8405xx Mass Flow Transducers (General Compact Analog Meter - RoHS) Product Description and Specifications Rev G

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1. DOCUMENT USAGE AND CONTROL

The following rules and guidelines should be followed whenever using or revising this document:

» *Before using* check the *ECO history.* This will inform you of any changes that have been made to the document since your last use.

» The BOM is considered the controlling document governing the construction of the instrument. Where there is a disparity between the assembly procedures and the BOM, the Bill of Materials is to be considered correct. Check the BOM to insure that the correct revision drawings and documents are being used. The master for this document is archived on the LAN.

» *USE THE STANDARD **ECO** SYSTEM (9020186: Engineering Change) TO PROCESS ANY CHANGES TO THIS DOCUMENT. For example; a discrepancy between the BOM and this assembly procedure. ALL CHANGES TO THIS DOCUMENT MUST COMPLY WITH TSI POLICIES OUTLINED IN 9020174 (Document and Data Control).*

» Record all changes made to this documentation in the table below:

2. ECO HISTORY

DATE	REV	ECO NO.	DESCRIPTION OF CHANGE
5/9/07	A		Release of preliminary specification
7/16/07	B	101178	Initial Production Release of Specification. Replacement of 840530 with 840520.
1/7/09	C	102297	Optimization of C-coefficients for calibration of 840521, 840522, 840523 and 840533 meters. Model Revisions (Table 2) updated.
8/27/10	D	103435	Optimization of C-coefficients for calibration of 840521, 840522, 840523 and 840533 meters. Model Revisions (Table 2) updated.
2/14/13	E	105542	Update to RoHS process. New EEPROM manufacturer P/N. Added warranty statement. Corrected equations in 6.5.5 and adjusted 6.4 EEPROM Map accordingly.
5/7/15	F	107595	Remove references to tin-lead solder and replace with RoHS compliant solder. Correct product revision table, 840522 is Revision F.
2/21/23	G	114236	Serial format changed, see section 5.2 for details. Expanded detail to note 4 in section 6.4 regarding C coefficient changes.

Table 1: Revision Control

3. PURPOSE AND SCOPE

This document contains the application notes and performance specifications for the TSI 8405xx flowmeter. This is a controlled document. Changes to this document or to the flowmeter should be updated in this document if applicable.

4. APPLICABLE DOCUMENTS

The following documents are related to and applicable to the product contained in this document:

8405xx Product BOMs

5. PRODUCT SPECIFICATIONS

5.1. Description

The TSI flow transducer described here contains two sensors, one for sensing flow and the other for measuring temperature. Each sensor has a separate non-linear voltage output. To determine the mass-flowrate of the gas passing through the flow transducer, the voltage output of each sensor must be measured and then used in the algorithm described in this document. A microprocessor (not provided by TSI) is required to process the flow transducer outputs using the supplied algorithm. Calibration constants unique to each flow transducer are stored on an Electrically Erasable PROM chip (EEPROM) on the unit. These are read by the microprocessor at power up and used in the flow calculation.

The circuit that senses flow is commonly known as a thermal sensor or hot-film anemometer. This particular flow transducer utilizes a thin-film sensor maintained at a temperature of 150°C. The velocity of the gas moving past the sensor determines the heat transfer rate between the sensor and the gas. This heat transfer rate is translated into a voltage required to maintain the sensor temperature at 150°C. Therefore, this voltage is a function of the mass flow of gas past the sensor. The heat transfer rate is also influenced by the gas temperature. A thermistor circuit is used to measure gas temperature and a correction is made using the algorithm provided.

The model 8405xx will be calibrated in Air and/or 100% oxygen. Two of the models will also be calibrated in Heliox. A function will need to be applied to determine a flowrate of an air/oxygen mixture, using a combination of the two calibration tables.

All models in the 8405xx family are manufactured to meet RoHS Directive 2011/65/EU.

The following table states the revisions of the flowmeters that are covered under this revision of the specification document.

TSI Model Number	Flowmeter Revisions covered under this specification
840521	E
840522	F
840523	E
840520	C
840533	E

Table 2: Model Revisions

5.2. Serial Number (TSI)

All flowmeters will contain a 10 digit serial number. The format of the serial number is as follows:

TSI Serial Number: **MMMYYXXXXX**

MMM - Alphanumeric representing model number
MMM = 5xx for the 8405xx
YY - Year of manufacture (last two digits of year, e.g. 01=2001)
XXXXX - Sequential number that restarts at 00001, at the beginning of each new year of manufacture

5.3. Labeling and Packaging

- Standard TSI Shipping labels will be used.
- Flow meters are packed in groups of ten units.
- Flow meters ordered with -SINGLE appended onto the model number are bagged and boxed individually.
- Calibration certificates will be shipped with flow meters.
- A Serial Number sticker will be located on flow body of each unit.

5.4. Performance Specifications

Model	840521/22/23/20/33
Gas	840521: Air 840522: Oxygen 840523: Air and Oxygen 840520: Heliox (80% Helium, 20% Oxygen) 840533: Air and Oxygen and Heliox (80% Helium, 20% Oxygen)
Flow Range	Air: 0-300 SLPM Oxygen: 0-300 SLPM Heliox: 0-80 SLPM
Humidity Range	Dry Gas (< 10% RH)
Process Gas Temp Range	5 - 46°C
Operating Pressure	Ambient Pressure
Accuracy Specification	Air: 2.0% or 0.05 SLPM at standard conditions, whichever is greater. Oxygen: 2.0% or 0.05 SLPM at standard conditions, whichever is greater. Heliox: 2.75% or 0.10 SLPM at standard conditions, whichever is greater.
Temperature Specification	0.1% per °C temp adder, 0.001 slpm/°C offset adder
Pressure Drop	See Section 5.9
Number of Stored Gas Calibration	840521: Single 840522: Single 840523: Dual 840520: Single 840533: Triple
Power Supply	5V±10% to power sensor. 2.7V – 5.5V to power Eeprom
Connector	Molex 87832-1010 (2.00mm Pitch 2 Row 10 Pin) Suggested Mating Parts: Molex 51110-1060 (Wire) or Molex 87568-1074/87568-1073 (IDC)
Calibration Data Storage	On Board EEProm with I2C communication.
Flow Voltage Vf Range	0.3-2.0 V nominal, 0-2.5 V extremes (See section 5.6) Extreme for low voltage is zero flow and 50°C. Extreme for high voltage is span flow (300 SLPM) and 0°C.
Temp Voltage Vt Range	0.628 V (at 50 °C) to 1.95 V (at 0 °C) (See section 6.6)
Response time for flow signal	< 2.5 ms
Leak rate	< 0.0703 cm H2O/sec for 5 seconds when pressurized to -703.7cm H2O
Burst pressure	Up to 100 psi
Weight	21 grams
Power Consumption	Air/O2: 0.785 Watts (Max; 5.5V supplied at 5°C) Heliox: 0.810 Watts (Max; 5.5V supplied at 5°C)
RoHS Compliance	Meets RoHS Directive 2011/65/EU

Table 3: Performance Specifications

5.5. PCB, Materials and Dimensions

PCB: PCB must maintain IPC Class 2

Material:

Wetted Material:

Body: Lexan 141-RS-86815

O-rings (for sensor and thermistor mount): Buna-N

Sensor and Thermistor Pins: Phosphor-Bronze 510

Sensor wetted material: Alumina, Gold, RoHS Compliant solder

Thermistor wetted material: Epoxy, Tin-Plate Copper, RoHS Compliant solder

Grease (for o-rings): Krytok, if needed.

