

11. TRADITIONAL MEASUREMENT OF VOLUME FLOW RATE

11.1. Volume flow rate deduced from velocity measurement data

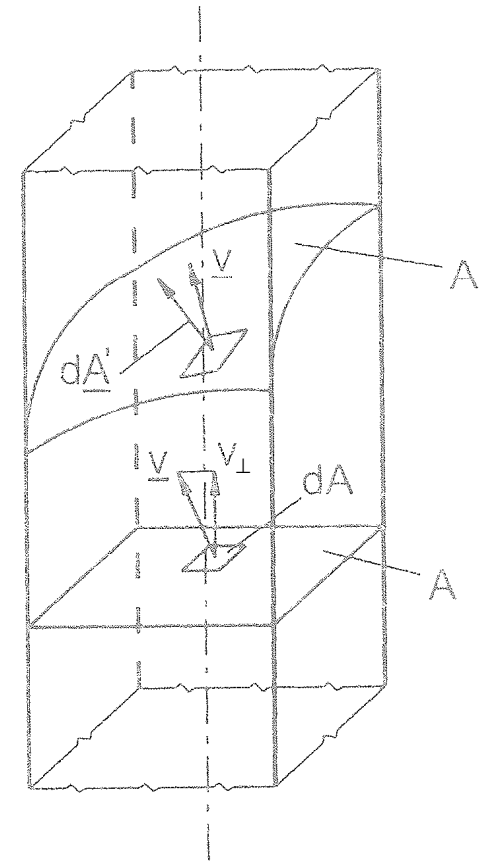
11.1.1. Application example

11.1.2. Principle and layouts

$$q_V = \int_{A'} \underline{v} \, dA' = \int_A \underline{v} \, dA = \int_A v_{\perp} \, dA$$

$$\approx \sum_{i=1}^n v_{\perp i} \Delta A_i = \Delta A_i \sum_{i=1}^n v_{\perp i}$$

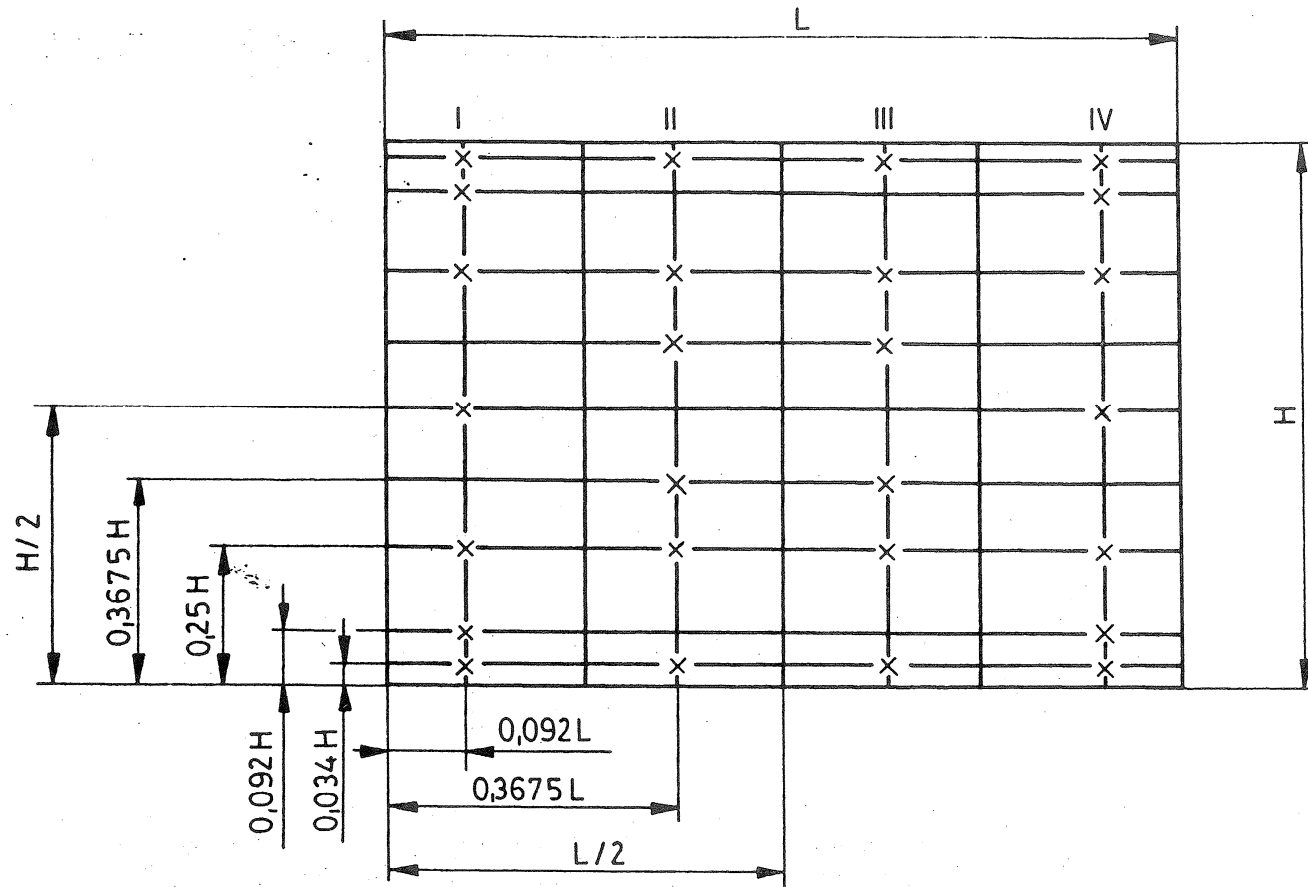
$$= n \cdot \Delta A_i \left(\frac{1}{n} \sum_{i=1}^n v_{\perp i} \right) = A \bar{v}_{\perp}$$



