ACCELERATING
INNOVATION

[1-1675] Velocity of Sound Corrections in Micro Motion Coriolis Meters

Disclaimer

Important Reminders

Thad Triandos

Test Engineer Emerson,

Micro Motion

Thad Triandos	Background
Thad Triandos	Customer Impact
Thad Triandos	Velocity of Sound Theory
Thad Triandos	Velocity of Sound Correction
Thad Triandos	Test Results
Thad Triandos	Conclusions

Background

- Velocity of Sound (VoS) – Also referred to as speed of sound is how quickly disturbances travel through a medium.
- Under very specific conditions Coriolis mass flow meters can experience errors due to VoS.
  - Generally, these conditions are not met.
- In most cases VoS is high enough there is no error.
- For ethane, ethylene, and CO_2 the VoS is low and changes drastically over operating conditions.
  - In large meters this leads to large measurement errors in mass flow.

Customer Impact

- For smaller meters (CMF300 and smaller) have performed well in gas applications and at labs.
  - Larger meters can have bias errors up to several percent. This error can vary greatly depending on T&P conditions.
- This new correction allows for the entire meter range to be used on difficult applications.
- Ethylene $0.67 per kg
- Typical flow rate is 50,000 kg/h = 1,200,000 kg/day
  - 1% is $12,000 per day
- Trend toward larger meters where the effect is greater (with increased production)

Customer Impact in Difficult-to-measure Fluids
(CO_2 and Ethylene)

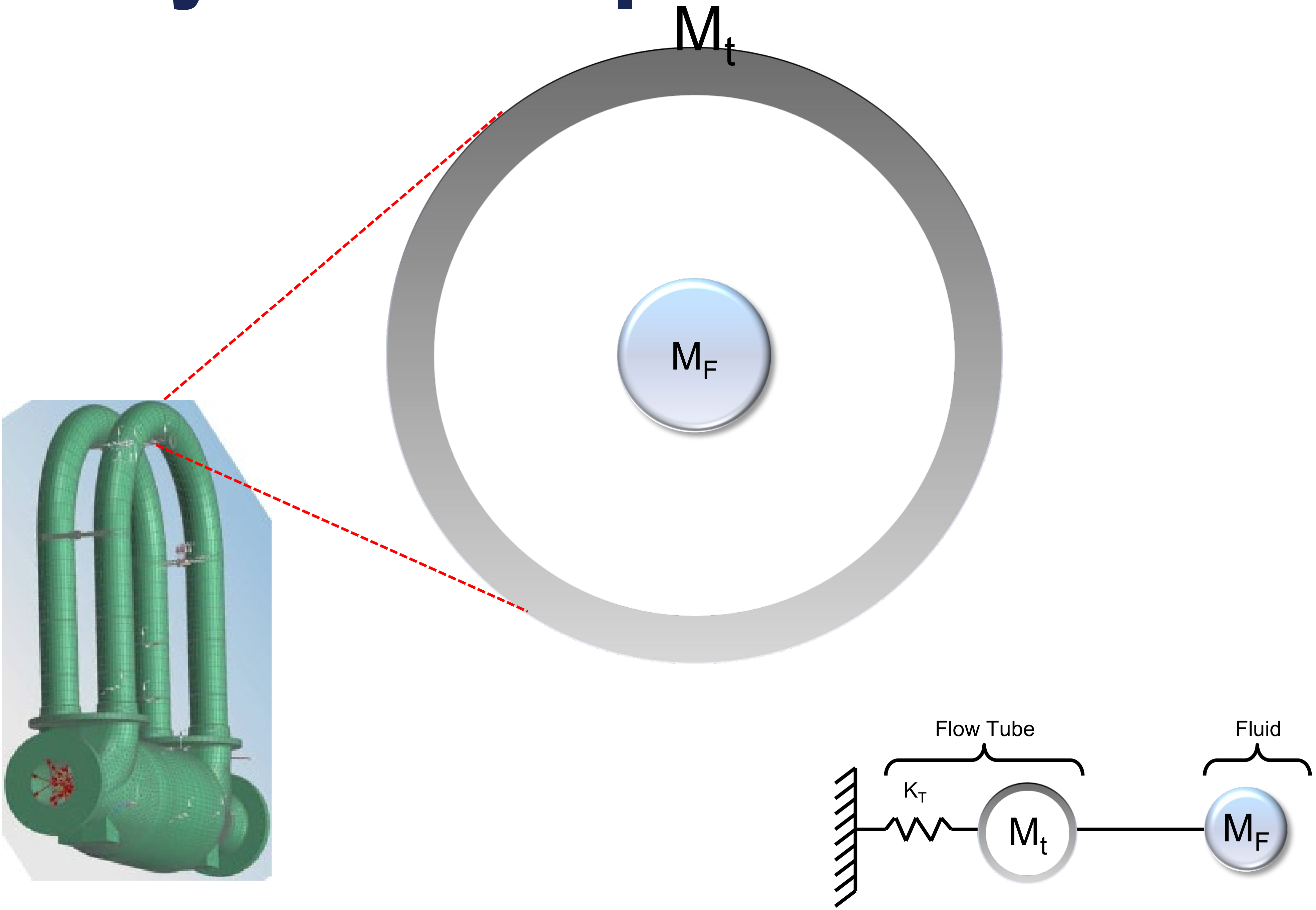
- Coriolis meters measure mass flow directly
  - Volumetric meters require a density measurement
  - Density can be difficult to estimate due to temperature and pressure variations
- Coriolis has superior turndown when compared to other technologies
  - No need for orifice plate changes
  - Minimizes opportunity for leakage
- Improved accuracy over entire range.
- Good solution for situations where proving is not an option
  - Opportunity to use series metering for in-situ ‘proving’

Field Example

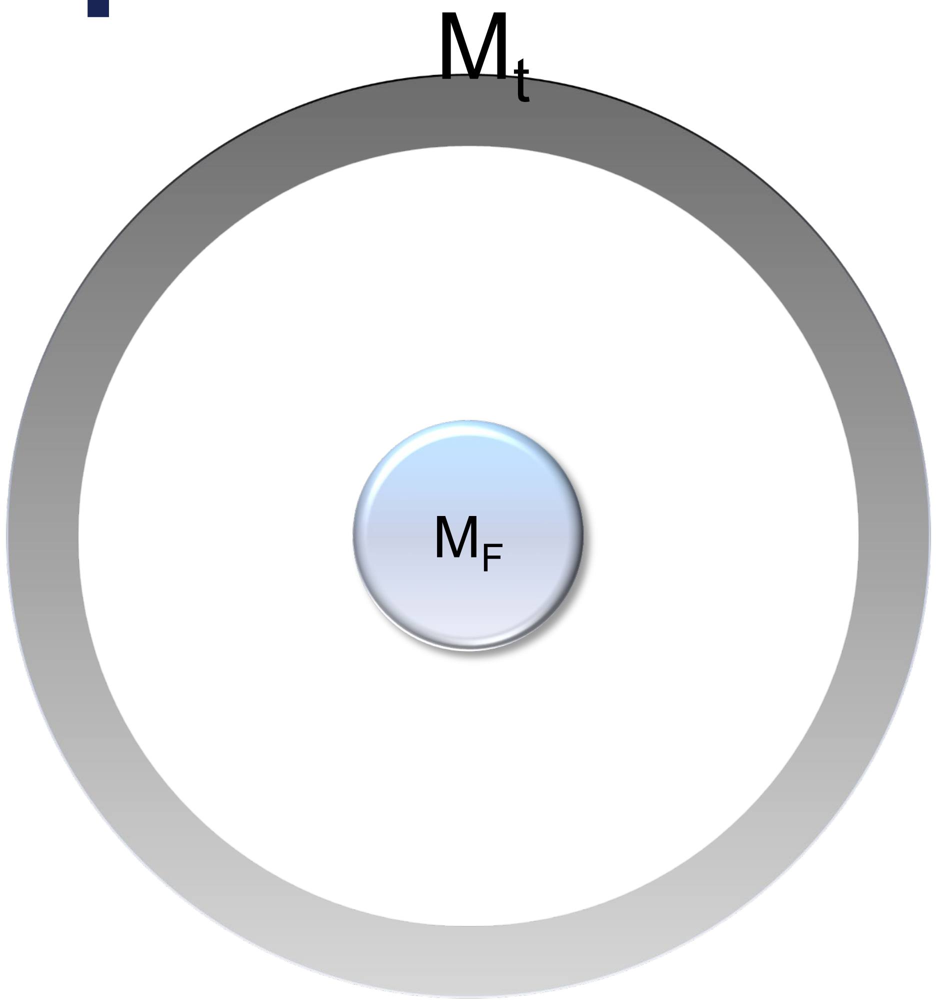
- Ethylene skid at large mid-stream user in Houston.
- Three parallel lines could be replaced with one line of a larger meters.
- Six meters and associated piping and valving is expensive.
- A single large meter is better.

