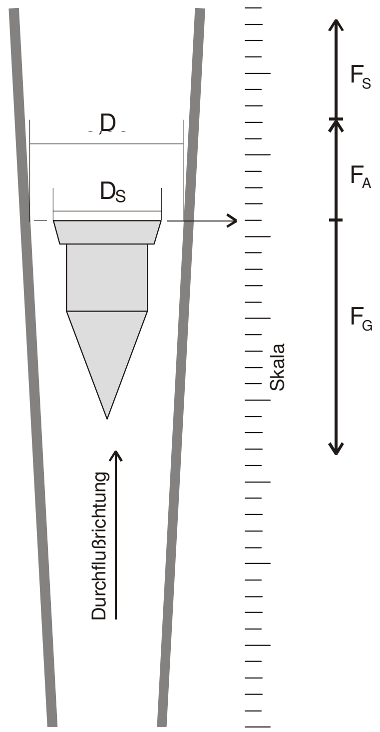
The physics of variable area flow meters



The flow rate of gases and liquids can be easily and relatively accurately determined using variable area flow meters. A tapered ce, is fitted vertically with flow from bottom to top. The upward flowing medium causes the float to rise until the annular gap between float and tube wall is so large that the forces acting on the float are balanced and the float has attained its floating state.

Three forces act on the float (Fig. 1). The force due to weight F_G is directed downwards:

$$F_G = V_S \cdot \rho_S \cdot g \qquad (1)$$

Two forces act upwards:
buoyancy F_A:

$$F_A = V_S \cdot \rho_m \cdot g \qquad (2)$$

and drag F_S:

$$F_S = c_w \cdot A_S \cdot \frac{\rho_m \cdot v^2}{2} \qquad (3)$$

The following applies to the state of equilibrium, or floating state:

$$F_G = F_A + F_S \qquad (4)$$

The flow rate is:

$$q_v = v \cdot A = v \cdot \frac{\pi}{4} \cdot (D_k^2 - D_s^2) \qquad (5)$$

Drag coefficient c_w is transferred into the flow coefficient.

$$\alpha = \sqrt{\frac{1}{c_w}} \qquad (6)$$

The flow coefficient α is dependent on the geometric shape of the measuring tube and float, and also includes the friction factor. As an empirical value, α appears in device-related characteristics that are included in the calculation. These characteristics also include the Ruppel factor, which allows inclusion of the product-related parameters viscosity and density.

Considering the above equations, it is possible to form the general flow equation for variable area flow meters.

Volume rate of flow:

$$q_v = \frac{\alpha}{\rho_m} D_S \sqrt{g \cdot m_S \cdot \rho_m (1 - \frac{\rho_m}{\rho_S})} \tag{7}$$

Mass rate of flow:

$$q_m = \alpha \cdot D_S \sqrt{g \cdot m_S \cdot \rho_m (1 - \frac{\rho_m}{\rho_S})} \tag{8}$$

Due to the taper of the measuring tube, the size of the annular gap will change according to the vertical position of the float. Thus, the float position supplies information on the flow rate. When a glass measuring tube is used, therefore, the measured value can be read direct from the scale attached to the measuring tube.

Compared to the differential-pressure method, e.g. at orifice plates or in the venturi tube, there is a physical analogy: The method of calculation is similar. The significant difference can be described as follows: In the differential-pressure method of measurement the cross-sectional flow area remains constant and the differential pressure changes with the flow rate, whereas in the float principle the cross-sectional area changes and the pressure difference remains the same.

V_S: Volume of float
A: Annular gap area
A_S: Cross-sectional area of float at the reading line
m_S: Mass of float
ρ_S: Density of float
ρ_m: Density of liquid product
c_W: Drag coefficient
v: Flow velocity of liquid product
D_K: Inside diameter of cone at reading line
D_S: Diameter of float at reading line