DISCRETISATION:

For rectangular cross-sections:

- $k \times k$
- Log-lin method ISO 3966-1977



Dr. János VAD: Flow measurements

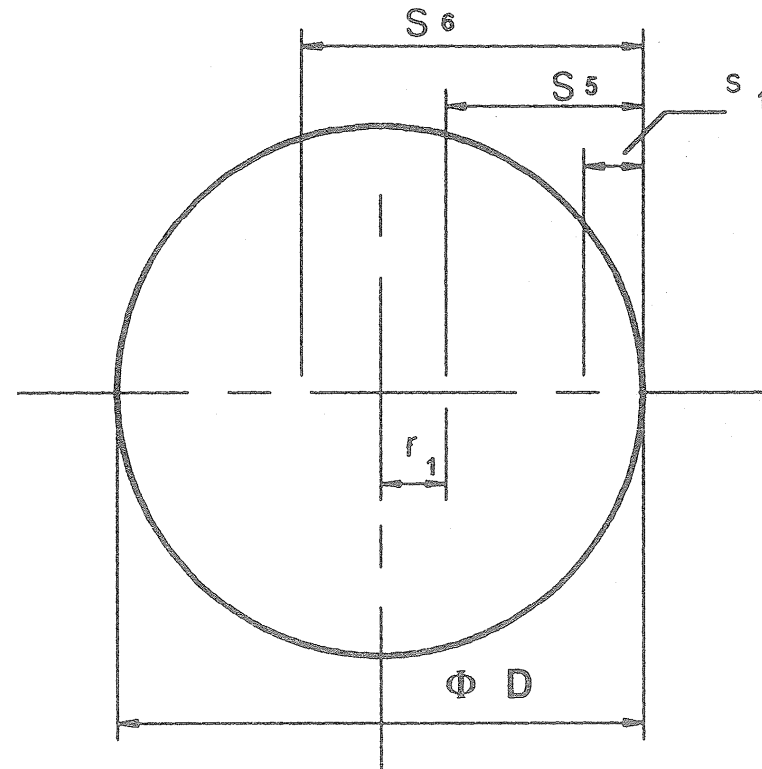
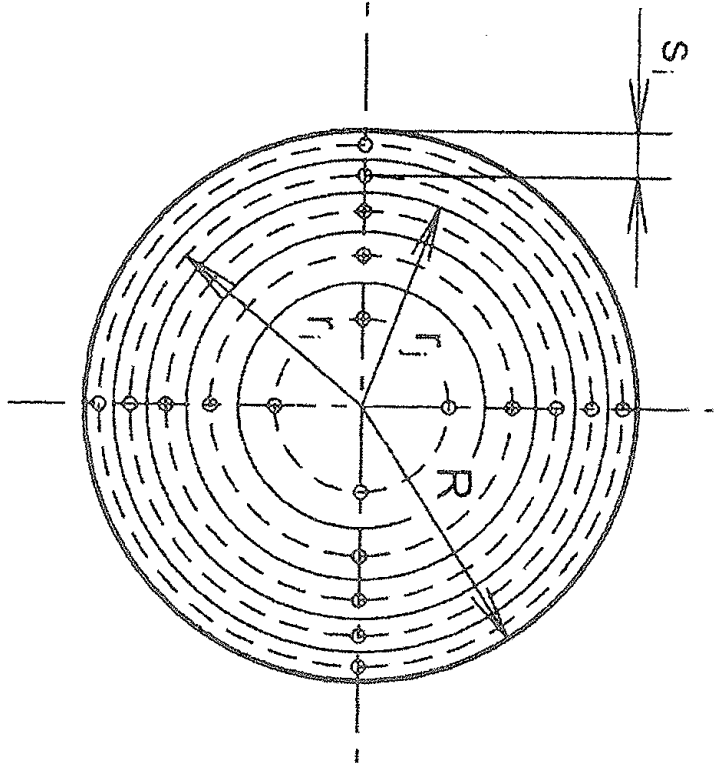
$$\bar{v}_\perp = \frac{\sum_{i=1}^n k_i v_{\perp i}}{\sum_{i=1}^n k_i}$$

