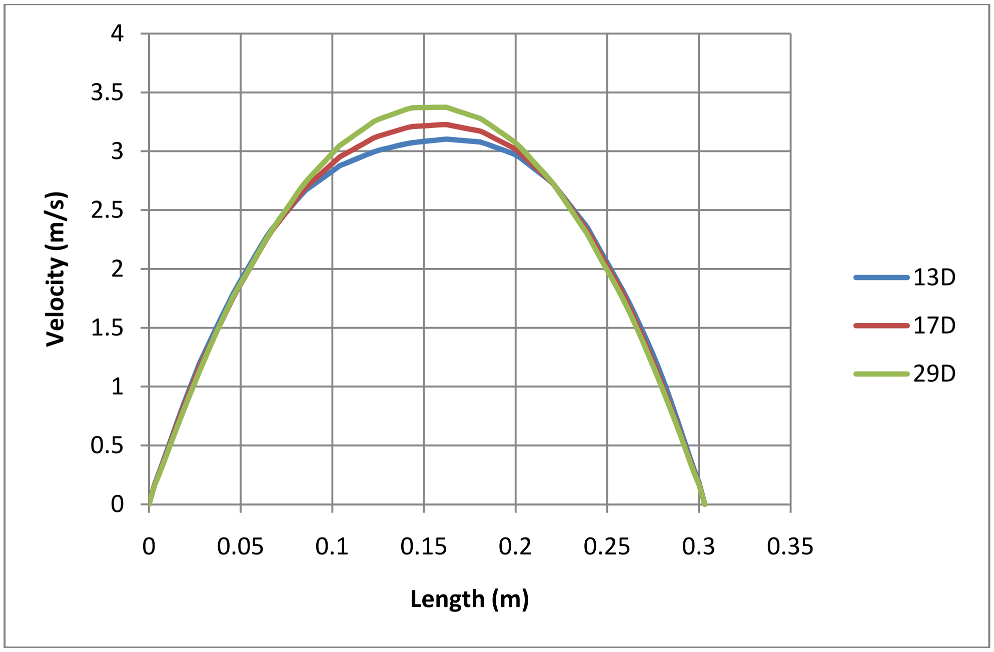


Figure 21 – 2 Elbows out of Plane, Re 1000, Flow Conditioner

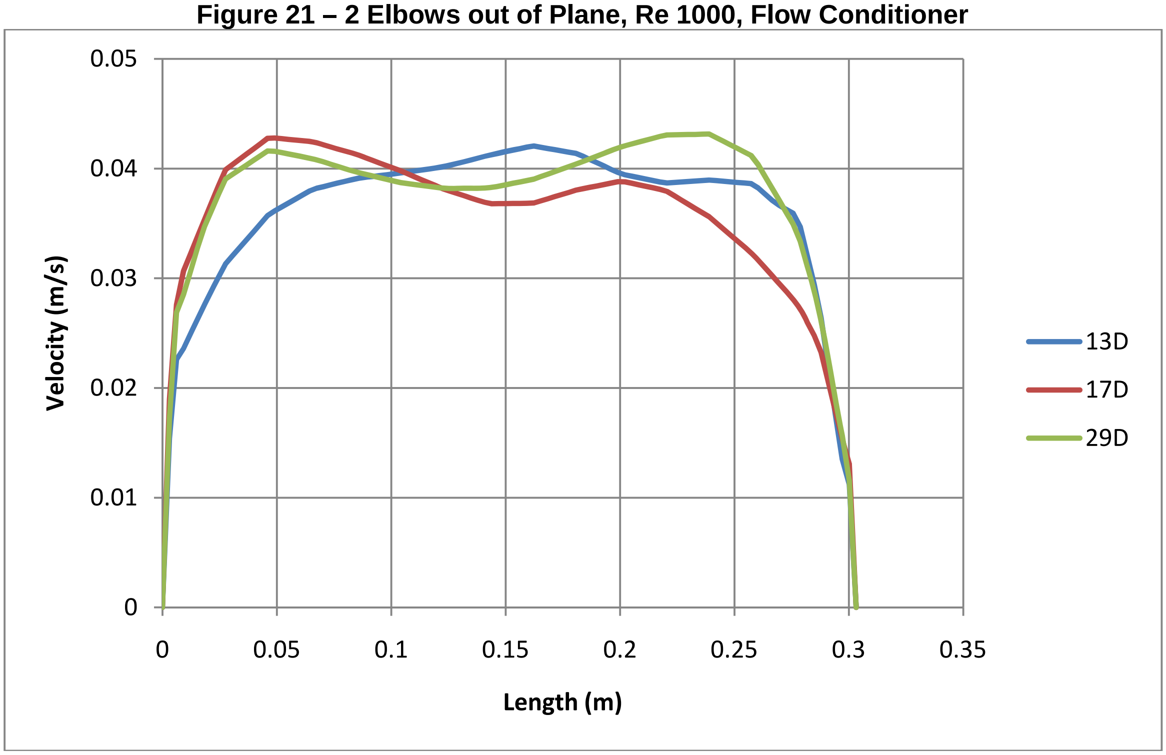


Figure 22 – 2 Elbows out of Plane, Re 10,000, No Flow Conditioner

