Calculation of correction factors for variable area flow meters at deviating working conditions

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0 Foreword

The calibration of variable area flow meters for gases gets wrong when there is a change of

- standard density of the medium and/or
- working pressure and/or
- working temperature

The indicated volume flow rate needs to be corrected by a multiplication factor. The determination of these correction factors is the subject of the following document.

1 Theoretical fundamentals

For gases of low density as compared to the density of the float, the following applies:

$$q_{\mathrm{M}} \sim \sqrt{D}$$

where: q_M is the mass in kg/h flowing through the variable area flow meter per unit of time, and D is the density of the gas at working conditions. For two different gas densities D_1 and D_2 with mass flows q_{M1} and q_{M2}, it follows that:

$$q_{M2} = \sqrt{\frac{D_2}{D_1}} \cdot q_{M1} = K_{\mathrm{M}} \cdot q_{M1}$$

This means: when the mass flow rate q_{M1}, corresponding to a certain vertical position of the float with calibration density D_1 is known, the mass flow rate of a medium of different density D_2 can be calculated by multiplying it by the factor $K_{\mathrm{M}} = \sqrt{D_2/D_1}$.

The unit m³/h at standard conditions (t=0℃ and p=1.013 bar abs), abbreviated to: m³/h at STP, is also commonly used but is not universally applicable. It depends on the standard density of the gas in question. When gases of different density are used, this will affect calculation of the correction factor.

The following relation can be derived from equation $q_V = q_M / D$ for the volume rate of flow q_V :

$$q_V \sim \frac{1}{\sqrt{D}}$$

where: q_v is the volume rate of flow in m³/h flowing through the variable area flow meter, and D the density of the gas at working conditions. We will not abbreviate "at working conditions". In case the abbreviation "at STP" is not mentioned we always refer to the working conditions. Between volume rates of flow q_{v1} and q_{v2}, which correspond to a certain vertical position of the float at different working conditions, the interrelationship is then as follows:

$$q_{v2} = \sqrt{\frac{D_1}{D_2}} \cdot q_{v1} = K_v \cdot q_{v1}$$

2 Conversion when using one gas[1]

The density of the medium at working conditions is frequently not known directly. It is linked to the variables pressure and temperature by way of the ideal gas equation. For a sufficiently rarefied gas the following applies:

$$D \sim \frac{p}{T}$$

The following conversion factors can be derived for mass rate of flow (measured in kg/h or m³/h at STP) and volume rate of flow (in m³/h) when using one and the same gas and a constant temperature:

$$K_M^p = \sqrt{\frac{p_2}{p_1}} \quad \text{and} \quad K_V^p = \sqrt{\frac{p_1}{p_2}}$$

These conversion factors provide information on the effect of the working pressure. At constant pressure, we obtain the following equations describing the effect of the working temperature:

$$K_M^T = \sqrt{\frac{T_1}{T_2}} \quad \text{and} \quad K_V^T = \sqrt{\frac{T_2}{T_1}}$$

[1] The physical composition is constant, while pressure and temperature vary.

The effects of pressure and temperature are independent of each other and are calculated by multiplication of the appropriate factors.

Note: Users frequently ask the following question: What is the volume taken up by the standard cubic meters of the gas at standard conditions while retaining its total mass? The corresponding conversion factor is derived from the ratio of density at working conditions to density at standard conditions. Based on the ideal gas equation, we obtain:

$$V_N = \frac{p_B}{p_N} \cdot \frac{T_N}{T_B} \cdot V_B$$

where: p_B and p_n , and T_B and T_N signify, respectively, pressure and temperature at working and at standard conditions. This is an application of the ideal gas law and should not be confused with the conversion of scales on calibrated glass cones by means of the above square root terms!

3 Conversion where different gases are used

The flow rate of a gas shall be reduced to the known data of another gas. The following applies: the density ratio of two gases remains constant while pressure and temperature change. If the ratio of the densities of two gases D_1 and D_2 at defined values for pressure and temperature (e.g. at standard conditions) is known, it is possible to calculate the density of gas 2 at working conditions from the density of gas 1 at the same conditions by multiplying by the factor $\sqrt{D_2/D_1}$. From this we obtain the conversion factor for the mass rate of flow measured in kg/h

$$K_M = \sqrt{\frac{D_2}{D_1}} \quad \text{(measured in } kg\, h^{-1}\text{)}$$

In the unit m^3/h at STP, due to the dependence of the gas unit, the conversion factor has the reciprocal value

$$K_V = \sqrt{\frac{D_1}{D_2}} \quad \text{(measured in } m^3\, h^{-1} \text{ at STP)}$$

where: D_1 and D_2 are the densities of gases 1 and 2 with the same parameters for pressure and temperature for both gases (e.g. at STP).

To convert the volume rate of flow (e.g. in m^3/h), the following formula applies:

$$K_V = \sqrt{\frac{D_1}{D_2}} \quad \text{(measured in m}^3\text{/h)}$$

The conversion factors with reference to pressure and temperature are the same as those given in 2. To determine the flow rate, all three factors (calibration density, pressure and temperature) always need to be considered.