weighting

	I	II	III	IV
h/H \ l/L	0,092	0,367 5	0,632 5	0,908
0,034	2	3	3	2
0,092	2	—	—	2
0,250	5	3	3	5
0,367 5	—	6	6	—
0,500	6	—	—	6
0,632 5	—	6	6	—
0,750	5	3	3	5
0,908	2	—	—	2
0,966	2	3	3	2

**For circular cross-sections:
•10-point method**

$$v(r_i) = v_{\max} \left[1 - \left(\frac{r_i}{R} \right)^n \right]$$



$s_i/D = 0.026; 0.082; 0.146; 0.226; 0.342; 0.658; 0.774; 0.854; 0.918; 0.974$

Accurate integration: for 2nd order paraboloid profile only!

• ***Log-lin method ISO 3966-1977***

3 partial areas

$$v_i(y) = A_i \lg y + B_i y + C_i$$

$$s_i/D = 0.032; 0.135; 0.321; 0,679; 0.865; 0.968$$

General notes

- The nose of the probe is to be adjusted parallel to the wall of the duct

- ρ_{dyn_ref} Check of steadiness

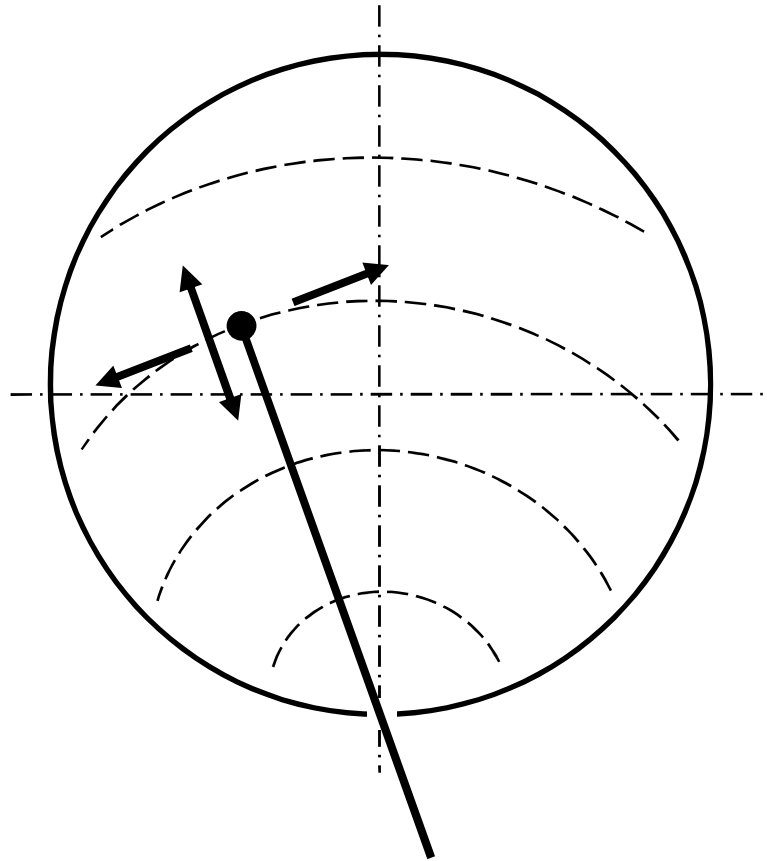
$$v_{ref0} = \sqrt{\frac{2}{\rho} P_{dyn_ref_0}} \quad v_{ref_i} = \sqrt{\frac{2}{\rho} P_{dyn_ref_i}}$$