Dimensions:

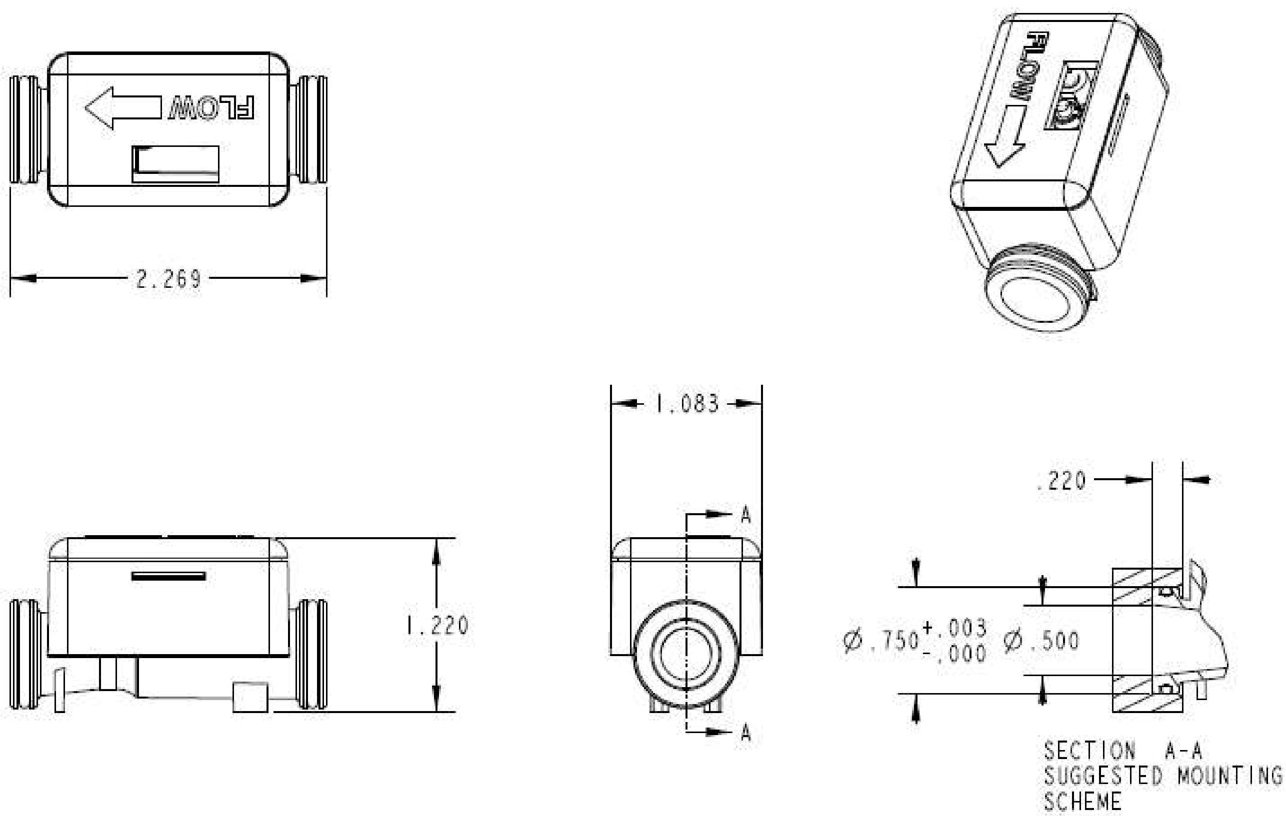


Figure 1: Flowbody Geometry

5.6. Flow Response

Shown below is a typical flow response curve for a meter of this configuration. Output voltage on the 8405xx will be scaled between 0.25 and 2.0 volts nominally.