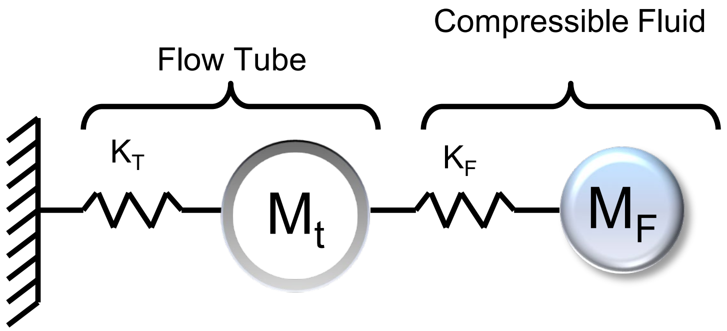
Velocity of Sound Theory

VOS Theory: Non-Compressible Fluids



VOS Theory: Compressible Fluids

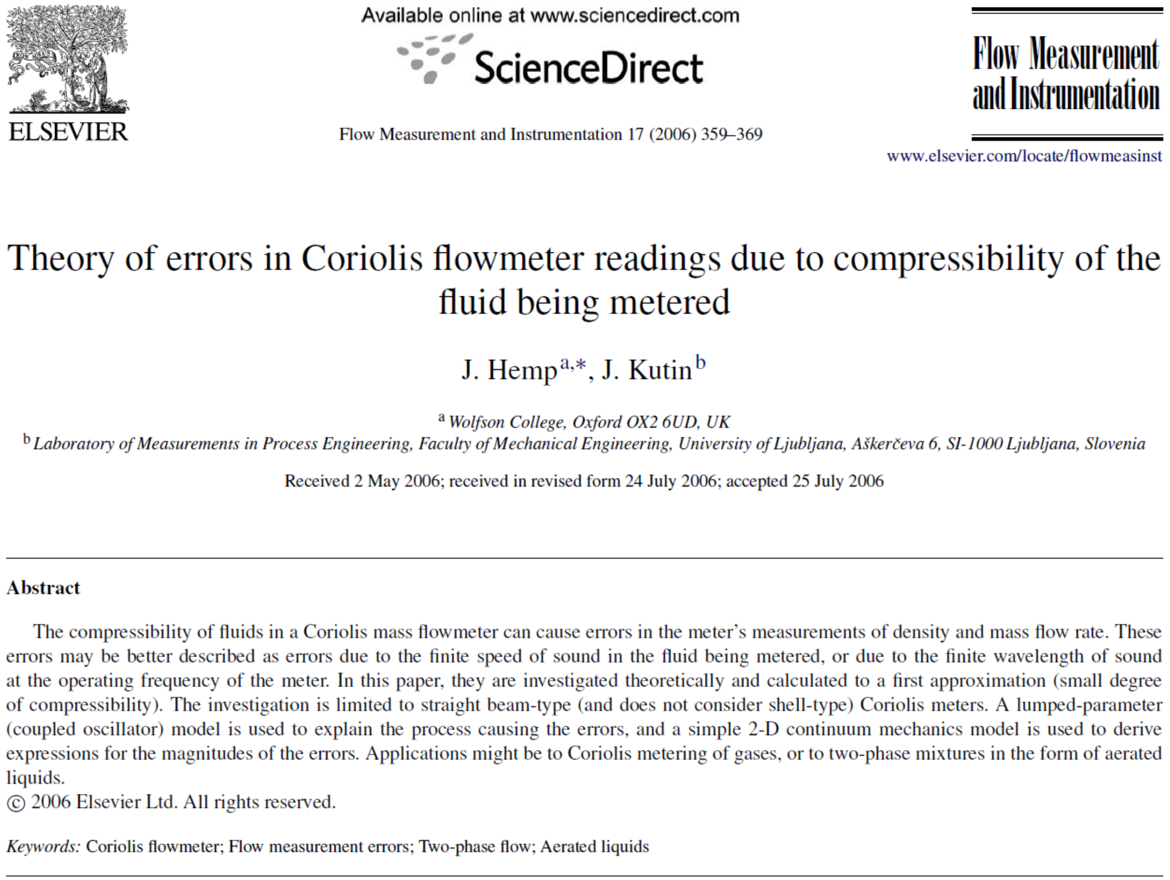




Velocity of Sound Correction

The New Correction

- Patent pending.
- Direct application of research from academia
- $mass\ flow\ error = m_e = 0.5 \times \left(\frac{2\pi f b}{2a}\right)^2 \times 100\%$
  - f = Tube Frequency -- known
  - b = Tube Diameter -- known
  - a = Velocity of Sound – hard to get
- Challenges with implementing the correction.
  - VoS is not direct measurement of Coriolis meters.
  - Equations of state are too complex.



ELSEVIER

Available online at www.sciencedirect.com
ScienceDirect
Flow Measurement and Instrumentation 17 (2006) 359–369

Flow Measurement and Instrumentation
www.elsevier.com/locate/flowmeasinst

Theory of errors in Coriolis flowmeter readings due to compressibility of the fluid being metered

J. Hemp[a,*], J. Kutin[b]

[a] Wolfson College, Oxford OX2 6UD, UK
[b] Laboratory of Measurements in Process Engineering, Faculty of Mechanical Engineering, University of Ljubljana, Aškerčeva 6, SI-1000 Ljubljana, Slovenia

Received 2 May 2006; received in revised form 24 July 2006; accepted 25 July 2006

Abstract

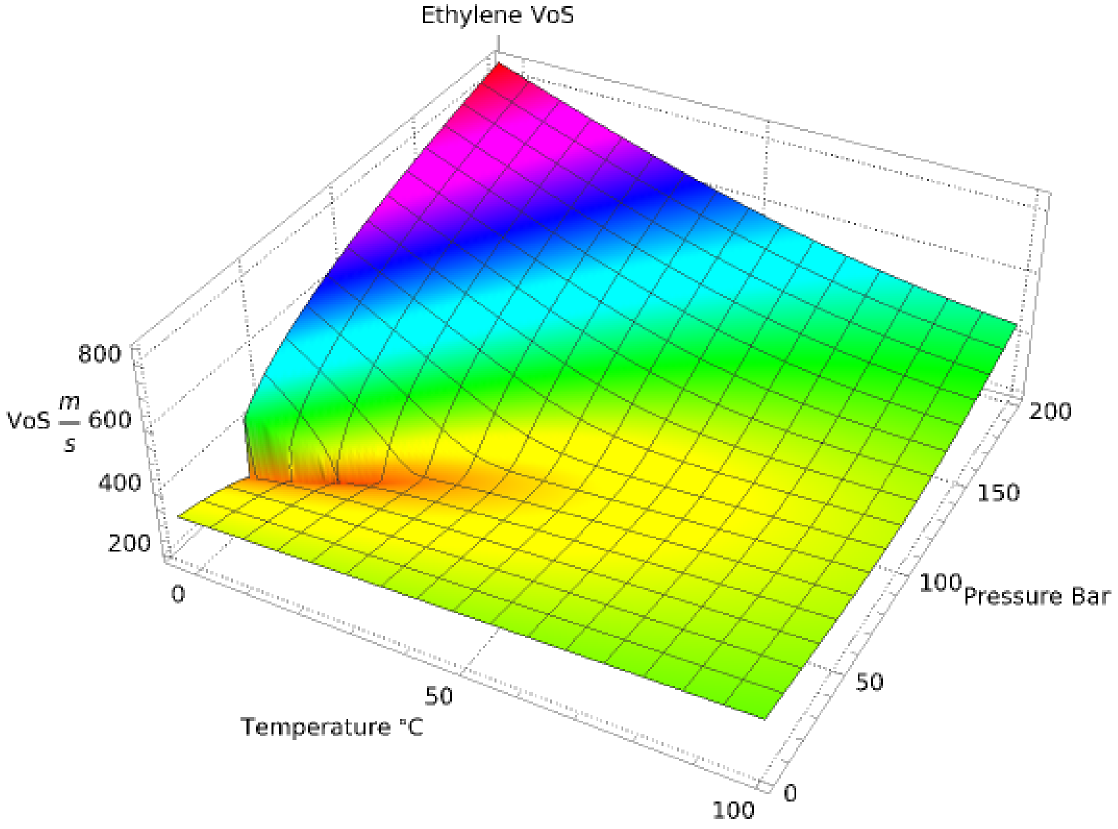
The compressibility of fluids in a Coriolis mass flowmeter can cause errors in the meter's measurements of density and mass flow rate. These errors may be better described as errors due to the finite speed of sound in the fluid being metered, or due to the finite wavelength of sound at the operating frequency of the meter. In this paper, they are investigated theoretically and calculated to a first approximation (small degree of compressibility). The investigation is limited to straight beam-type (and does not consider shell-type) Coriolis meters. A lumped-parameter (coupled oscillator) model is used to explain the process causing the errors, and a simple 2-D continuum mechanics model is used to derive expressions for the magnitudes of the errors. Applications might be to Coriolis metering of gases, or to two-phase mixtures in the form of aerated liquids.