$$v_i = \sqrt{\frac{2}{\rho} P_{dyn_i}}$$

Correction:
$$v_{i\ corr} = v_i \frac{v_{ref0}}{v_{ref\ i}} = v_i \sqrt{\frac{P_{dyn_ref_0}}{P_{dyn_ref_i}}}$$

- Obtainment of density

- Advantages and disadvantages
- Quick scanning:

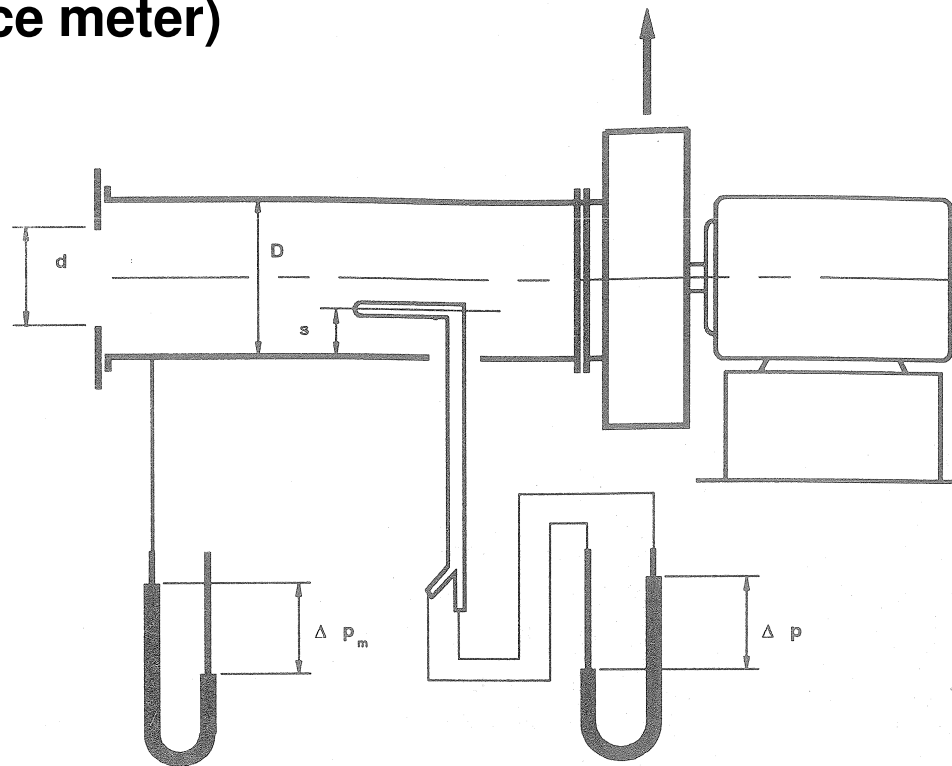
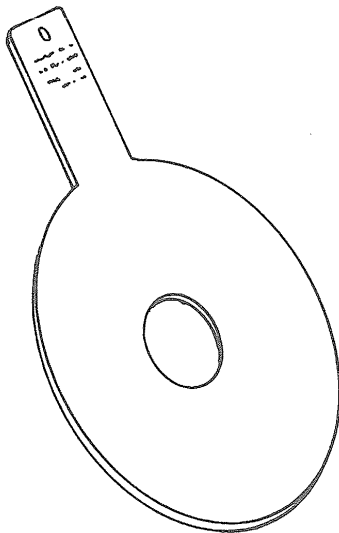


