



EPA-FRM Compatible Field Audit Calibrator

NIST Traceable – ISO 9001:2008

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NOTICE

When switching on your deltaCal the start up screen briefly displays the version of Firmware. If the number begins with **2.3** or lower this manual applies to your instrument. If the version begins with **2.4** it covers a slight range change and is detailed in **Appendix C**. If the version begins with **2.5** or higher it contains improved Firmware which permits the display significantly more information. These improvements are covered in **Appendix D**.

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1.0 Quick Start

In order to put the deltaCal to immediate use as an FRM Audit device, follow these steps.

Step 1: Remove the deltaCal from its carrying case and turn it on.

Step 2: Remove the "10 micron" inlet from your FRM sampler, but leave the 12 inch down tube in place.

Step 3: Install the deltaCal measuring head on the 12 inch down tube in place of the 10 micron inlet. If the instrument to be audited is not already running, start it now.

Step 4: You may now read the deltaCal screen to determine volumetric flow rate, ambient temperature and barometric pressure.

Step 5: Shut off the audited unit, open the filter cassette holder and remove the cassette. The filter temperature-monitoring probe will now be visible. Plug the hand held temperature probe provided with the deltaCal into the control module. Hold the tip of the probe within 1 cm. of the filter temperature probe, without touching it. Ensure that direct sunlight does not fall on either sensor. You may now audit filter temperature.

For a diagram of the immediate application refer to Figure 1.

2.0 Introduction

The BGI deltaCal is an EPA FRM compatible flow audit device, based on the air flow measurement principle of the venturi¹. It was developed by BGI and is manufactured in BGI's ISO 9001-2000 facility. It provides a LCD indication of *volumetric* flow rate, barometric pressure, ambient temperature and a filter temperature probe. It operates on *either* four AA alkaline energy cells (batteries) or a (provided) line (mains) power module. The electronics are all housed in the control module.

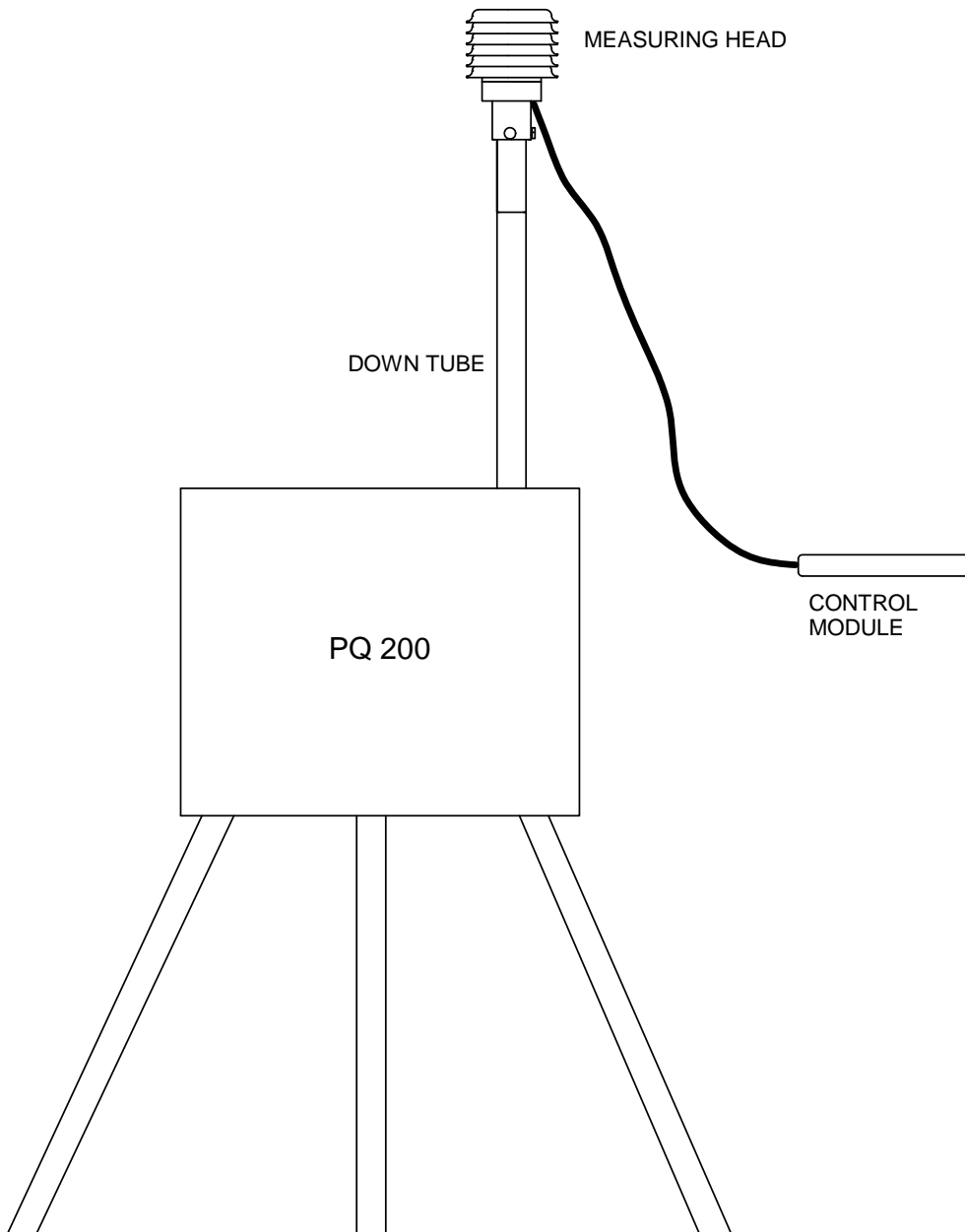


Figure 1- Instalation of deltacal on an FRM

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3.0 Specifications

Flow rate range: 2 – 20 Lpm ($\pm 1\%$)
 Temp. Operational range -30° C to 55° C
 Temp. Reading range -30° C to 55° C ($\pm .5^\circ$ C)
 Barometric pressure range 400 to 800 mm of Hg (± 5 mm)

Dimensions:

Measuring Head 5 in. Max OD (12.7 cm) X 10 in. high (25.4 cm)
 Control Module 8 in. high (20.3 cm) X 4 in. wide (10.15 cm) X 1.7 in. thick (4.32 cm)

Combined weight 2.2 lbs (1 kg)

Hand held temp probe

Length of cable: 33 in (83.8 cm)
 Length of probe: 5 in (12.7 cm)

Carrying case:

Dimensions: 18 in wide (45.7 cm) X 13 in high (33 cm) X 7 in. thick (17.8 cm)

Weight complete with contents: 5.5 lbs (2.5 kg)

One complete instrument comprises:

Quantity	Description	Catalog/Part No.
1	deltaCal	DC-1
1	Temperature Probe	DC-2
1	Plug in Power Supply	DC-3 (120/240V)
4	Extra AA batteries	replacements obtained locally by user
1	Instruction Manual	Download PDF file from BGI website
1	Fitted Hard Carrying Case	DC-4
1	Software Disk	DC-5

The deltaCal, in its carrying case is shown in figure 2

Replacement supplies (not included with initial purchase).

