11. TRADITIONAL MEASUREMENT OF VOLUME FLOW RATE

11.1. Volume flow rate deduced from velocity measurement data

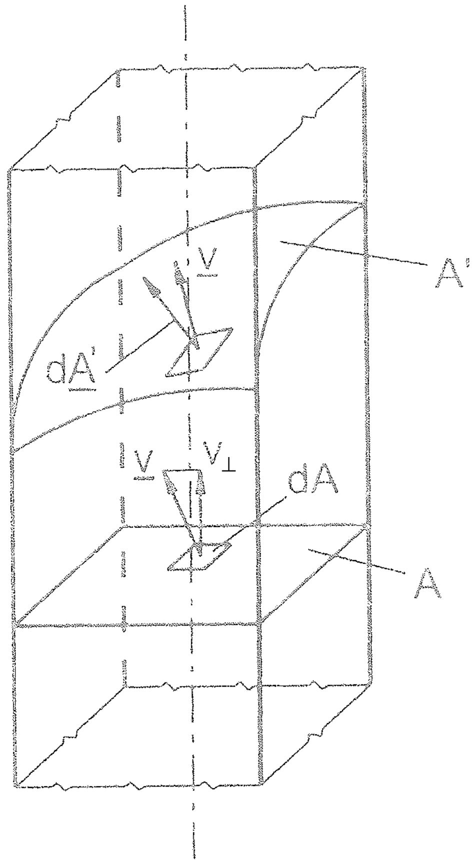
11.1.1. Application example

11.1.2. Principle and layouts

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

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

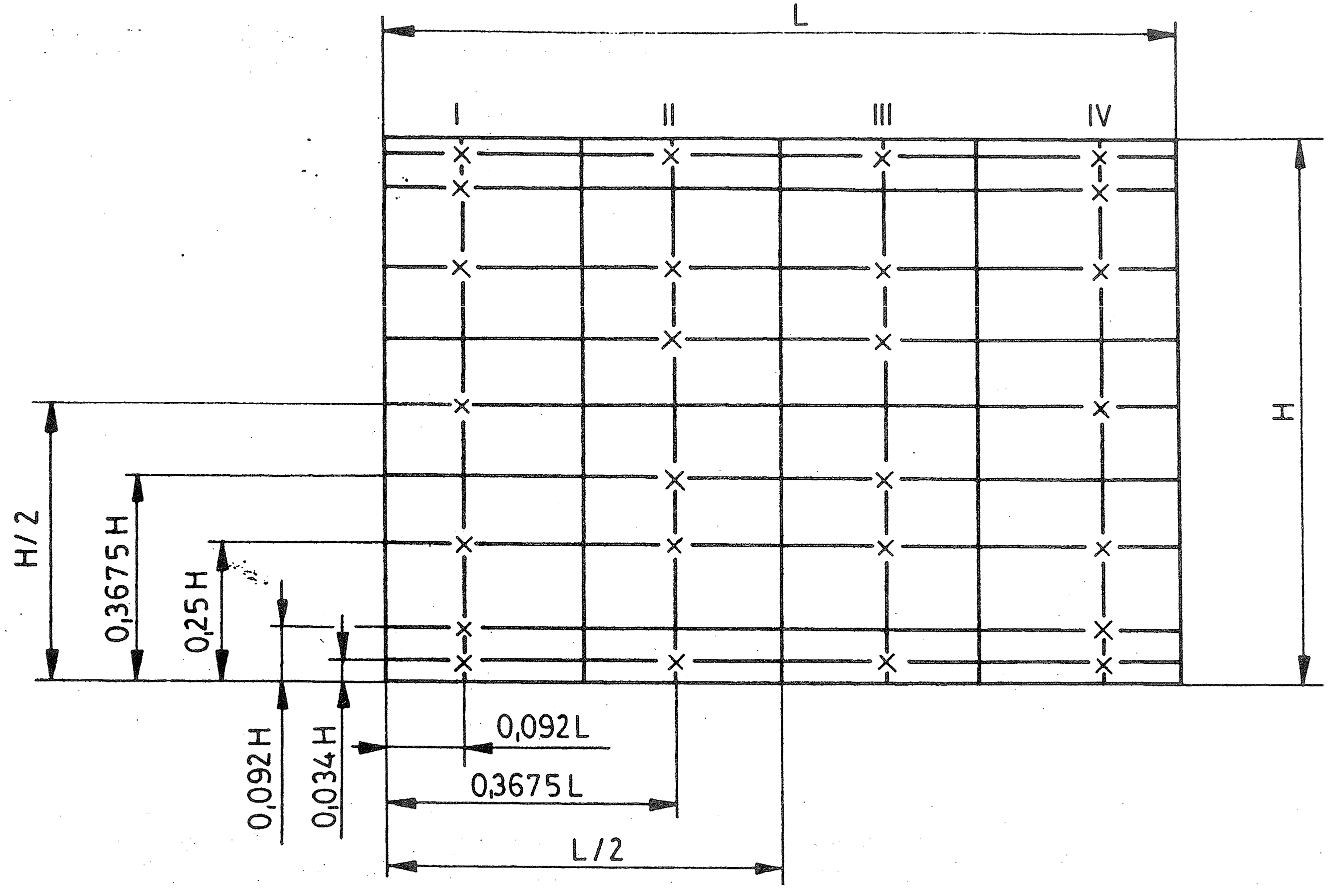
$$= n \cdot \Delta A_i \left(\frac{1}{n} \sum_{i=1}^{n} v_{\perp i} \right) = A\,\overline{v}_{\perp}$$