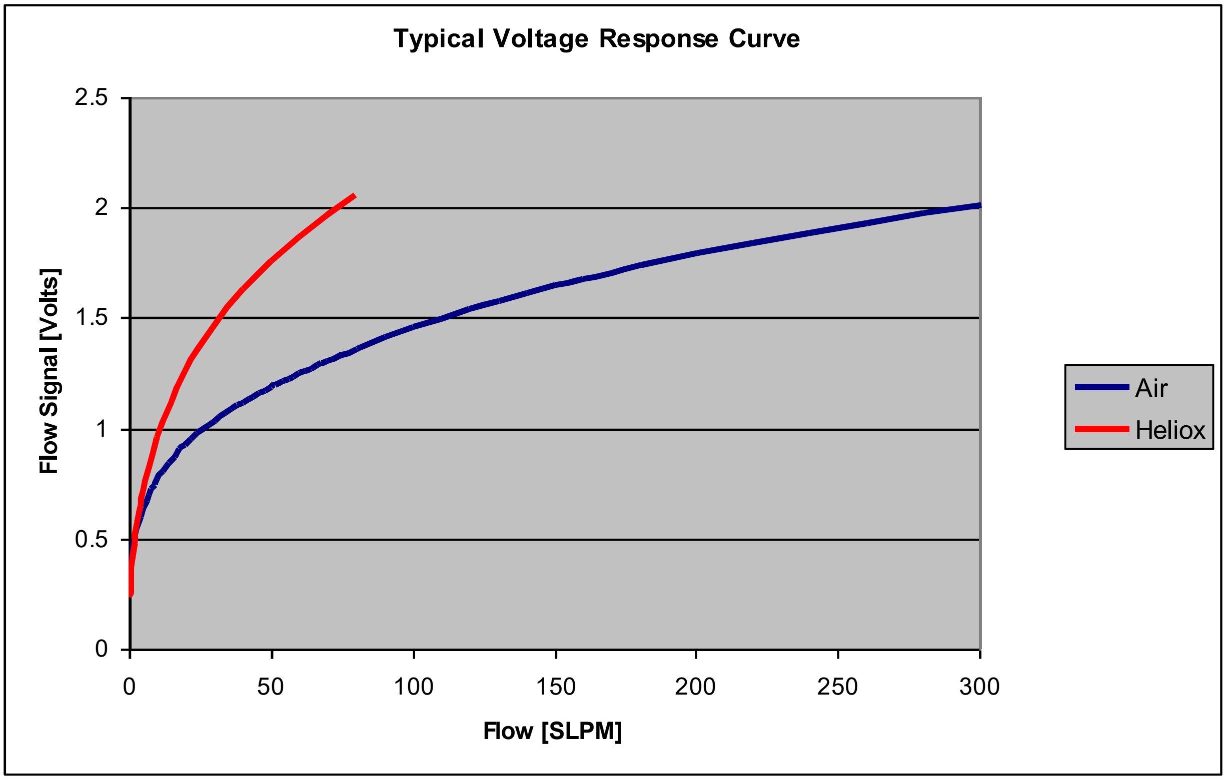


Figure 2: Typical Flow Response Curve

5.7. Temperature Skewing

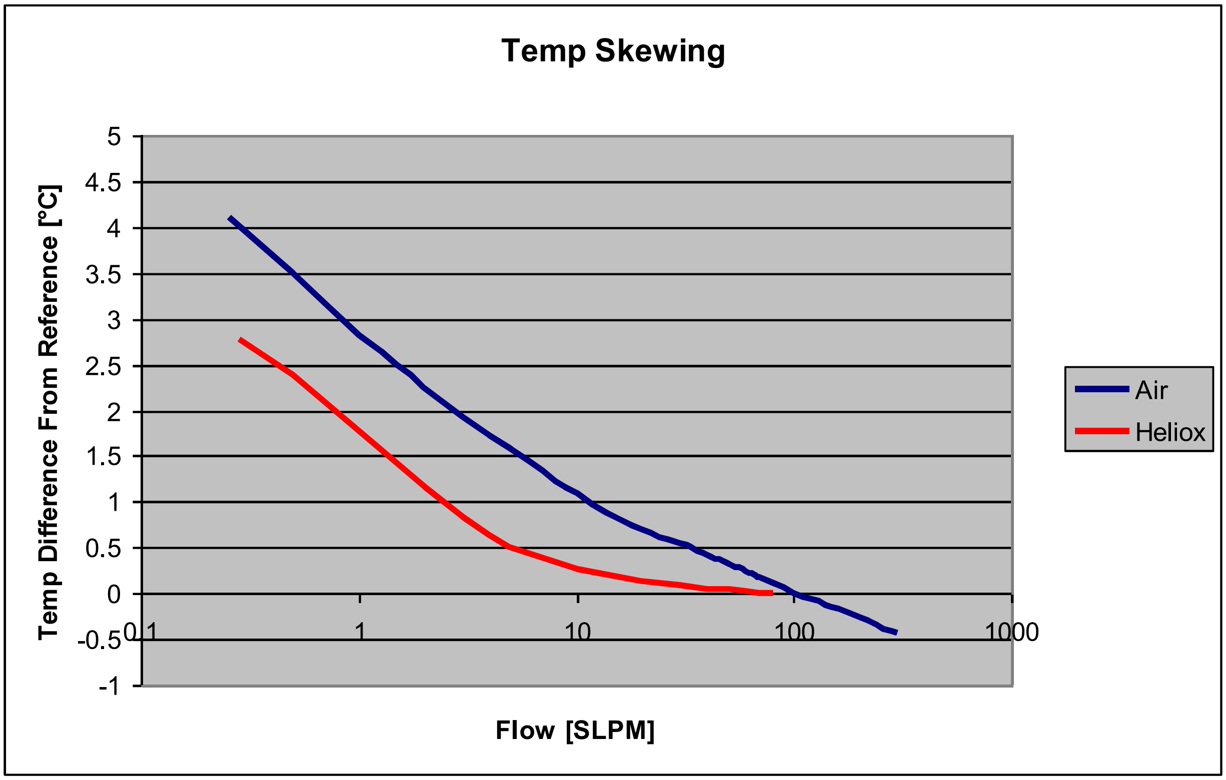


Figure 3: Temperature Skewing vs. Flow

Note: The above graph shows how the temperature measured by the flowmeter thermistor differs from the temperature reference used during calibration. The temperature difference is zero at the flowrate where the temperature correction offset was measured, which was 100 l/min.