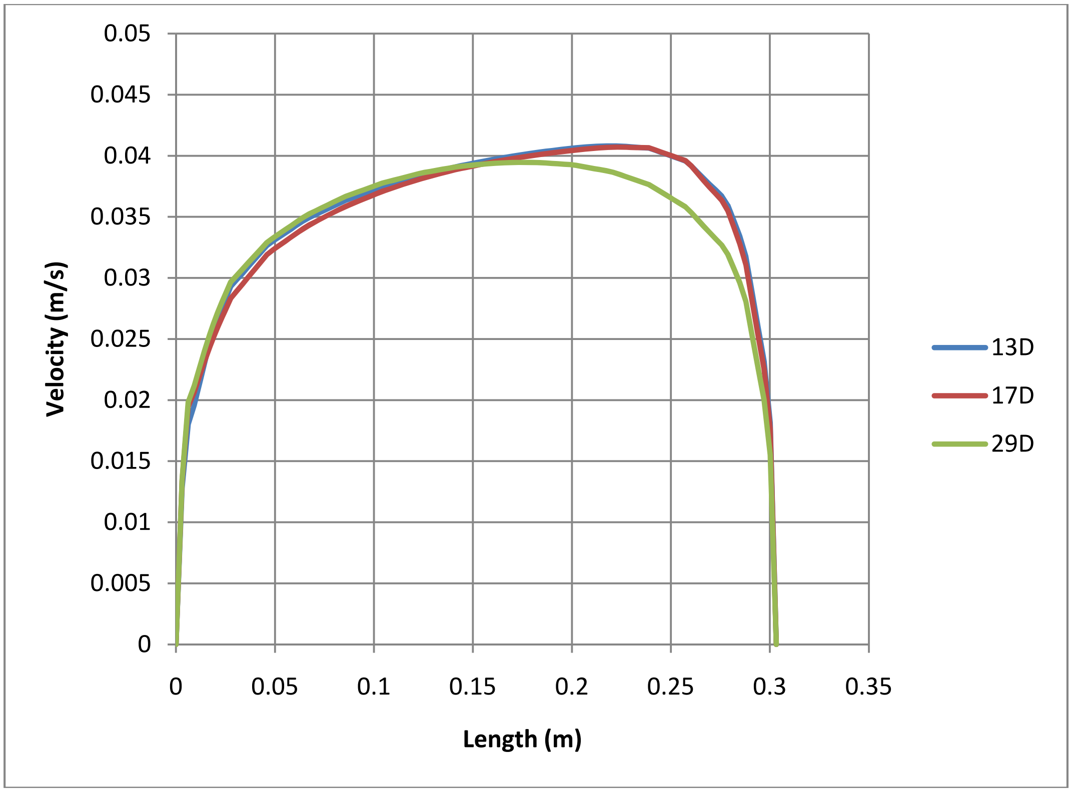


Figure 23 – 2 Elbows out of Plane, Re 10,000, Flow Conditioner, Actual Velocities

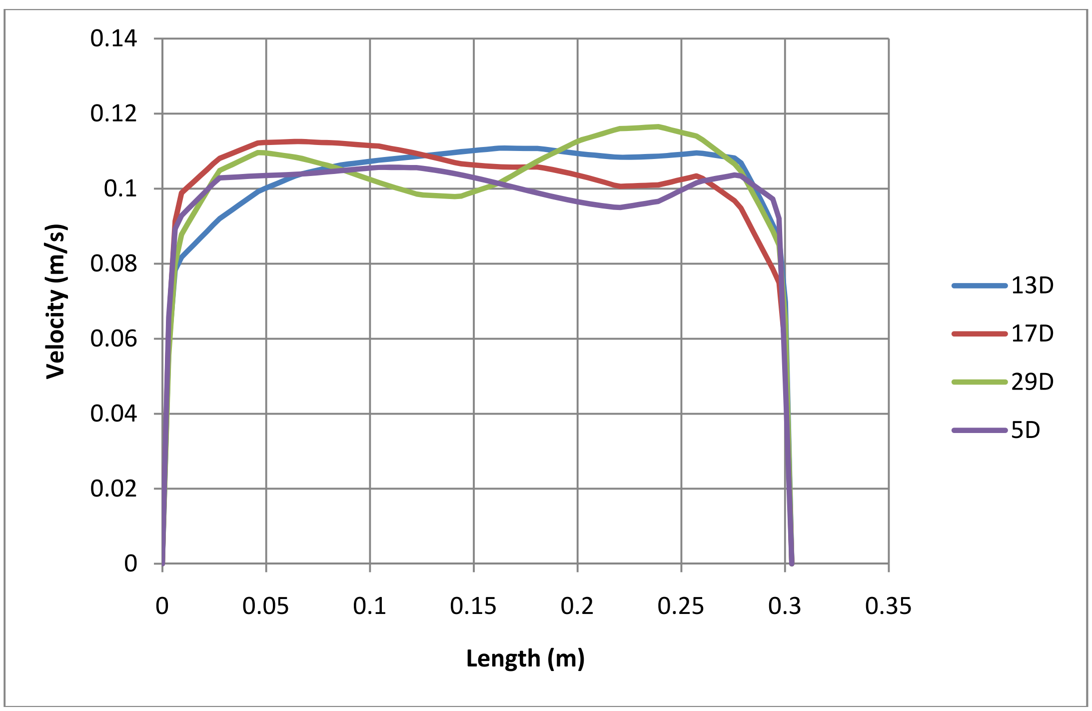


Figure 24 – 2 Elbows out of Plane, Re 50,000, No Flow Conditioner, Actual Velocities

