Dome-loaded Back Pressure Regulator improves Mass Flow Controller calibration process

by Jeff Jennings, PE

Thermal mass flow meters and mass flow controllers are widely used throughout laboratories and industry in situations requiring precise control of gas flow rate..

Fig 1: Thermal mass flow controller showing flow control valve on outlet

As shown in the Figure 2, mass flow controllers are often used to supply inert and other gases into laboratory reactors and vessels.

In order to calibrate these devices precisely, it is accepted good practice to control the outlet pressure of the devices in the same range as the application pressure. This article describes how a sensitive dome-loaded back pressure regulator can improve the quality and efficiency of the MFC and MFM calibration process.

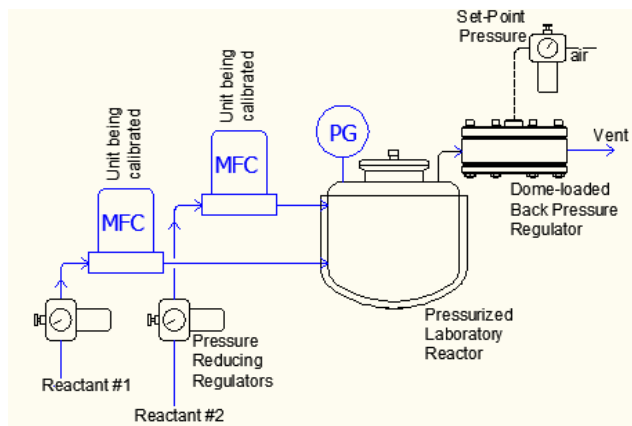

Fig. 2: Mass flow controllers supplying multiple gases into a research reactor. The back pressure regulator is used to control the overall reaction pressure.

Thermal mass flow meters

Thermal mass flow meters (MFM's) are the dominant method of measuring gas flow in laboratory and small scale applications. MFMs sense mass flow by measuring the amount of heat transferred by the gas flow in a thin hot tube in the gas stream. They can use either a constant temperature method (variable power input), or a constant power method (variable temperature).

For all but the smallest MFMs, the flow sensor is situated in a small side stream of the overall stream flow, and a laminar flow divider is typically used to provide reliable scaling from the small side-stream flow sensor to the overall flow meter stream (see Fig. 3). For example, a 100:1 laminar flow divider would divert only 1% of the stream gas flow through the heated sensor, but the resulting flow signal would be multiplied by 100X to project the overall stream mass flow.

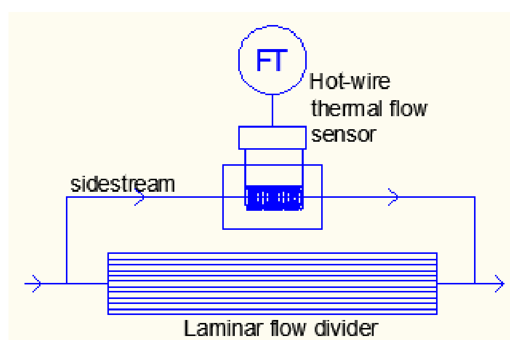

Fig. 3: Schematic showing how a laminar flow divider is used to accurately scale the flow signal from a small side-stream flow sensor

Mass Flow Controllers

Mass flow controllers are similar to MFMs, but also control the gas flow by using a flow control valve downstream of the flow sensor (see Fig. 4). These MFCs are extremely popular in small scale research reactors because they allow the user to simply input the desired mass flow rate through an analog or digital command signal, with the actual mass flow signal returned to the host computer. In an MFC, the flow sensor is exposed to the inlet supply pressure.

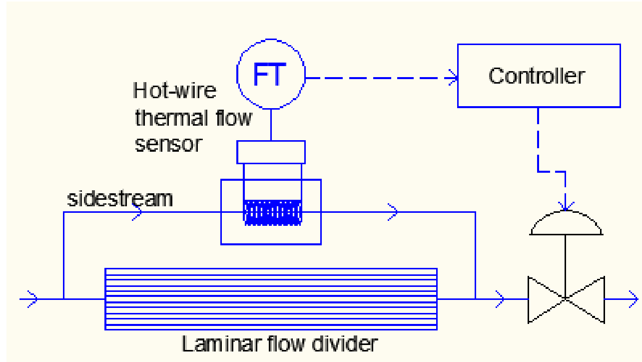

Fig. 4: Thermal Mass Flow Controller schematic - a flow control valve located on the outlet of the flow sensor maintains desired mass flow rate

Variability with Pressure

Although the fundamental principle of thermal MFMs suggests that they can read mass flow regardless of gas pressure and density, in practice there is a small effect of gas pressure on the output of these devices. The ratio of flow signal variation per unit pressure change is expressed as the Pressure Coefficient; a typical Pressure Coefficient is in the range of 0.01%/psid. Though this number appears small, for a high pressure reactor application where the MFM might experience a pressure change from 500 psi to 900 psi, the resulting mass flow reading variation would be 4% (400 psid x 0.01%/psid).

