Department of Technologies and
Installations for Waste Management

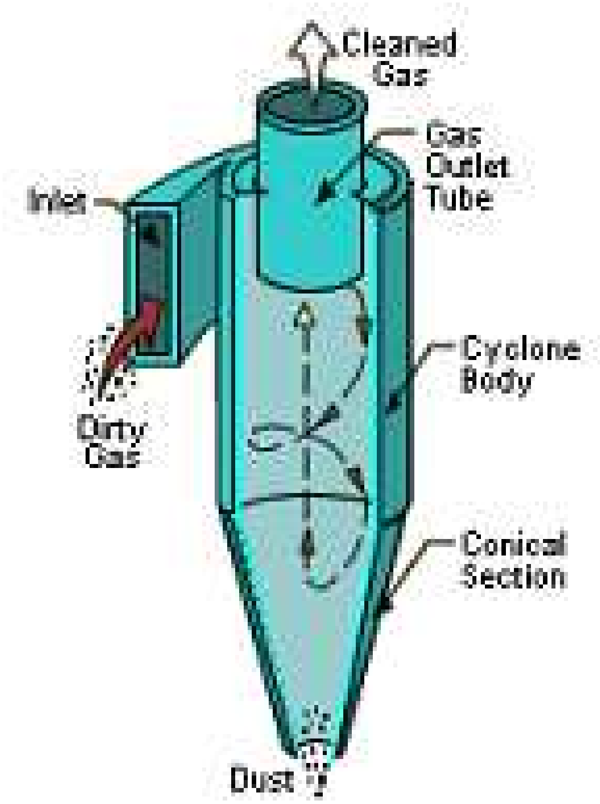
Emission and Transport of Air Pollutants

Project1

Methods of emission control – Dedusting in Cyclone

Dust cyclone

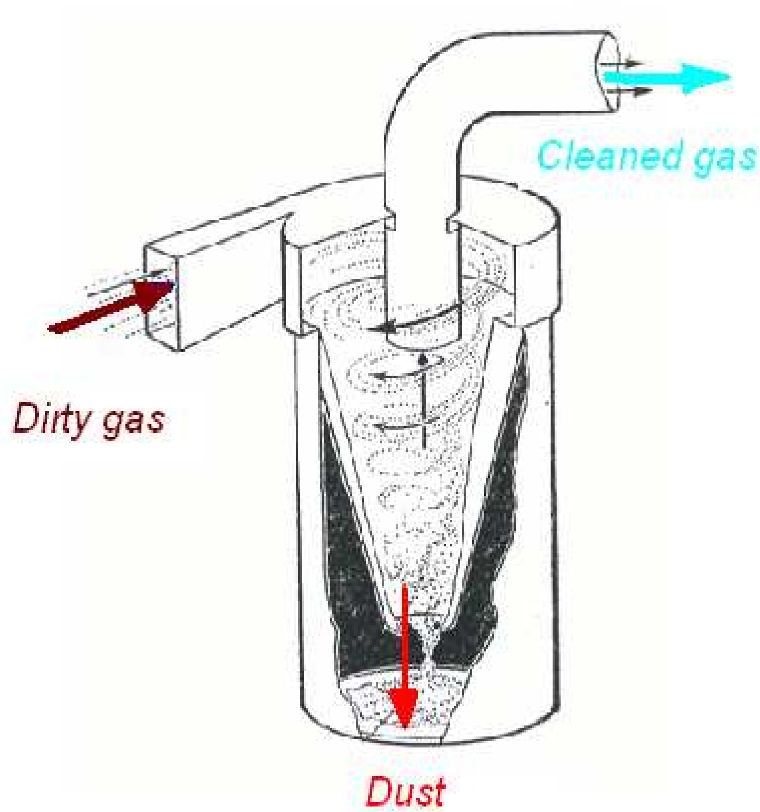
The operation theory is based on a vortex motion where the centrifugal force is acting on each particle and therefore causes the particle to move away from the cyclone axis towards the inner cyclone wall. However, the movement in the radial direction is the result of two opposing forces where the centrifugal force acts to move the particle to the wall, while the drag force of the air acts to carry the particles into the axis. As the centrifugal force is predominant, a separation takes place.



