TELEDYNE INSTRUMENTS
Hastings Instruments
A Teledyne Technologies Company

APPLICATION NOTE

HASTINGS

Gas Blending for Stoichiometry-Part A

How to control the proper ratio of gas flows to achieve proper chemical balance

Don't be intimidated by the fancy Greek name. Stoichiometry just means getting the proper amount of each chemical into a reaction. At a microscopic level it's balancing a chemistry equation; like to make water (H_2O) you need to start with two hydrogen atoms for every oxygen atom. Since hydrogen and oxygen are both gases with diatomic molecules (H_2 and O_2), the molecular equation is also "two parts hydrogen to one part oxygen". But if you have 20 trillion hydrogen and only 9.6 trillion oxygen molecules in a reaction, you'll end up with a bit of water (0.00058 micrograms actually) and some hydrogen gas left over due to the imbalance in stoichiometry. At the macroscopic level, the idea scales-up accordingly with the use of a molar equation instead of a molecular equation. In a lab where granular or liquid chemicals are mixed, the weight or volume is measured to ensure proper stoichiometry. When processing with a continuous reaction, the flow of chemicals is controlled in set ratios to ensure proper stoichiometry. Since gases are difficult to weigh and their volume changes dramatically with temperature and pressure, a flow instrument called a mass flow controller (MFC) is often used. As opposed to volumetric flow devices like rotameters and critical orifices, thermal mass flow controllers are relatively unaffected by changes in pressure and temperature and therefore reliably provide the desired stoichiometric blend.

Objectives

- ✓ Determine precise flow rates for desired chemical mix ratios.
- ✓ Select instrumentation to effectively deliver gas flow ratios.

Method for Determining Flow Rates

Proper stoichiometric blending begins with determining the flow rates for each gas. What's fortunate is that MFCs are calibrated with a system of units, standard liters per minute (slm) or standard cubic centimeters per minute (sccm), which lets us avoid conversions and complex calculations. Unlike weight or volume units, these slm and sccm are directly related to the molar measure—independent of the gas type. How is this possible? This system of units uses the fact that a mole of ideal gas occupies 22.4 standard liters. So really the slm and sccm units *are* molar flow rates (just expressed in a more visually intuitive volumetric flow disguise). For further convenience in these applications, the MFCs can be calibrated directly in molar flow units. In either case, there is no need to account for the density or molar weight of any particular gas.

Example 1: Calculation using gas ratios

In an oxygen/acetylene torch the molar ratio for complete combustion in the primary flame is 1:1. However, depending on whether the operation requires a reducing, neutral, or oxidizing flame, this ratio can be modified. In this case, a controlled *imbalance* in the stoichiometry is desired. A secondary flame burns the resulting carbon monoxide and hydrogen with additional oxygen to produce carbon dioxide and water vapor. These processes are shown below.

Primary Flame $2C_2H_2 + 2O_2 \rightarrow 4CO + 2H_2$ Secondary Flame $4CO + 2H_2 + 3O_2 \rightarrow 4CO_2 + 2H_2O$

So overall, the blend ratio is typically more oxygen than acetylene. Let's say for a particular application the ratio of oxygen to acetylene is 1.2:1 and the total flow is 20 slm. What should each flow be? We could guess that since 12 and 10 slm are the right ratio, but too much total flow, something a little less for both must be right. To get an exact answer we can use a little math. With the ratio $R = Q_2/Q_1$ (note the order) and the total flow Q_{total}, the two gas flows Q_1 and Q_2 can be calculated by:

$$Q_1 = \frac{Q_{total}}{R+1} \qquad Q_2 = Q_{total} - Q_1$$

Which means for our example where $R = 1/1.2 = 0.833$ and $Q_{total} = 20$ slm, the proper flows are $Q_1 = 10.91$ slm for the oxygen and $Q_2 = 9.09$ slm for the acetylene.

Example 2: Calculation in % of total flow

A vacuum brazing furnace operates with a 96% nitrogen 4% hydrogen environment and a total flow of 6 slm. The flows can be determined as in Example 1, but with $R = 4/96 = 1/24$ and $Q_{total} = 6$ slm, the nitrogen flow is 5.76 slm and the hydrogen flow is the remaining 0.24 slm (240 sccm).

Example 3: Calculation in parts per million (ppm)

An air pollution calibration sample is to have 150 ppm (parts per million) SO_2 in a dry air as it's delivered at 50 slm to a test chamber. To determine the flow of the SO_2 we must first recognize that this is stated differently from the other examples. In this case the SO_2 ratio corresponds to the total, not to the other component gas. Here we can simply multiply the ratio 150/1000000 by the total flow to get 0.0075 slm or 7.5 sccm of SO_2. The dry air component is therefore 49,992.5 slm, which for practical reasons, is indistinguishable from 50 slm.

Method for Instrumentation

MFC Selection and the Role of Gas Conversion Factors

The selection of the proper MFCs for gas blending applications focuses on gas type, flow range, and to a lesser extent material compatibility. The full scale (FS) range of an MFC and the gas type are specified at the time of ordering. Normally, Hastings MFCs are delivered already calibrated for the specified gas type and FS range, making subsequent set up simple. However, for a more flexible inventory or in situations where the gas type may change, the base FS range can instead be set in nitrogen-equivalent flow. In this case, other gases' FS ranges are determined by using a gas conversion factor or GCF (a list of GCFs is in MFC manuals). Taking Example 1 above, the selection of an appropriate MFC involves first multiplying the nitrogen full scale by the conversion factors which are 1.00 for oxygen and 0.6255 for acetylene. So for oxygen the range is conveniently the same as the nitrogen-equivalent. Therefore a 20 slm nitrogen FS MFC would be suitable, nominally operating in the upper half of its FS range and giving some ability to adjust the flow up or down from the 10.91 slm set point. When used with acetylene, a 20 slm nitrogen FS MFC would actually flow 12.51 slm FS. This would be a suitable range to deliver the 9.09 slm set point and allow for future adjustment. In situations such as this, where an MFC is used with a gas which is different from its nameplate gas, conversion factors can be accounted for in the set point generating electronics.

For this application the Hastings HFC 202 is the recommended product unless higher flows or lower available pressure restrictions are required, in which case the HFC 203 or HFC 303 become better choices.

Electronics for Ratio Control

When blending two or more gases, a "master/slave" approach is implemented to control the total flow while ensuring a constant mix ratio. This can be accomplished most conveniently by using the power supply/readout functionality built into the Hastings PowerPod 400. When ordered with the MFCs, the PowerPod is pre-configured by the factory with the settings for the full scale and gas conversion factors for each MFC. Once programmed with a ratio factor for the slave channel(s), the PowerPod delivers a user controlled set point to the master MFC and a ratio set point to each slave MFC. In this way, the total flow and the mix ratio can each be set, tuned, and controlled independently.

In addition to the master/slave functionality, the PowerPod has flow totalizer capability on each channel and can communicate via RS-232 or RS-485 to provide additional functions.

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