DISCRETISATION:

For rectangular cross-sections:

- **k x k**
- **Log-lin method ISO 3966-1977**



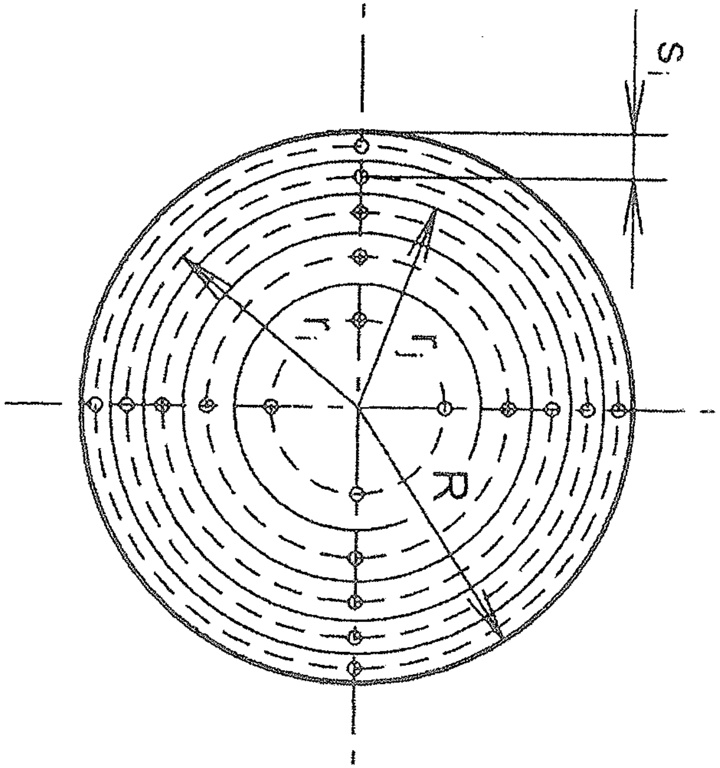
$$\bar{v}_{\perp} = \frac{\sum_{i=1}^{n} k_i v_{\perp i}}{\sum_{i=1}^{n} k_i}$$