Dust cyclone

The gas stream enters the cyclone tangentially and creates a weak vortex of spinning gas in the cyclone body.

Large-diameter particles move toward the cyclone body wall and then settle into the hopper of the cyclone.



Dust cyclone

Cyclone battrery

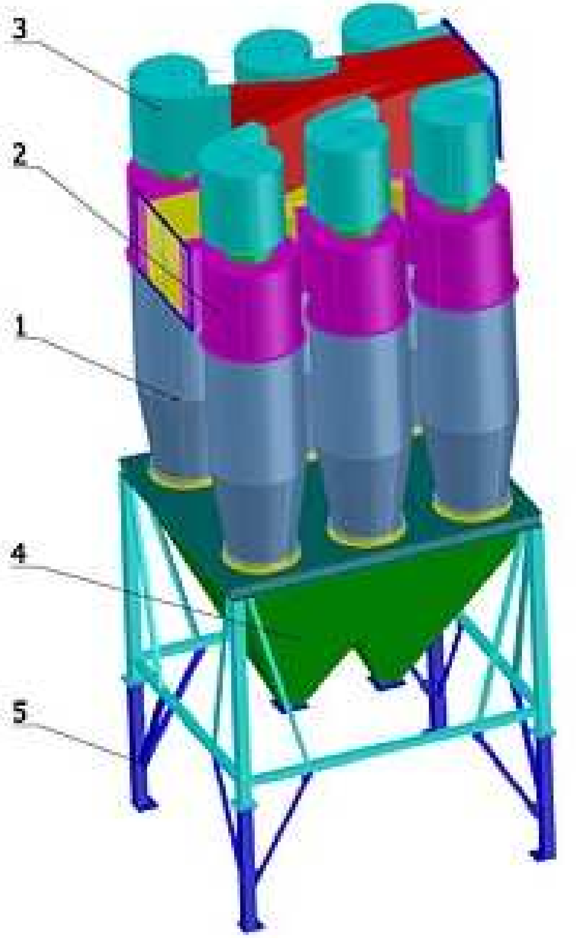
1 – tubular cyclone body

2 – inlet system

3 – outlet system

4 – hopper

5 – support construction



Project 1 - Cyclone

Design a cyclone to ash removal from exhaust gas. The exhaust gas is product of combustion of ...... kg/s fine coal. The coal composition is presented in table 1.

Excess air ratio is λ = ... Ash density

is ρ_a = 1300 kg/m^3. Ash in exhaust gas is 20% of fuel ash. The ash composition is presented in table 2. The temperature of exhaust gas (before cyclone) is ....Assume ash removal efficiency η_n=0,7. Exhaust gas flows into cyclone via tangential inlet.

Project 1 - Cyclone

Tab. 1 Fine coal characteristic

Fine coal composition	Contribution [%]
c	58,64
h	3,21
n	0,84
o	1,16
s	0,73
cl	0,25
p	25,52
w	9,65

Project 1 - Cyclone

Tab. 2 Ash characteristic

Ash grain size, μm	Contribution of fraction, [%]
0-10	15
10-20	10
20-60	35
>60	40

Cyclone

Molar fuel composition, kmol/kg

Minimal oxygen requirement $n_{o,min}$, kmol/kg

Minimal air requirement $n_{a,min}$, kmol/kg

Real air requirement n_a, kmol/kg

Molar exhaust gas composition, kmol/kg

total amount of exhaust gas n", kmol/kg

Cyclone

Dry exhaust gas composition [], kmol/kmol
Wet exhaust gas composition () kmol/kmol
Exhaust gas stream in standard conditions, m_n^3/s
Exhaust gas stream m^3/s
Stream of dust in exhaust gas (before cyclone), $\dot{m}_{a1}$, kg/s
Stream of dust in exhaust gas (after cyclone), $\dot{m}_{a2}$, kg/s
Dust emission (before cyclone), E_{a1}, g/m^3
Dust emission (after cyclone), E_{a2}, g/m^3