11.2. Volume flow rate measurements using contraction elements

11.2.1. Application example

11.2.2. Principle and layouts

• Inlet orifice plate (inlet orifice meter)



Assumption of ideal fluid: inviscid, incompressible flow

$$p_0 = p + \rho \frac{v^2}{2} \quad v = \sqrt{\frac{2}{\rho}(p_0 - p)} = \sqrt{\frac{2}{\rho} \Delta p_m}$$

$$q_v = \frac{d^2 \pi}{4} v = \frac{d^2 \pi}{4} \sqrt{\frac{2}{\rho} \Delta p_m}$$

Reality: viscous, compressible flow

A/ Effect of viscosity

flow coefficient α

dependence on d/d_{in} , Re

for the inlet orifice meter: $\alpha = 0.6$

$$q_v = \alpha \varepsilon \frac{d^2 \pi}{4} \sqrt{\frac{2}{\rho} \Delta p_m}$$

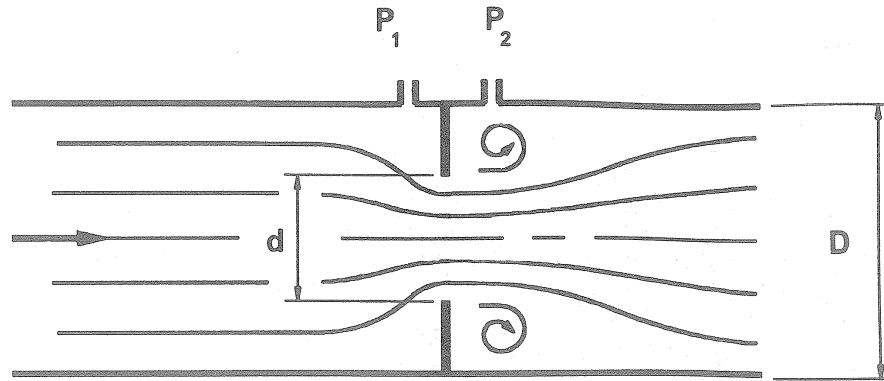
B/ Effect of compressibility

expansion coefficient ε

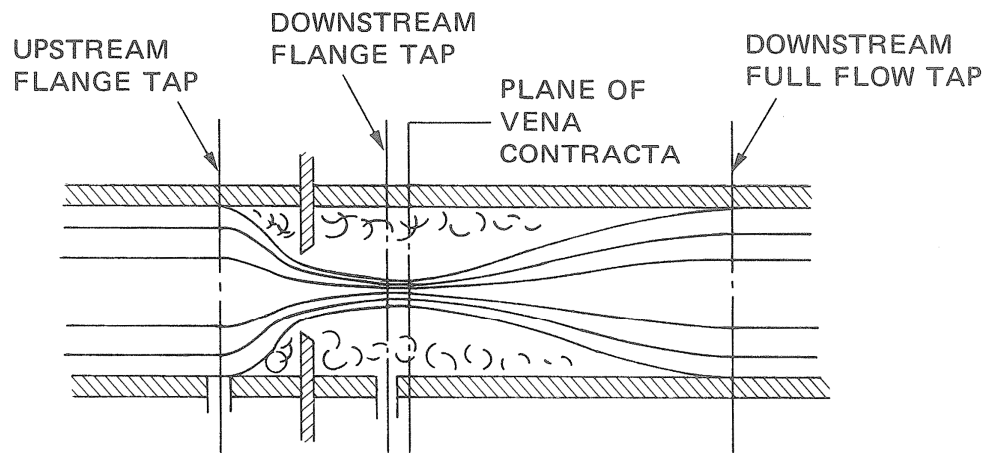
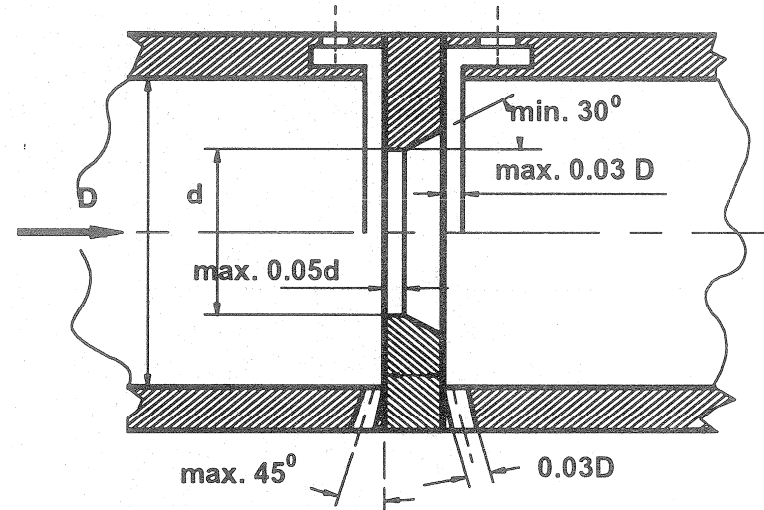
dependence on d/d_{in} , Δp , p_{in} , κ