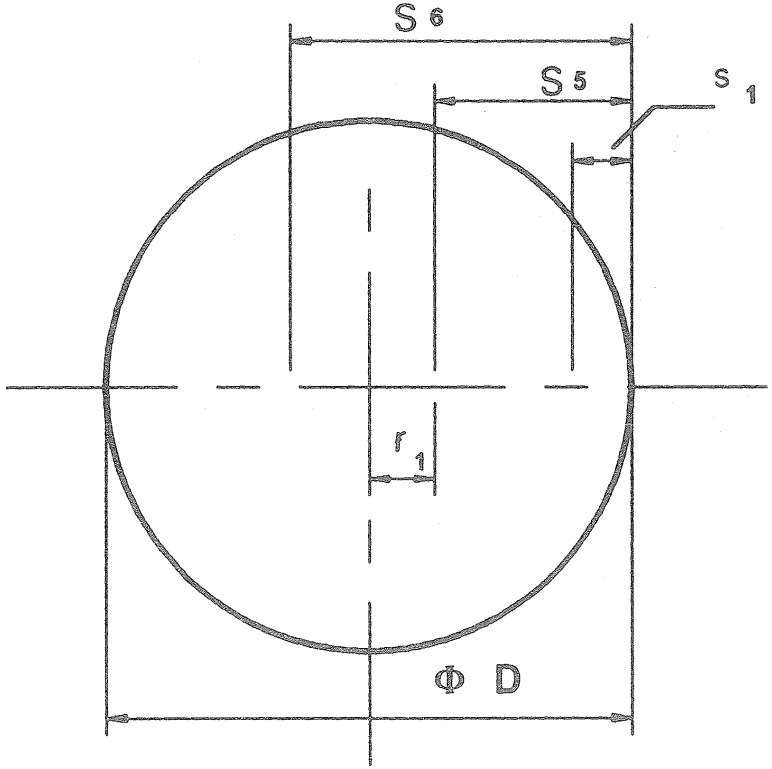
weighting

h/H \ l/L	I	II	III	IV
	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

- $p_{\_dyn\_ref}$ Check of steadiness

$$v_{ref\,0} = \sqrt{\frac{2}{\rho} p_{dyn\_ref\_0}} \qquad v_{ref\_i} = \sqrt{\frac{2}{\rho} p_{dyn\_ref\_i}}$$

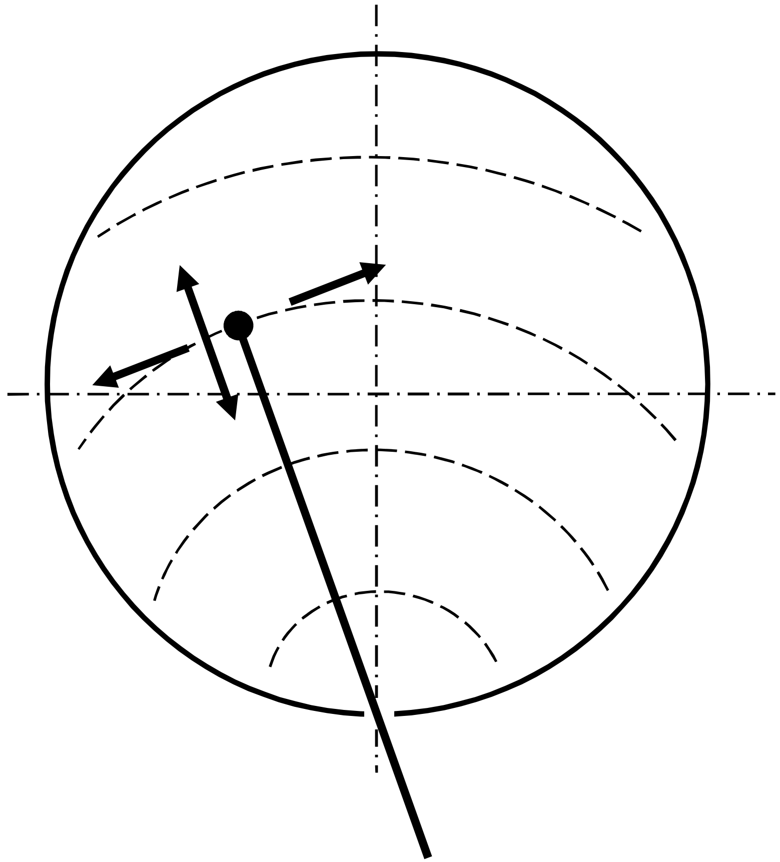
$$v_i = \sqrt{\frac{2}{\rho} p_{dyn\_i}}$$