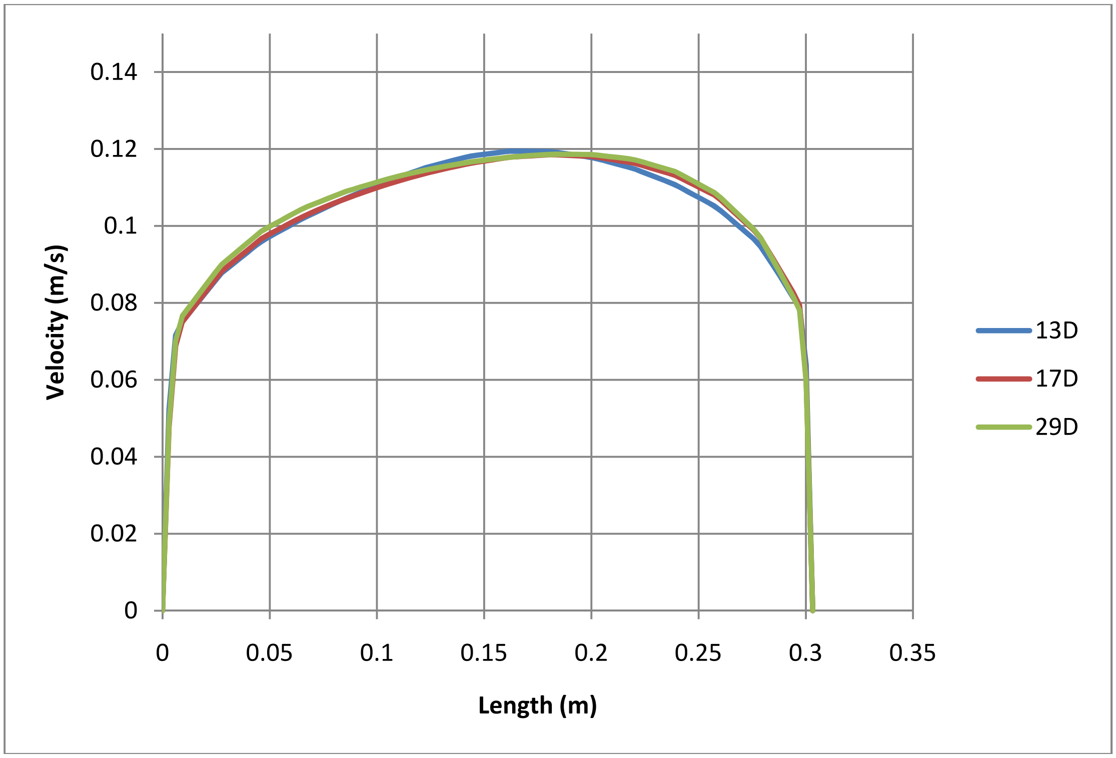


Figure 25 – 2 Elbows out of Plane, Re 50,000, Flow Conditioner, Actual Velocities