5.8. Pressure Drop

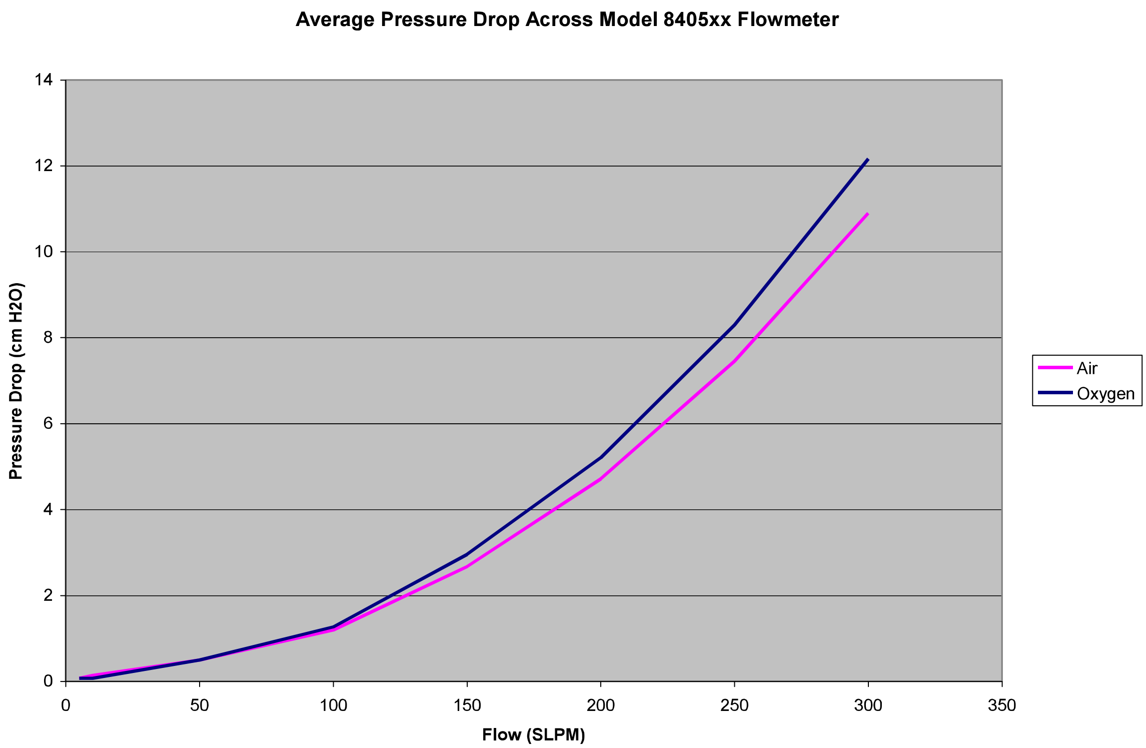


Figure 4: Pressure Drop for Air and Oxygen as Related to Flow

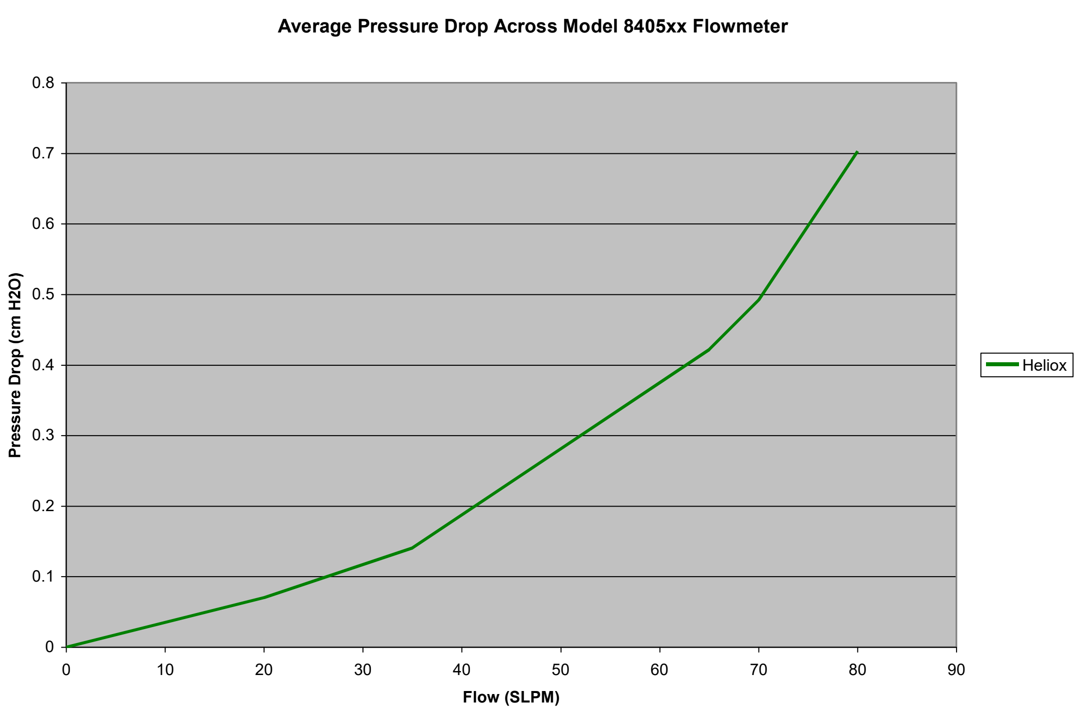
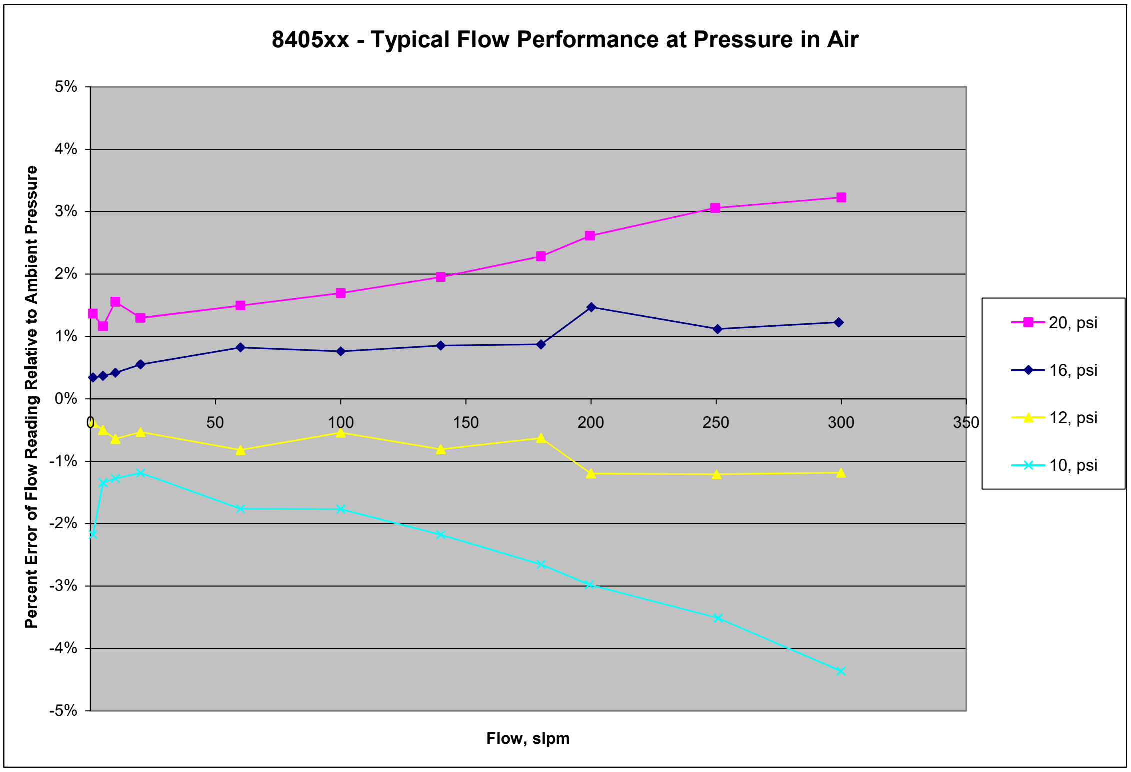


