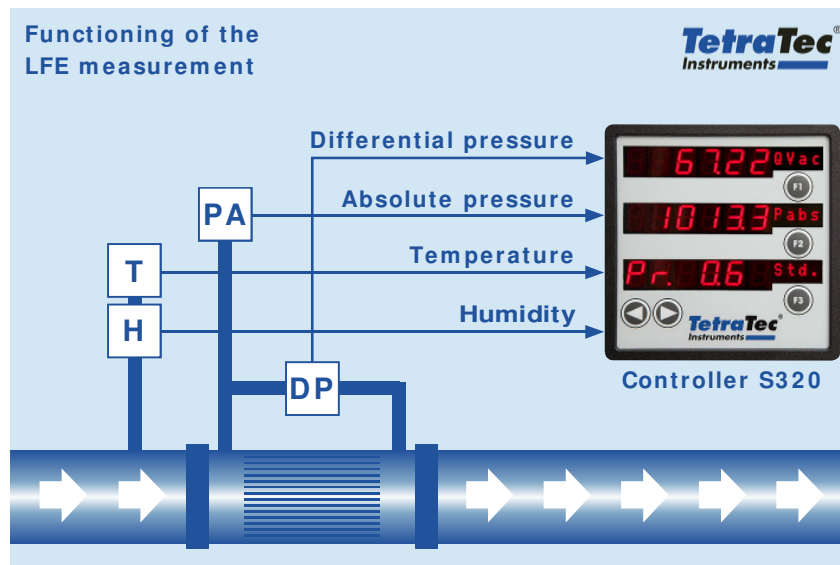


Gas Flow Measurement with Laminar Flow Elements (LFE)

1.) Measurement principle

Laminar Flow Elements are measurement instruments for the actual volume flow and are working according to the Hagen-Poiseuille law. Flowing through them with air or other gases is creating because of the viscous friction of the gas a permanent pressure drop or loss across the LFE matrix which is about linear to the average velocity of the gas in the matrix of the LFE. LFE consist normally of capillary bundles or a spirally wound matrix of fine stainless steel sheet material consisting of a flat and a triangle shaped sheet. The two differential pressure taps are at the inlet and at the outlet of the matrix.



According to the Hagen-Poiseuille law the actual volume flow through straight pipes at laminar flow conditions with liquids and gases creates a linear proportional pressure drop Δp dependent to the viscosity η of the flowing media.

$$Q_{vac} \sim \Delta p / \eta \tag{1}$$

Or differently said: to create a actual volume flow Q_{vac} through the LFE it is necessary to apply a certain driving force by a differential pressure Δp between inlet and outlet. The bigger the flow should be and the bigger the viscosity is the bigger force must be applied.

$$\Delta p \sim Q_{vac} \cdot \eta \tag{2}$$

2.) Calibration

The calibration of a Laminar Flow Element determine the relation factor of equation (1) between the actual volume flow Q_{vac} and the differential pressure Δp at the LFE. This constant includes manufacturing tolerances and LFE-specific data like diameter, length, number of capillaries. On the other side is the relation $Q_{vac} = c_{kal} \cdot \Delta p$ only valid for a specific value of the viscosity of the flowing media which is basically dependent on the gas type and gas temperature.

LFE Calibration data therefore are always related to a specific calibration gas and conditions. Using the LFE at the same conditions than at the calibration conditions the actual volume flow can be calculated directly from the differential pressure on the LFE.

$$Q_{vac} = c_{kal} \cdot \Delta p \tag{3}$$

Using the LFE at other conditions than at the calibration conditions the actual volume flow can be calculated from the product of differential pressure and the relation factor of calibration and actual viscosity.

$$Q_{vac} = c_{kal} \cdot \Delta p \cdot \eta_{kal} / \eta \quad (4)$$

In the most cases LFE will be used with air as flowing media. The Viscosity of air is up to 6 bar independent of the pressure and basically dependent on the temperature:

$$\eta_{Luft}(T) = 14,58 \cdot \frac{T^{3/2}}{(110,4 + T)} \quad (5)$$

There means: η Viscosity in [μ Poi]
 T Temperature in [$^{\circ}$ K]; $T = 273,15 + t$
 t Temperature in [$^{\circ}$ C]

Example: A LFE is calibrated with air at a temperature of $t_{kal} = 21,1^{\circ}$ C.

At calibration a volume flow of 22,36 l/min and a differential pressure of 10 mbar is measured at the LFE ($c_{kal} = 2,236$ l/(min·mbar)). Now the LFE is used at an air temperature of 25° C.

At a pressure drop of 10mbar the volume flow will change now against the calibration to:

$$\begin{aligned} Q_{vac} &= 2,236 \text{ l/(min·mbar)} \cdot 10\text{mbar} \cdot \eta(294,25^{\circ}\text{K}) / \eta(298,15^{\circ}\text{K}) \\ &= 22,36 \text{ l/min} \cdot 181,86\mu\text{Poi} / 183,72\mu\text{Poi} = 22,13 \text{ l/min} \end{aligned}$$

If one would not consider the temperature change ΔT against the calibration temperature the following deviations in flow would appear in a range of about 10 and 30° C:

Δt [$^{\circ}$ C]	1	5	10
ΔQ [%v.M.]	0,26	1,3	2,6

3.) LFE Evaluation

Equation (3) and (4) are a simplification of the real correlations and assume a totally linear relation. In reality one observes at LFE in general a slight deviation of the linear relation (1) between Q_{vac} and Δp in the size of up to 2%. To achieve a better measurement accuracy it is recommended to use a polynomial development of the second and even higher order to describe the calibration data precisely:

$$Q_{kal} = B \cdot \Delta p + C \cdot \Delta p^2 \quad (6)$$

or
$$Q_{vac} = (B \cdot \Delta p + C \cdot \Delta p^2) \cdot \eta_{kal} / \eta_{ac} \quad (7)$$

The deviation of the calibrated and the polynomial value reduces so normally on less than 0,2%.

4.) LFE Flow Conversion

To convert the actual volume flow of the LFE into mass or standard volume flow **the continuity law (conservation of the mass) and density calculation of the gas law** of thermodynamics is applied:

$$Q_m = \rho_{ac} \cdot Q_{vac} = \rho_{no} \cdot Q_{vno} = \rho \cdot Q \quad (8) \text{ with density } \rho = \frac{m}{V} = \frac{P \cdot M}{Z \cdot R \cdot T} = \frac{P}{Z \cdot R_s \cdot T} \quad (9)$$

All quantities in SI units [m, kg, s, Pa, K]; air: $R_s=287,0651$ J/(kg·K); $Z(\text{ideal}) = 1$

5.) Validity Range

The above description is valid for a temperature range of 0 – 70° C. To correct humidity influences and higher temperatures the viscosity calculation of Kestin-Whitelaw should be used. The viscosity is independent of the pressure up to 6 bar. Caused by compression effects and acceleration into the entrance into the capillary pressure dependencies will appear which can shift the characteristics against the calibration of about 1%/bar. This can be avoided by a calibration at the planned operation pressure or / and corrected by using the better Reynolds number based evaluation called „universal flow“ procedure.