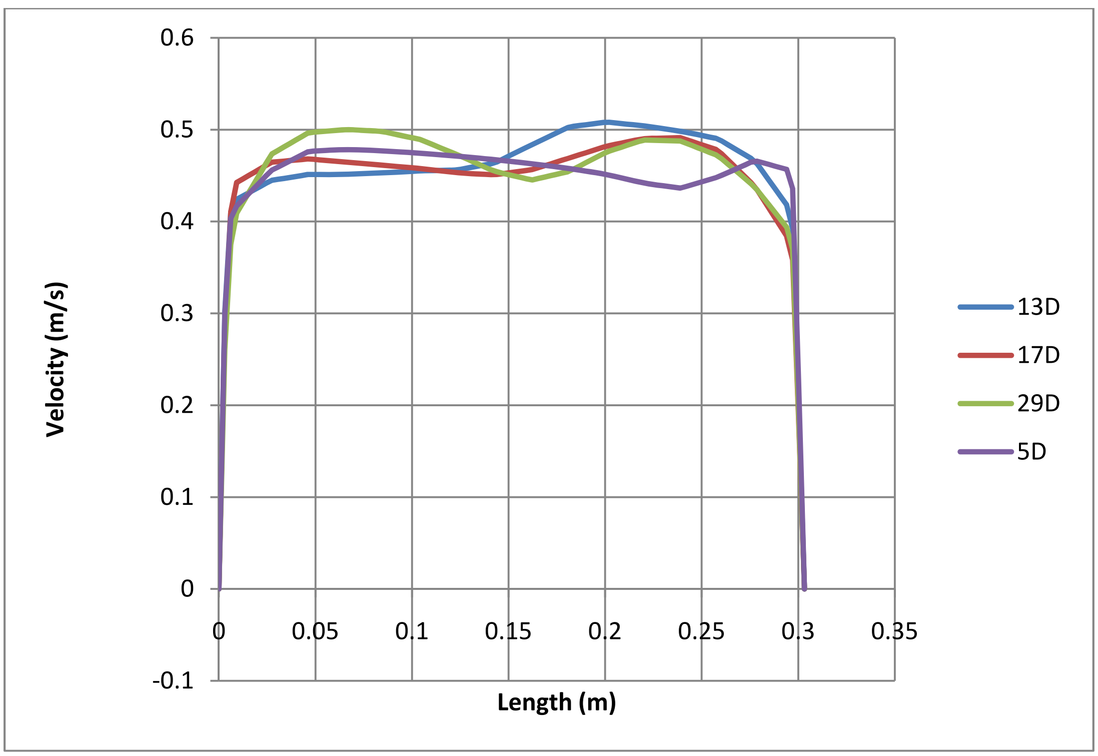


Figure 26 – 2 Elbows out of Plane, Re 140,000, No Flow Conditioner, Actual Velocities

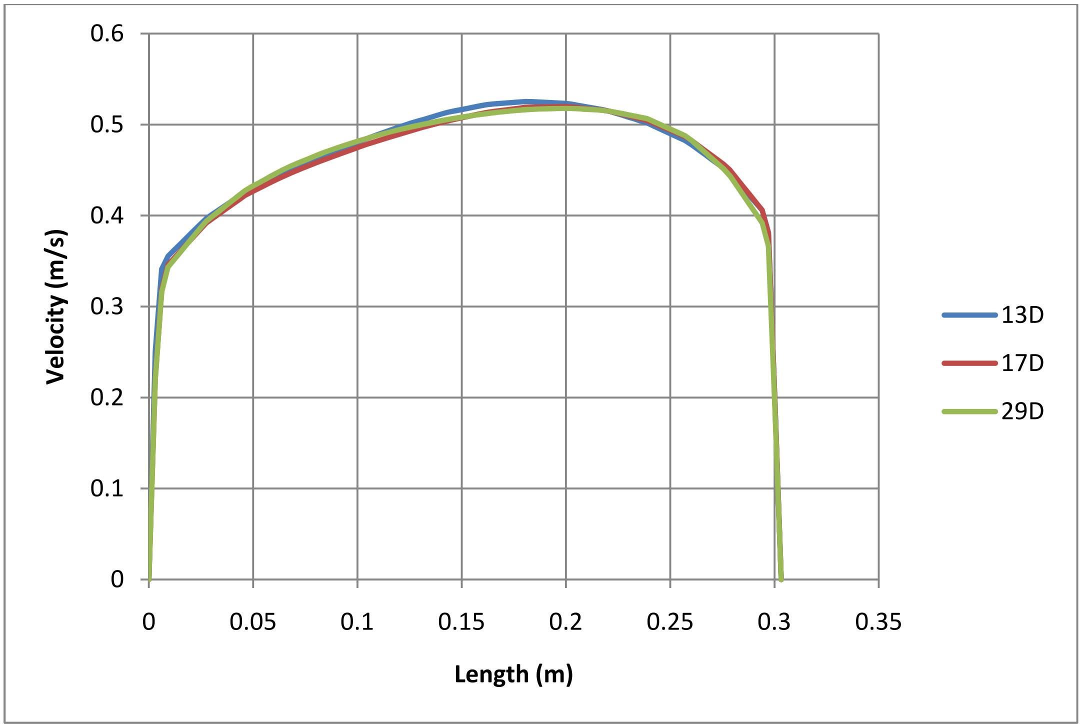


Figure 27 – 2 Elbows out of Plane, Re 140,000, Flow Conditioner, Actual Velocities