1	Set of 4 pressure tap "O" rings	DC-6
1	Replacement Thumb Screw (ea.)	DC-7
1	Replacement socket "O" rings (2)	X010

Adapters for non FRM applications

DC-8	deltaCal to ¼ in. hose barb
DC-9	deltaCal to 5/16 in. hose barb

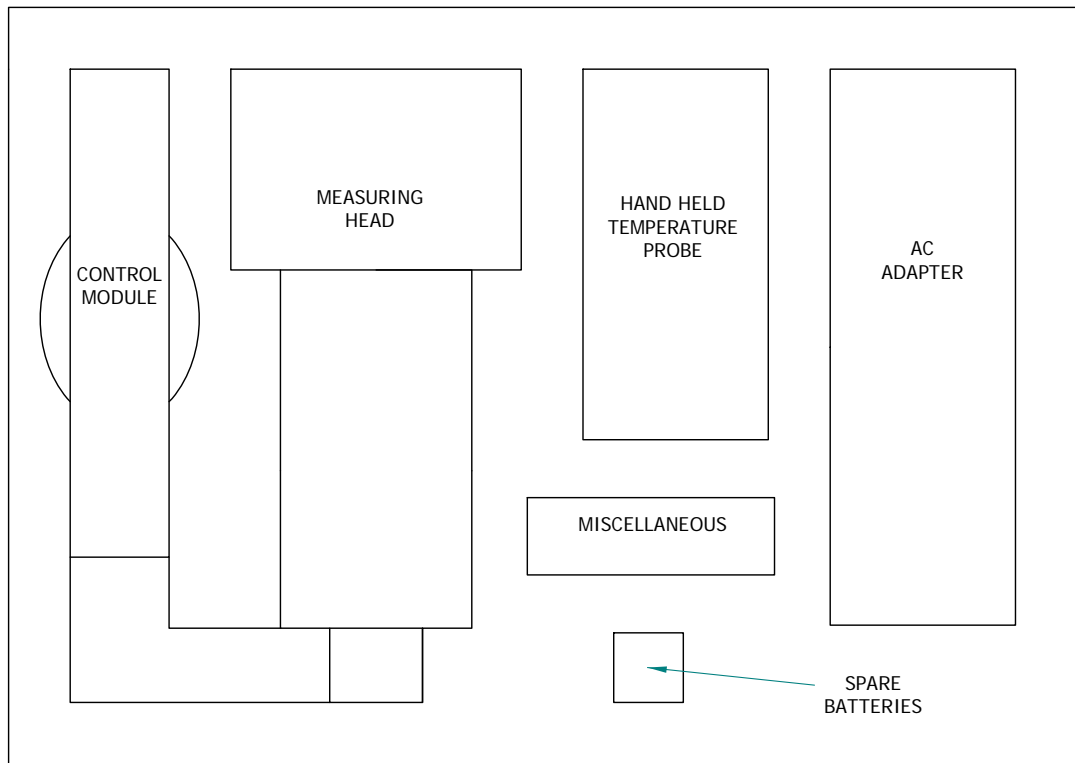


Figure 2- deltaCal In Travel case

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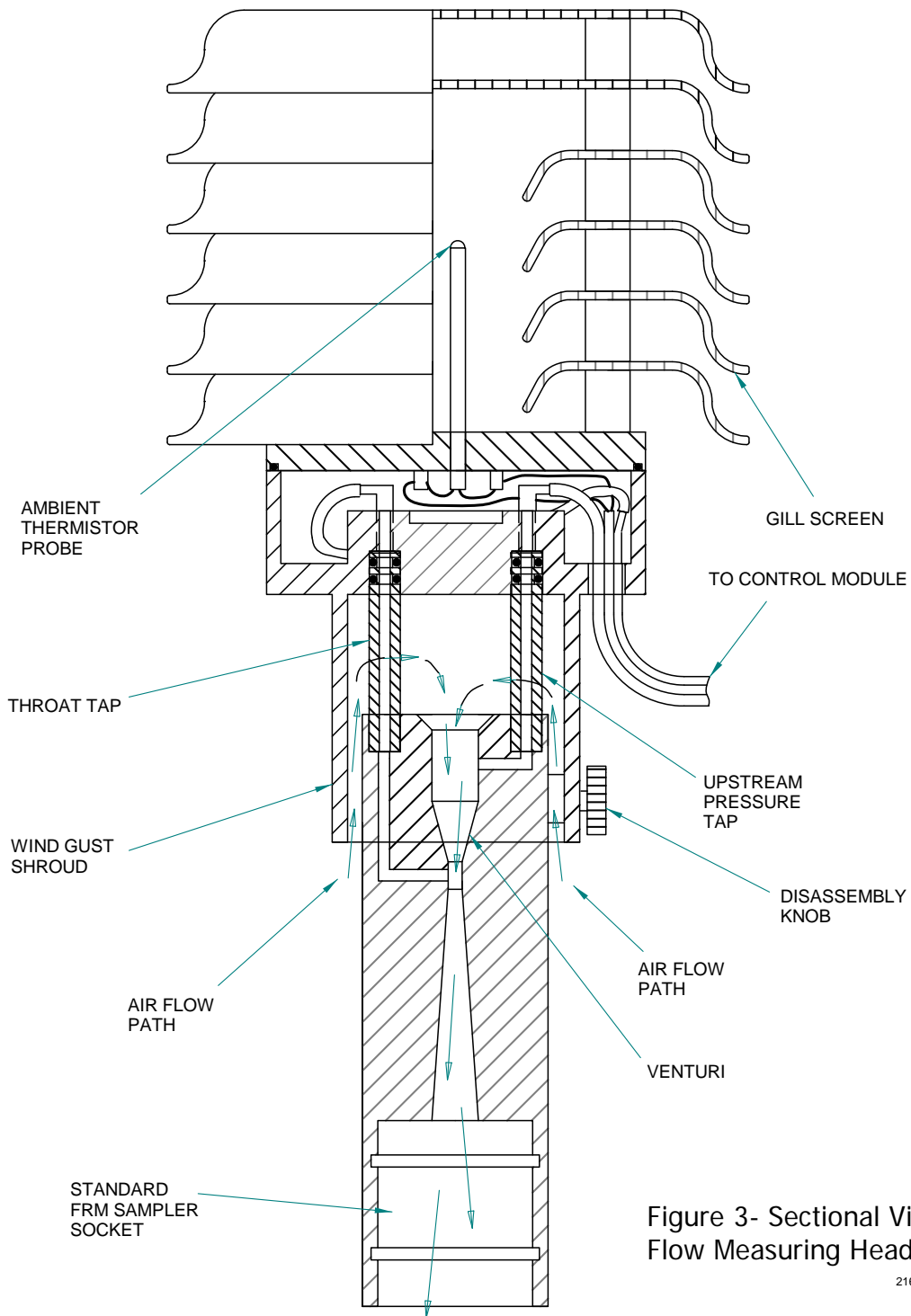