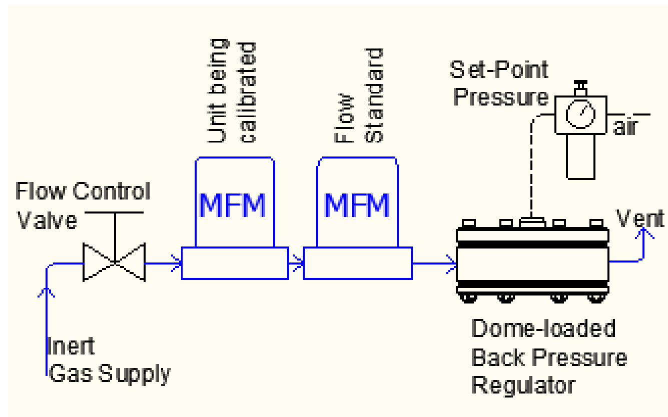

Fig. 5: A back pressure regulator is used downstream of both the MFM being calibrated and its MFM flow standard. A flow control valve controls the flow rate.

Back Pressure Control for MFM calibration

Figures 5 show how a back pressure regulator can be used to aid in the calibration of an MFM. It allows the MFM to be calibrated at the desired pressure to avoid any effects from the Pressure Coefficient.

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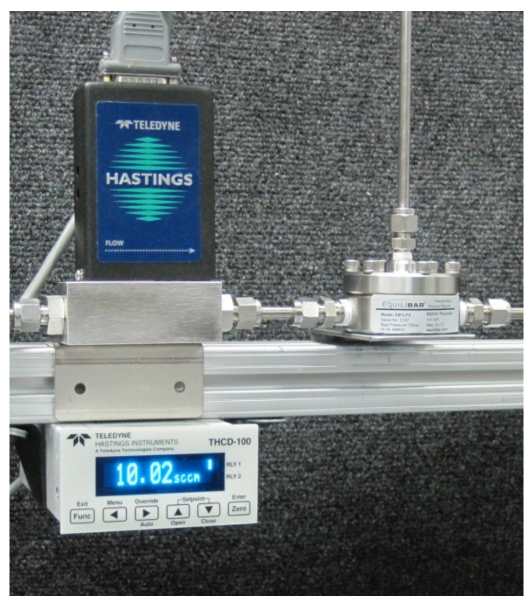

Fig 6: Thermal mass flow controller from Teledyne Hastings with Equilibar precision back pressure regulator downstream

Back Pressure Control for MFC's

For MFC's, a BPR can also be useful in improving the accuracy of calibration and tuning process, though for different reasons. Because the MFC has a control valve built into the downstream of the instrument, the flow sensor itself sees the inlet supply pressure, not the exit pressure. However, the capacity and tuning of the control valve is dependent on having a specified differential pressure across the MFC. Let's take as an example a laboratory process with a Nitrogen supply of 2000 psig, with the MFC discharging into a 1200 psig reactor. The control valve is sized and tuned for a 800 psig differential. While it may be possible to calibrate this instrument with an atmospheric discharge pressure (2000 psig differential), it is preferable to calibrate and verify both the flow sensor and the control valve by emulating the actual process conditions.

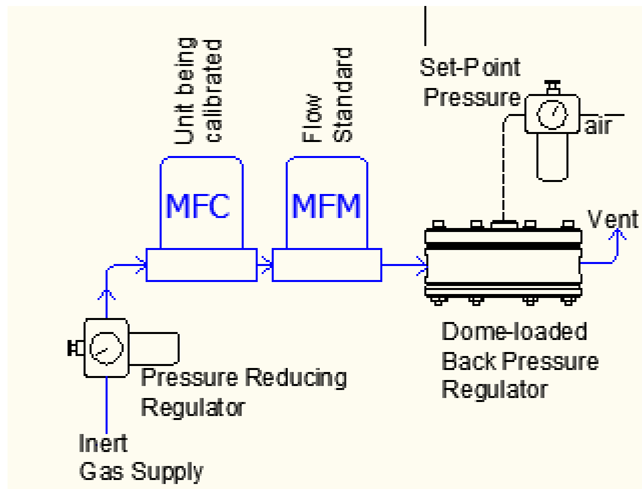

Fig. 7: A back pressure regulator is used downstream of the MFC being calibrated and its MFM flow standard.

As the schematic at right shows, a BPR on the exit of the MFC allows the user to fully replicate the process conditions during the calibration and tuning process.

Back Pressure Regulators with ultra-wide flow range

Although the required pressure control could be accomplished by using traditional back pressure regulators, the wide flow ranges typically encountered on a calibration bench might require switching between several different BPRs to provide precise pressure control. For example, a given MFC might have a flow rate range (max/min) of 100:1. However, a typical laboratory might have two or three ranges of MFCs installed, requiring a calibration technician to control back pressure through ranges from several standard milliliters/minute (std. ml/min) to hundreds of standard liters/minute (slpm).

