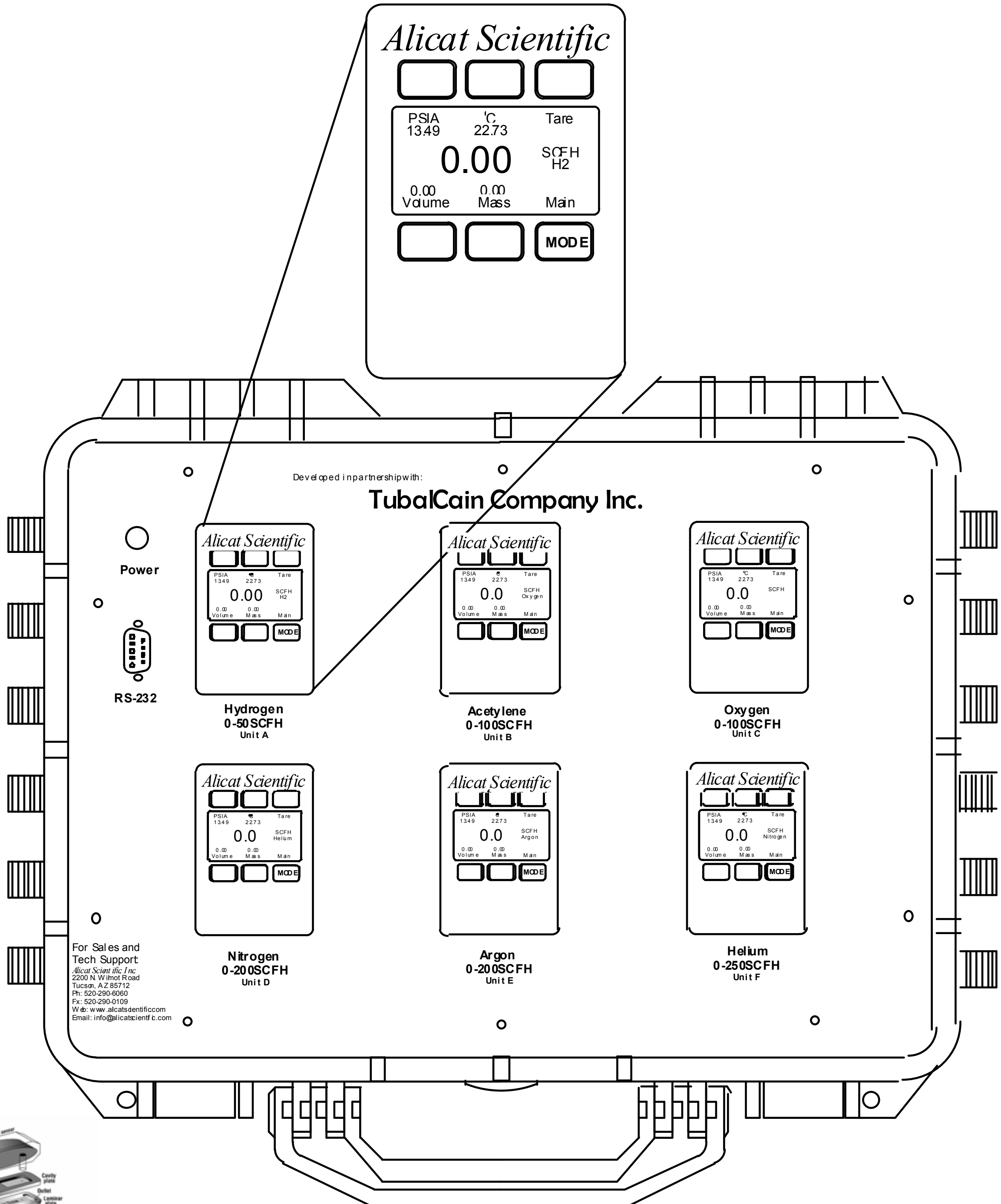
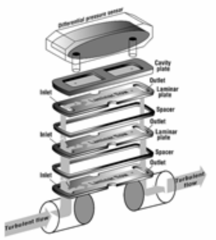
Plasma Booth Equivalency Device (PBED) Operating Manual





Based on Laminar Flow Technology

Developed in partnership with

TubalCain Company Inc.