Figure 3- Sectional View of Flow Measuring Head

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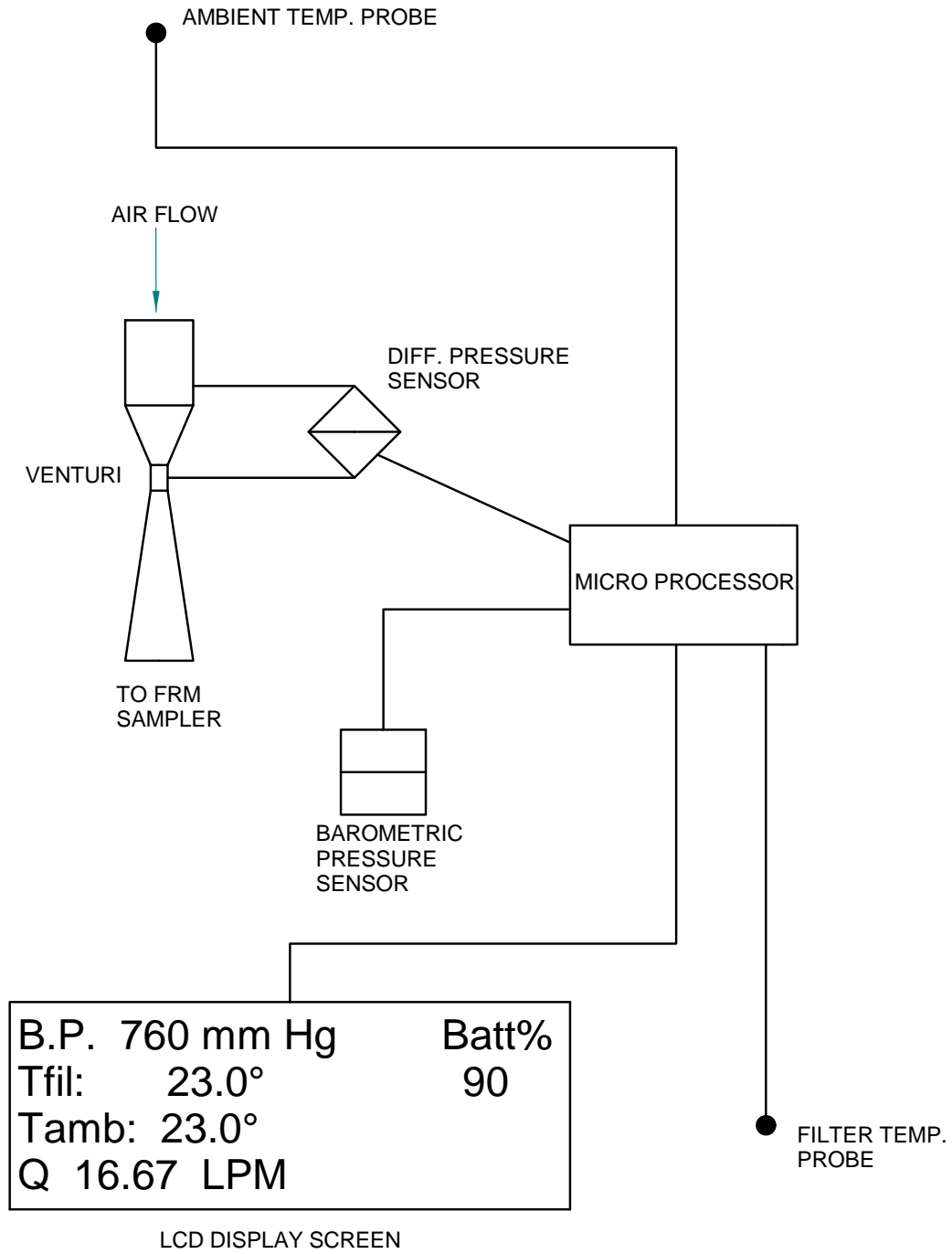


Figure 4- Schematic Diagram of deltaCal

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4.0 Principle of Operation

The deltaCal measures volumetric flow rate by utilizing a pressure transducer to assess the pressure drop caused by air being drawn through a venturi. As the flow rate through the venturi increases the pressure drop increases as the square root¹. A four times increase in pressure drop yields twice the flow rate. A desirable feature of the venturi is that most of the pressure drop created by the instrument is recovered in the expansion section of the venturi. Therefore, measurements are made at nearly the true operating conditions of the sampler.

The signal from the pressure transducer is sent to the microprocessor where, it is combined, via an algorithm with information from the barometric pressure sensor and the ambient temperature sensor. To eliminate "fluttering" of the on screen display of volumetric flow rate, the first 20 readings are averaged and then carried on as a rolling average. Barometric pressure and temperature are monitored and displayed on a continuous basis, when the instrument is switched on. An additional temperature probe may be used for the purpose of auditing an FRM sampler's filter temperature. The temperature of the probe is displayed on the screen when it is plugged into the module. A cutaway diagram of the measuring head is shown in figure 3 and a schematic diagram of the system is shown in Figure 4.

5.0 Instrument Set-up

Remove the instrument from its carrying case and plug in the filter temperature probe to the labeled port provided in the end panel. (See Figure 5).

Important points to be noted concerning the utilization of the deltaCal

- A. The measuring head must have no air flowing through it.

Every time the instrument is switched on, it re-zeros itself. If air is flowing, that flow rate will be set as zero.