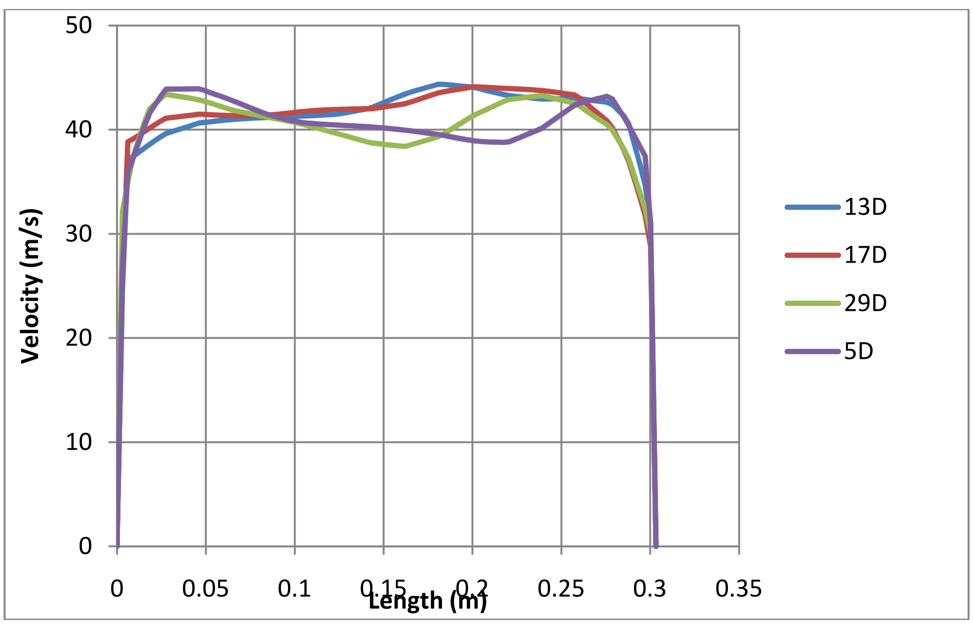


Figure 28 – 2 Elbows out of Plane, Re 40,000,000 No Flow Conditioner, Actual Velocities

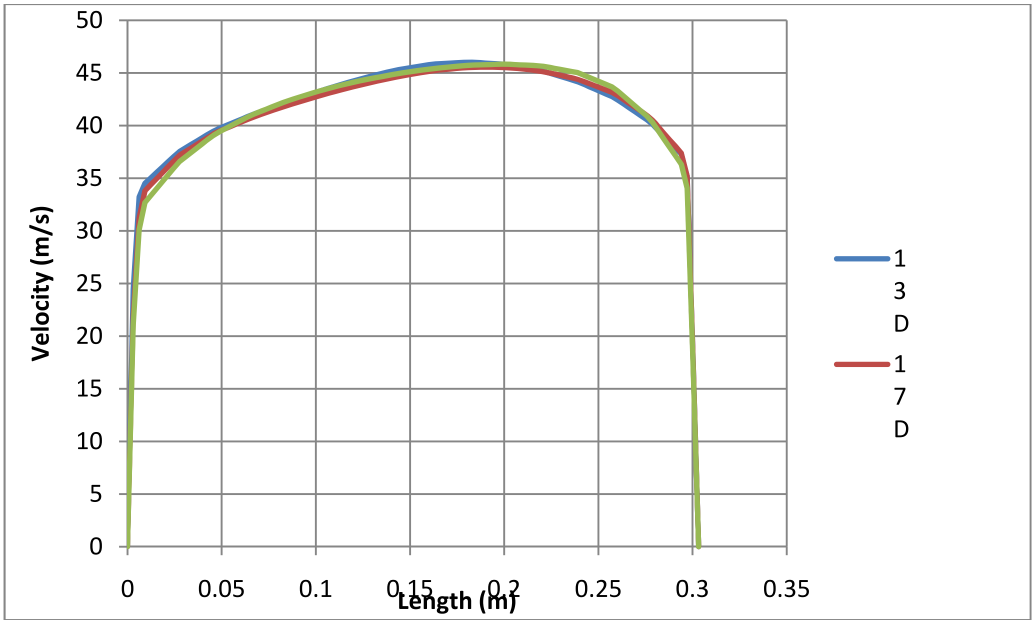


Figure 29 – 2 Elbows out of Plane, Re 40,000,000 Flow Conditioner, Actual Velocities

Table 2 – Maximum Swirl Angles (degrees)

Re	5D	13D	17D	29D
1000	4.4°	2.4°	1.4°	.6°
10,000	10.5	12.5	10.5	7.3
50,000	11.5	11.5	12.5	9
140,000	5	13	10.5	7.5
40,000,000	6	10	12	8.5