for the inlet orifice meter: $\varepsilon = 1$

•Through-flow orifice plate (through-flow orifice meter)

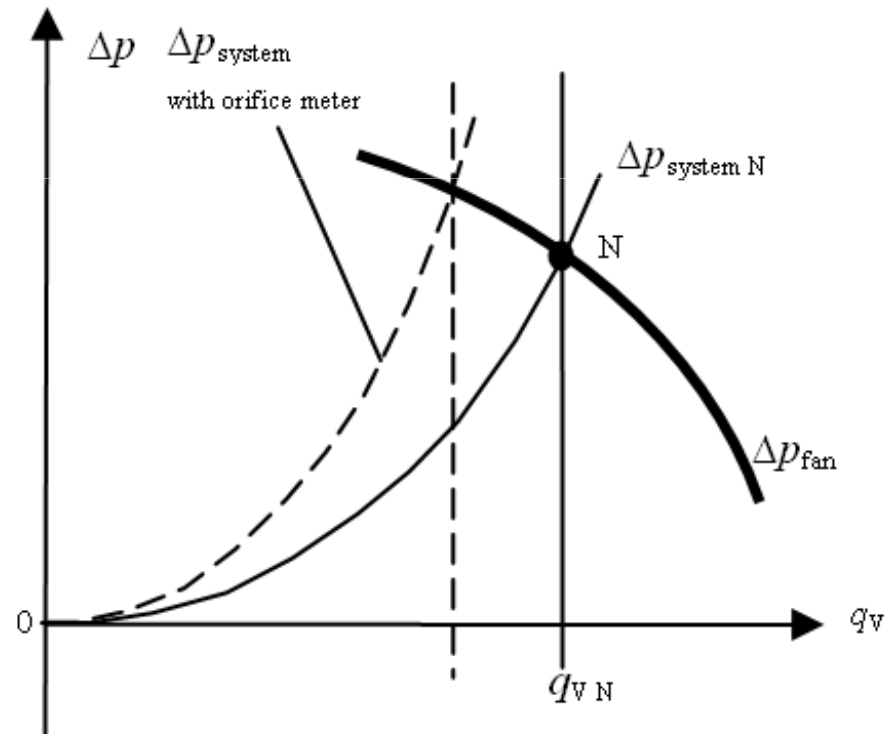


ISO 5167

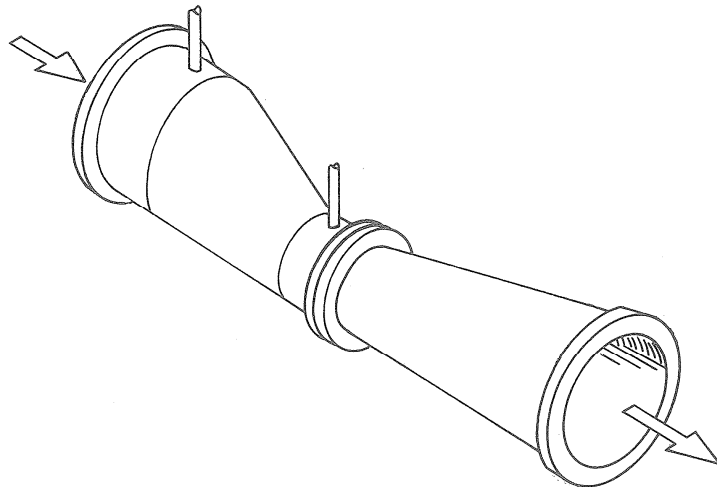
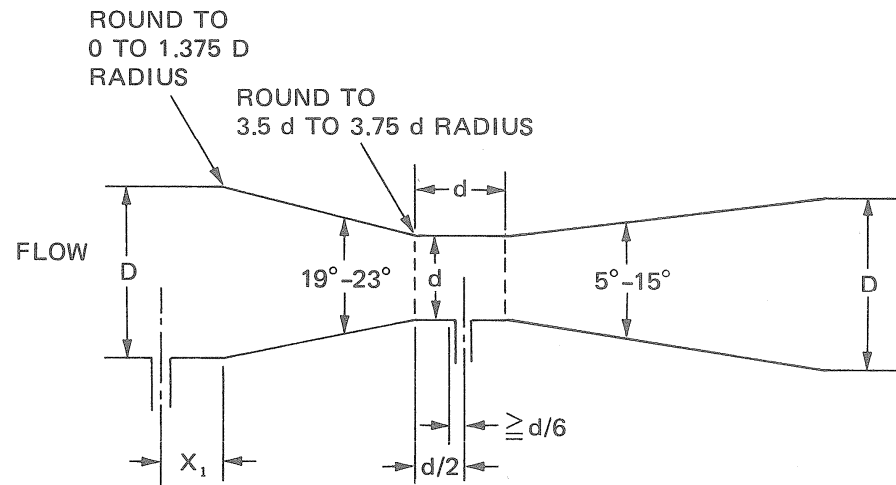


- Geometry
- α, ε
- Installation – Examples
- Accuracy – Examples
- Problems