Correction: $$v_{i\,corr} = v_i \frac{v_{ref\,0}}{v_{ref\;i}} = v_i \sqrt{\frac{p_{dyn\_ref\_0}}{p_{dyn\_ref\_i}}}$$

- Obtainment of density

•Advantages and disadvantages

•Quick scanning:

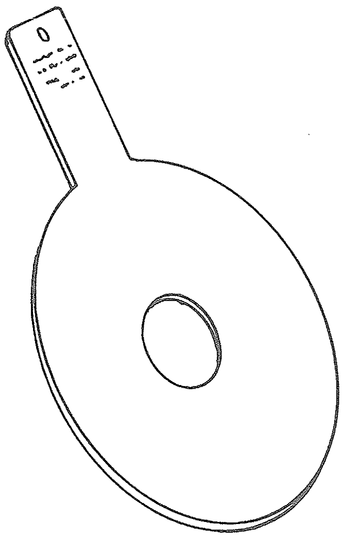


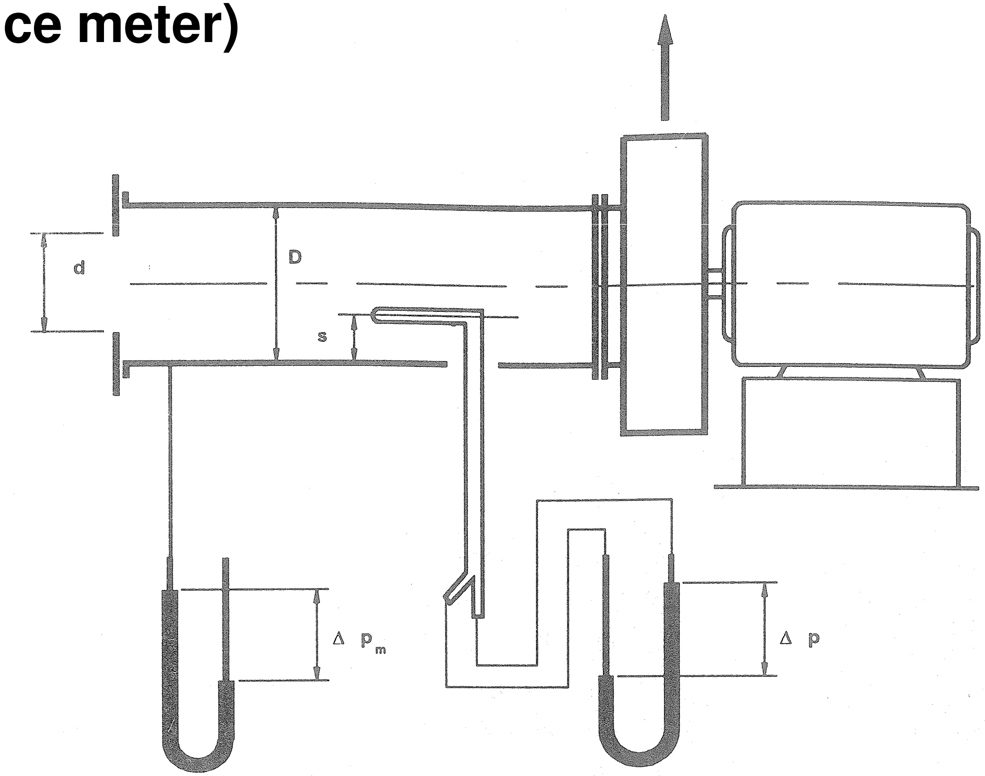
11.2. Volume flow rate measurements using contraction elements