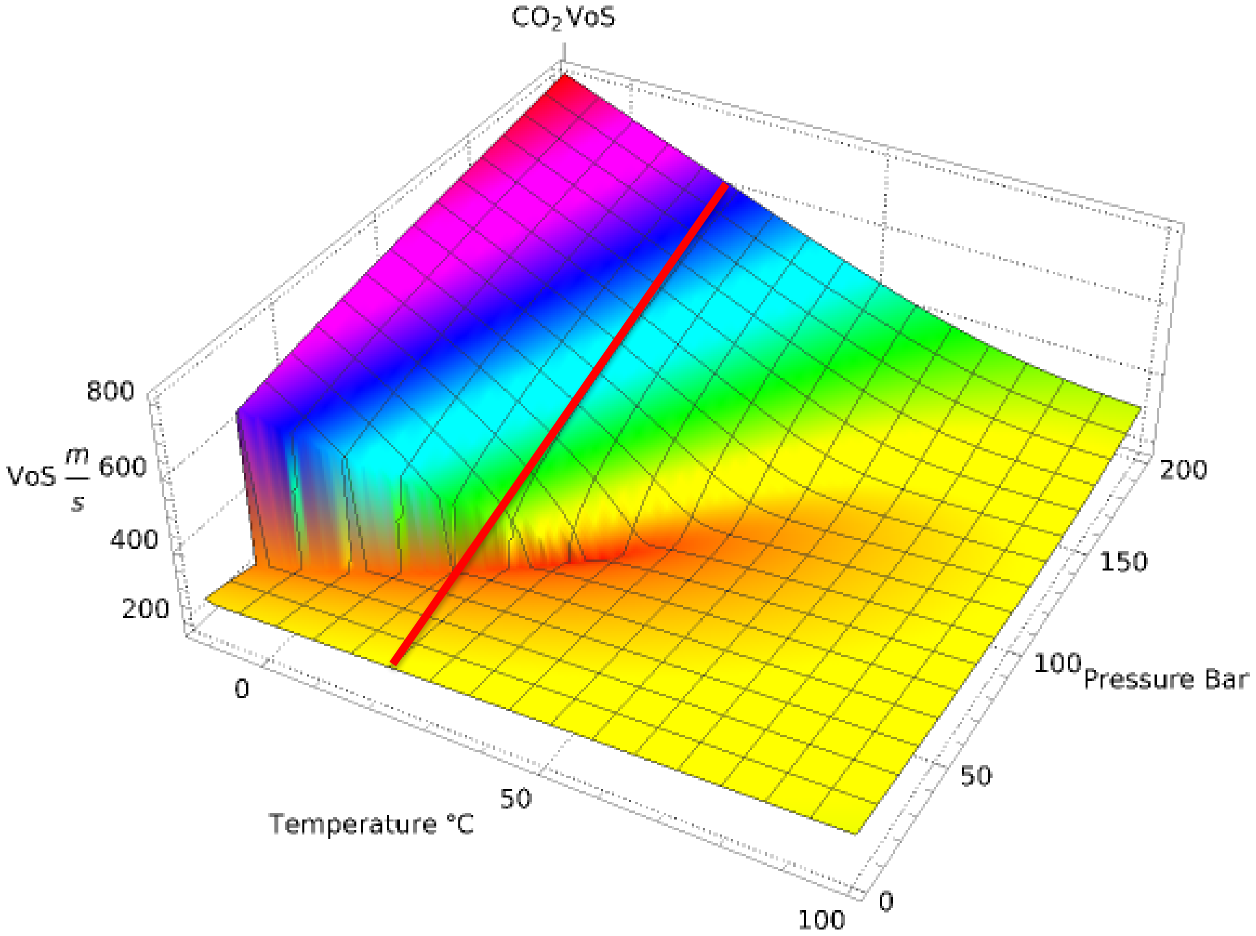
Keywords: Coriolis flowmeter; Flow measurement errors; Two-phase flow; Aerated liquids

---

VoS Example

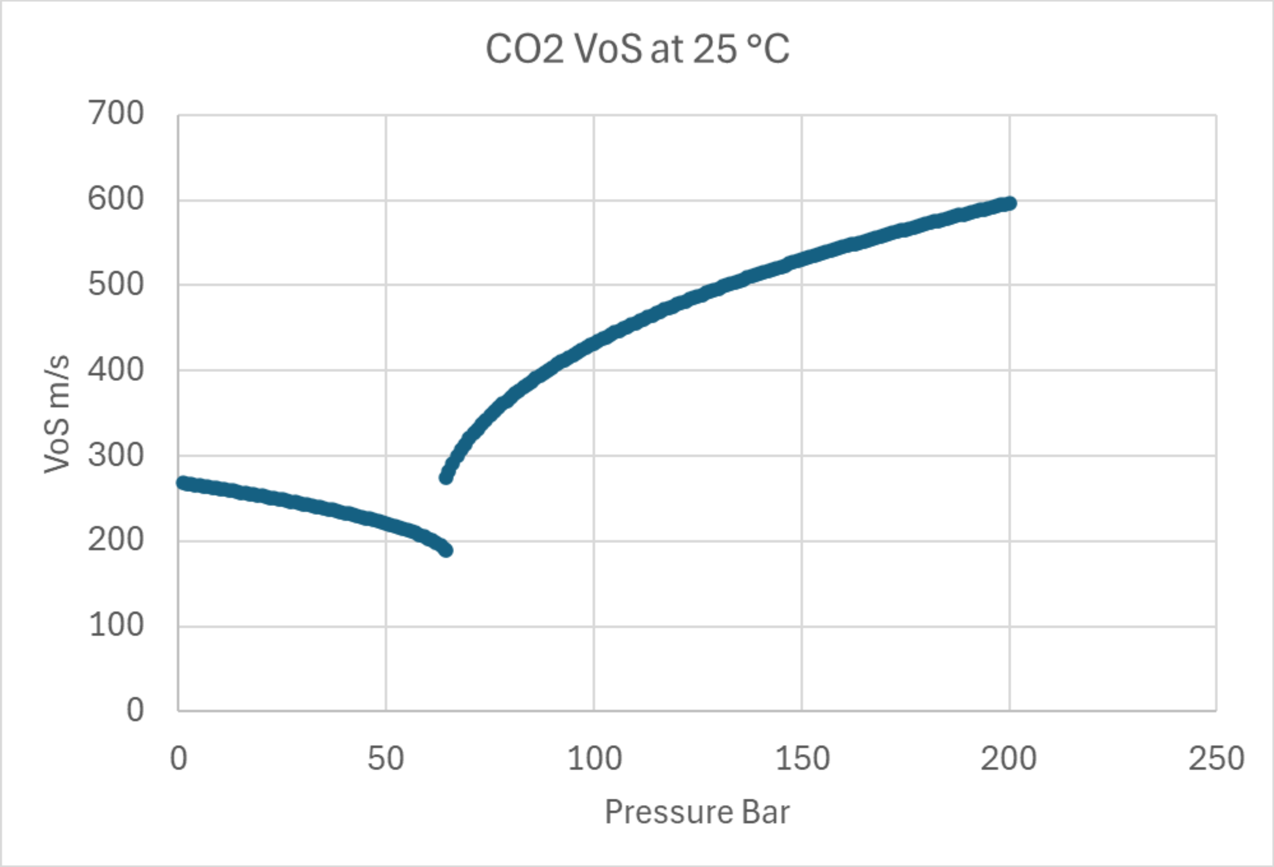
- VoS of CO_2 and Ethylene across typical operating range.
- CO_2 and Ethylene behave very similarly.