- B. The control module must be in the position in which it is going to be used, when switching on. (Horizontal or vertical). The case houses the pressure transducers, which are subject to the force of gravity. Positional changes can give rise to minor errors. This effect applies to all devices containing pressure transducers.

- C. In order to perform the most precise measurement audit, it is necessary for the deltaCal to be in thermal equilibrium with the ambient environment in which the sampler to be audited is located. The best procedure is to deploy the deltaCal, out of its carrying case, for one hour prior to the audit, in the vicinity of the sampler to be audited. With the introduction of anodized Aluminum components during 2004 this time constraint is reduced to 10 minutes. Additionally, *if the deltaCal is subject to a temperature change of more than five degrees during use, it should be rebooted.*

When the deltaCal is switched on and no external power is being utilized XX % battery capacity remaining is displayed on the screen. So long as more than 10% is indicated, it is safe to proceed in that at least one hour of power is available. If the provided AC adaptor is utilized, the screen will indicate "DC In" and there is no limit to the run time.

Note Use of an AC power supply, other than the one provided, can cause severe damage to circuit components. If the unit provided becomes lost or dysfunctional, use only AA batteries for operation. The audit is now ready to be performed.

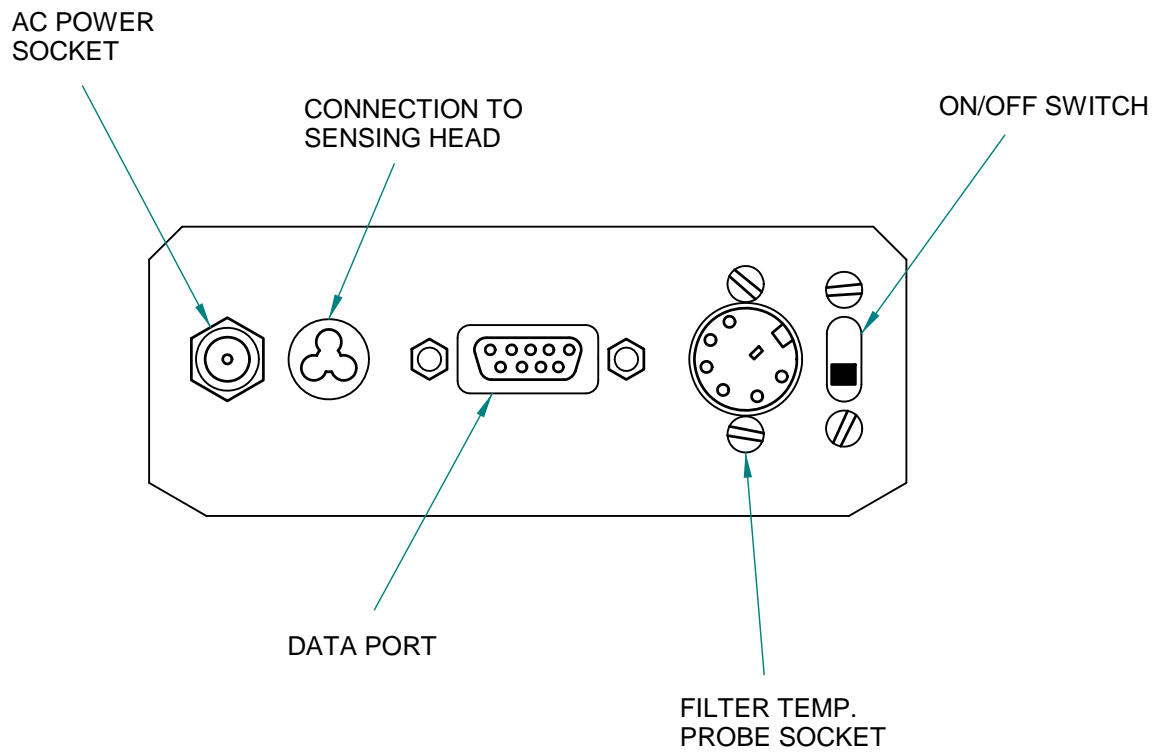


Figure 5- deltaCal Control Panel

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Table 1 Audit Data Format

Audited Instrument:

Make: _____ Model: _____ S/N: _____

Date: _____ Time: _____ deltaCal S/N: _____

Flow Rate – Lpm

Sampler: _____

% diff. = $[(\text{deltaCal}-\text{sampler})/\text{deltaCal}] \times 100$

DeltaCal: _____

Allowed diff. = 4%; Pass _____ Fail _____

Ambient Temp. – C

Sampler: _____

DeltaCal: _____

Allowed diff. = ± 2 C; Pass _____ Fail _____

Barometric Pressure – mm of Hg

Sampler: _____

DeltaCal: _____

Allowed diff. = ± 10 mm; Pass _____ Fail _____

Stop sampler, open filter holder, remove cassette and hold tip of Temp. Probe adjacent to samplers Filter Temp. Probe *without touching it.*

Filter Temp. C

Sampler: _____

DeltaCal: _____

Allowed diff. = ± 2 C; Pass _____ Fail _____

6.0 Using the deltaCal

6.1 To perform an audit

One of two procedures should now be performed.

Procedure A. Turn *off* the sampler to be audited. Remove the “10 micron” louvered inlet. Leave the 12 inch down tube in place. Plunge the deltaCal measuring head onto the 12-inch down tube. Turn *on* the deltaCal, wait for the screen to finish the start up boot, *and then* turn on the air sampler.

Procedure B. With the sampler to be audited *running*, remove the “10 micron” louvered inlet. When the screen has finished its start up boot, plunge the measuring head onto the 12 inch down tube

The flow resistance of the deltaCal head may cause momentary instability in the air samplers flow control circuit. Once the air samplers main screen flow rate indicator stabilizes, the reading may be taken. A simple audit data format is shown in Table 1.

Once the dynamic reading of flow rate is completed, the air sampler pump may be shut down per manufacturer’s instructions and the filter temperature sensor may be audited. Open the filter cassette clamping mechanism and remove the cassette. You can now view the filter temperature sensor. Hold the probe of the deltaCal filter temperature sensor within 1 cm. of the samplers sensor *without actually touching it*. Shield both sensors from direct sunlight. Read both the samplers indicated filter temperature and the deltaCal’s probe temperature and record them.

It should be noted that some brands of sequential samplers may require minor disassembly to gain access to the filter temperature sensor.

6.2 To perform a calibration.

The procedures and calculations for using the deltaCal to calibrate a sampler are the same as an audit, *except* the flow rate tolerance of is $\pm 2\%$ rather than $\pm 4\%$ as allowed for an audit. While full EPA procedures are carefully spelled out in the FRM², it is important to note that the flow rate should be calibrated at the operational point and 10% above and below that point, as indicated in Table 2.