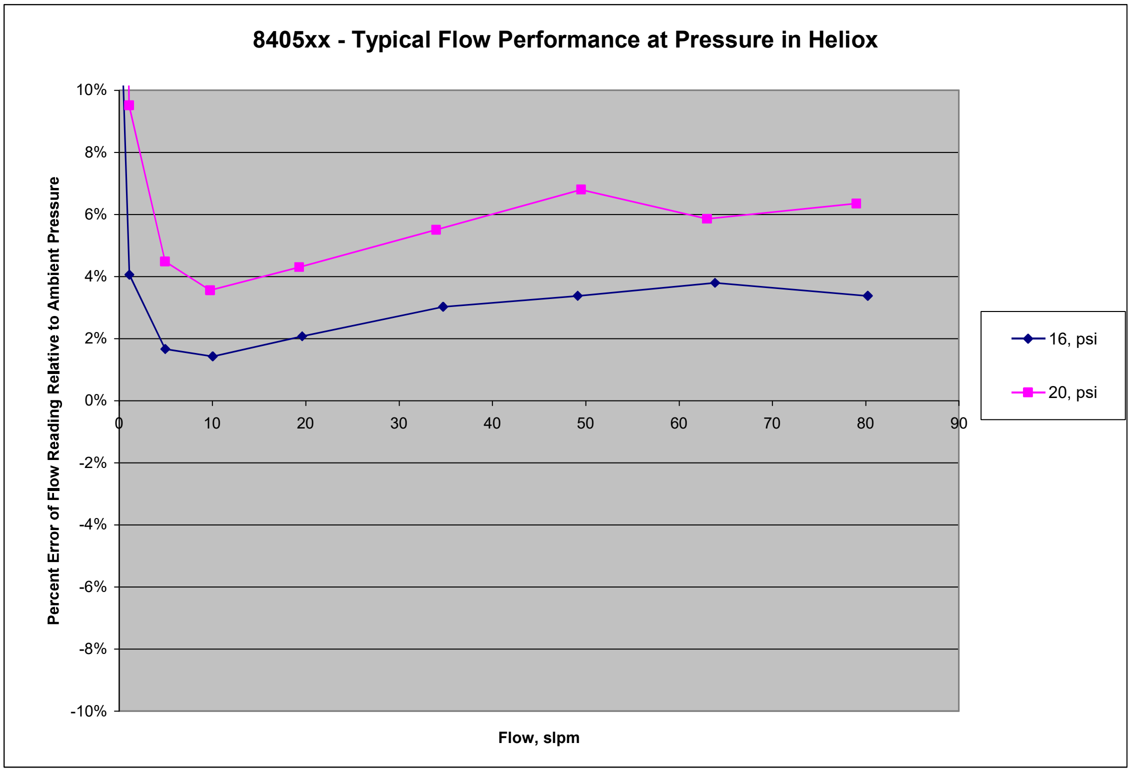
Figure 5: Pressure Drop for Heliox as Related to Flow

5.9. Pressure Effects



Note: This graph shows the correction needed to eliminate the pressure effect. The flow meters will read high in positive pressure and low in negative pressure.

Figure 6: Effect of pressure on Air flow rate measurement



Note: This graph shows the correction needed to eliminate the pressure effect. The flow meters will read high in positive pressure.

Figure 7: Effect of pressure on Heliox flow rate measurement

5.10. Humidity Effects

TSI flow sensors are calibrated in clean dry gas. The introduction of moisture into the gas causes the 8405xx flowmeter to output a flow rate slightly higher than actual for two reasons.

1. The 8405xx sensor element is a mass flow sensor. Increasing the RH level adds water to the gas flow which increases the total mass flow rate of the system. The 8405xx flow sensor is sensitive to this.
2. The 8405xx sensor element is a thermal device. Increasing the RH level increases the thermal conductivity of the gas stream. This in turn removes more heat from the thermal sensor, which increases the flow rate output from the 8405xx flowmeter.

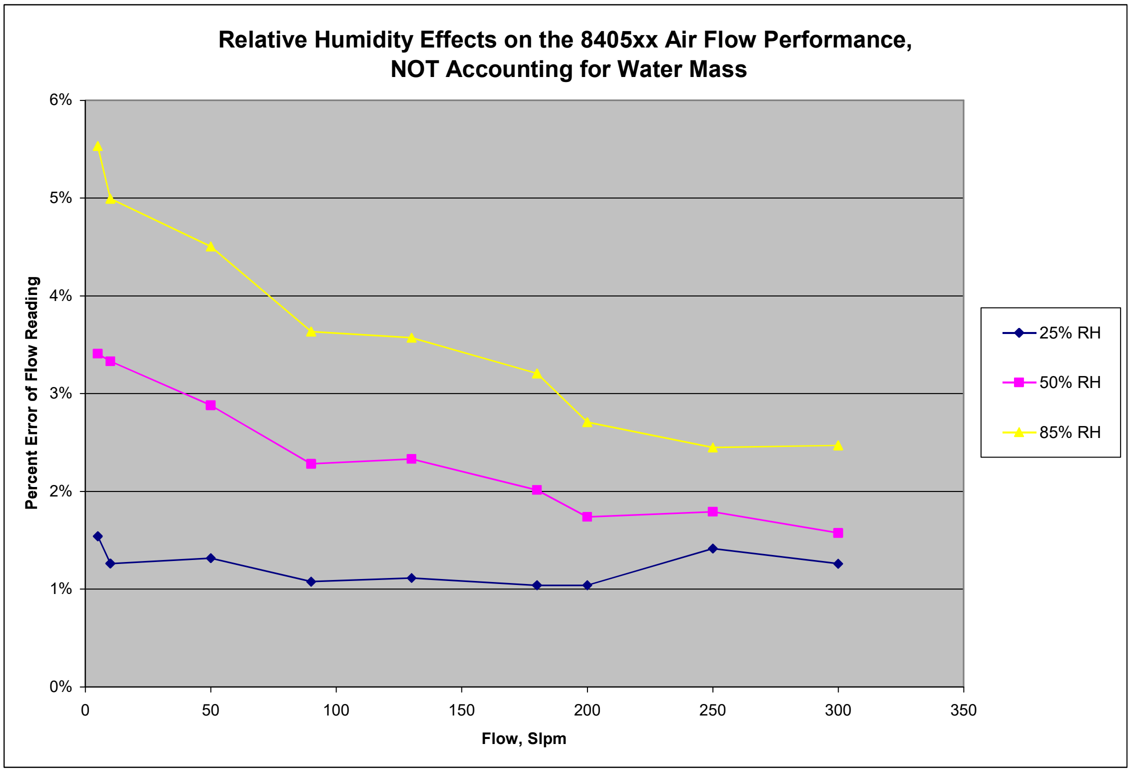


Figure 8: Effect of humidity on flow rate for Air when operating at 25°C and 1 atmosphere (Not accounting for water mass)