11.2.1. Application example

11.2.2. Principle and layouts

•**Inlet orifice plate (inlet orifice meter)**





Assumption of ideal fluid: inviscid, incompressible flow

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

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

Reality: viscous, compressible flow

<u>A/ Effect of viscosity</u>

flow coefficient α

dependence on d/d_in, Re

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

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

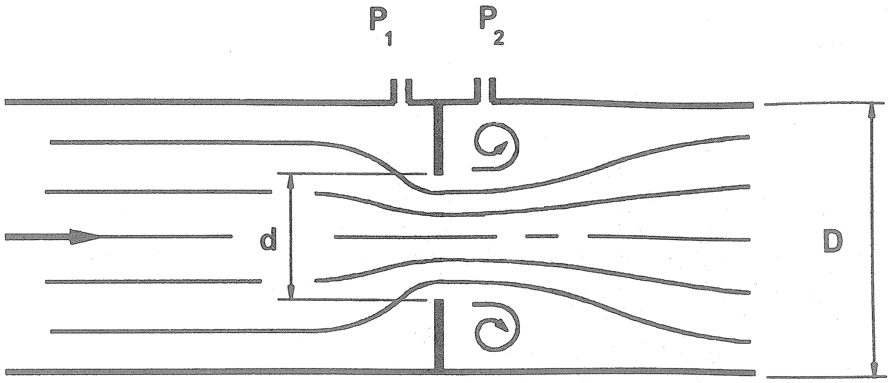
<u>B/ Effect of compressibility</u>

expansion coefficient ε

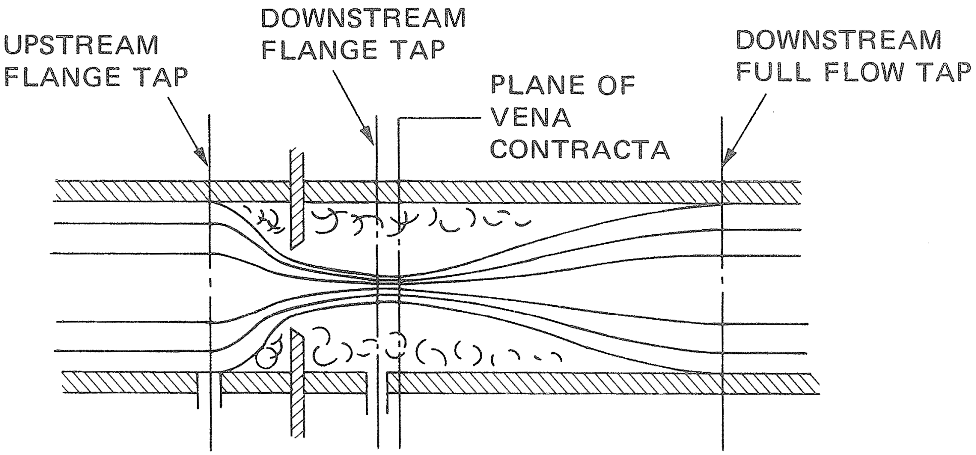
dependence on d/d_in, Δp, p_in, κ

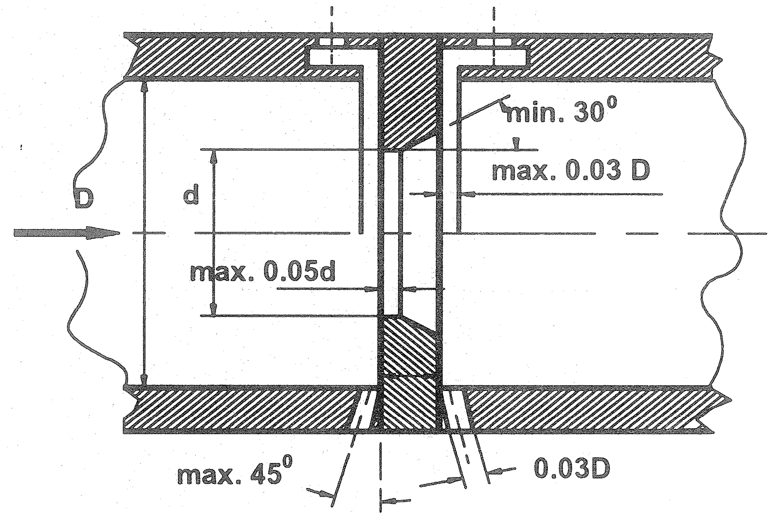
for the inlet orifice meter: $\varepsilon = 1$