Table 2 EPA FRM Calibration Points

		$\pm 2\%$
Standard Flow Rate – Lpm	16.67	16.34 – 17.00
10% Below Standard – Lpm	15.00	14.7 – 15.30
10% Above Standard – Lpm	18.30	17.97 – 18.71

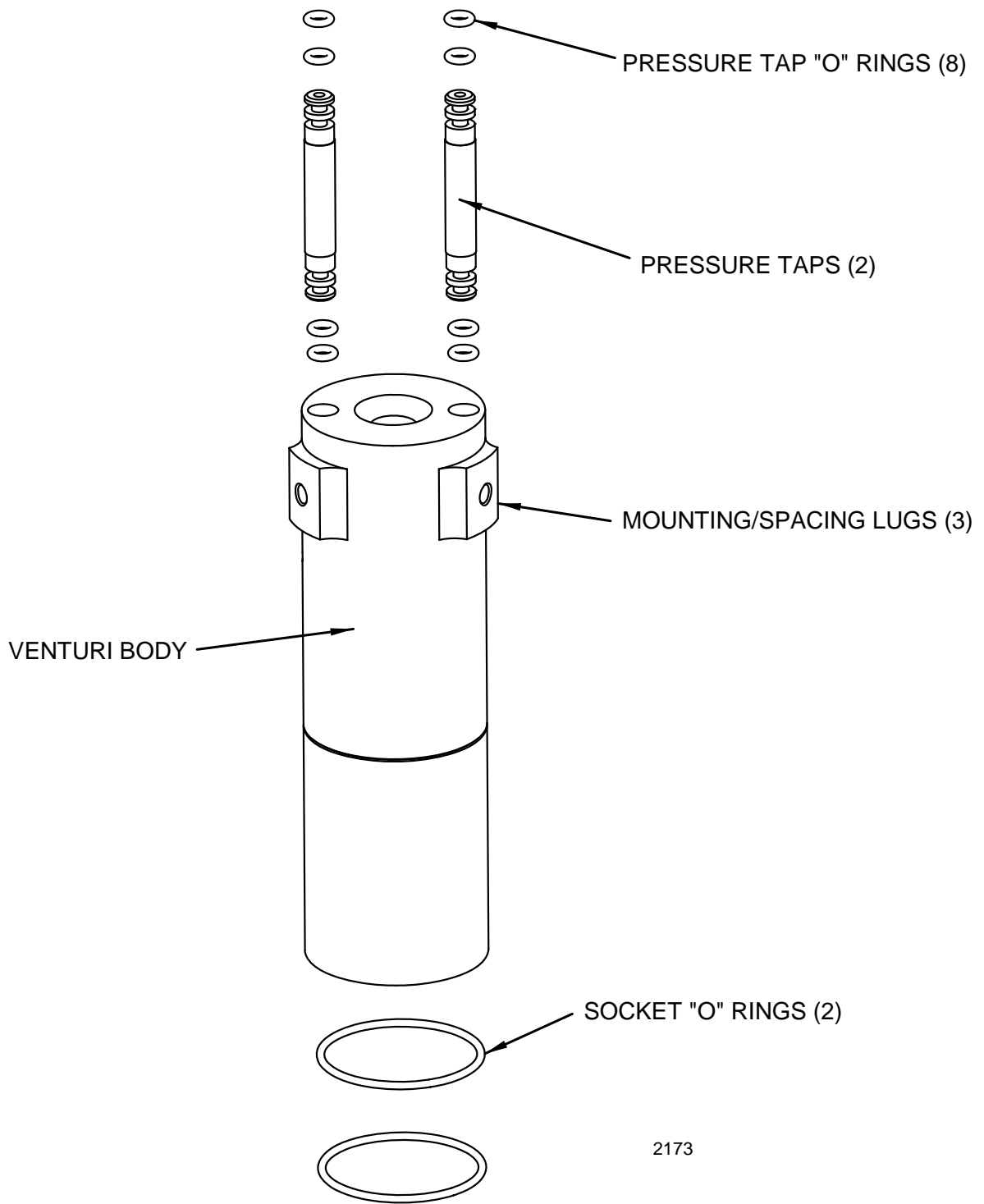


Figure 7 – Salient Details of Venturi Body

7.0 Software

By January 2008, the software for all BGI electronic calibrators has been replaced by a completely new suite known as BGI Open. This suite and a complete instruction manual may be downloaded at: http://www.bgiusa.com/cal/bgi_open.htm

8.0 Maintenance

Beyond battery replacement, the only part of the instrument requiring attention is the flow passage through the venturi. After *long* periods of use, some atmospheric dust can coat the interior flow surfaces. The presence of such a deposit may be ascertained by viewing the interior of the venturi under bright light; direct overhead sunlight being preferable. Holding the instrument in the inverted position, glance into the interior, seeking any discoloration of the white or Silver surface. If it is determined that cleaning is required, refer to Figure 3.

Remove the three knurled thumbscrews from the side of the measuring head and set aside. Grasp the body of the instrument, under the shoulder, in one hand and the venturi in the other. Gently pull the two sections apart. *Avoid any pulling force to the Gill Screen.* Set aside the upper section of the measuring head with the Gill screen attached and you are left with the venturi body shown in Figure 7. Rinse the entire venturi body in warm soapy water. Any deposits, which are not floated away, may be removed externally with a soft cloth. If internal deposits are not removed by soaking, the best procedure is to immerse the unit in an ultrasonic bath containing soapy water. If an ultrasonic bath is not available, judicious use of a pipe cleaner is recommended.

Following cleaning, the venturi may be dried utilizing compressed air, or if not available, allowed to air dry. Be especially certain to blow all liquid out of the pressure taps and their attendant passages.

Inspect the silicone rubber "O" rings on each pressure tap. If any damage is observed, replace all four. Prior to reassembly, lubricate the "O" rings with a wipe of light grease. Prior to reinstalling the venturi into the body of the instrument, note that there is only one rotational position in which both the pressure taps *and* the three screw holes on the body can be aligned. Hence, incorrect assembly is impossible. Having ascertained the correct rotational position for reassembly, gently insert the venturi section into the recess, until the tips of the pressure taps bottom. Rotate the venturi section gently back and forth (clockwise/counterclockwise) until the tips of the pressure taps go into the recesses provided. Slide the venturi longitudinally, back and forth until the three screw holes line up and reinstall the three thumb screws, hand tight.