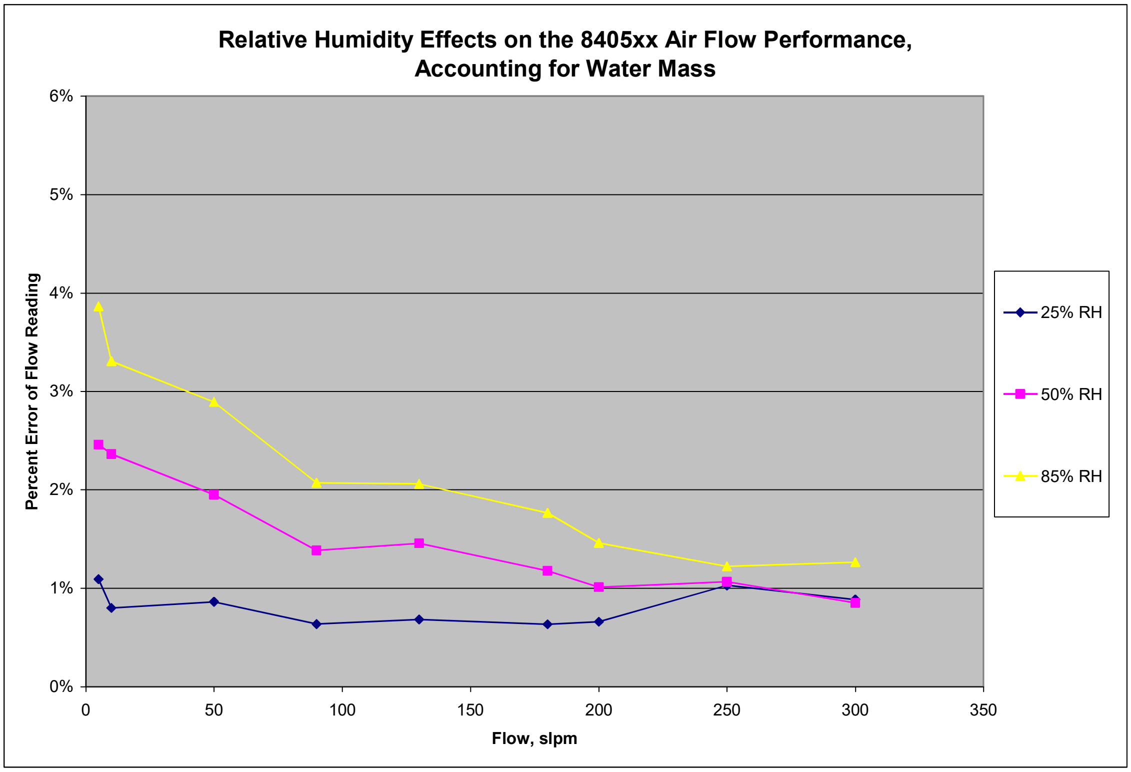


Figure 9: Effect of humidity on flow rate for Air when operating at 25°C and 1 atmosphere (Accounting for water mass)

5.11. Flowmeter Calibration information

Each meter will be shipped with a calibration certificate that will show its flow performance against the flow reference after the meter has been calibrated.

6. APPLICATION NOTES

6.1. General Information

The following precautions must be taken in order to successfully apply the flow transducer:

The flow sensing element is susceptible to contamination. Material deposited on the sensor surface has the effect of insulating the sensor from the gas, thereby altering the relationship between the heat transfer rate and gas flow. It is critical that any form of contamination be eliminated from the gas flow before the gas is passed through the flow transducer. This is the responsibility of the customer, not TSI.

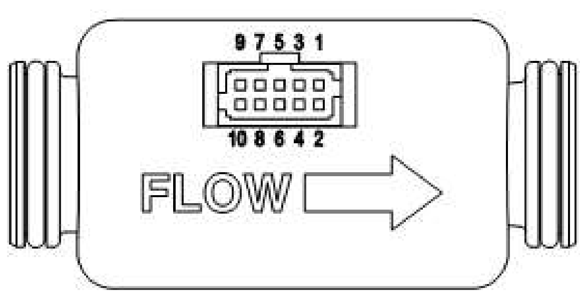
It is extremely important to prevent liquid of any kind from condensing on or contacting the flow sensing element. Liquids normally evaporate quickly due to the elevated sensor temperature. During the time the liquid is evaporating, large heat transfer rates will occur resulting in erroneous readings. Insoluble deposits on the flow sensing element may result once the liquid evaporates resulting in irreversible contamination. Preventing this problem is the responsibility of the customer, not TSI.

If possible, avoid locating the flow transducer such that the environmental temperature differs greatly from the gas temperature. Temperature differentials above 5°C will begin to affect the flow transducer's accuracy.

6.2. Pin Connections

Pin #	*Description*
1	Flow output voltage Channel 1 (Vf1) Air/O2
2	Flow output voltage Channel 2 (Vf2) Heliox
3	Temperature output voltage (Vt)
4	Analog signal ground
5	EEPROM serial clock
6	EEPROM serial data
7	EEPROM Write Protect (Leave Floating)
8	Power supply (+5V for analog)
9	Power supply ground
10	Power supply EEPROM (+2.7V to +5.5V)

Table 4: Pin Connections



6.3. Retrieving Data from the EEPROM

The calibration data unique to each flow transducer is stored on a 8192-bit EEPROM on the unit's printed circuit board. Data is read out serially 8 bits at a time from the one of 1024 addresses.

The temperature correction will be a number between -1.00 and +1.00 °C. Each time the temperature is read from the flowmeter, this correction must be added to it.

The CRC is calculated on bytes 2 through 1023. The CRC should be calculated and compared to the stored value each time data is read from the EEPROM. This will indicate if data has been corrupted.

6.4. EEPROM Data Map

Description	Address	Bytes[1]	Format	Conversions/Notes
CRC[2]	0	2	unsigned int 16	Calculation of CRC shown below
Serial Number[3]	2	6	unsigned int 64	
Model Number	8	4	unsigned int 32	
Revision[4]	12	1	char	Convert to ASCII letter
Year	14	2	unsigned int 16	Year of calibration
Month	16	1	unsigned int 8	Month of calibration
Day	18	1	unsigned int 8	Day of calibration
Tcal	20	4	IEEE float	Calibration temperature, ºC (currently set to 21.1 ºC)
S	24	4	IEEE float	Span Channel 1
Z	28	4	IEEE float	Zero Channel 1
S2	32	4	IEEE float	Span Channel 2
Z2	36	4	IEEE float	Zero Channel 2
Tcorr	40	4	IEEE float	Temperature Correction, ºC (to be added to thermistor temp)
Cal Gas Air	44	1	unsigned int 8	1 if Gas is Calibrated. 0 if Gas is not Calibrated.
Coefficients Memory Start Location for Air	46	2	unsigned int 16	Memory location offset for Calibration Coefficients.
Cal Gas Oxygen	48	1	unsigned int 8	1 if Gas is Calibrated. 0 if Gas is not Calibrated.
Coefficients Memory Start Location for Oxygen	50	2	unsigned int 16	Memory location offset for Calibration Coefficients.
Cal Gas Heliox	52	1	unsigned int 8	1 if Gas is Calibrated. 0 if Gas is not Calibrated.
Coefficients Memory Start Location for Heliox	54	2	unsigned int 16	Memory location offset for Calibration Coefficients.
Cal Gas 4	56	1	unsigned int 8	1 if Gas is Calibrated. 0 if Gas is not Calibrated.
Coefficients Memory Start Location for Gas 4	58	2	unsigned int 16	Memory location offset for Calibration Coefficients.

