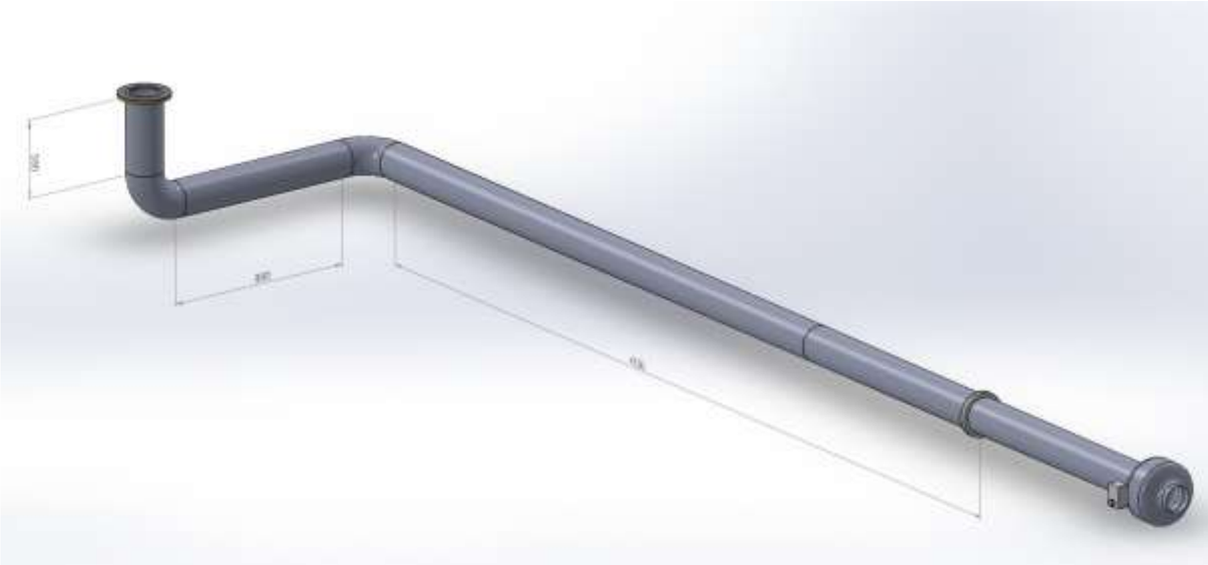

H05

SENSITIVITY OF DIFFERENT FLOW-RATE MEASURING METHODS IN A PIPELINE

1. Aims of the measurement

The aim of the measurement is to investigate the sensitivity of different flow-rate measuring methods. The two main groups of flow-rate measuring methods are: one based on velocity measurement and one based on pressure differential. The accuracy of both methods is heavily influenced by installation and surroundings. During the measurement the effect of different installation failures and other disturbances are investigated.

2. Description of the measurement facility

The measuring facility is a 160mm diameter pipeline system with modular elements, which allows multiple test configurations. The available pipeline elements are:

2 pcs of straight pipe segment with 3m length
1 pcs of straight pipe segment with 800mm length
2 pcs of straight pipe segment with 200mm length
2 pcs of 90° elbows
1 pc of straight pipe segment with trough flow orifice plate
1 pc of fan with adjustable rpm
1 pc of inlet orifice plate with adjustable diameter (plate)
1 pc of inlet cone
1 pc of butterfly valve

One of the 3m straight pipe segments is perforated at 0.5D, 1D, 2D, 5D 10D of the length for the inserting of the velocity measuring equipment (Prandtl tube). The perforation are shifted in

backward direction with the length of Prandtl tube, hence the stagnation point of the Prandtl tube is in the right position..
The power of the fan equipped in the measurement facility can be adjusted, but the scale division of the fan is NOT linearly proportional to the flow-rate. The power control allows the operator to set different operating modes in the pipeline, it allows changing the Reynold number of the fluid flow.

3. Theoretical background, flow-rate measuring methods

Multiple methods are available to measure flow-rate in a pipeline. 7 of them are available to be equipped in the measuring facility. These methods are:

- trough flow orifice plate
- Venturi tube
- flowrate measurement with specific inlet element, like
  - inlet orifice plate
  - bellmouth inlet
  - Borda inlet
- velocity based methods
  - 6 Point method
  - 10 10 Point method

The highest accuracy can be reached with the trough flow orifice plate, but this method needs the highest investment and in has the highest pressure loss.
The different methods detailed:

Detailed description of the methods:

Trough flow **orifice plate**

ISO 5167 specifies the geometry and method of use (installation and operating conditions) of trough flow orifice plates when they are inserted in a conduit running full to determine the flowrate of the fluid flowing in the conduit. The principle of the method of measurement is based on the installation of an orifice plate (spec. contraction) into a pipeline in which a fluid is running full. The presence of the orifice plate causes local velocity increase (continuity eq.) and thereby a static pressure difference (Bernoulli eq.) between the upstream and downstream sides of the plate. The pressure difference will be proportional to the mass flowrate/ volume flow rate.