The two "O" rings in the socket of the instrument, which fits over the 12 inch down tube, during calibration procedures, should be frequently inspected for wear and tearing. They should be replaced at the first sign of wear and always kept lightly greased for ease of use.

9.0 Safety

There are no owner serviceable components in the measuring head of the instrument other than the venturi and "O" rings described in the previous section. The only user serviceable items in the electronic control module are the four AA batteries. These should only be replaced with good quality alkaline energy cells and should be promptly removed when expired, to prevent leakage and chemical damage to the electronic components. When the instrument is placed in long term storage (more than two months) always remove the batteries.

Do not substitute other power supplies. Use only the unit provided, or severe electrical problems will occur.

Even though there is no reason to disassemble the electronics box, should the need arise, always unplug the line current power supply (if it is in use) and remove the batteries.

Adjustable potentiometers are contained within the electronic housing, which are factory set during calibration. If these are turned, the calibration will be lost and factory recalibration will be required.

The filter temperature probe has a range of -50 to $+50\text{C}$, its accuracy is as indicated on the traceability certificate and it is not recommended that it be utilized outside of the normal EPA range (-30 to 40C) for which it is intended. The tip of the probe should not be applied to surfaces above 50C , as it will be irreparably damaged. Under no circumstances should it be inserted into any area, which might cause damage to the probe or that the probe might cause damage to.

10.0 Warranty Information

BGI Incorporated warrants equipment of its manufacture and bearing its nameplate to be free from defects in workmanship and material. We make no warranty, express or implied, except as set forth herein. BGI's liability under this warranty extends for a period of one (1) year from the date of BGI's shipment. It is expressly limited to repairing or replacing at the factory during this period and at BGI's option, any device or part which shall within one year of delivery to the original purchaser, be returned to the factory, transportation prepaid and which on examination shall in fact be proved defective.

BGI assumes no liability for consequential damages of any kind. The purchaser, by acceptance of this equipment, shall assume all liability for consequences of its misuse by the purchaser, his employees or others. This warranty will be void if the equipment is not handled, installed, or operated in accordance with our instructions. If damage occurs during transportation to the purchaser, BGI must be notified immediately upon arrival of the equipment. The Equipment will be returned via collect shipment.

A defective part in the meaning of this warranty shall not, when such part is capable of being repaired or replaced, constitute a reason for considering the complete equipment defective. Acknowledgment and approval must be received from BGI prior to returning parts or equipment for credit. BGI Incorporated makes engineering changes and improvements from time to time on instruments of its manufacture. We are under no obligation to retrofit these improvements and/or changes into instruments which have already been purchased.

No representative of ours has the authority to change or modify this warranty in any respect.

Appendix A. NIST Traceability

A1.0 Introduction

NIST traceability for the deltaCal is established with the use of devices which are of themselves traceable and for which, BGI holds current traceability certificates. Calibrations are performed under a set of ISO 9000-2000 procedures, subject to annual audit. During a flow rate

calibration, the room temperature is established with an ASTM certified/traceable thermometer. Barometric pressure and absolute pressure are established with electronic manometers. These are backed by three Primary Standard Mercury Instruments/

A2.0 Flow Rate Calibration

A schematic diagram of an instrument undergoing flow rate calibration is shown in Figure 1A. Two traceable critical Venturi are utilized for this purpose. Their details are listed on the calibration certificate. Readings of flow rate are taken as shown in Figure A2, which is a typical calibration. While the deltaCal utilizes barometric pressure and ambient temperature to constantly display readings of volumetric flow rate, the initial venturi calibration is performed and normalized to a base value. While any values are sufficient, "engineering standard values" of 20C and 760mm of Hg have been selected. Utilizing an Excel spreadsheet, the flow rate vs. pressure drop equation for the individual venturi under test is determined. This equation is then installed in the individual unit's microprocessor.

A3.0 Barometric Pressure Calibration

The barometric pressure sensor is set to match the actual current barometric pressure as determined by a Mercury barometer. A negative pressure of 150 mm of Hg is applied to the barometric pressure transducer and the output reading is adjusted to comply with BP – 150mm.

A4.0 Temperature Calibration

The Thermistors provided for measurement of ambient and filter temperature are of a very high standard and are batch tested at the temperature extremes of –20 C and +50 C, utilizing an ASTM certified/traceable thermometer as a reference.