Calibration Coefficients Structure				
# of Coefficients	Offset	1	unsigned int 8	13 Coefficients Max; Gas 4 has 12 Coefficients Max
K [5]	Offset + 2	4	IEEE float	Temp comp constant for temp > Tcal
(reserved)	Offset + 6	4	IEEE float	
(reserved)	Offset + 10	4	IEEE float	
(reserved)	Offset + 14	4	IEEE float	
L	Offset + 18	4	IEEE float	Temp comp constant for temp < Tcal
(reserved)	Offset + 22	4	IEEE float	
(reserved)	Offset + 26	4	IEEE float	
(reserved)	Offset + 30	4	IEEE float	
$V_{f70}i$	Offset + 34 + 16i	4	IEEE float	
Ai	Offset + 38 + 16i	4	IEEE float	
Bi	Offset + 42 + 16i	4	IEEE float	
Ci	Offset + 46 + 16i	4	IEEE float	

Table 5: Memory Map

Notes:

1 Most significant byte is always at lower address.
Addresses are kept as even numbers and can contain 2 bytes of data. If only 1 byte (as in revision character) is used, the following byte is not significant and may be zero.

2 CRC is calculated as shown below:

```
unsigned int CalcCRC(unsigned char *ubuff, unsigned int num)
{
	unsigned int crc;
	unsigned int bit_count;
	unsigned int i;

	crc = 0x0000;
	for(i = 0; i < num; i++)
	{
		crc ^= ubuff[i];
		for(bit_count = 8; bit_count; bit_count--)
		{
			if(crc & 0x0001)
			{
				crc >>= 1;
				crc ^= 0xa001;
			}
			else
				crc >>= 1;
		}
	}
	return crc;
}
```

3 Serial number is ten digits and is interpreted as follows: MMMYYWWXXX

4 Revision can change for multiple reasons. One possible cause for the revision level to change is a modification to the "C" coefficients. TSI reserves the right to change C coefficients at any time without prior customer notification or approval. Consult TSI for additional information regarding revision level changes.

5 Temperature compensation coefficients have different values for above T_{Cal} and below T_{Cal} .

6.5. Mass Flowrate Calculation

1. At power up, read in the flow transducer's calibration data from the EEPROM.
2. Measure the flow voltage (V_f) and the temperature voltage (V_t).
    - Air/O2 uses Flow Voltage Channel 1 (Pin 1), and Heliox uses Flow voltage Channel 2 (Pin 2).
3. Determine the gas temperature (T) using V_t and referring to Table 4. This step is independent of process gas.
4. Add the temperature correction to the temperature derived from step 3. This step is independent of process gas.

$$T = T + T_{corr}$$

5. Determine Sensor Overheat Temp. Use the K coefficient if gas temp is above 21.11°C. Use the L coefficient if gas temp is below 21.11°C. The coefficients are stored in EEprom, one set of K and L for air, a second set of K and L for oxygen, and a third set of K and L for heliox The coefficients may be different between the different gases.

$$T_{over} = K \ \ \textit{(If T found in step 4} \geq \textit{21.11)}$$

or

$$T_{over} = L \ \ \textit{(If T found in step 4} < \textit{21.11)}$$

6. Calculate $V_{f\,Std}$ *using* the following equation. $V_{f\,Std}$ is what V_f would be if the gas temperature were 21.11 °C (70 °F). Same equation is used independent of process gas.

$$V_{f\,Std} = (V_f + Z) \cdot \sqrt{\frac{T_{over} - 21.11}{T_{over} - T}} - Z$$

Note: When using Flow Voltage Channel 2 for Heliox substitute Z2 for Z.

7. Use the calculated value of $V_{f\,Std}$ to look up the appropriate set of A, B and C coefficients from the EEPROM data. Calibration coefficients are found by finding the closest voltage in the calibration table that is less than $V_{f\,Std}$. Coefficients will be different between gases.

8. Calculate mass flow (Q) using the following equation.

$$Q = A + BV_{f\,Std}^{2} + CV_{f\,Std}^{5}$$

Q = flow rate in Standard Liters Per Minute (SLPM).

TSI's standard conditions are 70°F (21.11°C) and 14.7 psi (760 mmHg).

6.6. Temperature Conversion Table

Temp (˚C)	Resistance (Ω)	Vt (Volts)	Temp (˚C)	Resistance (Ω)	Vt (Volts)	Temp (˚C)	Resistance (Ω)	Vt (Volts)
-20	1103400	2.2923	11	197560	1.6598	42	46863	0.7977
-19	1038600	2.2804	12	187840	1.6315	43	44917	0.7749
-18	977910	2.2681	13	178650	1.6028	44	43062	0.7525
-17	921100	2.2552	14	169950	1.5739	45	41292	0.7306
-16	867910	2.2417	15	161730	1.5448	46	39605	0.7092
-15	818070	2.2277	16	153950	1.5156	47	37995	0.6883
-14	771370	2.2131	17	146580	1.4861	48	36458	0.6679
-13	727590	2.1979	18	139610	1.4566	49	34991	0.6480
-12	686530	2.1821	19	133000	1.4270	50	33591	0.6286
-11	648020	2.1658	20	126740	1.3974	51	32253	0.6097
-10	611870	2.1488	21	120810	1.3678	52	30976	0.5913
-9	577940	2.1312	22	115190	1.3382	53	29756	0.5733
-8	546070	2.1130	23	109850	1.3087	54	28590	0.5558
-7	516130	2.0942	24	104800	1.2793	55	27475	0.5388
-6	488000	2.0748	25	100000	1.2500	56	26409	0.5223
-5	461550	2.0548	26	95447	1.2209	57	25390	0.5062
-4	436680	2.0342	27	91126	1.1920	58	24415	0.4906
-3	413280	2.0129	28	87022	1.1633	59	23483	0.4754
-2	391270	1.9911	29	83124	1.1348	60	22590	0.4607
-1	370540	1.9687	30	79422	1.1066	61	21736	0.4464
0	351020	1.9457	31	75903	1.0788	62	20919	0.4325
1	332640	1.9222	32	72560	1.0512	63	20136	0.4190
2	315320	1.8981	33	69380	1.0240	64	19386	0.4060
3	298990	1.8734	34	66356	0.9972	65	18668	0.3933
4	283600	1.8483	35	63480	0.9708	66	17980	0.3810
5	269080	1.8226	36	60743	0.9447	67	17321	0.3691
6	253800	1.7934	37	58138	0.9191	68	16689	0.3576
7	242460	1.7700	38	55658	0.8939	69	16083	0.3464
8	230260	1.7430	39	53297	0.8692	70	15502	0.3355
9	218730	1.7156	40	51048	0.8449			
10	207850	1.6879	41	48905	0.8211			