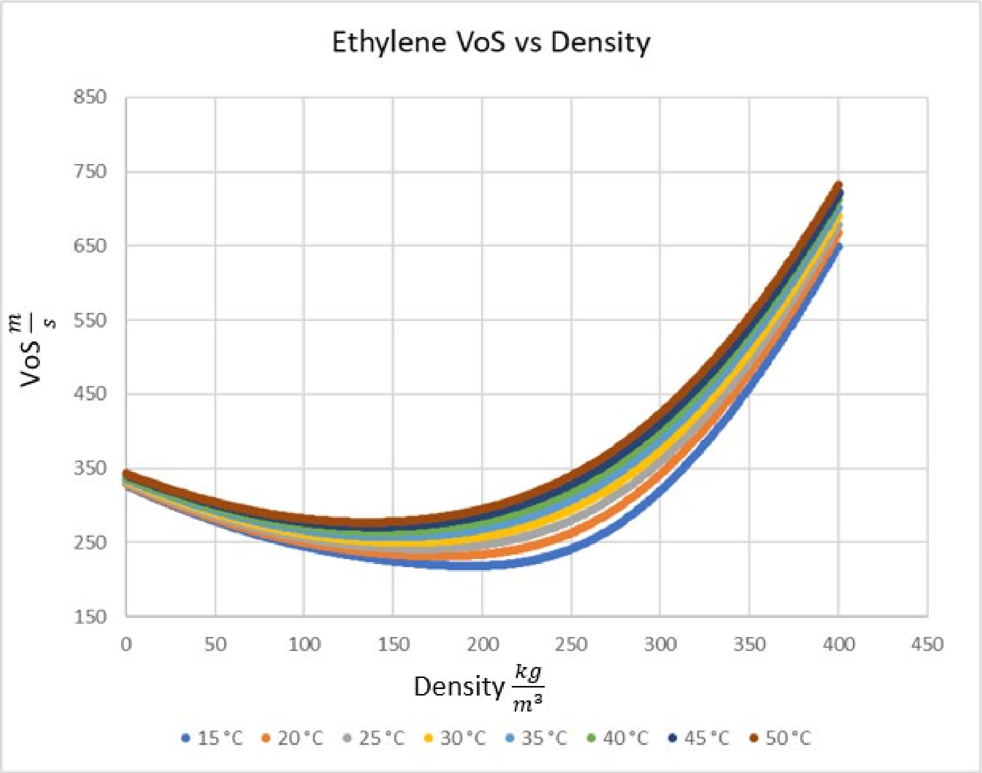
VoS Example

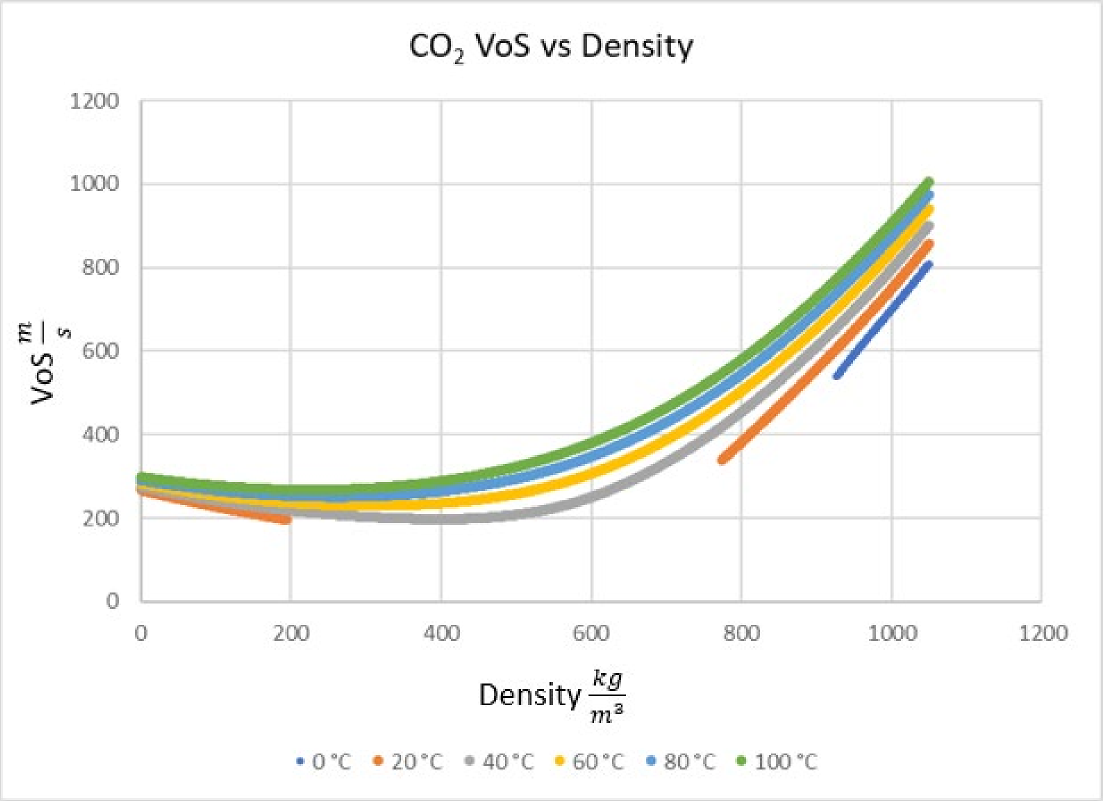
- VoS can change very rapidly this makes it hard to correct for.
- VoS has a high sensitivity to changes in pressure.
- Calculating VoS by equation of state using T&P requires high accuracy T&P measurement.
  - Small input errors in T&P result in large errors in calculated VoS



VoS Measurement

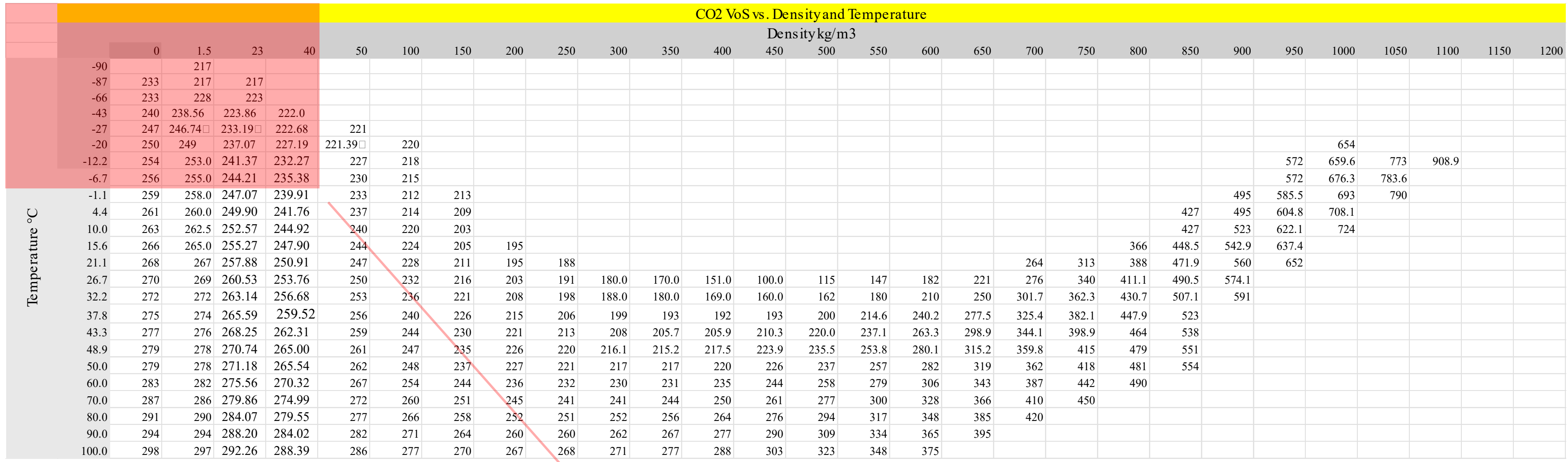
- Density and temperature are direct measurements making them ideal measurements to calculate VoS
- When VoS is low it has low sensitivity to density changes
- When VoS is high VoS error is further minimized





VoS Calculation

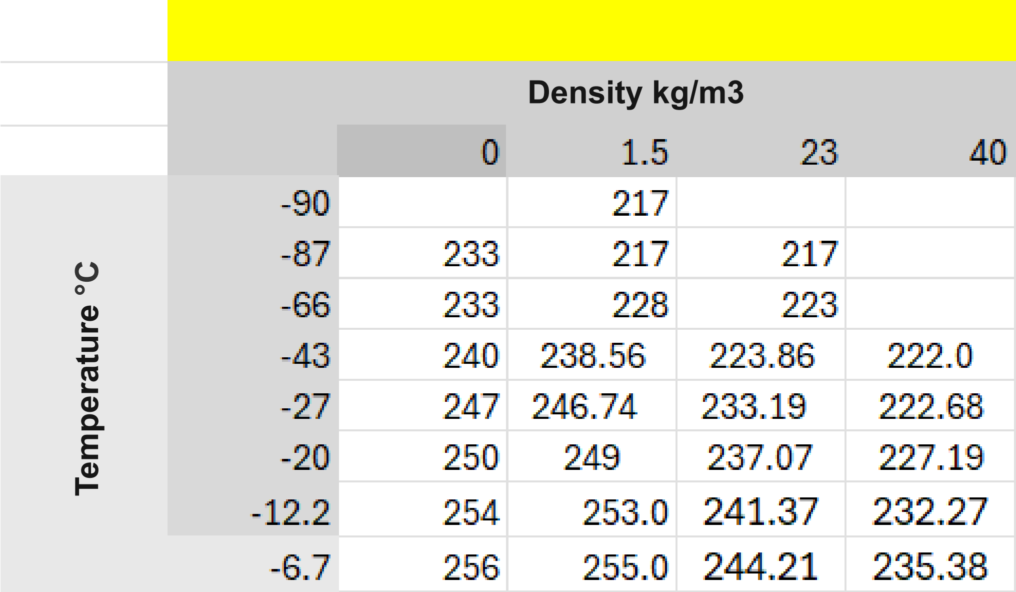
- This table is the same previous slides graphs.
- The transmitter uses the following table to calculate VoS using the meters temperature and density.
- Table is populated with data from NIST's REFPROP.