4 Examples

4.1 Conversion of the mass rate of flow

A variable area flow meter that had been calibrated for air at a pressure of 1 bar and a temperature of 20℃ (= 293 K) is now being operated at a pressure of 4 bar and an working temperature of 30℃ (= 303 K). At the float reading line the relevant indicated mass rate of flow is 10 $m^3 h^{-1}$ at STP (cubic meters per hour at standard conditions). The actual flow rate then works out at

$$q_M^{new} = \sqrt{\frac{p_2}{p_1}} \cdot \sqrt{\frac{T_1}{T_2}} \cdot q_M^{old}$$

$$= \sqrt{\frac{4\,\text{bar}}{1\,\text{bar}}} \cdot \sqrt{\frac{293\,\text{K}}{303\,\text{K}}} \cdot 10 \ \text{m}^3\text{/h at STP}$$

$$= 2 \cdot 0.983 \cdot 10 \ \text{m}^3\text{/h at STP}$$

$$= 19.66 \ \text{m}^3\text{/h at STP}$$

At the now changed working conditions (q_M^{new}) described above, and at an indicated flow value based on the old working conditions (q_M^{old}) of 10 m³/h at STP , the flow rate is now 19.66 m³/h at STP. Or to put it another way: if you want to know the mass rate of flow in m³/h at STP which you have to set for one scale mark at 10 m³/h at STP because of the changed flowing conditions described above, the answer will read 10 m³/h at STP divided by 1.966 = 5.086 m³/h at STP.

4.2 Conversion of the volume rate of flow

A variable area flow meter that had been calibrated for air at a pressure of 1 bar and a temperature of 20℃ (= 293 K) is now operated at a pressure of 4 bar and an operating temperature of 30℃ (= 303 K). At a certain vertical position of the float, the relevant indicated volume flow rate is 10 m³/h at working conditions. The flow rate at working conditions then works out at

$$q_V^{new} = \sqrt{\frac{p_1}{p_2}} \cdot \sqrt{\frac{T_2}{T_1}} \cdot q_V^{old}$$

$$= \sqrt{\frac{1\,\text{bar}}{4\,\text{bar}}} \cdot \sqrt{\frac{303\,\text{K}}{293\,\text{K}}} \cdot 10 \ \text{m}^3\text{/h}$$

$$= 0.5 \cdot 1.017 \cdot 10 \ \text{m}^3/\text{h}$$

$$= 5.085 \ \text{m}^3/\text{h}$$

At the now changed working conditions (q_M^{new}) described above, and at an indicated flow value based on the old working conditions (q_M^{old}) of 10 m³/h, the actual flow rate is now 5.085 m³/h. Or to put it another way: if you want to know the volume rate of flow in m³/h which you have to set for one scale mark at 10 m³/h at field conditions, the answer will read 10 m³/h divided by 0.5086 = 19.66 m³/h.

4.3 Calculation of the mass rate of flow for different gases

A variable area flow meter that had been calibrated for air at a pressure of 1 bar and a temperature of 20°C (= 293 K) is now operated at a working pressure of 4 bar and a working temperature of 30°C (= 303 K) using a different medium with a calibration density of 0.25 (referred to air with a calibration density 1.0). At a certain vertical position of the float, the relevant indicated mass rate of flow amounts to .... m³/h at STP. The actual flow rate then works out at

$$q_M^{new} = \sqrt{\frac{D_1}{D_2}} \cdot \sqrt{\frac{p_2}{p_1}} \cdot \sqrt{\frac{T_1}{T_2}} \cdot q_M^{old}$$

$$= \sqrt{\frac{1.0}{0.25}} \cdot \sqrt{\frac{4\,\text{bar}}{1\,\text{bar}}} \cdot \sqrt{\frac{293\,\text{K}}{303\,\text{K}}} \cdot 10 \ m^3 h^{-1} \ \text{at STP}$$

$$= 2 \cdot 2 \cdot 0.983 \cdot 10 \ m^3 h^{-1} \ \text{at STP}$$

$$= 39.32 \ m^3 h^{-1} \ \text{at STP}$$

4.4 Conversion of the volume rate of flow for different gases

A variable area flow meter that had been calibrated for air at a pressure of 1 bar and a temperature of 20°C (= 293 K) is now operated at a working pressure of 4 bar and a working temperature of 30°C (= 303 K) using a different medium with a calibration density of 0.25 (referred to air with a calibration density 1.0). At a certain vertical position of the float, the relevant indicated volume rate of flow amounts to 10 m³/h (cubic meters per hour at working conditions). The actual flow rate then works out at

$$q_V^{new} = \sqrt{\frac{D_1}{D_2}} \cdot \sqrt{\frac{p_1}{p_2}} \cdot \sqrt{\frac{T_2}{T_1}} \cdot q_V^{old}$$

$$= \sqrt{\frac{1.0}{0.25}} \cdot \sqrt{\frac{1\,\text{bar}}{4\,\text{bar}}} \cdot \sqrt{\frac{303\,\text{K}}{293\,\text{K}}} \cdot 10 \ \text{m}^3/\text{h}$$

$$= 2 \cdot 0.5 \cdot 1.017 \cdot 10 \ \text{m}^3/\text{h}$$

$$= 10.17 \ \text{m}^3/\text{h}$$

Literature: [1] VDE/VDI Codes VDE/VDI 3513, *Schwebekörper-Durchflussmesser: Berechnungsverfahren*, VDI-Verlag GmbH, Düsseldorf (1971)