Table 6: Temperature Conversion

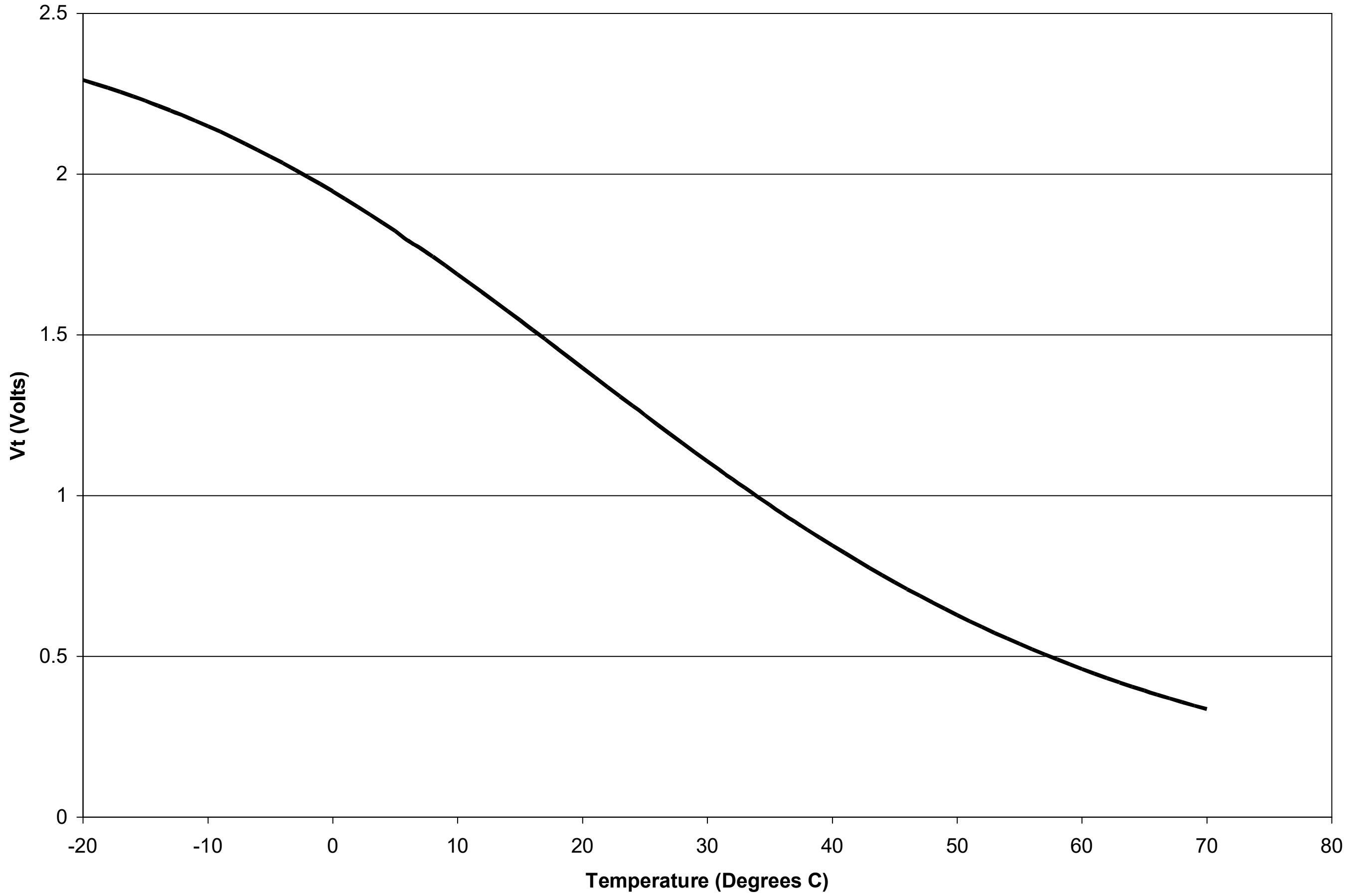


Figure 10: Temperature Curve

7. WARRANTY INFORMATION

7.1. Warranty Statement

LIMITATION OF WARRANTY AND LIABILITY. Seller warrants the goods sold hereunder, under normal use and service as described in the operator's manual, shall be free from defects in workmanship and material for **12 months**, or if less, the length of time specified in the operator's manual, from the date of shipment to the customer. This warranty period is inclusive of any statutory warranty. This limited warranty is subject to the following exclusions and exceptions:

a. Hot-wire or hot-film sensors used with research anemometers, and certain other components when indicated in specifications, are warranted for 90 days from the date of shipment;

b. Pumps are warranted for hours of operation as set forth in product or operator's manuals;

c. Parts repaired or replaced as a result of repair services are warranted to be free from defects in workmanship and material, under normal use, for 90 days from the date of shipment;

d. Seller does not provide any warranty on finished goods manufactured by others or on any fuses, batteries or other consumable materials. Only the original manufacturer's warranty applies;

e. Unless specifically authorized in a separate writing by Seller, Seller makes no warranty with respect to, and shall have no liability in connection with, goods which are incorporated into other products or equipment, or which are modified by any person other than Seller.

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TO THE EXTENT PERMITTED BY LAW, THE EXCLUSIVE REMEDY OF THE USER OR BUYER, AND THE LIMIT OF SELLER'S LIABILITY FOR ANY AND ALL LOSSES, INJURIES, OR DAMAGES CONCERNING THE GOODS (INCLUDING CLAIMS BASED ON CONTRACT, NEGLIGENCE, TORT, STRICT LIABILITY OR OTHERWISE) SHALL BE THE RETURN OF GOODS TO SELLER AND THE REFUND OF THE PURCHASE PRICE, OR, AT THE OPTION OF SELLER, THE REPAIR OR REPLACEMENT OF THE GOODS. IN THE CASE OF SOFTWARE, SELLER WILL REPAIR OR REPLACE DEFECTIVE SOFTWARE OR IF UNABLE TO DO SO, WILL REFUND THE PURCHASE PRICE OF THE SOFTWARE. IN NO EVENT SHALL SELLER BE LIABLE FOR LOST PROFITS OR ANY SPECIAL, CONSEQUENTIAL OR INCIDENTAL DAMAGES. SELLER SHALL NOT BE RESPONSIBLE FOR INSTALLATION, DISMANTLING OR REINSTALLATION COSTS OR CHARGES. No Action, regardless of form, may be brought against Seller more than 12 months after a cause of action has accrued. The goods returned under warranty to Seller's factory shall be at Buyer's risk of loss, and will be returned, if at all, at Seller's risk of loss.

Buyer and all users are deemed to have accepted this LIMITATION OF WARRANTY AND LIABILITY, which contains the complete and exclusive limited warranty of Seller. This LIMITATION OF WARRANTY AND LIABILITY may not be amended, modified or its terms waived, except by writing signed by an Officer of Seller.