CO2 VoS vs. Density and Temperature

Density kg/m3

Temperature °C	0	1.5	23	40	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200
-90		217																										
-87	233	217	217																									
-66	233	228	223																									
-43	240	238.56	223.86	222.0																								
-27	247	246.74□	233.19□	222.68	221																							
-20	250	249	237.07	227.19	221.39□	220																		654				
-12.2	254	253.0	241.37	232.27	227	218																	572	659.6	773	908.9		
-6.7	256	255.0	244.21	235.38	230	215																	572	676.3	783.6			
-1.1	259	258.0	247.07	239.91	233	212	213															495	585.5	693	790			
4.4	261	260.0	249.90	241.76	237	214	209														427	495	604.8	708.1				
10.0	263	262.5	252.57	244.92	240	220	203														427	523	622.1	724				
15.6	266	265.0	255.27	247.90	244	224	205	195												366	448.5	542.9	637.4					
21.1	268	267	257.88	250.91	247	228	211	195	188									264	313	388	471.9	560	652					
26.7	270	269	260.53	253.76	250	232	216	203	191	180.0	170.0	151.0	100.0	115	147	182	221	276	340	411.1	490.5	574.1						
32.2	272	272	263.14	256.68	253	236	221	208	198	188.0	180.0	169.0	160.0	162	180	210	250	301.7	362.3	430.7	507.1	591						
37.8	275	274	265.59	259.52	256	240	226	215	206	199	193	192	193	200	214.6	240.2	277.5	325.4	382.1	447.9	523							
43.3	277	276	268.25	262.31	259	244	230	221	213	208	205.7	205.9	210.3	220.0	237.1	263.3	298.9	344.1	398.9	464	538							
48.9	279	278	270.74	265.00	261	247	235	226	220	216.1	215.2	217.5	223.9	235.5	253.8	280.1	315.2	359.8	415	479	551							
50.0	279	278	271.18	265.54	262	248	237	227	221	217	217	220	226	237	257	282	319	362	418	481	554							
60.0	283	282	275.56	270.32	267	254	244	236	232	230	231	235	244	258	279	306	343	387	442	490								
70.0	287	286	279.86	274.99	272	260	251	245	241	241	244	250	261	277	300	328	366	410	450									
80.0	291	290	284.07	279.55	277	266	258	252	251	252	256	264	276	294	317	348	385	420										
90.0	294	294	288.20	284.02	282	271	264	260	260	262	267	277	290	309	334	365	395											
100.0	298	297	292.26	288.39	286	277	270	267	268	271	277	288	303	323	348	375												



Density kg/m3

Temperature °C	0	1.5	23	40
-90		217		
-87	233	217	217	
-66	233	228	223	
-43	240	238.56	223.86	222.0
-27	247	246.74	233.19	222.68
-20	250	249	237.07	227.19
-12.2	254	253.0	241.37	232.27
-6.7	256	255.0	244.21	235.38

Sensitivity Analysis

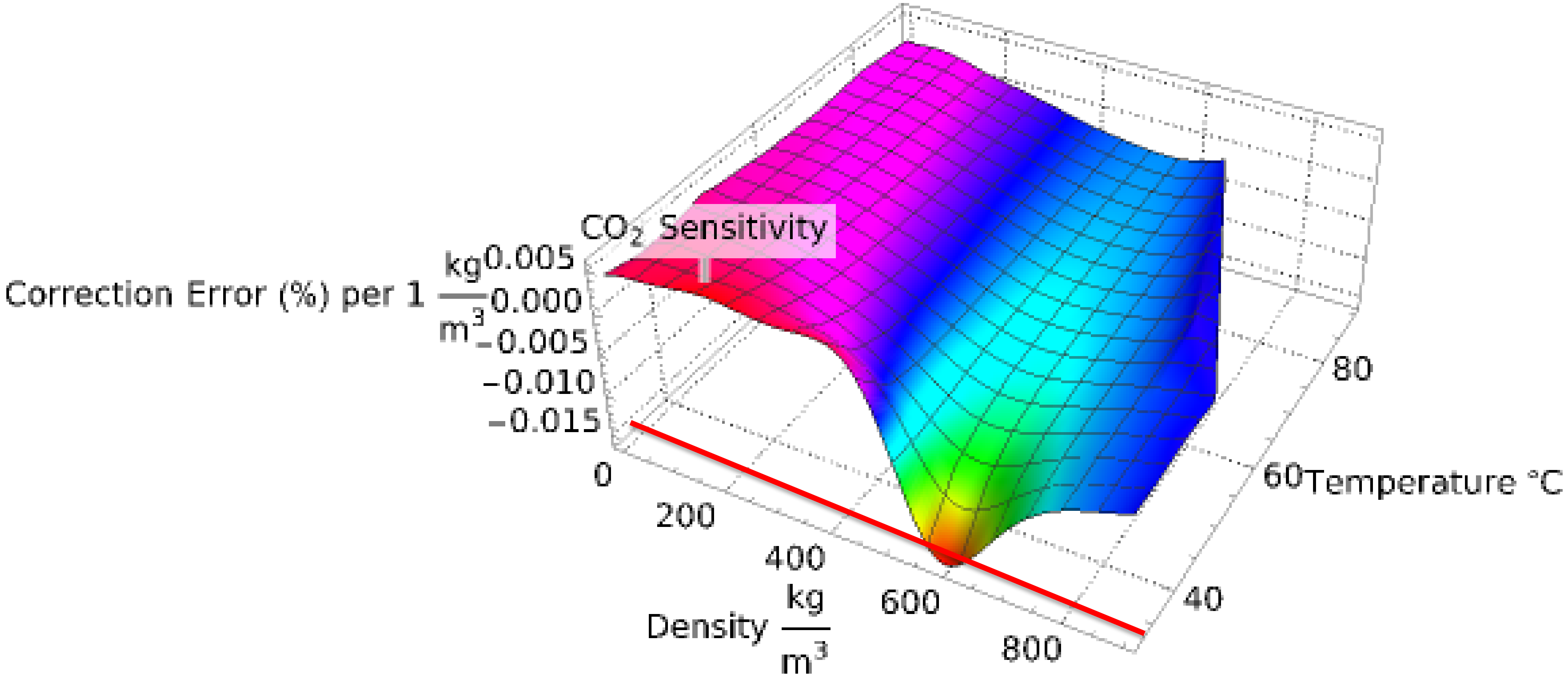
- How much uncertainty is there in the correction, due to small errors in independent variables
- Independent variables:
  - Temperature
  - Frequency
  - Density
    - Since the velocity of sound is estimated from the density measurement, errors in the correction can be quantified and shown to be small in the region of interest close to the critical point

- $mass\ flow\ error = m_e = 0.5 \times \left(\frac{2\pi f b}{2a}\right)^2 \times 100\%$

$$\delta f_{x,y,z} = \sqrt{\left[\frac{\partial f}{\partial x}\delta x\right]^2 + \left[\frac{\partial f}{\partial y}\delta y\right]^2 + \left[\frac{\partial f}{\partial z}\delta z\right]^2}$$