Table of Contents

	Page
Introduction	3
PBED Application with Rotameters	3
Operating Principle	4
Installation	5
Plumbing	5
Application	5
Power and Signal Connections	5
M Series Mass Flow Meter Operation	6
Main Mode	6
Mode	6
Tare	6
Gas Absolute Pressure	7
Gas Temperature	7
Volumetric Flow Rate	7
Mass Flow Rate	8
Volume Flow vs. Mass Flow	8
Volumetric and Mass Flow Conversion	8
Identity Mode	10
RS-232 Output	11
Configuring HyperTerminal®	11
Data Format	11
Collecting Data	12
Troubleshooting	12
Maintenance and Recalibration	13
Warranty	14
Miscellaneous Information	14
Gas Viscosity Table	14
Flow Conversion Table	14
Performance Specifications	15

Note: Although we provide assistance on Alicat products both personally and through our literature, it is the complete responsibility of the user to determine the suitability of any product to their application.

Introduction

Thank you for purchasing an Alicat Scientific Plasma Booth Equivalency Device. Please take the time to find and read the pertinent information contained in this manual for your specific device. This will help to ensure that you get the best possible service life from your instrument. This manual covers the following Alicat Scientific instruments:

PBED

The PBED integrates 6 Alicat Mass Flow Meters for ease of use in checking and adjusting Plasma and Thermal Spray Booths.

The Alicat mass flow meters utilize a full graphic display that allows simultaneous viewing of all operating parameters. Selected parameters can be toggled to the large primary display for ease of viewing.

PBED Application with Rotameters

The majority of plasma and thermal spray consoles in use have rotameter control of gas flows. The rotameters in usage are often specified as ±10%, or ±15% of full scale accuracy. One of the primary intended uses of the Plasma Booth Equivalency Device is to reveal the booth-to-booth variances in gas flow measurement, including rotameter-control consoles, and by understanding the differences booth-to-booth, to enable the spray shop to better achieve similar if not identical flows in the different booths.

The sensitivities of variable area rotameters, as well as their specified accuracy / inaccuracy is shown with the use of the PBED. The rotameters, when calibrated are tested at a specific pressure and temperature. Departures from the given pressure and temperature can produce significant effects and consequent inaccuracies in the readings from the rotameters. For example, a 10 psi change in pressure will result in an approximate 7-8% change in reading, while a 10 degree Fahrenheit change in temperature (gas temperature, not ambient temperature at the spray booth) will cause an approximate 1% change in rotameter reading. The effects are cumulative. Thus, while the manufacturer of the rotameters specified ±10%-15% of full scale accuracy for the rotameter, the stated accuracy/inaccuracy was for gas flowing through the meter at a given pressure and temperature. Deviations from these conditions cause the stated inaccuracy percentage to increase. On the plasma spray consoles, the pressure gauges themselves, very often bourdon tube type gauges, are imprecise. That imprecision also adds to the total variance booth-to-booth. It has been found when using a PBED-type device for calibration verification, variances in rotameter-control consoles have exceeded 35%.

Further complications in flow measurement comparisons between the PBED device and the plasma spray consoles are that many of the consoles' rotameters read in "Flow Meter

Reading", or FMR, units, and not in Standard Liters per Minute or Standard Cubic Feet per Hour, etc.

The user of the PBED device should not expect exact agreement with the rotameter-controlled plasma spray console. The PBED device does facilitate precise evaluation of flows and pressures within a given booth, and comparisons booth-to-booth.

For further technical discussions regarding the use of the PBED in assisting with creating identical flows between booths, please contact TubalCain Company, Inc.

