Mass Flow Controllers, Gas Reactant Flow Rate and Correction for Non-Standard State Conditions

Many flow rate controllers used to deliver gas phase reactant to fuel cells are *mass* flow controllers. A mass flow controller is designed to deliver an exact quantity of mass of reactant at a specific rate. This can lead to confusion as to the actual volume of reactant delivered because we usually express the reactant flow in terms of a volumetric rate, such as liter per minute (L/min) or cubic centimeter per minute (ccm). That is, we must always specify the mass (or molar equivalent) flow rate in which case one must use a *standard* volume flow rate.

Recalling the ideal gas law, we note that the *volume* of a fixed mass of gas, m (g), depends on the temperature and pressure of the gas,

$$P \cdot V = n \cdot R \cdot T = \frac{m}{M} \cdot R \cdot T$$

where the number of moles n (moles) can be replaced with the equivalent mass m by normalizing by the molecular weight M (gram/mole) of the gas. Therefore, one has to specify both temperature and pressure in addition to the mass of gas in order to determine the volume the gas will occupy.

The temperature and pressure dependence of a volume of gas means that mass flow controllers must be defined at some standard state condition. The appropriate units are *standard liter per minute* (SLM) or *standard cubic centimeter per minute* (sccm). These units, SLM and sccm, are actually units of mass flow rate, which is consistent with the concept that we are dealing with mass flow control and not volume flow control. A common standard state condition used by industry is 0 °C and 1 atmosphere (= 760 torr). However, different mass flow controller manufacturers have different definitions of standard state conditions for their products (*e.g.*, 1 atm, 25 °C).

As an example, let's consider a mass flow controller with standard state conditions of 0 °C and 1 atmosphere. When we ask for 1000 ccm of reactant from a mass flow controller we are really requesting 1000 *sccm*. If the gas were at 0 °C and 1 atmosphere, then the volume rate of gas delivered would in fact be 1000 ccm. However, if the gas were at 25 °C and at 1 atmosphere, the volume of gas delivered would be,

$$= 1000\ sccm_{0\ ^oC, 1\ atm} \cdot \left(\frac{273.15 + 25\ ^oK}{273.15\ ^oK} \right) = 1092\ ccm_{25\ ^oC, 1\ atm}$$

This amounts to a 9 % difference in volume flow rate in gas at these two temperatures. Note, however, the molar and mass flow rates are exactly the same. The difference in volume flow rate lies in the fact that the gas expands at higher temperature.

150 East Connecticut Ave, Southern Pines, North Carolina, USA 28387
Phone: +1-910-695-8884 · Fax: +1-910-695-8886 · www.scribner.com · Email: info@scribner.com

By knowing the standard state conditions of the mass flow controller, fuel cell users can account for the difference in temperature and pressure of the gas the mass flow controller is exposed to relative its standard state conditions, allowing precise accounting and control of reactant stoichiometry and utilization.

150 East Connecticut Ave, Southern Pines, North Carolina, USA 28387
Phone: +1-910-695-8884 · Fax: +1-910-695-8886 · www.scribner.com · Email: info@scribner.com