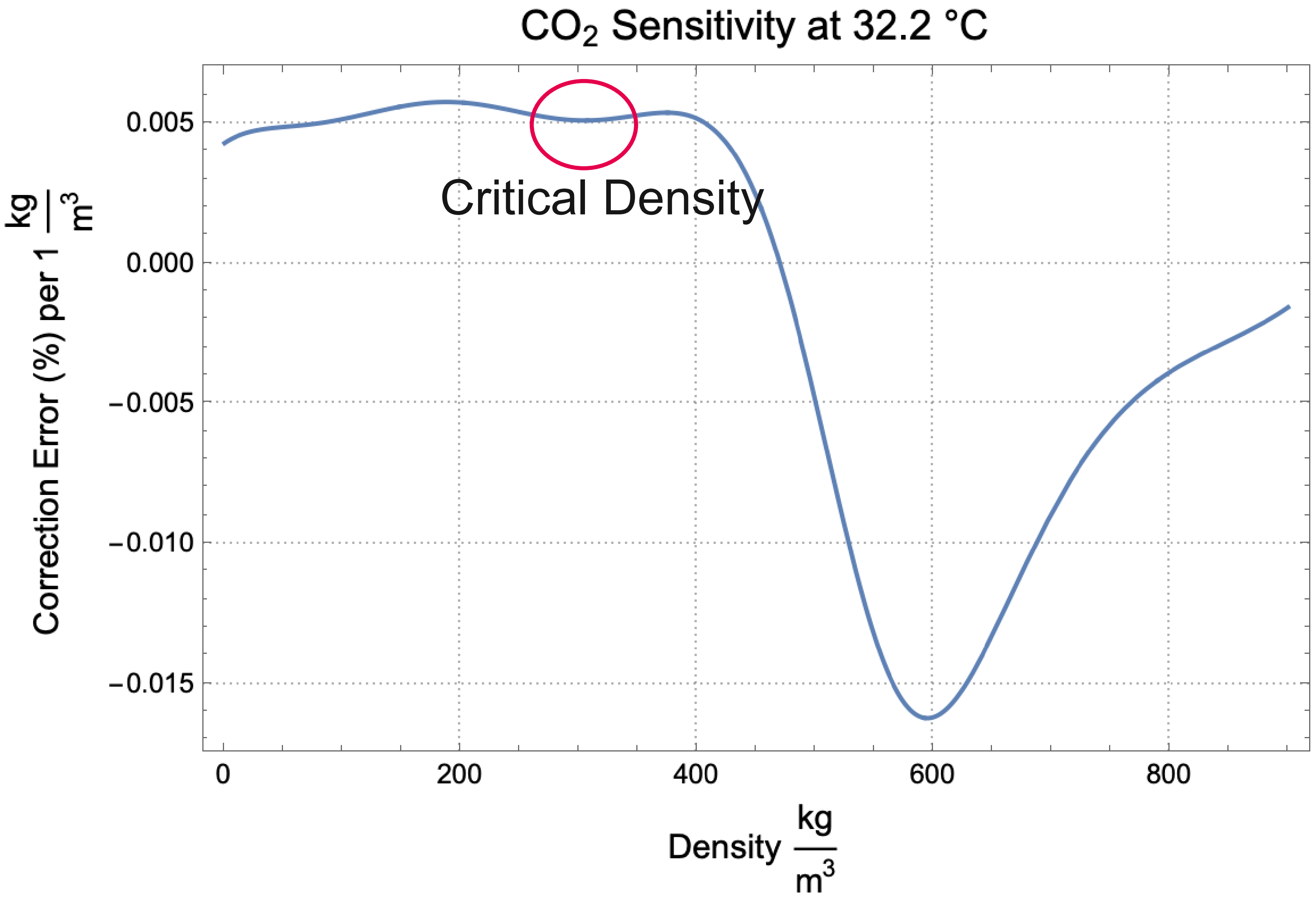
$$\delta E_{\dot{m}} = \frac{\partial E_{\dot{m}}\left(b, \rho, \omega\right)}{\partial \rho}\delta \rho$$

Sensitivity of The Correction



Sensitivity of The Correction

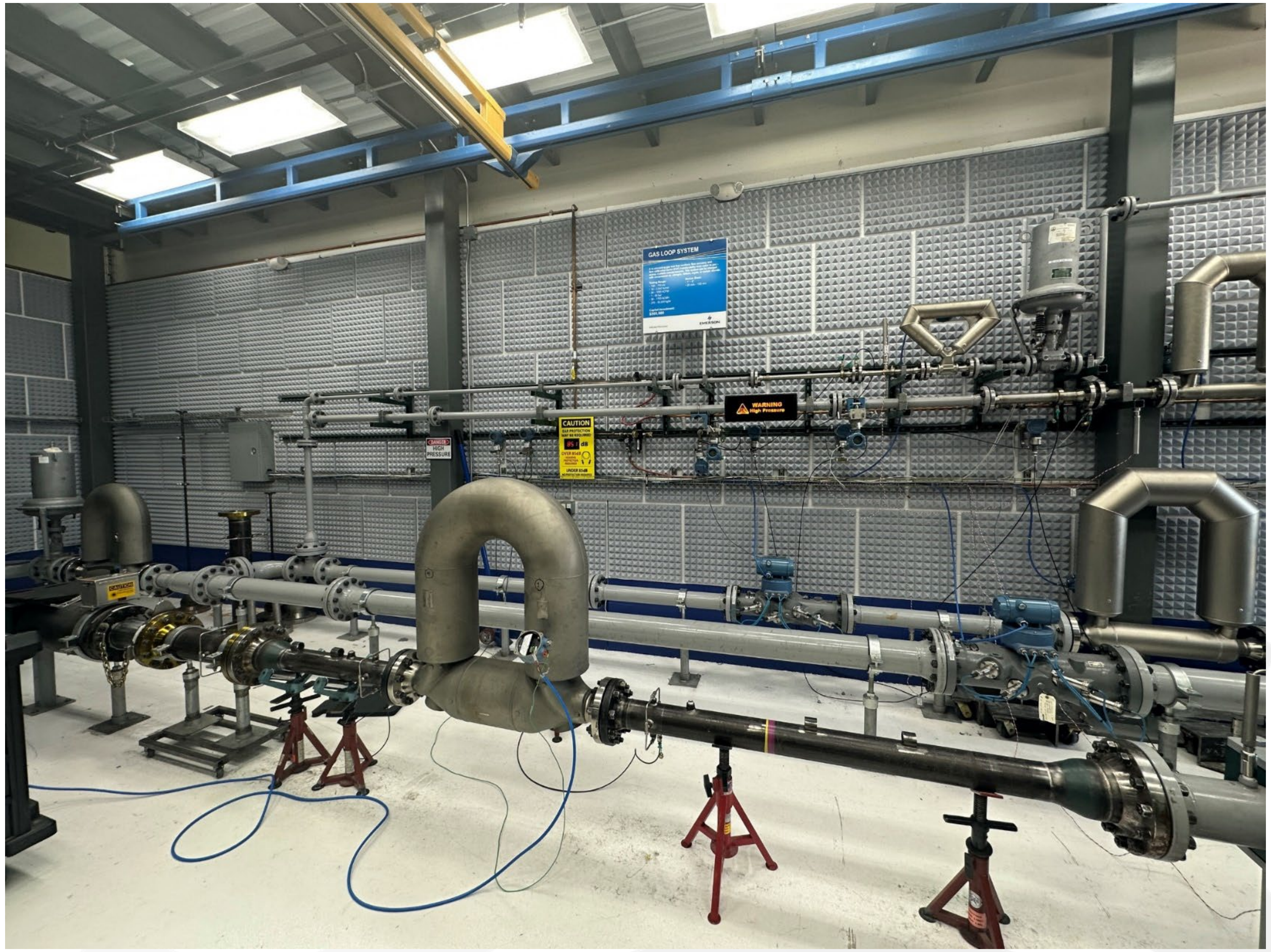
- The correction has a low sensitivity to density error through the entire measurement range.
- Our density method works because its not sensitive to errors in density
- This includes the transition from a gas to super critical fluid and critical phase.
  - Critical point is at 31.1 °C and 369.71 kg/m3



Testing

Micro Motion Boulder Test Lab

- Test pressure up to 750 psi
- Any inert gas
  - CO^2, He and air are most common
- Temperature stability = ± 0.25°C
- Lab mass flow uncertainty is <0.3%