$$q_V = \alpha \varepsilon \frac{d^2 \pi}{4} \sqrt{\frac{2}{\rho} \Delta p_m}$$



•Venturi meter ISO 5167

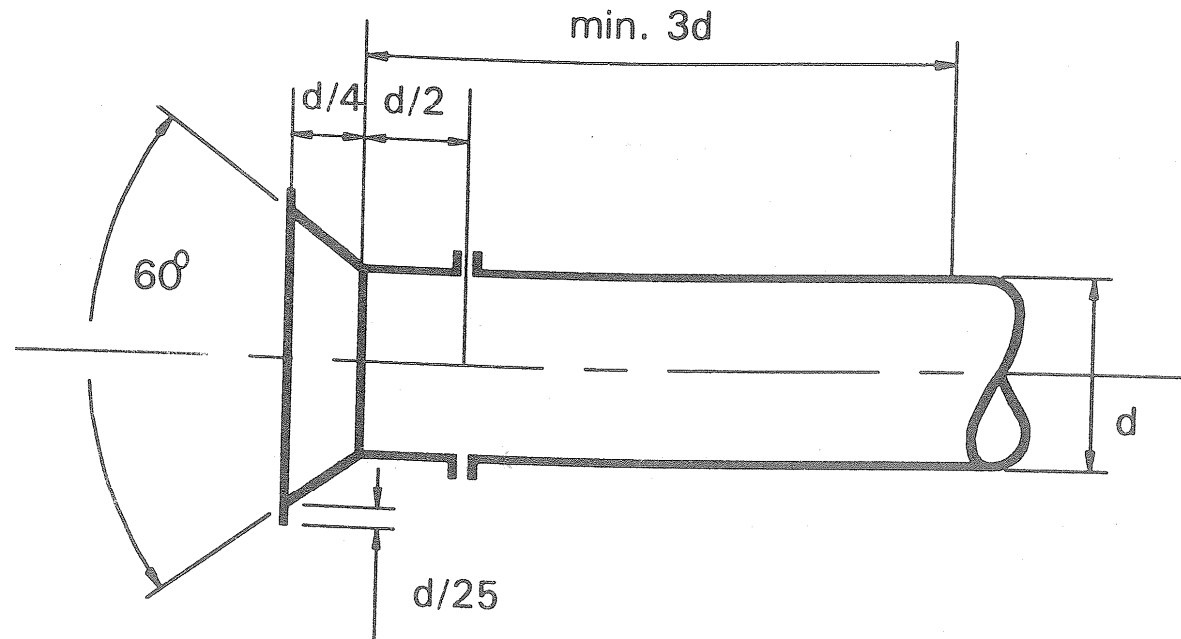


• **Inlet cone** ISO 5221-1984 (E)

$$Re = \frac{4q_v}{\pi \rho d v}$$

$$(\alpha\varepsilon) = 0.955 \pm 0.020 \quad \text{if} \quad 2 \cdot 10^5 < Re < 3 \cdot 10^5$$