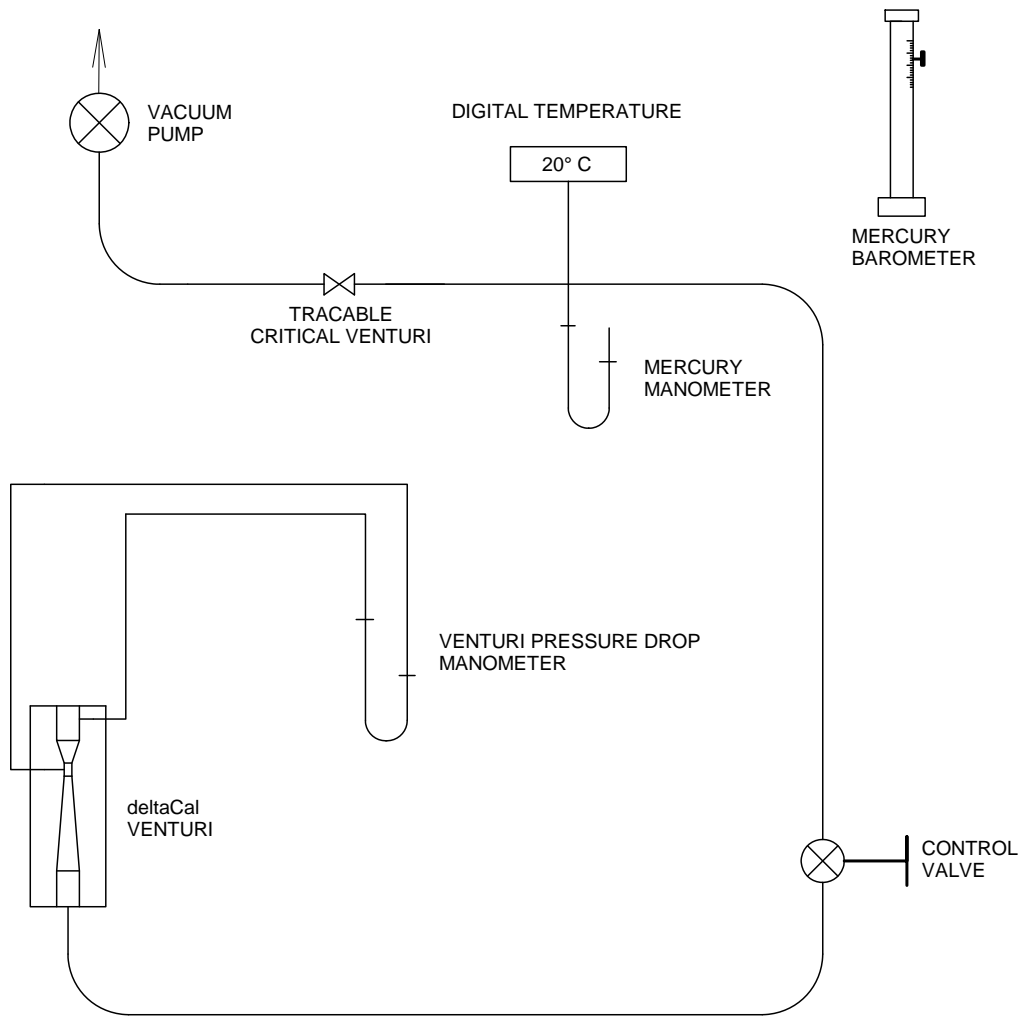


Figure A1- Schematic Diagram of Calibration Setup

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A5.0 Recalibration

Recalibration is immediately necessary if physical damage has occurred to such an extent that the instrument is rendered inoperable. In such cases, an instrument will be recalibrated as part of the repair procedure. There are no moving or wear parts in the instrument, therefore, barring physical damage, there is no reason for recalibration, except as required by ISO, company or regulatory requirements. These requirements are almost universally on a one-year basis, after being placed in service. Units received for recalibration will be thoroughly inspected and any requisite repairs will be performed prior to recalibration.

Appendix B. Use of the deltaCal with non-volumetric samplers.

[NOTE: If your instrument is Version 2.5.X or higher, ignore this section and go to Appendix D]

The flow measurement function of the deltaCal is designed to check the flow rate of "true" volumetrically flow-controlled instruments. A truly volumetric flow controlled instrument is one, which is constantly taking account of ambient pressure and temperature. Air sampling instruments of this type are largely limited to those devices originally designed for EPA 2.5 *Designated* sampling. Mass flow controlled instruments are frequently utilized for air sampling, because of their extreme stability. There are two types of mass flow controllers. The older type contains a heater and thermistor. This type is referred to as "Anemometric", as this is what is used in a hot wire anemometer. An example of this type is the mass flow controlled high-vol sampler. This systems flowrate, is altered by the density of the air, (barometric pressure and ambient temperature). This system has been supplanted by true mass flow sensor (thermistor-heater-thermistor)³. This system is not affected by variations in air density. Once the flow rate is set, the mass of air flowing through the instrument is constant. An example of a modern type of mass flow controlled air sampler is the BGI PQ100. In some areas of the United States and in most of the world it is recognized that what is referred to as mass flow is more properly called Standard Flow, i.e. flow or volume corrected to a specified set of standard conditions.

Since a true mass flow controlled sampler must be set, upon calibration to a user selected barometric pressure and temperature, the deltaCal may be utilized on instruments of this type. A simple calculation will be necessary to determine if a mass flow controlled instrument is operating correctly. This calculation is shown in the following illustrative example.

Set conditions of instrument

Set flow rate: **16.7** Lpm
Reference Temp: 20C
Reference BP: 760 mm of Hg

True flow rate through sampler = $Q_{ind} (T_{cal}/T_{ind}) \times (BP_{ind}/BP_{cal})$

When the deltaCal *indicated* readings are: Temp. (T_{ind}) = 3C; BP (BP_{ind}) = 730 mm of Hg and Q = 16.4

Then the mass flow rate at the set conditions is = $16.4 (20 + 273.18)/(3 + 273.18) \times (730)/(760) =$
16.7 lpm

Thus, it has been shown that the audited flow rate through the air sampler is within 0% of the set mass flow rate. This same relationship can be used to audit at any set of condition within the range of the deltaCal.

Alternatively, a precalculation may be made and the deltaCal may be used to calibrate a mass flow controlled air sampler. Desired set conditions of the air sampler.

Set flow rate: 16.7 Lpm
Reference temp: 0C
Reference BP: 760 C

Conditions in area where calibration is being performed,

Ind. Temp: 18C
Ind. BP: 770 mm of Hg

The air sampler must be adjusted so that the flow rate indicated on the deltaCal is equal to:

$$\begin{aligned} &= 16.7(T_{\text{ind}}/T_{\text{cal}}) \times (BP_{\text{cal}}/BP_{\text{ind}}) \\ &= 16.7 (18 + 273.18)/(0 + 273.18) \times (760)/(770) = \mathbf{17.57} \text{ Lpm} \end{aligned}$$

Other, semi-volumetric air sampling devices may also be calibrated by this technique utilizing the deltaCal. Examples of semi-volumetric flow controlled instruments are those which utilize a critical orifice for flow control or keep the flow constant by measuring some function of flow rate and adjust pump speed to keep flow rate approximately constant. These devices do not adjust for the density of the air and are generally accepted to maintain a set flow rate at $\pm 5\%$, when used indoors.

Appendix C. Venturi Changes

Instruments with version numbers beginning with **2.4.X** have a new Venturi with a slight dimensional change. These units are further identified by a groove running around the Venturi body, which is always fabricated from Aluminum. The flow rate range has been shifted from the original 2-20 lpm to **1.5 to 19.5 lpm**. The purpose of this change is to accommodate a revived interest in Dichotomous particulate samplers. These samplers require a measurement capability at 1.67, 15 and 16.7 lpm. This is a permanent change applied to all deltaCals produced from approximately the beginning of 2007, onwards.

Appendix D. Expanded Firmware

Instruments with version numbers beginning with **2.5.X** onwards have had their utility expanded with a major change to their firmware. In order to understand and utilize these changes it is necessary to present a more comprehensive explanation of the differences between **Standard** and **Actual** flow rate than was previously presented.

There are two ways that practitioners of air sampling measure and talk about flow rate.

Those doing compliance sampling for Industrial Hygiene/Occupational Health speak of **Volumetric** or **Actual** Air Flow rates. It is the volume of air at the existing pressure and temperature at the sampling site. The US EPA also specifies this type of measurement for PM_{2.5}. *Electronic* meters of the bubble, piston, venturi and orifice type "read out" in volumetric flow rate or **Q_A**. There are exceptions which do both.