Cyclone

Dynamic viscosity η, μ [Pas], [Ns/m^2], [kg/sm]

Exhaust gas density ρ [kg/m^3]

Kinematic viscosity ν [m^2/s]

$$\nu = \frac{\eta}{\rho}$$

Cyclone

Dynamic viscosity η, μ [Pas], [Ns/m²], [kg/sm]

$$\eta_m = \frac{\sum_{i=1}^{n} z_i \cdot \eta_i \cdot \sqrt{M_i \cdot T_{ki}}}{\sum_{i=1}^{n} z_i \cdot \sqrt{M_i \cdot T_{ki}}}$$

Formula Sutherlanda:

$$\eta = \eta_o \cdot \left(\frac{273 + C}{T + C} \right) \cdot \left(\frac{T}{273} \right)^{3/2}$$

Cyclone

Dynamic viscosity η, μ [Pas], [Ns/m^2], [kg/sm]

Tab. 3. Gas charakteristic

i	$\sqrt{M_i \cdot T_{ki}}$	$\eta_o \cdot 10^6$ [Pas]	C_m [K]
H_2O	108,0	8,17	650
CO_2	115,5	13,84	274
N_2	59,5	16,65	118
O_2	70,2	19,42	138

$$\eta_{SO_2} = 1{,}9 \cdot 10^{-5}\, Pa \cdot s$$

$$\eta_{HCl} = 2{,}2 \cdot 10^{-5}\, Pa \cdot s$$

$$T_{kSO_2} = 157{,}7^o C$$

$$T_{kHCl} = 51{,}4^o C$$

Cyclone

Exhaust gas density ρ [kg/m³]

$$p \cdot v = \frac{(MR) \cdot T}{M} \qquad where \quad v = \frac{1}{\rho} \qquad \rho_{sp} = \frac{p}{\frac{(MR)}{M} \cdot T_{sp}}$$

Cyclone

Kinematic viscosity ν [m²/s]

$$\nu = \frac{\eta}{\rho}$$

Cyclone

I Input data

II Maximum limit value of diameter of ash grain (knowing composition of ash fraction and efficiency of separation in cyclone)

III Cyclone construction (framework)

IV Assumption of average inlet gas velocity and calculation (extrapolation) of r_{cmax} value. Acceptance of radius of cyclone r_c.
Condition: $r_c < r_{cmax}$, $\dot{V}_{eg} = A_w \cdot \bar{v}_i$, $\dot{V}_{eg} \leq 2{,}5 \frac{m^3}{s}$ $d_a^* \leq d_{amax}^*$, $\eta \geq \eta_n$

V Calculation of flow resistances and loss of pressure Δp,
Condition: $\Delta p \leq \Delta p_{perm}$