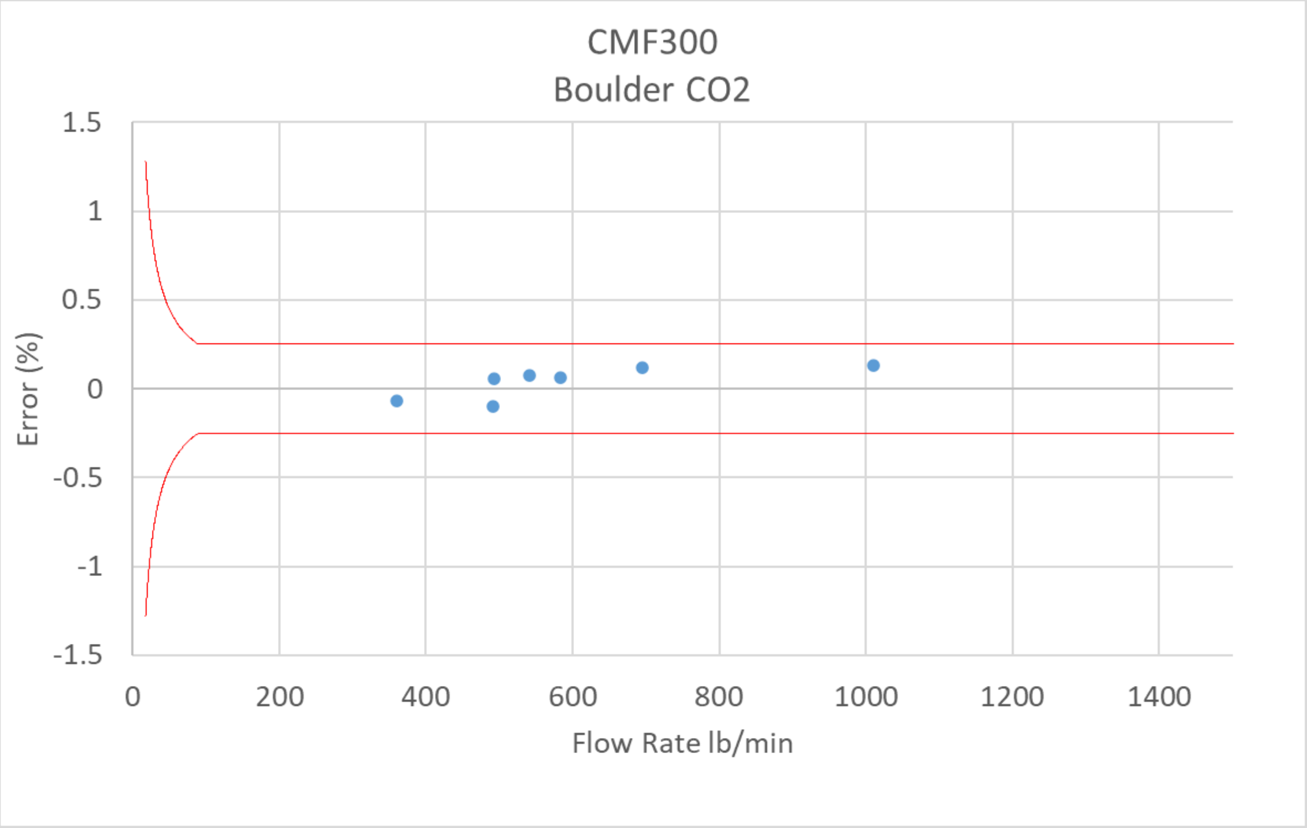


Fortis BC Test Lab

- Turbine meter references.
- CO_2 standard test media
- +/-0.29% mass flow measurement uncertainty.
- ISO 17025 Certified

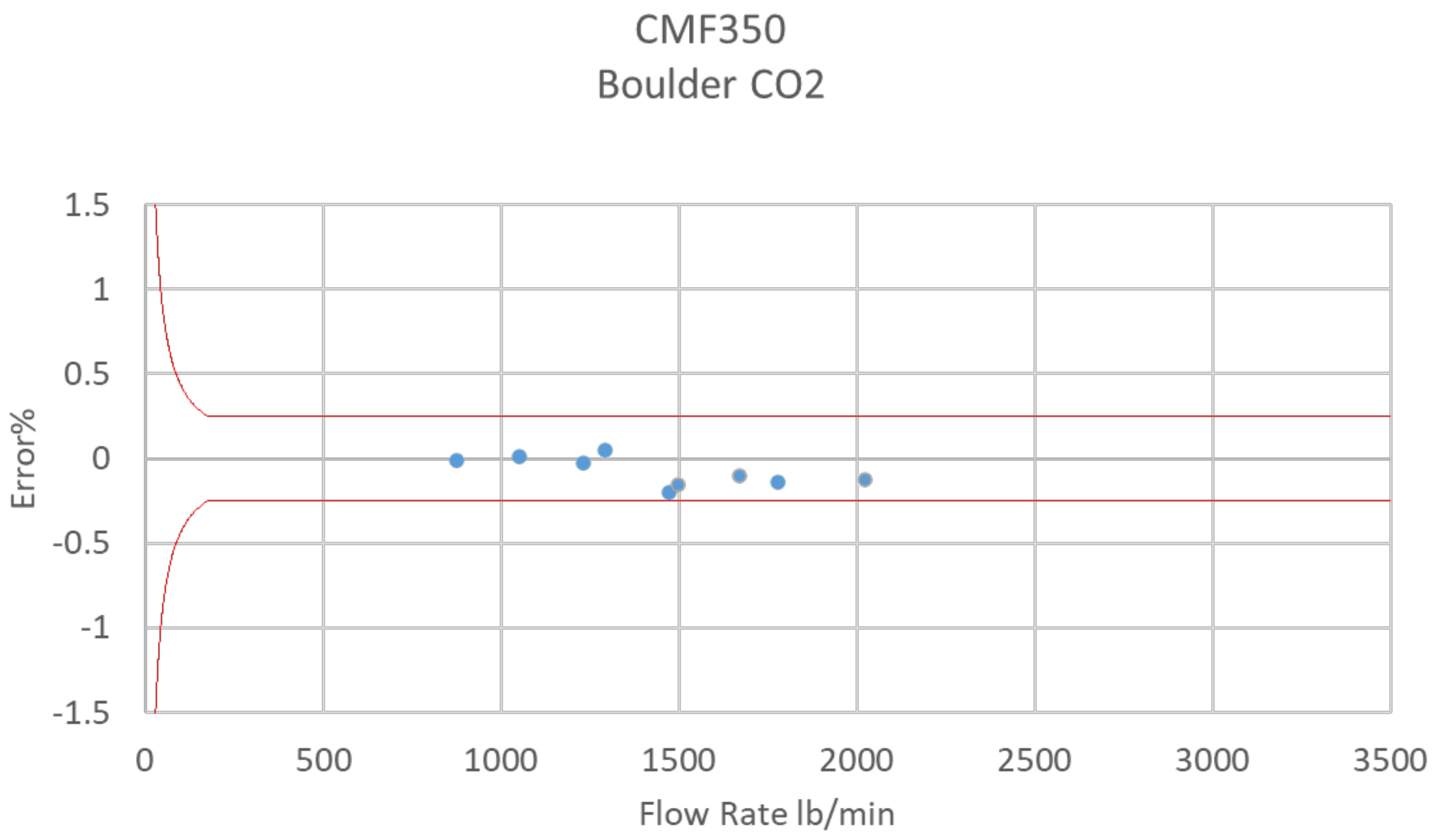
Test Results CMF300

- No correction
- Test pressures range from 250psi to 700psia
- Test temperatures range from 14-30 °C



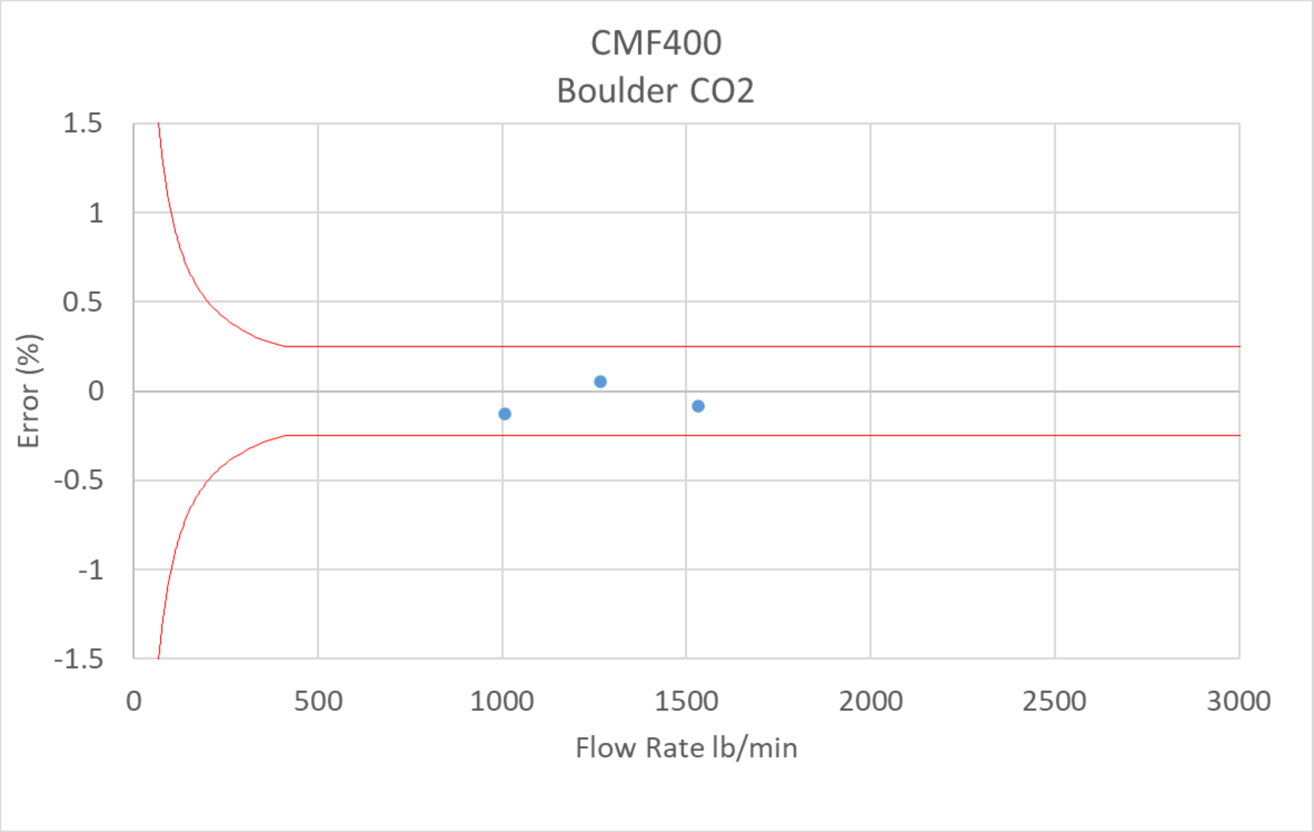
Test Results CMF350

- Correction Enabled
- Test pressures range from 250psi to 700psia
- Test temperatures range from 14-30 °C
- Error due to VoS at these conditions can be 0.54% to 0.86%