Fig. 8: The Equilibar dome-loaded back pressure regulator functions differently from traditional designs and maintains precision through a very wide flow rate window

A new type of dome-loaded BPR has been recently introduced by Equilibar that allows for much wider flow rate ranges while also offering extremely tight pressure stability. These qualities are ideal for improving the efficiency and stability of the MFM and MFC calibration process.

Equilibar's patented technology allows for min/max flow ratios of 1000:1 and in some cases up to 10,000:1 while maintaining the inlet pressure within a 1-2% precision window. This is a dramatic improvement over traditional spring-loaded BPR's, which exhibit as much as 30% pressure variation across flow rate ranges as narrow as 10:1.

As shown in the Figure 9, the Equilibar® BPR requires a 1:1 set-point reference pressure to be applied to its dome. This dynamic gas loading helps provide the high pressure stability across the wide flow rate ranges.

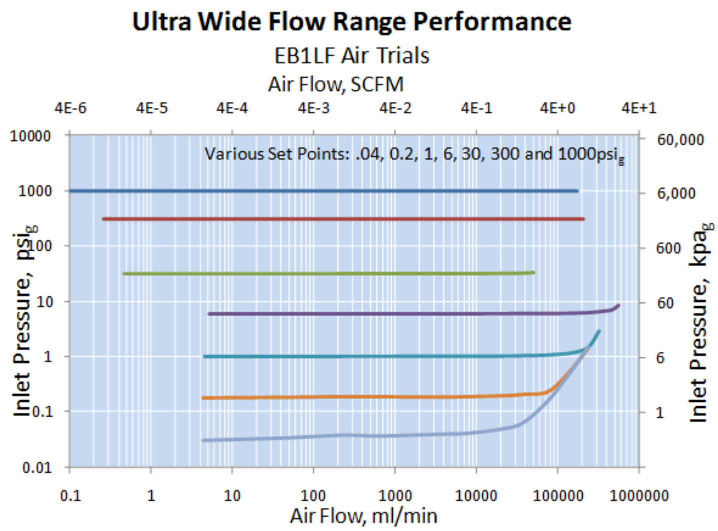

Fig. 9" Chart showing very stable in inlet pressures through approximately six orders of flow rate magnitude using Equilibar® back pressure regulator.

Fuel Cell Developer documents improvements to MFC calibration

A multi-national fuel cell development company reports significant benefits to their MFC calibration program by incorporating the Equilibar® BPR. By installing the BPR downstream of their MFC, they are able to very quickly replicate the exact process conditions of the MFC (both inlet and outlet pressures). Prior to installing the Equilibar, they had tried both needle valves and PID actuated control valves to provide the required back pressure control. The PID control valve process required significant tuning and settling time in order to properly control the back pressure. Very low flow rates were also problematic. Although the needle valve is a reliable method of applying back pressure, it required tedious adjustment for each data point of the calibration process.

After installing an Equilibar GS back pressure regulator, the calibrating technician was able to immediately record the data as soon as the flow standard reading was achieved, with no delay or manual adjustment. This client reported an average time savings of 30% during the overall calibration process, with certain configurations offering time savings up to 70%. The fuel cell

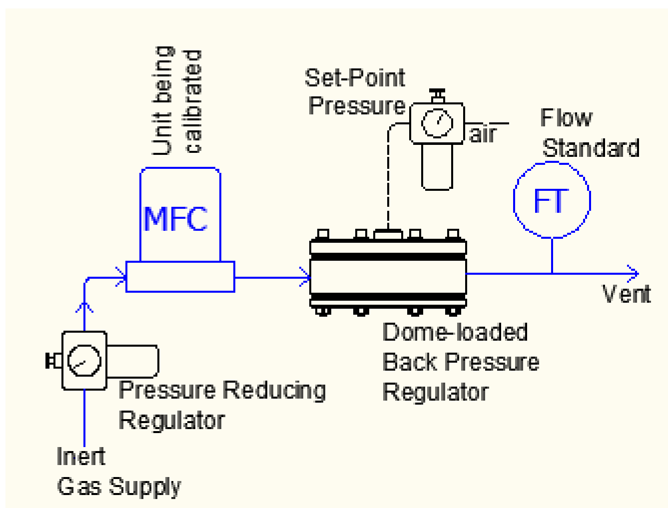

Fig. 10: Schematic showing how a flow standard requiring atmospheric pressure can be installed downstream of the back pressure regulator

developer also observed an improvement in the overall accuracy of the calibration process due to the lack of pressure drifts between different flow settings.

Figure 10 shows how the Equilibar BPR was installed before an atmospheric flow standard in order to simulate reactor pressure conditions on the MFC. Where an MFC calibration standard is available, the fuel cell client also utilized the Equilibar BPR as shown in previous Figure 7 as well.

Conclusion

As we have shown, precision back pressure regulators can be used in several configurations to improve both the function and calibration accuracy of mass flow meters and controllers. Back pressure regulators with ultra wide flow ranges can be used as a flexible tool to save time during the calibration and tuning process.

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