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



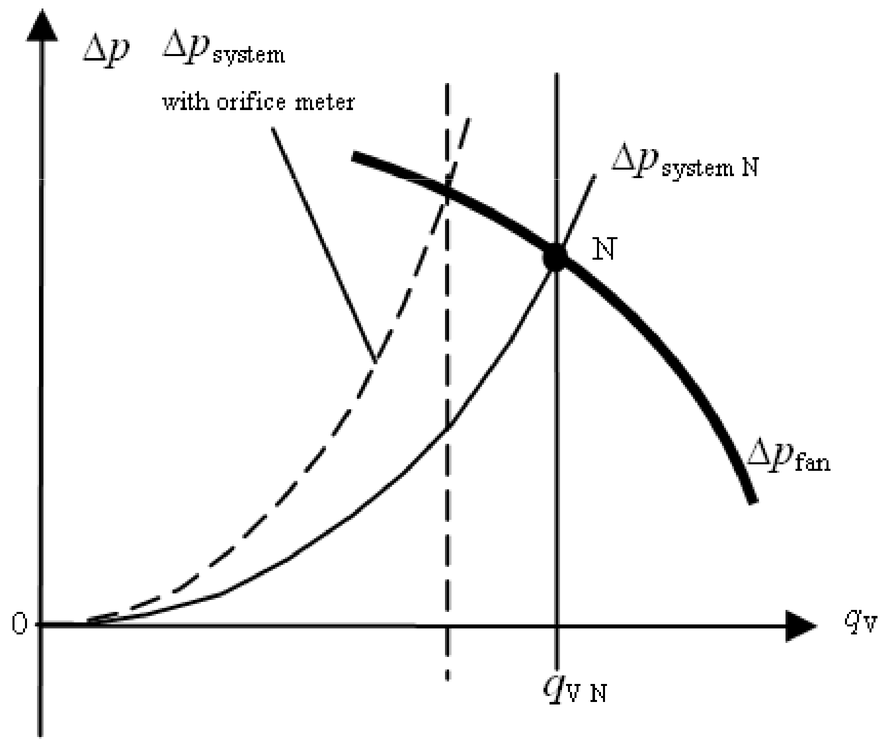
ISO 5167



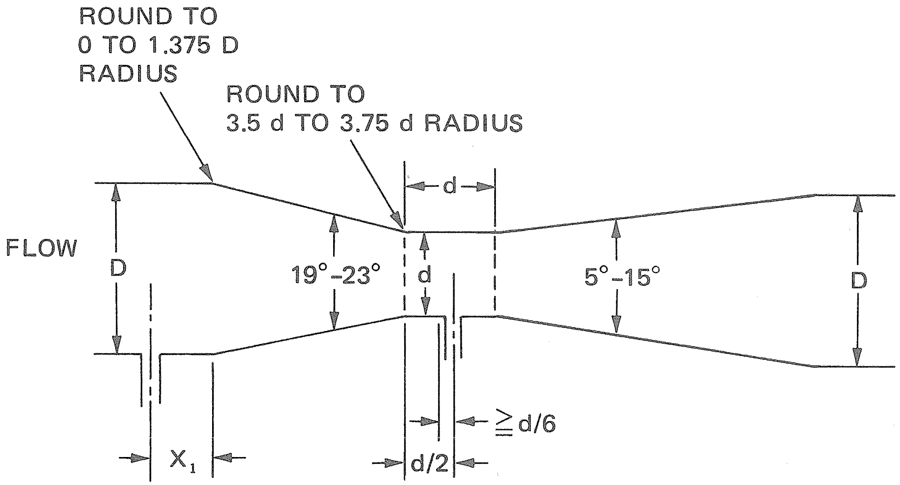


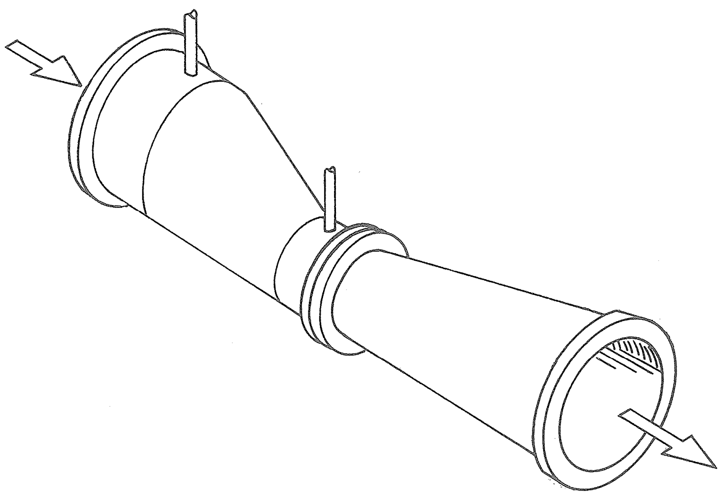
- *Geometry*
- *α, ε*
