Tip of the Week

July 18, 2005

Measuring Gas Velocity Pressure under Weird Conditions

The following Tip comes courtesy of Doug Rhoades.

Measuring flow rates at various types of processing plants can present some interesting problems. We'll talk about a few of these here. In order to understand these problems, though, we need to review a few basics about velocity measurements.

The Bernoulli Equation

We typically measure velocity with a pitot tube. This measurement is defined by a familiar form of Bernoulli's equation:

$$V_s = 85.49(C_p)\sqrt{\overline{\Delta P}}\sqrt{\frac{(T_s + 460)}{M_s P_s}}$$

Our primary direct measurement is the pitot differential pressure, or ΔP. Rearranging Bernoulli's equation shows us how ΔP relates to the other parameters we measure:

$$\overline{\Delta P} = \left(\frac{V_s}{85.49(C_p)}\right)^2 \frac{M_s P_s}{(T_s + 460)}$$

There are three parameters here that can change (even *during* a test run) in the equation that will have an influence on what we measure for ΔP:

- temperature (T_s)
- pressure (P_s)
- molecular weight (M_s)

Figure 1 shows the relationship between gas temperature and expected velocity pressure. ΔP is charted relative to the velocity pressure expected at 68°F, with all other variables held constant. The figure shows that P is an inverse function of temperature (for a given velocity).

Figure 2 shows the direct linear relationship between expected ΔP and duct pressure. The velocity pressure has been normalized to where a value of 1.0 is shown at a pressure of 29.921 in. Hg (one standard atmosphere).

P is also linearly related to the gas molecular weight. This is shown in Figure 3. The data are normalized to a standard molecular weight of 28.84 lb/lb-mole (ambient air). If the gas molecular weight changes drastically from this value, the measured P will be affected proportionally.

SCR Ducts

SCR ducts are large, and the gas they transport is hot. These factors combine to make velocity measurements at these locations a challenge.

Most ductwork is designed for an average gas velocity of around 60 ft/s under normal operating conditions. For normal flue gases, the gas density is anywhere between 0.04 and 0.08 lb/ft^3. Under these normal gas densities, the measurements can be straightforward. However, when the gas density varies from this accustomed range, difficulties can occur.

Before the inlet of an SCR (i.e., economizer outlet conditions) the gas temperature can be as high as 750°F. The gas density at this temperature will be around 0.03 lb/ft^3. This, combined with the large dimensions of the duct, means that the gas velocity will fall to around 10 ft/s. This results in a   P of around 0.05 in.W.C close to the SCR (compared to around 0.5 in. W.C. at an ESP exit).

High Pressure Processes

Many chemical and refinery processes operate at high pressures. Catalytic cracking units are an example where the duct pressure is as high as 36 psig (103 in. Hg absolute pressure). From Figure 2, you would expect fairly high   P readings for a given flow rate (almost 3.4 times as high as at STP).

Hydrogen Streams

The molecular weight of hydrogen is only 2.0 lb/lb-mole. We're used to working with gases that are about 10 times as dense as hydrogen (air and nitrogen). If a process gas is hydrogen, you can expect very low   Ps for a given velocity. Digital recording devices are strongly recommended when low velocity pressures are expected.

Dynamic Processes

For many chemical processes, gas conditions may go through extreme variations over a relatively short time frame. A typical example involves a process reactor running without any flow until a valve is switched and the duct pressure goes from zero (gauge) to 6 psi for about five minutes as the reactor is purged with nitrogen. The duct pressure may then drop to near zero gauge for the next hour as the liquid product is introduced to the reactor. This occurs while purging the headspace with nitrogen.

During this time, the temperature will probably change as liquid (heat sink) is added to the reactor. The pressure is also dynamically changing during the first five minutes as the valve is switched.

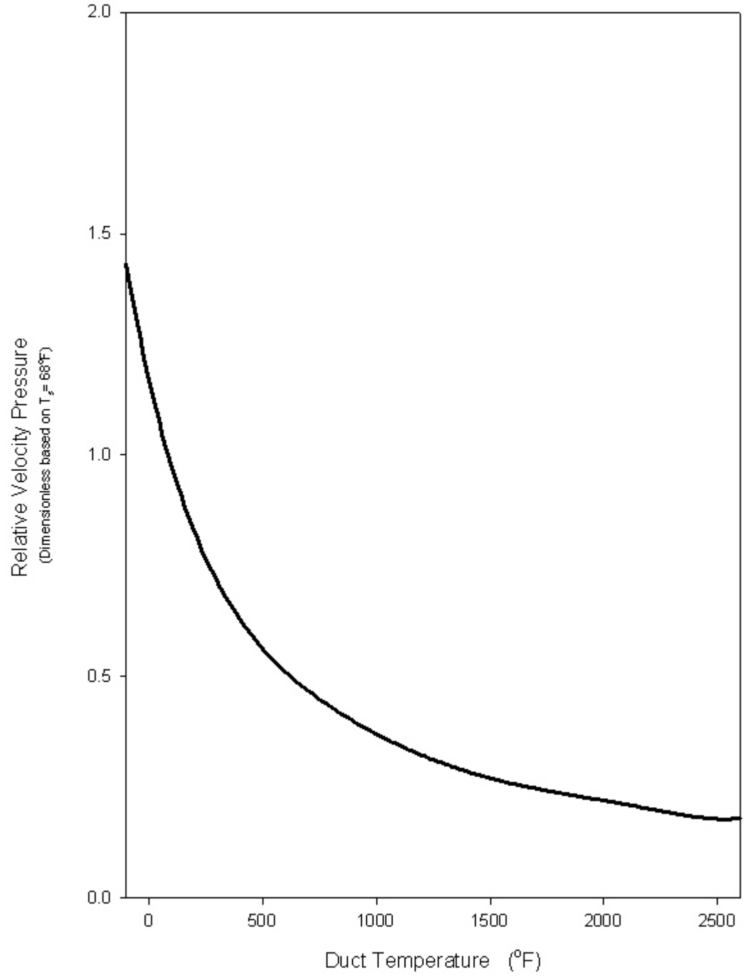

Figure 1: Relative Expected Velocity Pressure as a Function of Temperature.