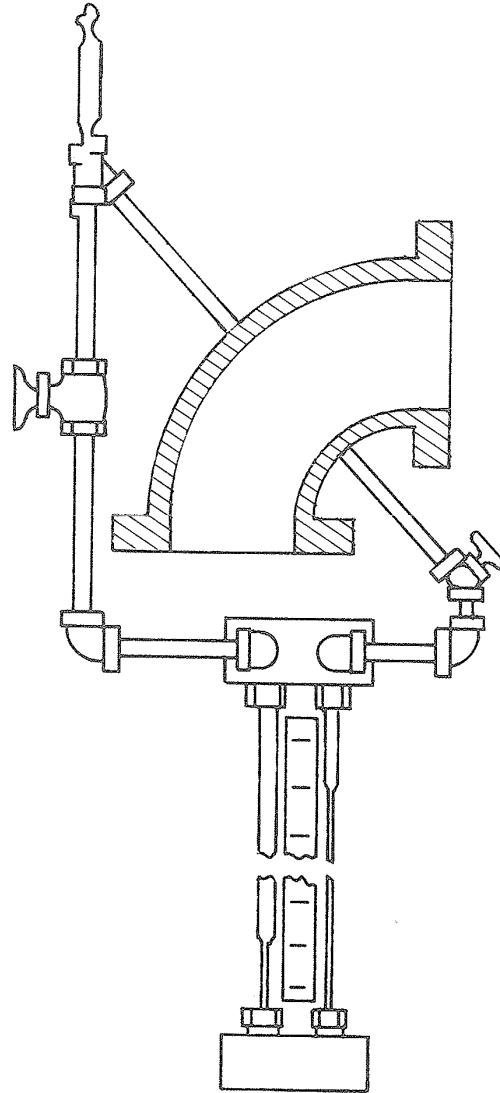
$$(\alpha\varepsilon) = 0.960 \pm 0.015 \quad \text{if} \quad Re \geq 3 \cdot 10^5$$



11.3. Other types of traditional flowmeters

Example:

- Elbow meter



Dr. János VAD: Flow measurements

11.4. Comparison between volume flow rate measurement deduced from velocity data (VEL) and using contraction elements (CON)

ASPECT	CON	VEL
1/ Intrusiveness	<p style="text-align: center;">“ - ”</p> <p>Introduces considerable losses \Rightarrow the operating state may be modified \Leftrightarrow to be included already in the system design state</p>	<p style="text-align: center;">“ + ”</p> <p>Negligible intrusiveness (wall bores)</p>
2/ Following temporal changes in the operational state	<p style="text-align: center;">“ + ”</p> <p>Follows unsteady flow rate continuously</p>	<p style="text-align: center;">“ - ”</p> <p>Does not follow (surface integration) (\Leftrightarrow correction..?)</p>
3/ Requirements	<p style="text-align: center;">“ - ”</p> <p>Strict (manufacturing, installation, system is to be stopped...)</p>	<p style="text-align: center;">“ + ”</p> <p>Moderate (no requirements, only recommendations, system may run continuously...)</p>

4/ Expenses	<p style="text-align: center;">“ - ”</p> <p>High (manufacturing, installation, operation: losses to be covered)</p>	<p style="text-align: center;">“ + ”</p> <p>Moderate</p>
5/ Accuracy	<p style="text-align: center;">“ + ”</p> <p>High (limited uncertainty, guaranteed by the standard) Legally <u>defensible</u>!</p>	<p style="text-align: center;">“ - ”</p> <p>Moderate (limits of uncertainty are not guaranteed) Legally <u>assailable</u>!</p>

CON: high-precision, continuous, legally defensible measurements
(e.g. accounting, process control, etc.)

VEL: occasional (case study) measurements, brief estimation
(e.g. fault diagnostics)