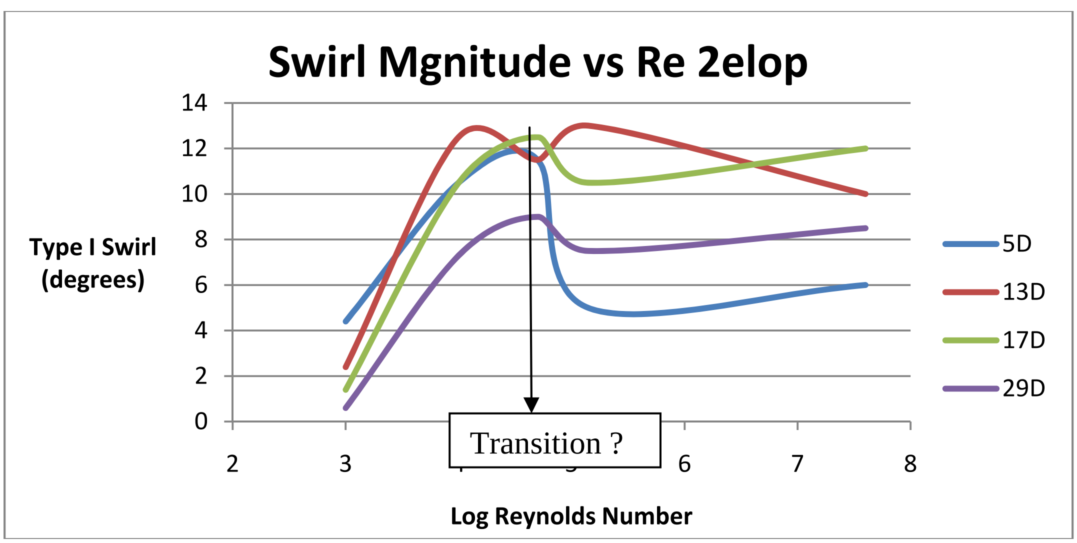


Figure 30 – Swirl Magnitude vs Re

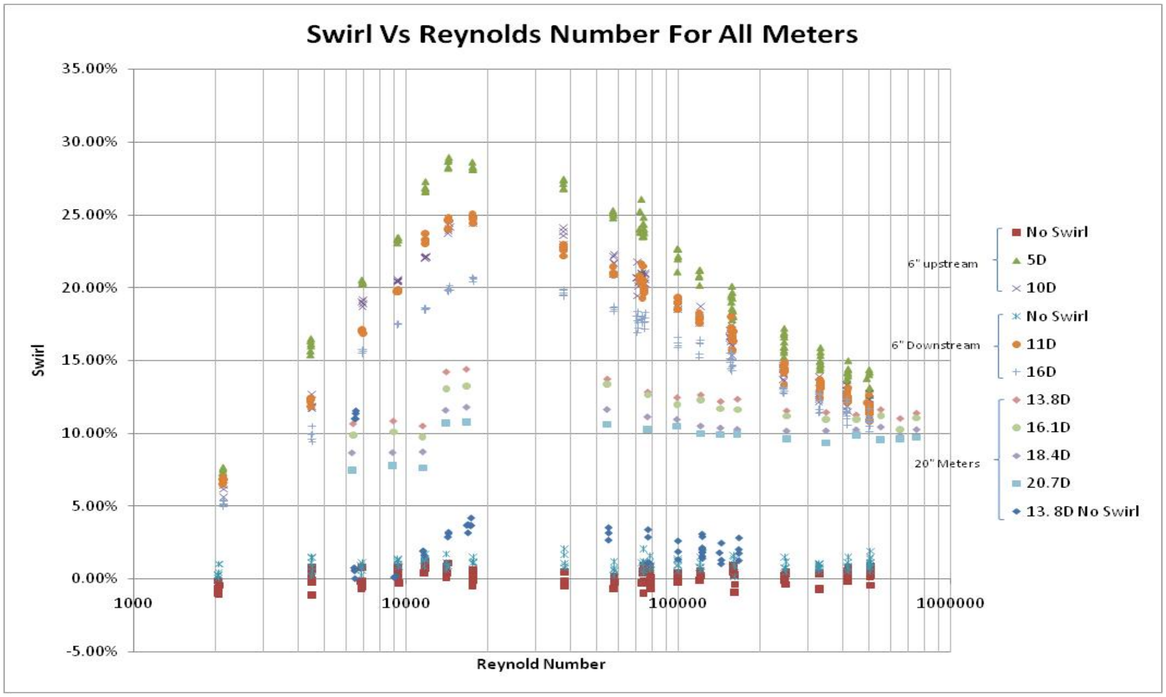


Figure 30 – Siwrl angle verses Re – Terry Cousins – Caldon 2010 CEESi SEA used with Permission.

Conclusion – 2 elbows out of plane

Again, there is no differentiation between liquid phase or vapour (gas) phase in the performance of a flow conditioner downstream of two elbows out of plane.

It appears that the installation effect(s) are low in Laminar flow regime, change in a step wise fashion (a singularity) in the transitional regime where the installation effects seem to `pop up out of no where, then asymptote to an infinite Re level. The installation effects severity follow the moody diagram to some extent.

The close coupled two elbows out of plane and two tees out of plane (which is worse in severity) are absolutely the worst pipe installation effects that the design Engineer can produce. This is the reason it was chosen for this study.

Although within the good metering limits not causing metering difficulties, this installation almost over loeads the flow conditioner. This can be mitigated by separating the two fittings.

Figure 30 indicates possible confirmation of this postulation by Caldon of Pittsburgh, USA.

Conclusion - General

What does this all mean?

1. There is no liquid verses vapour (gas) phase delineation of the metering world. If this is indeed the case, some oil meter run distances are too short.

2. I suspect that a lot of the oil metering facilities are operating in the transitional or laminar regions and do not even know it. What this means, is that the installation effect will be dormant until the fluid goes turbulent (and visa versa), the installation effects becomes multiplied by many factors. The operator only sees a meter factor change and decides to re-prove the meter.

3. At low Re laminar flow, no mixing is occurring, viscous forces over take the flow and installation effects are somewhat attenuated

4. At transitional ranges Re 1000 to say 20,000 Unaccounted for fluid behaviour is occurring, which is not trivial to address. Installation effects instantaneously go from low to maximum magnitudes and back again. No symptoms outside the pipe are indicated to warn the operator.