Operating Principle

All Alicat Scientific gas flow meters are based on the accurate measurement of volumetric flow. The volumetric flow rate is determined by creating a pressure drop across a unique internal restriction, known as a Laminar Flow Element (LFE), and measuring differential pressure across it. The restriction is designed so that the gas molecules are forced to move in parallel paths along the entire length of the passage; hence Laminar (streamline) flow is established for the entire range of operation of the device. Unlike other flow measuring devices, in laminar flow meters the relationship between pressure drop and flow is linear. The underlying principle of operation of the 16 Series flow meters is known as the Poiseuille Equation:

$Q = (P_1 - P_2)\pi r^4 / 8\eta L$ (Equation 1)

Where:
- Q = Volumetric Flow Rate
- P_1 = Static pressure at the inlet
- P_2 = Static pressure at the outlet
- R = Radius of the restriction
- η = (eta) absolute viscosity of the fluid
- L = Length of the restriction

Since π, r and L are constant; Equation 1 can be rewritten as:

$Q = K(\Delta P/\eta)$ (Equation 2)

Where K is a constant factor determined by the geometry of the restriction. Equation 2 shows the linear relationship between volumetric flow rate (Q) differential pressure (ΔP) and absolute viscosity (η) in a simpler form.

Installation

Plumbing

All Alicat Scientific flow meters are equipped with standard B size (9/16" – 18) hose fittings for inlet and outlet port connections. They are position insensitive and may be used in any orientation that is convenient. Because the flow meters set up a laminar flow condition within the flow body, no straight runs of pipe are required upstream or downstream of the meter. The inlet and outlet ports are equal in size and symmetric (in-line).

Application

Maximum operating line pressure is 125 PSIG (862 kPa). **Caution: Exceeding the maximum specified line pressure may cause permanent damage to the solid-state differential pressure transducer.** If the line pressure is higher than the 100 PSIG (690 kPa), a pressure regulator should be used upstream from the flow meter to reduce the pressure to 100 PSIG (690 kPa) or less if possible. Although the meter's operation is uni-directional, reversing the flow direction will inflict no damage as long as the maximum specified limits are not exceeded. The differential pressure sensor utilized in Alicat Scientific flow meters is a very sensitive device capable of detecting minute differences in pressure. Avoid installations (such as snap acting solenoid valves upstream) that apply instantaneous high pressure to the meter as permanent damage to the differential pressure sensor could result. This damage is not covered under warranty!

Power Connections

Power should be supplied to your PBED through the AC/DC adapter jack with the included power adapter.

Leak Testing

When using Snoop™ or another liquid for leak testing, ensure no liquid gets in the top area housing the displays or the power connection. This area is not waterproofed and display damage could ensue.

M Series Mass Flow Meter Operation

The M Series Mass Flow Meter is designed to provide a multitude of useful flow data in one simple, rugged device. The membrane switch user interface and dynamically labeled graphic display combine to provide exceedingly flexible and user-friendly operation. All M Series meters have a default Main Mode and an Identity Mode. The device defaults to Main Mode as soon as power is applied to the meter.

Main Mode

The main mode screen defaults on power up with the mass flow on the primary display. The following parameters are displayed in the main mode as shown in Figure 8:

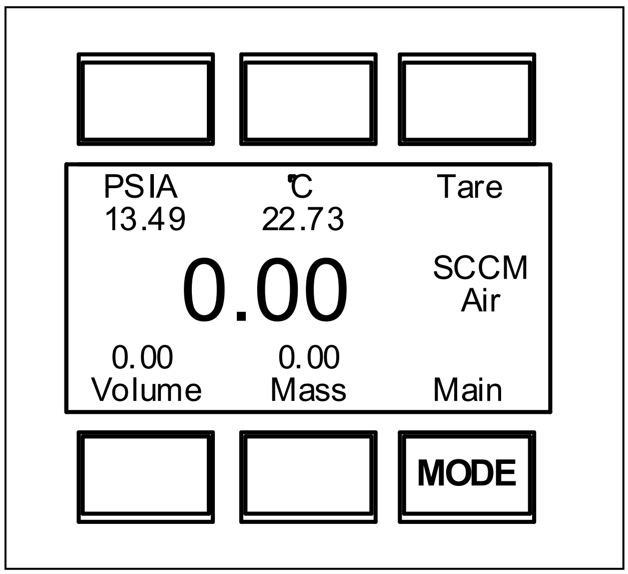


Figure 1. Main Mode Display, M Series Flow Meter

MODE - The MODE button in the lower right hand corner toggles the display between modes.