Cyclone

Tab. 4. The average diameter of ash grain for each fraction

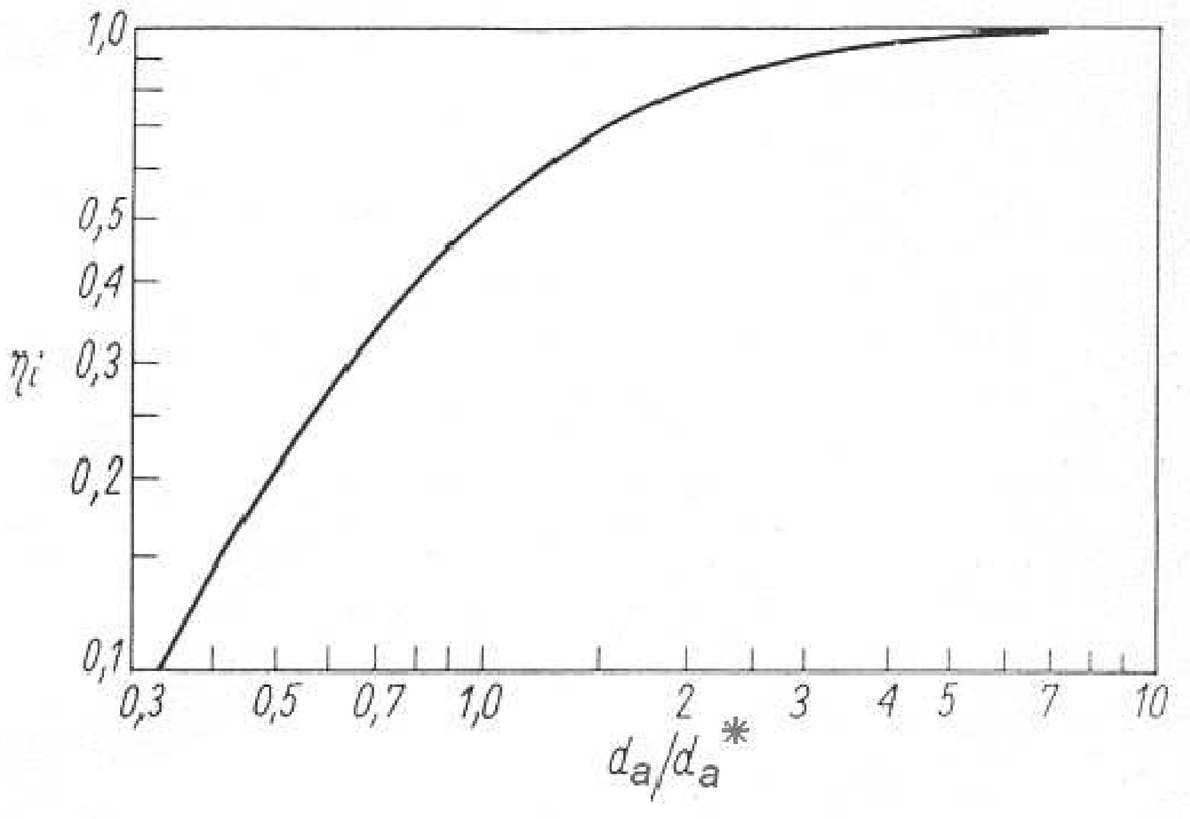
Ash grain diameter, μm	Contribution of fraction, %	Average diameter of ash grain for each fraction, d_{ai}, μm
0-10	15	
10-20	10	
20-60	35	
60-100	40	