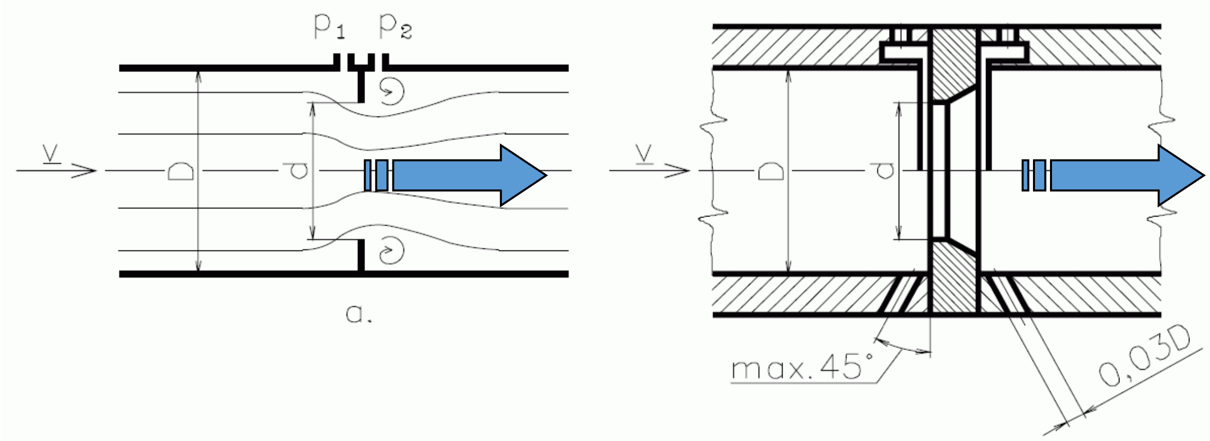

Figure 1. Trough flow orifice plate

The volume flowrate can be determined by using the following equation:

$$q_v = \frac{C}{\sqrt{1-\beta^4}} \varepsilon_1 \frac{d^2\pi}{4} \sqrt{\frac{2}{\rho_1}\Delta p}$$

where

C discharge coefficient

β diameter ration (β=d/D=0,75 in this measurement)

ε expansibility factor (ε=1, if Δp≤5000Pa)

d orifice inner diameter (d=120mm)

D pipeline inner diameter (D=160mm)

Δp pressure difference of the orifice

ρ_l density of fluid

C discharge coefficient can be determined using the following equation:

$$C = 0{,}5961 + 0{,}0261\beta^2 - 0{,}216\beta^8 + 0{,}000521\left(\frac{10^6\beta}{\mathrm{Re}_D}\right)^{0,7} + (0{,}0188 + 0{,}0063A)\beta^{3,5}\left(\frac{10^6}{\mathrm{Re}_D}\right)^{0,3} +$$

$$+ 0{,}011(0{,}75-\beta)\left(2{,}8 - \frac{D}{0{,}0254}\right)$$

where Re_D is the Reynolds number calculated with the pipeline diameter (duct Reynolds number) and A is a specific constant $A = \left(\frac{19000\beta}{\mathrm{Re}_D}\right)^{0,8}$.

Iteration

Iteration must be used to solve all the equations since the Reynolds number is calculated from flow velocity in the pipeline and the velocity is calculated from the flowrate, which is calculated from the discharge function which is the function of the Reynolds number.

In the first iteration step C should be set C'=0,6. The flowrate (q_V') should be calculated with the pre-set of the discharge coefficient. From the flowrate the velocity (v') is to be calculated. With the calculation of a new discharge coefficient C'' the first iteration step is done. The iteration should be repeated until the change of the discharge coefficient s less than 0.1%.

1. iteration step

C' → q_V' → v' → Re_D' → C''

2. iteration step

C'' → q_V'' → v'' → Re_D'' → C'''

3., 4., 5.,…...

The calculation should be converging fast, 5-6 iteration step is enough in most cases.

Flowrate measurement using inlet orifice

There are different inlet elements which are suitable for flowrate measurement but they have to be calibrated using an accurate flowrate measuring equipment. The great benefits of this method are the simplicity and the potential (swirl-free) inlet flow which causes more uniform inlet

velocity distribution. The available inlet elements in this measurement facility are the inlet orifice with replaceable plate, the Borda inlet and the bellmouth inlet.
The volume flowrate can be determined by using the following equation, which is very similar to the equation used to determine flowrate trough an orifice plate:

$$q_v = k \frac{d_b^2 \pi}{4} \sqrt{\frac{2}{\rho_1} \Delta p_b}$$

where

k	flow rate coefficient
d_b	inner diameter of the inlet orifice plate
ρ_1	density of the fluidum
Δp_b	pressure difference of the orifice (p_1=atmospheric pressure)

While calibrating the inlet element, an other accurate flowrate measuring equipment should be inserted in the pipeline to determine the real flowrate. If the two flowmeters are connected in sequence, the same flowrate will flow though they, which makes it possible to determine the unknown flow rate coefficient of the inlet element.