Tare – Pushing the dynamically labeled Tare button in the upper right hand corner tares the flow meter and provides it with a reference point for zero flow. *This is a very simple but important step in obtaining accurate measurements*. It is good practice to "zero" the flow meter each time it is powered up. If the flow reading varies significantly from zero after an initial tare, give the unit a minute or so to warm up and re-zero it. If possible, it is helpful to zero the unit near the expected operating pressure by positively blocking the flow downstream of the flow meter prior to pushing the "Tare" button. Zeroing the unit while there is any flow will directly affect the accuracy by providing a false zero point. If in doubt about whether the flow is positively blocked, remove it from the line and positively block both ports before pressing the "Tare" button. If the unit reads a significant negative value when removed from the line and blocked, it is a good indication that it was given a false zero. It is better to zero the unit at atmospheric pressure and a confirmed no flow conditions than to give it a false zero under line pressure.

Gas Absolute Pressure: The M Series flow meters utilize an absolute pressure sensor to measure the line pressure of the gas flow being monitored. This sensor references hard vacuum and accurately reads line pressure both above and below local atmospheric pressure. This parameter is located in the upper left corner of the display under the dynamic label "PSIA". This parameter can be moved to the primary display by pushing the button just above the dynamic label (top left). The engineering unit associated with absolute pressure is pounds per square inch absolute (PSIA). This can be converted to gage pressure (psig = the reading obtained by a pressure gauge that reads zero at atmospheric pressure) by simply subtracting local atmospheric pressure from the absolute pressure reading:

$$\text{PSIG} = \text{PSIA} - (\text{Local Atmospheric Pressure})$$

The flow meters use the absolute pressure of the gas in the calculation of the mass flow rate. For working in metric units, note that 1 PSI = 6.89 kPa.

Gas Temperature: The M Series flow meters also utilize a temperature sensor to measure the line temperature of the gas flow being monitored. The temperature is displayed in engineering units of degrees Celsius (°C). The flow meters use the temperature of the gas in the calculation of the mass flow rate. This parameter is located in the upper middle portion of the display under the dynamic label "°C". This parameter can be moved to the primary display by pushing the button above the dynamic label (top center).

Volumetric Flow Rate: The volumetric flow rate is determined as described in the Flow Measurement Operating Principle described elsewhere in this manual. This parameter is located in the lower left corner of the display over the dynamic label "Volume". This parameter can be moved to the primary display by pushing the button below the dynamic label (lower left). In order to get an accurate volumetric flow rate, the gas being measured must be selected. This is important because the device calculates the flow rate based on the viscosity of the gas at the measured temperature. If the gas being measured is not what is selected, an incorrect value for the viscosity of the gas will be used in the calculation of flow, and the resulting output will be inaccurate in direct proportion to the difference in the two gases viscosities.

Gas viscosity, and thus gas composition, can be very important to the accuracy of the meter. Anything that has an effect on the gas viscosity (e.g. water vapor, odorant additives, etc.) will have a direct proportional effect on the accuracy. Selecting methane and measuring natural gas for instance, will result in a fairly decent reading, but it is not highly accurate because natural gas contains small and varying amounts of other gases such as propane that result in a viscosity that is somewhat different than pure methane.

Absolute viscosity changes very little with pressure therefore a true volumetric reading does not require a correction for pressure. Changes in gas temperature do affect viscosity. For this reason, the M Series utilizes the temperature sensor to internally compensate for this change and no outside temperature correction is required for volumetric measurement.

<u>Mass Flow Rate:</u> The mass flow rate is the volumetric flow rate corrected to a standard temperature and pressure (14.695 psia and 25°C). This parameter is located in the lower middle portion of the display over the dynamic label "Mass". This parameter can be moved to the primary display by pushing the button located below the dynamic label (bottom center). The meter uses the measured temperature and the measured absolute pressure to calculate what the flow rate would be if the gas pressure was at 1 atmosphere and the gas temperature was 25°C. This allows a solid reference point for comparing one flow to another.