Cyclone

The average diameter of ash grain

$$d_a = \frac{\sum_{i=1}^{n} g_i \cdot d_{ai}}{\sum_{i=1}^{n} g_i}$$

Cyclone efficiency as a function of ash grain diameter ratio



Find d_a^*

for given efficiency

Cyclone construction parameters

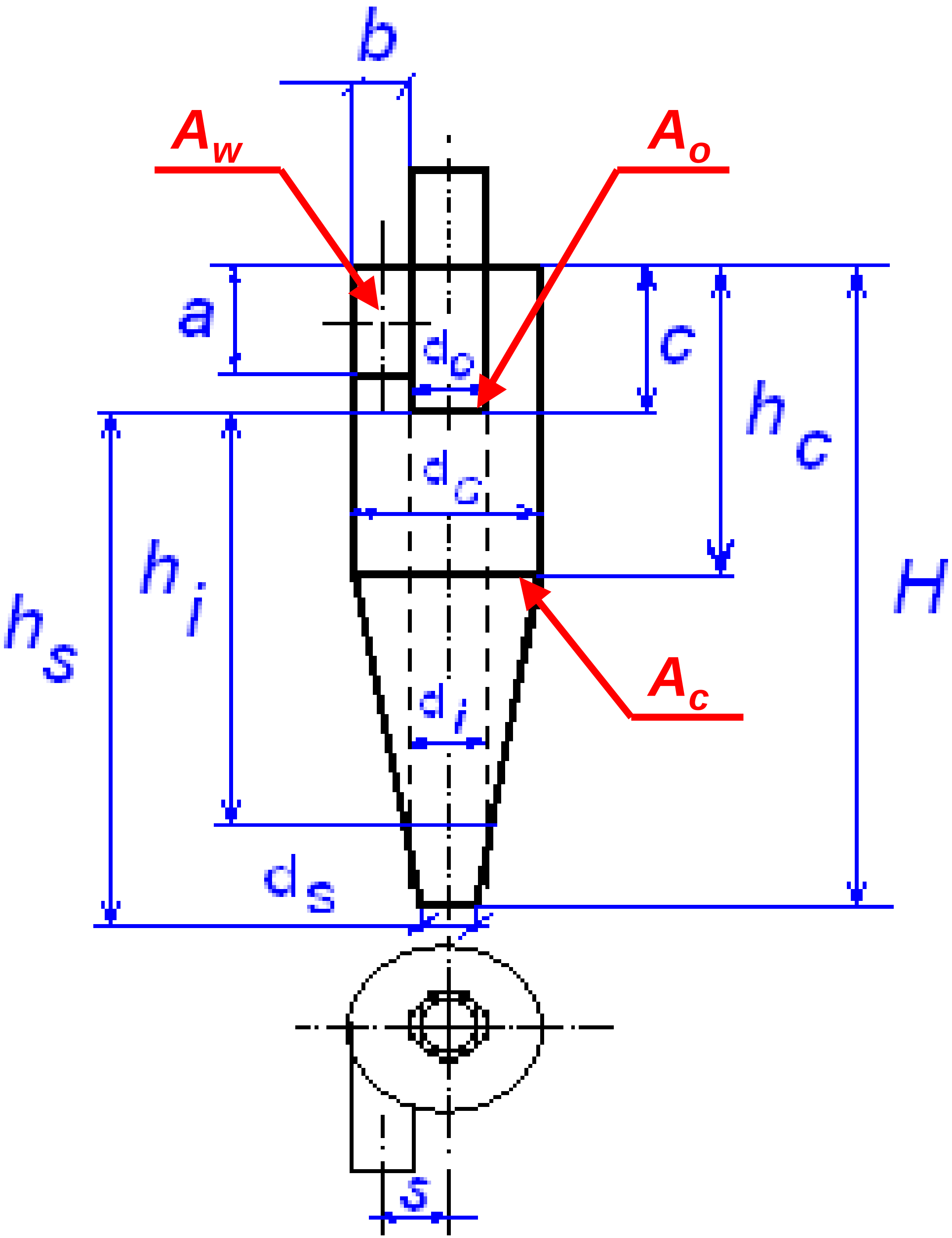
$$r_c = 0{,}1 - 0{,}5\ m$$

$$\frac{r_o}{r_c} = 0{,}35 - 0{,}8$$

$$\frac{h_i}{r_o} = 4{,}6 - 16{,}4$$

$$\frac{A_o}{A_c} = 0{,}123 - 0{,}639$$

$$\frac{A_w}{A_c} = 0{,}135 - 0{,}230$$



Cyclone construction parameters

$$a < c$$

$$b < (r_c - r_o)$$

$$H = c + h_s$$

$$h_s = 4{,}6 \cdot r_o \cdot \left(\frac{4 r_c}{a \cdot b} \right)^{1/3}$$

$$c > h_c$$

$$\frac{a}{2r_c} = 0{,}45 - 0{,}6$$

$$\frac{b}{2r_c} = 0{,}2 - 0{,}3$$

$$\frac{a}{b} = 2 - 2{,}5$$

$$\frac{h_s}{2r_c} = 3{,}5 - 4{,}5$$

Cyclone construction parameters

$$\frac{r_o}{r_c} = 0{,}4 - 0{,}6$$

$$\frac{h_c}{2r_c} = 1{,}5 - 2{,}2$$

$$\frac{d_s}{2r_c} = 0{,}3 - 0{,}4$$

On the assumption that:

- Average inlet gas velocity: $\bar{v}_i = 8 - 15 \quad m/s$

Calculate

Maximum radius of cyclone cylindric part r_{cmax}

Smuchin, Kouzow Formula

$$d_a{}^* = \left(\frac{9 \cdot \eta_g}{\pi \cdot n \cdot \omega \cdot \rho_a} \cdot \ln \frac{r_c}{r_o} \right)^{1/2}$$

where

$$n = \frac{\bar{v}_i}{(1{,}6 \div 1{,}7) \cdot (r_c + r_o) \cdot \pi}$$

Number of gas stream circulation in cyclone

$$\omega = \frac{2\bar{v}_s}{r_c + r_o}$$

Angular velocity of gas stream

$$\bar{v}_s = \frac{\bar{v}_i}{(1{,}6 \div 1{,}7)}$$

Average value of tangent component of gas stream velocity

Fuchs Formula

$$d_a^* = \left(\frac{18 \cdot \eta_g \cdot a}{\pi \cdot n_o \cdot \rho_a \cdot \bar{v}_i} \right)^{1/2}$$

where

$$n_o = 2 \div 4$$

Number of gas stream circulation in cyclone

Lapple Formula

$$d_a{}^* = \left(\frac{9 \cdot \eta_g \cdot a \cdot b^2}{\dot{V}_g \cdot \rho_a \cdot \theta} \right)^{1/2}$$

where

$$\theta = \frac{\pi}{a} \cdot \left[2h_c + (H - h_c) \right]$$

Number of gas stream circulation in cyclone

or

$$\theta = 12 \cdot \pi$$

$$\theta = 2 \cdot \pi (0{,}5 \div 10)$$

Stream continuity condition

$$\dot{V}_{eg} = A_w \cdot \bar{v}_i$$

Flow continuity condition

$$\rho_1 v_1 A_1 = \rho_2 v_2 A$$

$$\dot{V}_{eg} = A_w \cdot \bar{v}_i$$

Loss of pressure

$$\Delta p = \xi \frac{{v_i}^2}{2} \rho_g$$

$\xi - pressure\ loss\ coefficient\ of\ cyclone$

$$\xi = \xi_i + \xi_o$$

$\xi_i - pressure\ loss\ coefficient\ of\ inlet\ part\ of\ cyclone$

$\xi_o - pressure\ loss\ coefficient\ of\ outlet\ part\ of\ cyclone$

Pressure loss coefficiens

$$\xi_i = \frac{r_o}{r_c}\left(\frac{v_{so}}{\bar{v}_o}\right)^2\left[\frac{1}{\left(1-\frac{v_{so}}{\bar{v}_o}\frac{h_s}{r_o}\lambda\right)^2}-1\right]$$

Where

$\left(\frac{v_{so}}{\bar{v}_o}\right) > 1$

$$\xi_o = K\left(\frac{v_{so}}{\bar{v}_o}\right)^{4/3}+\left(\frac{v_{so}}{\bar{v}_o}\right)^2$$

Where

$\left(\frac{v_{so}}{\bar{v}_o}\right) < 1$

$$\xi_o = K_o\left(1-\frac{v_{so}}{\bar{v}_o}\right)+K\left(\frac{v_{so}}{\bar{v}_o}\right)^{4/3}+\left(\frac{v_{so}}{\bar{v}_o}\right)^2 \approx 2\left(\frac{v_{so}}{\bar{v}_o}\right)^2$$