EPA, for Politico Legal, reasons uses **Q_S** known as **Standard** Air flow rate for reporting PM₁₀. This means that the flow rate is reported to **Standard** conditions. For the US EPA, these conditions are 25 C and 1 atmosphere pressure. (1 Atmosphere = 760 mm of Hg = 29.92 in of Hg = 1013.25 millibars = 1013.25 hecto Pascals).

Because the mass of air flowing could be calculated from Q_S it has come to be called **Mass flow**.

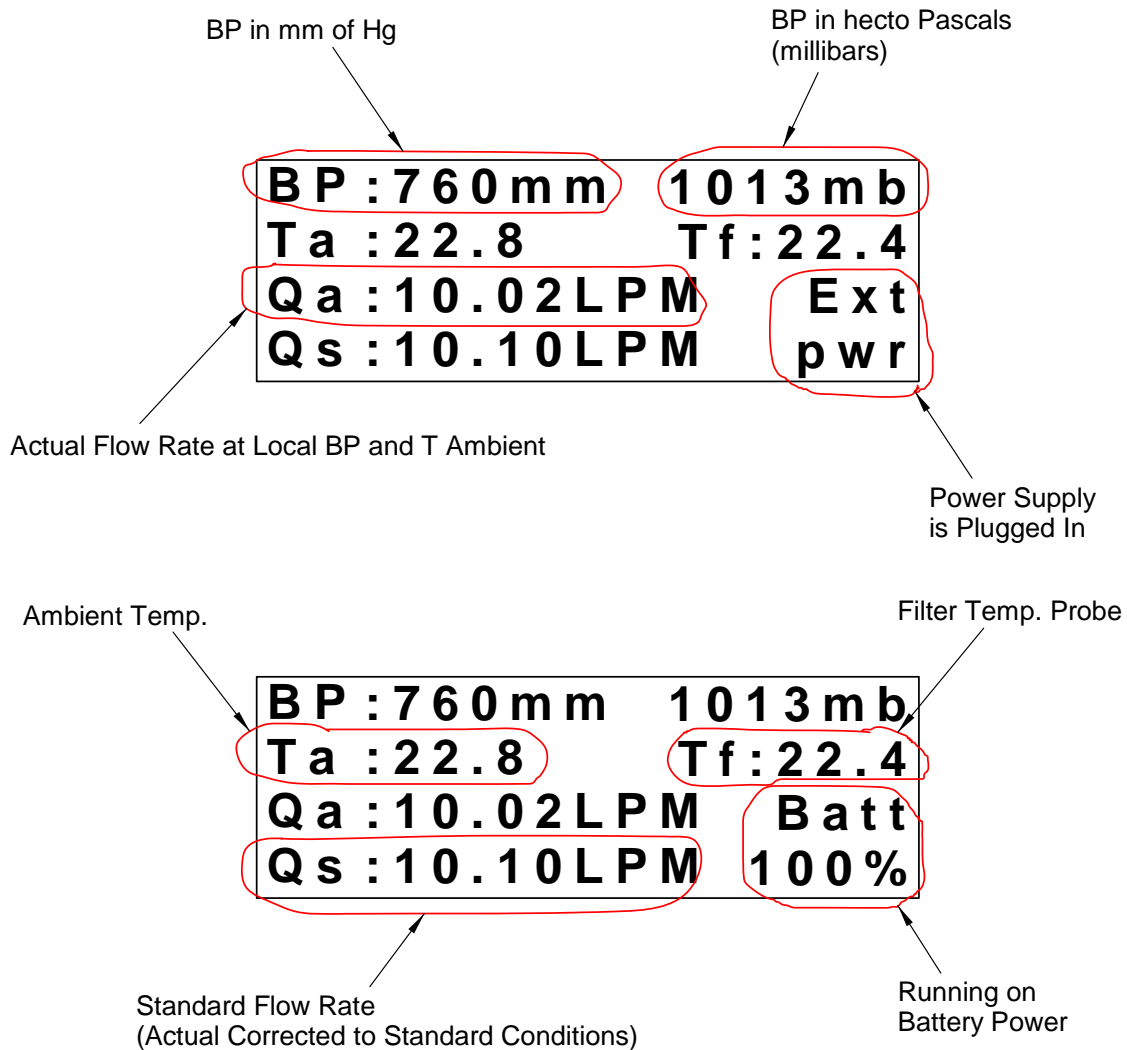
Throughout most of the world Q_S is not usually referred to as mass flow and it is to a different standard. The conditions outside of the U.S. are 0 C and 1013.25 mb.

Volumetric devices are in the majority and any of them may be used to measure Q_s if there is also knowledge of the T and BP, in the immediate locale, either from the instrument itself or supplemental instruments.

$$Q_s = Q_a * (BP_a/760)*(298.15/T_a+273.15)$$
 For U.S. applications when $T_s=25$ C and $BP_s=760$ mm of Hg

$$Q_s = Q_a * (BP_a/1013.25)*(273.15/T_a)$$
 For world applications when $T_s=0$ C and $BP_s=1013.25$ mb

Inasmuch as the deltaCal generates Q_a , T_a and BP information on a continuous basis it was decided in mid 2006 to implement new code which would provide both Q_a and Q_s information. At the same time, the two most popular Barometric pressure units (mm of Hg and millibars or hecto Pascals) are also provided. This results in two new screens;



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Remember, Q_s is always set to sea level conditions, but the Standard temperature is always factory set to either **25 C** (US EPA, Canada and other countries using US EPA conditions) or **0 C**. If the Firmware version contains the letter **W** (for world) the temperature base is **0 C**.

References

1. Fan Engineering, R. Jorgensen, ed. Buffalo Forge Co, Buffalo, NY. 6th Ed. 1961.
2. US EPA FRM 40 CFR Part 53, Federal Register, July 18, 1997.
3. Measurement Systems, E.O. Doebelin, McGraw-Hill Inc., New York, NY. 4th Ed. 1990.

Revision History

Version 1.1.2	First public release	August 2000
Version 1.1.3	Minor revisions	April 2001
Version 1.2	Revised calibration procedure	January 2002
Version 1.3	Added tolerances to specification page	July 2003
Version 1.4	Changed software to Version 1.4	October 2002
Version 1.4.1	Changed software to Version 1.6.1	July 2004
Version 1.4.2	Added 7.4.3 Troubleshooting	November 2004
Version 1.5.0	Detail improvements, added appendix C & D	March 2007
Version 1.5.1	Minor corrections	April 2007
Version 1.6.1	Introduced BGI Open Software	January 2008
Version 1.6.2	Updated ISO Registration	March 2009
Version 1.6.3	Updated Figure 7	June 2009