Volume Flow vs. Mass Flow: At room temperature and low pressures the volumetric and mass flow rate will be nearly identical, however, these rates can vary drastically with changes in temperature and/or pressure because temperature and pressure of the gas directly affects the volume. For example, assume a volumetric flow reading was used to fill balloons with 250 mL of helium, but the incoming line ran near a furnace that cycled on and off, intermittently heating the incoming helium. Because the volumetric meter simply measures the volume of gas flow, all of the balloons would initially be the same size. However, if all the balloons are placed in a room and allowed to come to an equilibrium temperature, they would generally all come out to be different sizes. If, on the other hand, a mass flow reading were used to fill the balloons with 250 <u>standard</u> mL of helium, the resulting balloons would initially be different sizes, but when allowed to come to an equilibrium temperature, they would all turn out to be the same size.

This parameter is called corrected mass flow because the resulting reading has been compensated for temperature and pressure and can therefore be tied to the mass of the gas. Without knowing the temperature and pressure of the gas and thus the density, the mass of the gas cannot be determined.

Volumetric and Mass Flow Conversion: In order to convert volume to mass, the density of the gas must be known. The relationship between volume and mass is as follows:

Mass = Volume x Density

The density of the gas changes with temperature and pressure and therefore the conversion of volumetric flow rate to mass flow rate requires knowledge of density change. Using ideal gas laws, the effect of temperature on density is:

$$\rho_a / \rho_s = T_s / T_a$$

Where:

ρ_a	=	density @ ambient condition
T_a	=	absolute temp @ ambient condition in °Kelvin
ρ_s	=	density @ standard (reference) condition
T_s	=	absolute temp @ standard (reference) condition in °Kelvin
ºK	=	ºC + 273.15 Note: ºK=ºKelvin

The change in density with pressure can also be described as:

$$\rho_a / \rho_s = P_a / P_s$$

Where:

ρ_a	=	density @ ambient condition
P_a	=	ambient absolute pressure
ρ_s	=	density @ standard (reference) condition
P_s	=	Absolute pressure @ standard (reference) condition

Therefore, in order to determine mass flow rate, two correction factors must be applied to volumetric rate: temperature effect on density and pressure effect on density.

Although the correct units for mass are expressed in grams, kilograms, etc. it has become standard that mass flow rate is specified in SLPM (standard liters / minute), SCCM (standard cubic centimeters / minute) or SmL/M (standard milliliters / minute).

This means that mass flow rate is calculated by normalizing the volumetric flow rate to some standard temperature and pressure (STP). By knowing the density at that STP, one can determine the mass flow rate in grams per minute, kilograms per hour, etc.

STP is usually specified as the sea level conditions, however, no single standard exists for this convention. Examples of common reference conditions include:

0°C	and	14.695 PSIA
25°C	and	14.695 PSIA
0°C	and	760 torr (mmHG)
70°F	and	14.695 PSIA
68°F	and	29.92 inHG
20°C	and	760 torr (mmHG)

M Series Flow Meters reference 25ºC and 14.695 PSIA (101.32 kPa).

Identity Mode

The Identity Mode is accessed by pressing the "MODE" button until the dynamic label over the "MODE" button reads "I.D." as shown in Figure 7. The identity mode displays important information about your flow meter including the model number, serial number, and date of manufacture.

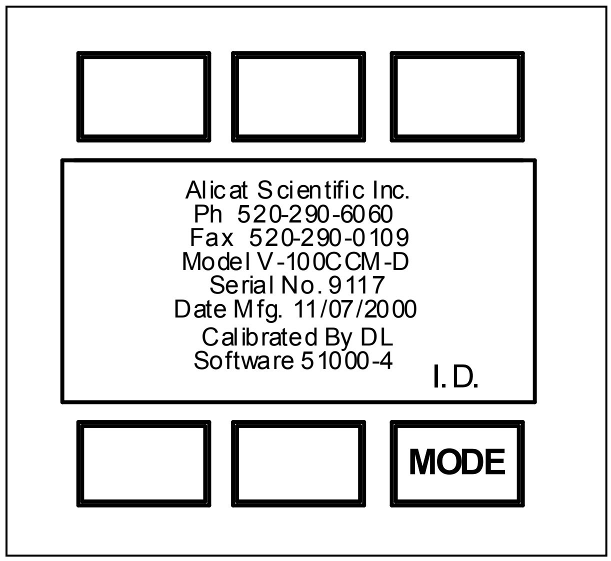


Figure 2. Identity Mode

RS-232 Output

Configuring HyperTerminal®:

1. Open your HyperTerminal® RS-232 terminal program (installed under the "Accessories" menu on all Microsoft Windows operating systems).
2. Select "Properties" from the file menu.
3. Click on the "Configure" button under the "Connect To" tab. Be sure the program is set for: 19,200 baud and an 8-N-1-None (8 Data Bits, No Parity, 1 Stop Bit, and no Flow Control) protocol.
4. Under the "Settings" tab, make sure the Terminal Emulation is set to ANSI.
5. Click on the "ASCII Setup" button and be sure the "Send Line Ends with Line Feeds" box is not checked, and that the "Append Line Feeds to Incoming Lines" box is checked. Those settings not mentioned here are normally okay in the default position.
6. To query a meter, once connected type the meter's identifier followed by a carriage return. The meter should respond as shown below. Note the identifier must be entered as a single capital letter. The default identifier is located under the flow meter's membrane switch on the front of the PBED.

Data Format:

The flow meters inside the PBED have been pre-set with identifiers for data display according to the following format:

Unit "A"	M-50SCFH-D	Hydrogen
Unit "B"	M-100SCFH-D	Acetylene
Unit "C"	M-100SCFH-D	Oxygen
Unit "D"	M-200SCFH-D	Nitrogen
Unit "E"	M-200SCFH-D	Argon
Unit "F"	M-250SCFH-D	Helium

The data stream on the screen represents the flow parameters of the main mode in the units shown on the display. For mass flow meters, there are 4 columns of data representing pressure, temperature, volumetric flow and mass flow. The first column is absolute pressure (in PSIA), the second column is temperature (in °C), the third column is volumetric flow rate (in CFH), and the fourth column is mass flow (in SCFH). For instance, if meter A was queried, the terminal output would be as follows.

```
A +014.70 +025.00 +050.04 +050.04
A +014.70 +025.00 +050.04 +050.04
A +014.70 +025.00 +050.04 +050.04
A +014.70 +025.00 +050.04 +050.04
```

M Series Mass Flow Meter Data Format

Collecting Data: The RS-232 output can be queried many times per second. It may be useful to capture the data in a text file. In HyperTerminal select "Capture Text" from the Transfer Menu. Type in the path and file name you wish to use. Push the start button. At this point all data typed in the terminal and received by the terminal will be saved in the capture file. When the data collection period is complete, simply select "Capture Text" from the Transfer Menu and select "Stop" from the sub-menu that appears.

Troubleshooting

Meter reads negative flow when there is a confirmed no flow condition.	This is an indication of an improper tare. If the meter is tared while there is flow, that flow is accepted as zero flow. When an actual zero flow condition exists, the meter will read a negative flow. Simply re-tare at the confirmed zero flow condition. Also note that while the meter is intended for positive flow, it will read negative flow with reasonable accuracy (it is not calibrated for bi-directional flow) and no damage will result.
Meter does not agree with another meter I have in line. See Also Page 3 of the Manual: PBED Application with Rotameters	Volumetric meters will often not agree with one another when put in series because they are affected by pressure drops. Volumetric flow meters should not be compared to mass flow meters. Mass flow meters can be compared against one another provided there are no leaks between the two meters and they are set to the same standard temperature and pressure. Both meters must also be calibrated (or set) for the gas being measured. Alicat Scientific mass flow meters are normally set to Standard Temperature and Pressure conditions of 25° C and 14.695 PSIA.
Meter does not agree with a known flow, meter is recently calibrated, and process flow is known to be clean, dry, and non-corrosive.	Other than above, check to see that meter was calibrated (or set in the optional gas select mode) for the gas being measured. The process gas (or selected gas) is listed under the primary display units on the main mode screen. Also, confirm that there are no leaks.

Flow flutters or is jumpy.	Alicat meters are very fast and will pick up any actual flow fluctuations such as from a diaphragm pump, etc. A flow dampener may be required. Also, inspect the inside of the upstream connection for debris such a Teflon tape shreds.
RS-232 Serial Communications is not responding.	Be sure that the port on the computer to which the meter is connected is active. Confirm that the port settings are correct per the RS-232 instructions in this manual.