- *Installation – Examples*
- *Accuracy – Examples*
- *Problems*

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



•Venturi meter ISO 5167



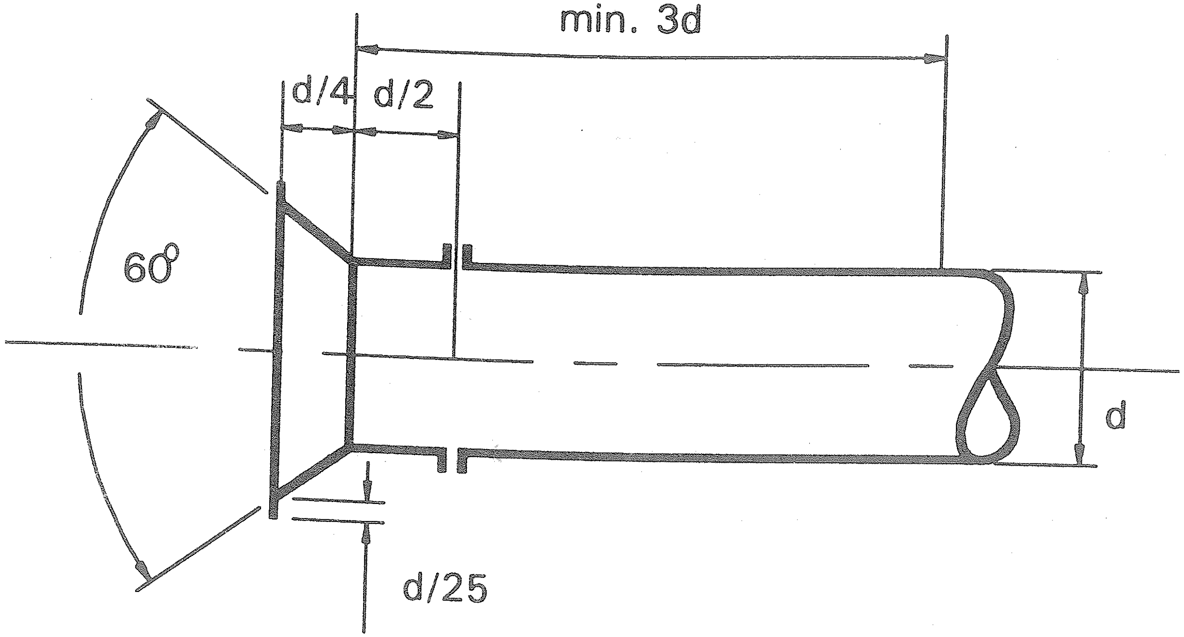


•**Inlet cone** ISO 5221-1984 (E)