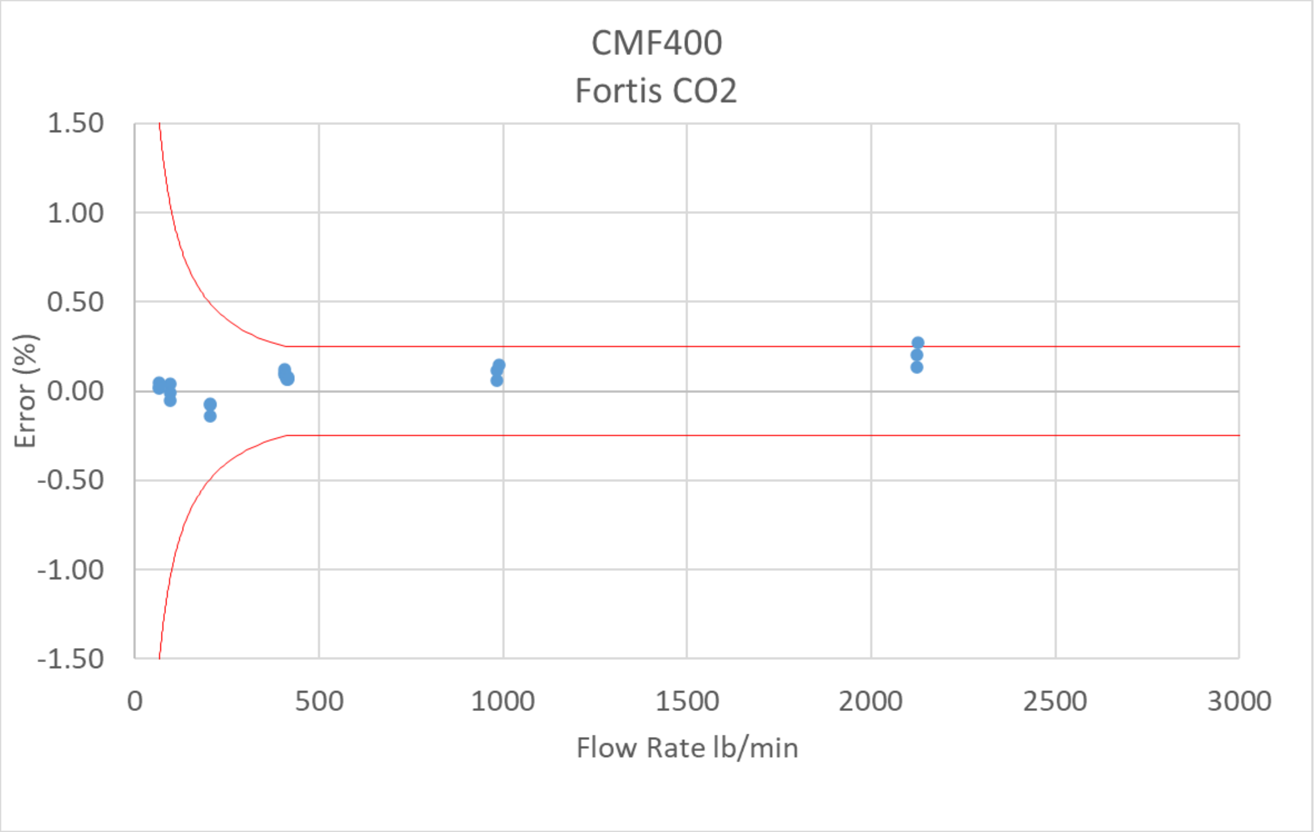


Test Results CMF400

- Correction Enabled
- Test pressures range from 250psi to 700psia
- Test temperatures range from 14-30 °C
- Error due to VoS at these conditions can be 1.61% to 2.54%



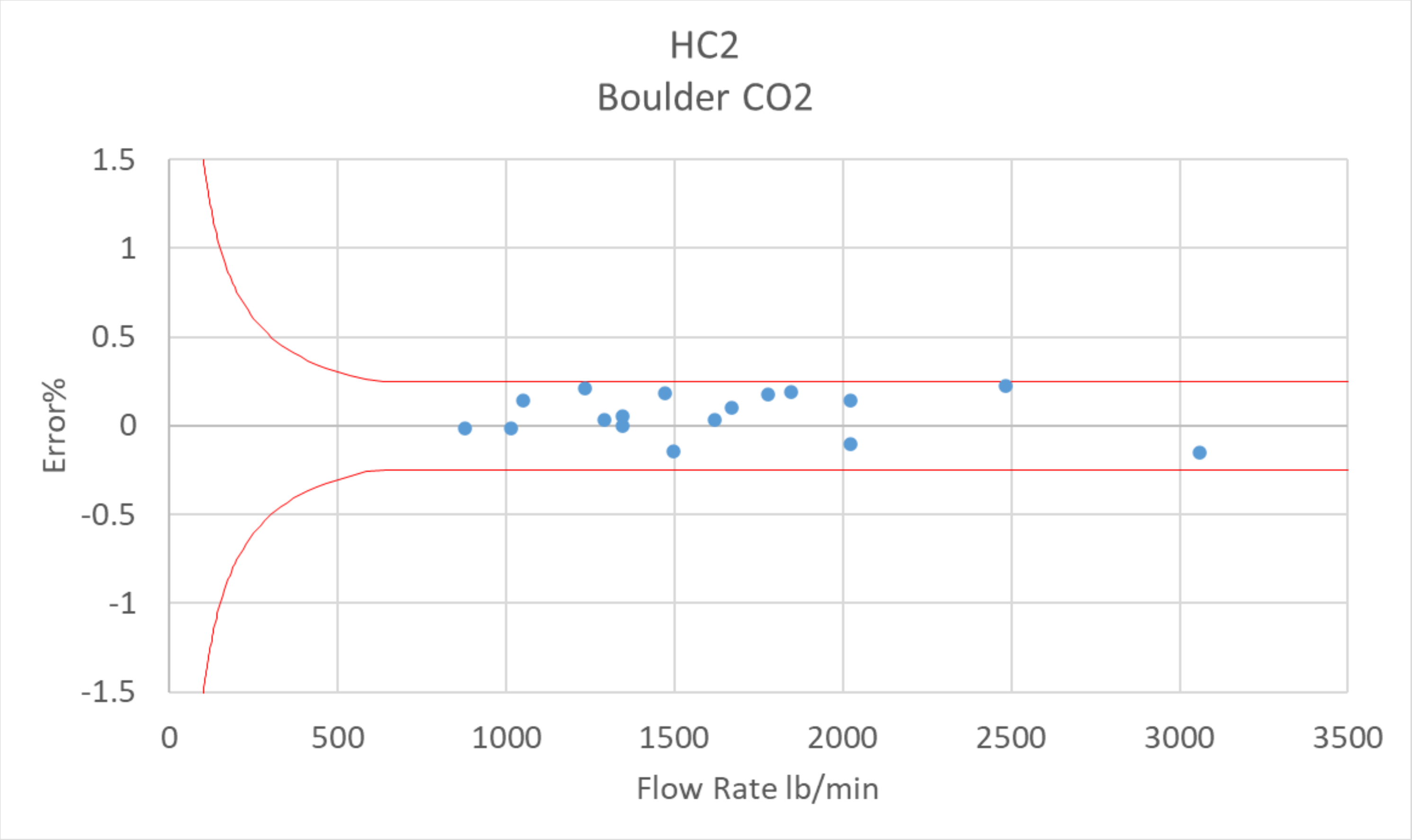
- Correction Enabled
- Test pressure 225psi
- Test temperatures range from 22-27 °C
- Error due to VoS at this condition is about 1.74%



EMERSON EXCHANGE 2025
ACCELERATING INNOVATION

Test Results HC2

- Correction Enabled
- Test pressures range from 250psi to 700psia
- Test temperatures range from 14-30 °C
- Error due to VoS at these conditions can be 0.70% to 1.10%



Conclusions

Conclusion

- MMI’s patent pending solution allows for meters larger than CMF300 to accurately and repeatably measure difficult gasses.
- Direct application of academic literature.
- Validated through testing at 3rd party labs.
- Correction is implemented in standard transmitter software.

EMERSON EXCHANGE 2025

ACCELERATING
INNOVATION

Thank You