5. At low turbulent Re just after transition, low momentum transfer may be occurring which lets the installation effect maintain maximum values.

6. At high Re the flow is more dominated by momentum exchange and the installation effects reduce to a nominal value (that is generally seen as normal effects in the high pressure gas phase metering world).

7. Calibrate your meters against Re if possible. (Prior liquid and Gas Turbine meter calibrations over the past 30 years substantiate this), not against flow rate at some given set of flow conditions. And calculate Re at your facility identifying what flow regime the meter is operating in.

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Appendix

Approximate Viscosity Conversions

Seconds Saybolt Universal SSU	Kinematic viscosity		Seconds Saybolt Furol SSF	Seconds Redwood 1 Standard	Seconds Redwood 2 Admiralty	Degrees Engler	Degrees Barbey	Kinematic centistokes
	Centistokes	ft^2/sec						
31	1.00	0.00001076	—	29	—	1.00	6200	1.00
31.5	1.13	0.00001216	—	29.4	—	1.01	5486	1.13
32	1.81	0.00001948	—	29.8	—	1.08	3425	1.81
32.6	2.00	0.00002153	—	30.2	—	1.10	3100	2.00
33	2.11	0.00002271	—	30.6	—	1.11	2938	2.11
34	2.40	0.00002583	—	31.3	—	1.14	2583	2.40
35	2.71	0.00002917	—	32.1	—	1.17	2287	2.71
36	3.00	0.00003229	—	32.9	—	1.20	2066	3.00
38	3.64	0.00003918	—	33.7	—	1.26	1703	3.64
39.2	4.00	0.00004306	—	35.5	—	1.30	1550	4.00
40	4.25	0.00004575	—	36.2	5.10	1.32	1459	4.25
42	4.88	0.00005253	—	38.2	5.25	1.36	1270	4.88
42.4	5.00	0.00005382	—	38.6	5.28	1.37	1240	5.00
44	8.50	0.00005920	—	40.6	5.39	1.40	1127	5.50
45.6	6.00	0.00006458	—	41.8	5.51	1.43	1033	6.00
46	6.13	0.00006598	—	42.3	5.54	1.44	1011	6.13
46.8	7.00	0.00007535	—	43.1	5.60	1.48	885	7.00

50	7.36	0.00007922	—	44.3	5.83	1.58	842	7.36
52.1	8.00	0.00008611	—	46.0	6.03	1.64	775	8.00
55	8.88	0.00009558	—	48.3	6.30	1.73	698	8.88
55.4	9.00	0.00009688	—	48.6	6.34	1.74	689	9.00
58.8	10.00	0.0001076	—	51.3	6.66	1.83	620	10.00
60	10.32	0.0001111	—	52.3	6.77	1.87	601	10.32
65	11.72	0.0001262	—	56.7	7.19	2.01	529	11.72
70	13.08	0.0001408	—	60.9	7.60	2.16	474	13.08
75	14.38	0.0001548	—	65.1	8.02	2.37	431	14.38
80	15.66	0.0001686	—	69.2	8.44	2.45	396	15.66
85	16.90	0.0001819	—	73.4	8.87	2.59	367	16.90
90	18.12	0.0001950	—	77.6	9.30	2.73	342	18.12
95	19.32	0.0002080	—	81.6	9.71	2.88	321	19.32
100	20.52	0.0002209	—	85.6	10.12	3.02	302	20.52
120	25.15	0.0002707	—	102	11.88	3.57	246	25.15
140	29.65	0.0003191	—	119	13.63	4.11	209	29.65
160	34.10	0.0003670	—	136	15.39	4.64	182	34.10
180	38.52	0.0004146	—	153	17.14	5.12	161	38.52
200	42.95	0.0004623	—	170	18.90	5.92	144	42.95
300	64.60	0.0006953	32.7	253	28.00	8.79	96	64.60
400	86.20	0.0009275	42.4	338	37.10	11.70	71.9	86.20
500	108.00	0.001163	52.3	423	46.20	14.60	57.4	108.00
600	129.40	0.001393	62.0	507	55.30	17.50	47.9	129.40
700	151.00	0.001625	72.0	592	64.60	20.44	41.0	151.00
800	172.60	0.001858	82.0	677	73.80	23.36	35.9	172.60
900	194.20	0.002090	92.1	762	83.00	26.28	31.9	194.20
1000	215.80	0.002323	102.1	846	92.30	29.20	28.7	215.80
1200	259.00	0.002788	122	1016	111	35.1	23.9	259.00
1400	302.30	0.003254	143	1185	129	40.9	20.5	302.30
1600	345.30	0.003717	163	1354	148	46.7	18.0	345.30
1800	388.50	0.004182	183	1524	166	52.6	15.6	388.50
2000	431.70	0.004647	204	1693	185	58.4	14.4	431.70
2500	539.40	0.005806	254	2115	231	73.0	11.5	539.40
3000	647.30	0.006967	305	2538	277	87.6	9.6	647.30
3500	755.20	0.008129	356	2961	323	102	8.21	755.20
4000	863.10	0.009290	408	3385	369	117	7.18	863.10
4500	970.90	0.01045	458	3807	415	131	6.39	970.90
5000	1078.80	0.01161	509	4230	461	146	5.75	1078.80
6000	1294.60	0.01393	610	5077	553	175	4.78	1294.60
7000	1510.30	0.01626	712	5922	646	204	4.11	1510.30
8000	1726.10	0.01858	814	6769	728	234	3.59	1726.10
9000	1941.90	0.02092	916	7615	830	263	3.19	1941.90
10,000	2157.60	0.02322	1018	8461	922	292	2.87	2157.60