$$\mathrm{Re} = \frac{4q_V}{\pi\rho d\nu}$$

$$(\alpha\varepsilon) = 0.955 \pm 0.020 \quad if \quad 2\cdot10^5 < \mathrm{Re} < 3\cdot10^5$$

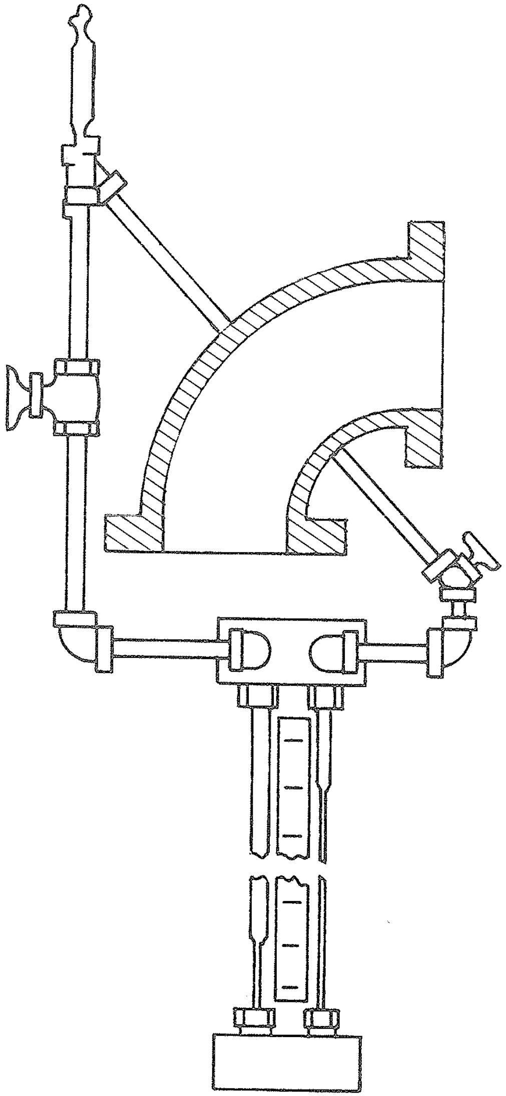
$$(\alpha\varepsilon) = 0.960 \pm 0.015 \quad if \quad \mathrm{Re} \geq 3\cdot10^5$$



11.3. Other types of traditional flowmeters

Example:

•Elbow meter



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

ASPECT	**CON**	**VEL**
1/ Intrusiveness	"–" Introduces considerable losses ⇒ the operating state may be modified ⇔ to be included already in the system design state	"+" Negligible intrusiveness (wall bores)
2/ Following temporal changes in the operational state	"+" Follows unsteady flow rate continuously	"–" Does not follow (surface integration) (⇔ correction..?)
3/ Requirements	"–" Strict (manufacturing, installation, system is to be stopped…)	"+" Moderate (no requirements, only recommendations, system may run continuously…)

4/ Expenses	"–" High (manufacturing, installation, operation: losses to be covered)	"+" Moderate
5/ Accuracy	"+" High (limited uncertainty, guaranteed by the standard) Legally defensible!	"–" Moderate (limits of uncertainty are not guaranteed) Legally assailable!

CON: high-precision, continuous, legally defensible measurements (e.g. accounting, process control, etc.)
VEL: occasional (case study) measurements, brief estimation (e.g. fault diagnostics)