Maintenance and Recalibration

General: Alicat Scientific Flow Meters require very minimal maintenance. They have no moving parts. The single most important thing that affects the life and accuracy of these devices is the quality of the gas being measured. It is designed to measure CLEAN, DRY, NON-CORROSIVE gases. A 50 micron filter mounted upstream of the meter is highly recommended. Moisture, oil, and other contaminates can affect the laminar flow elements and/or reduce the area that is used to calculate the flow rate. This directly affects the accuracy.

Recalibration: The recommended period for recalibration is once every year. Providing that the CLEAN, DRY, and NON-CORROSIVE mantra is observed, this periodic recalibration is quite sufficient. A label located on the back of the meter lists the recalibration due date. The meter should be returned to Alicat Scientific for recalibration near the listed due date. Before calling to schedule a recalibration, please note the serial number on the back of the meter. The Serial Number, Model Number, and Date of Manufacture are also available on the Identity Mode screen.

Cleaning: The PBED Series require no periodic cleaning. If required, the outside of the meter can be cleaned with a soft dry rag. Avoid excess moisture or solvents.

For repairs, re-calibrations, or recycling of this product, contact:

Alicat Scientific
2200 N. Wilmot Road
Tucson, AZ 85712
Ph. 520-290-6060
Fax 520-290-0109
email: info@alicatscientific.com
Web Address: http:/www.alicatscientific.com

Warranty

This product is warranted to the original purchaser for a period of one year from the date of purchase to be free of defects in material or workmanship. Under this warranty the product will be repaired or replaced at manufacturer's option, without charge for parts or labor when the product is carried or shipped prepaid to the factory together with proof of purchase. This warranty does not apply to cosmetic items, nor to products that are damaged, defaced or otherwise misused or subjected to abnormal use. See "Application" under the Installation section. Where consistent with state law, the manufacturer shall not be liable for consequential economic, property, or personal injury damages. Alicat Scientific, Inc. does not warrant or assume responsibility for the use of its products in life support applications or systems.

Appendices

Viscosity Table:

Absolute viscosities of common gases at 25°C in micro poise
(1 Poise = gram / (cm)(sec))

Propane	81.340
Hydrogen	89.230
Ethane	92.462
Methane	111.295
Nitrous Oxide	147.880
Carbon Dioxide	148.711
Carbon Monoxide	177.760
Nitrogen	177.820
Air	184.331
Helium	197.616
Oxygen	205.352
Argon	225.987
Neon	314.742

Flow Conversion Table:

	CCM	**CCH**	**LPM**	**LPH**	**CFM**	**CFH**
CFH	0.0021	0.00003	2.1189	0.035	60.0	1.0
CFM	0.000035	0.0000005	0.035	0.00059	1.0	0.0166
LPH	0.06	0.001	60.0	1	1699.0	28.316
LPM	0.001	0.000017	1.0	0.0166	28.316	0.4719
CCH	60.0	1.0	60000.0	1000.0	1699011.0	28317.0
CCM	1.0	0.0167	1000.0	16.667	28317.0	471.947

Performance Specifications for 16 Series Mass Flow Meters:

Specification	M Series	Units
Accuracy	+/-1%	Full Scale
Repeatability	+/-0.5%	Full Scale
Response Time* (typical)	10	ms
Pressure Drop** (typical)	0.4	PSID Full Scale
Operating Temperature	-10-50	°C
Zero Shift	0.02%	Full Scale / °C / ATM
Span Shift	0.02%	Full Scale / °C / ATM
Humidity Range	0-100%	Non-Condensing
Supply Current*** (typical)	30	mA
Excess Flow Rate	20X	Full Scale
Common Mode Pressure (max)	125	PSIG
Supply Voltage	7-30	Volts dc

* 10 ms represents a typical default response time for 63.2% of a step change. A variable register allows response time to be field adjustable to a certain extent via RS-232 communication. The primary trade off for response time is signal noise.

**Meters with flow ranges in excess of 250 (S)LPM can exhibit considerably higher pressure drops.

***30 mA represents typical current draw, 100mA available supply recommended.