Flowrate measurement using elbow

It is also possible to use the pipe elbow inserted in the system to measure the volume flow. It is known that in the case of curved streamlines, a pressure gradient is formed perpendicular to the velocity vector. (Euler equation in natural coordinate system)

$$-\frac{v^2}{R} = -\frac{1}{\rho} \cdot \frac{\partial p}{\partial n} + g_n$$

if the forcefield is neglectable:

$$\frac{v^2}{R} = \frac{1}{\rho} \cdot \frac{\partial p}{\partial n}$$

it means the centripetal acceleration of the fluid particles is the presure gradient divided by the density. The radial pressure gradient can be approximated by the quotient of the pressure difference between the outer and inner walls and the distance (Distance of the walls in the pipe = diameter D):

$$\frac{\partial p}{\partial n} \approx \frac{\Delta p}{D}$$

Thus, a simple relationship can be described on the center axis for centripetal acceleration

$$\frac{v^2}{R} = \frac{1}{\rho} \cdot \frac{\Delta p}{D}$$

from this, the velocity on the central axis can be calculated, which can be considered as the average cross-sectional velocity:

$$v = \sqrt{R \cdot \frac{1}{\rho} \cdot \frac{\Delta p}{D}}$$

where Δp is the pressure difference between the outer and inner wall, R is the mean radius of the elbow, ρ is the density of the fluid and D is the pipe diameter. The volume flow is the product of the mean velocity and the cross-section

$$q_V = \frac{D^2 \cdot \pi}{4} \cdot v$$

Determination of flow rate by using velocity measurement

Flow rate can be determined by using velocity measurement. The most equipped velocity meters are the Pitot tube and the Prandtl tube. To determine the flowrate, velocity measurement has to be done in several points of the cross section. Since the velocity measurement cannot be done in infinite number of points, we assumed that in the calculation of the flow rate the measured values are representative for part cross-sections with sufficient accuracy. Various standardized methods exist which provide the location and measurement errors committed during the measurement.

In case of rectangular or irregular cross-section we divide the cross-section into parts of equal size. The velocity measurement must be performed on the middle radius of the part cross sections. The average velocity has to be calculated and multiplied by the cross section to determine the flow rate.

On the one hand, the measurement accuracy improves if the area is divided into many parts since a more accurate picture of the spatial unevenness of velocity can be taken into account. On the other hand, it also means a much longer measurement time, which increases the risk of changes in the operating conditions.

In case of circular cross-section, the suggested methods are:

- the 6 point method (also known log-lin method, for turbulent flow),
- the 8 points method (defined in ISO 5801)
- and the 10 points method. The 6 points method fits the turbulent flow better and 10 points method is suggested for laminar pipe flow.

The distance of the measurement points from one inside wall of the airway lies within the limits given below, except that the minimum positional tolerance will be ± 1 mm.

6 points method	8 points	10 points
0,032 D	0,021D	0,026
0,135 D	0,117D	0,082 D
0,321 D	0,184D	0,146 D
0,679 D	0,345D	0,226 D
0,865 D	0,655D	0,342 D
0,968 D	0,816D	0,658 D
	0,883D	0,774 D
	0,979D	0,854 D
		0,918 D
		0,974 D

$S_i/D=$

The centre of the nose of the velocity meter shall be located successively along two (in 6 and 10 points method) or three symmetrically disposed diameters of the airway.

4. Measurement error:

The measurement error calculation needs to be done for the real flow-rate.

The approximate values of the absolute error of measured quantities are:

$X_1=\Delta p_i$,	error of the pressure measurement	$\delta\Delta p_i=2Pa$
$X_2=p_0$,	error of the atmospheric pressure measurement	$\delta p_0=100\ Pa$
$X_3=T_0$,	error of the temperature measurement	$\delta T_0=1K$

Uncertainty (relative error) of discharge coefficient C

(0,7 – β) %	for $0.1 \le \beta < 0.2$
0,5 %	for $0.2 \le \beta < 0.6$
(1,667β – 0,5) %	for $0.6 \le \beta < 0.75$

Do no forget during the measurement

- Before turning any measurement device on, or in general during the lab, make sure that safe working conditions are ensured. The other participants have to be warned of the starting of the machines and of any changes that could endanger the members of the lab.
- The atmospheric pressure and room temperature should be recorded before and after every measurement.
- The measurement units and other important factors (e.g. data sampling frequency, data of calibration) of every recorded value of the applied measurement devices should be recorded.
- Type and construction number of the applied measuring instrument should be included in the final report.
- Checking and harmonizing of the units of the recorded values with those used in further calculations.
- Manometers should be calibrated if necessary.
- The measurement ports of the pressure meter should be carefully connected to the correct pressure ports of the instrument.
- If inlet or outlet tubes are to be assembled with fans, connections should be airtight as escaping/entering air can significantly modify the measurement results

Suggested literature

[1] Lajos Tamás: Áramlástan alapjai (2004) 9.9.3 és 11.1.2 fejezet
[2] Lajos Tamás: Áramlástan alapjai (2004) 423.oldal
[3] Lajos Tamás: Áramlástan alapjai (2004) 488.oldal
[4] ISO 5801
[5] ISO 5167 Part II. Orifice Plates