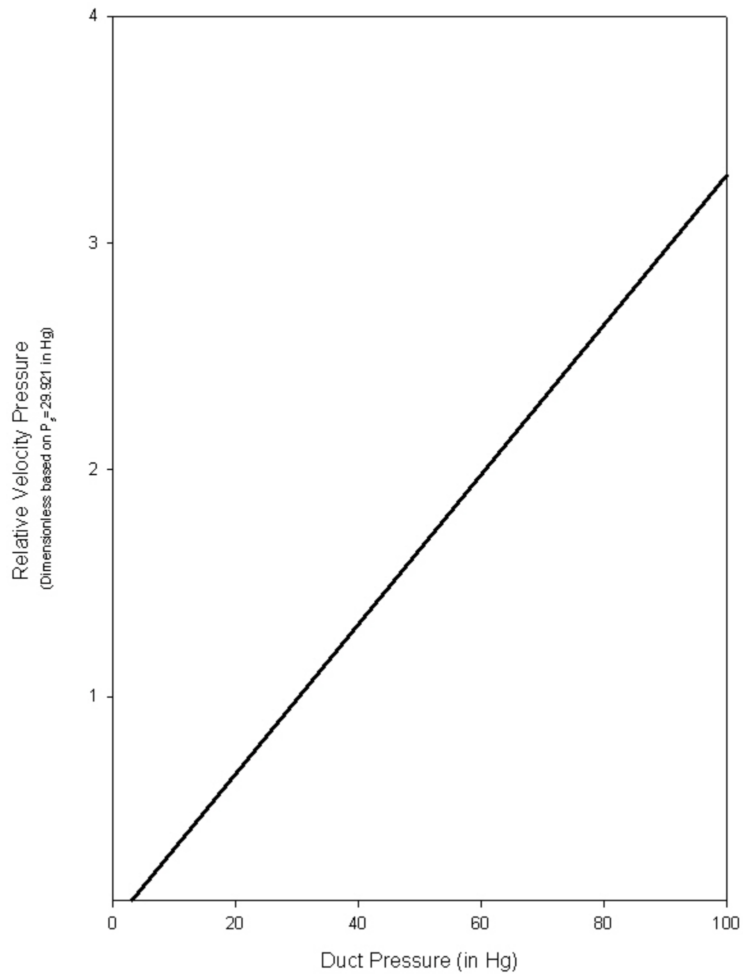

Figure 2: Relative Expected Velocity Pressure as a Function of Duct Pressure.

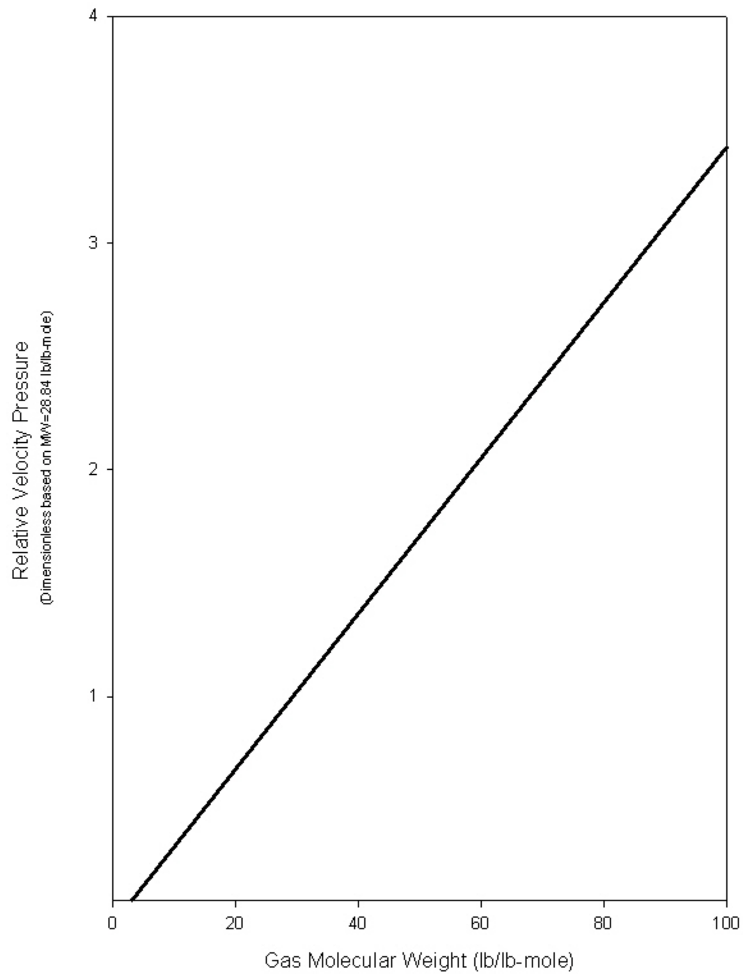

Figure 3: Relative Expected Velocity Pressure as a Function of Gas Molecular Weight.