15,000	3236.50	0.03483	1526	12692	—	438	1.92	3236.50
20,000	4315.30	0.04645	2035	16923	—	584	1.44	4315.30

Kinematic Viscosity

Multiply	⇒	**to get**
to get	⇐	**Divide**
ft^2/sec	92903.04	centistokes
ft^2/sec	0.092903	sq meters/sec
sq meters/sec	10.7639	ft^2/sec
sq meters/sec	1000000.0	centistokes
centistokes	0.000001	sq meters/sec
centistokes	0.0000107639	ft^2/sec

Absolute or Dynamic Viscosity

Multiply	⇒	**to get**
to get	⇐	**Divide**
lbf-sec/ft^2	47880.26	centipoises
lbf-sec/ft^2	47.8803	Pascal-sec
centipoises	0.000102	kg-sec/sq meter
centipoises	0.001	lbf-sec/sq ft*
Pascal-sec	0.0208854	Pascal-sec
Pascal-sec	1000	centipoises

*Sometimes absolute viscosity is given in terms of pounds mass. In this case—centipoises x 0.000672 = lbm/ft sec.

Absolute to Kinematic Viscosity

Multiply	⇒	**to get**
to get	⇐	**Divide**
centipoises	1/density (g/cm^3)	centistokes
centipoises	0.00067197/density (lb/ft^3)	ft^2/sec
lbf-sec/ft^2	32.174/density (lb/ft^3)	ft^2/sec
kg-sec/m^2	9.80665/density (kg/m^3)	sq meters/sec
Pascal-sec	1000/density (g/cm^3)	centistokes

Kinematic to Absolute Viscosity

Multiply	⇒	to get
to get	**⇐**	**Divide**
centistokes	density (g/cm^3)	centipoises
sq meters/sec	0.10197 x density (kg/m^3)	kg-sec/sq meter
ft^2/sec	0.03108 x density (lb/ft^3)	lbf-sec/ft^2
ft^2/sec	1488.16 x density (lb/ft^3)	centipoises
centistokes	0.001 x density (g/cm^3)	Pascal-sec
sq meters/sec	1000 x density (g/cm^3)	Pascal-sec

API Gravity (density)

Degree API	Specific Gravity	Weight	
		(lb/US gal)	(kg/m^3)
8	1.014	8.448	1012
9	1.007	8.388	1005
10	1.000	8.328	998
15	0.966	8.044	964
20	0.934	7.778	932
25	0.904	7.529	902
30	0.876	7.296	874
35	0.850	7.076	848
40	0.825	6.870	823
45	0.802	6.675	800
50	0.780	6.490	778
55	0.759	6.316	757
58	0.747	6.216	745

The formula for API Gravity can be expressed as:

Degrees API Gravity = (141.5 / Specific Gravity at 60^{o}F) - 131.5 (1)

References

Miller, W. Richard, “Flow Measurement Engineering Handbook”, McGraw-Hill, Third Edition, 1996, ISBN 0-07-042366-0

Colebrook, C.F., “Turbulent Flow in Pipes, with Particular reference to the Transition between the Smooth and Rough Pipe Laws”, J. Inst. Civ. Eng., vol. 11, pp. 133-136, 1938-1939.

Moody, L.F. “Friction Factors for Pipe Flows”, Trans. ASME, vol. 66, p 671, 1944.

White M. Frank, “Fluids Mechanics”, Second Edition, McGraw-Hill, 1986, ISBN 0-07-069673-x

American Gas Association Report No. 3, American Pertroleum Institute API 14.3, Gas Processors Association GPA 8185-90, “Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids”, Third Edition, October 1990, A.G.A. Catalog No. XQ9017

The International Oragnization for Standardization, “ISO 5167, Measurement of Fluid Flow by Means of Orifice Plates, Nozzles and Venturi Tubes Inserted in Circular Cross-Section Conduits Running Full”, first Edtion, 1980-02-01, Ref. No. ISO 5167-1980 (E)

Ranseth, Alan. Reynolds Number Calibration of Turbine Meters, TransCanada Calibrations Box 654 Ile De Chenes Manitoba Canada R0A 0T0 204 878 4373

Danny A. Sawchuk, E.I.T., A Visual Study of Installation Effects, Paper #9044, CSHM 2009 Calgary, Alberta, Canada, Canada Pipeline Accessories Co. Ltd., 10653 46th Street, Calgary, Alberta   T2C5C2