Pressure loss coefficiens

Coefficient of friction: $$\lambda = \lambda_g \left(1 + C\sqrt{S_m}\right)$$

Where

λ_g - friction coeffictient for gas without dust, assume $\lambda_g = 0{,}005$

$$S_m = \frac{\dot{m}_{p1}}{\rho_{eg}\dot{V}_{eg}}, \left[\frac{kg_{ash}}{kg_{eg}}\right]$$

C=2 where $S_m<1$

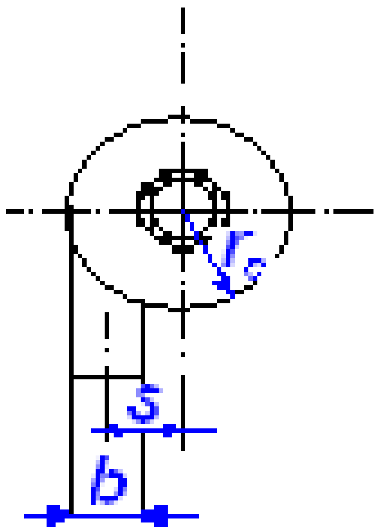
C=3 where $S_m>1$

Pressure loss coefficiens

$$\frac{v_{so}}{\bar{v}_o} = \frac{1}{\frac{A_w}{A_o}\frac{r_o}{s}\alpha + \frac{h_i}{r_o}\lambda}$$

where

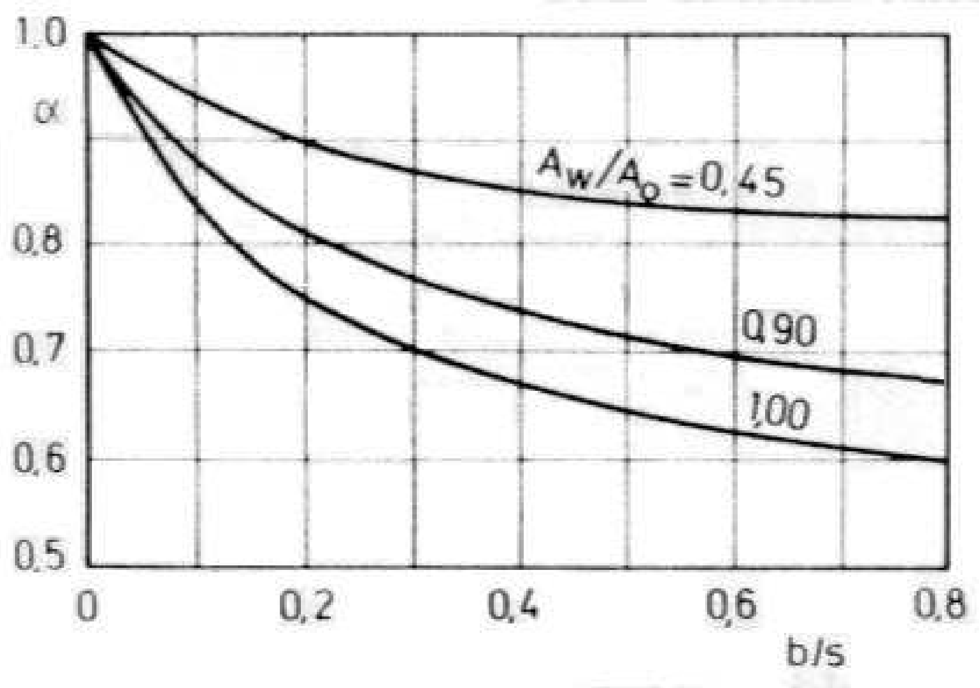
$$s = r_c - \frac{1}{2}b$$



Pressure loss coefficiens

$$\alpha = 1 - \left(0{,}54 - 0{,}153\frac{A_o}{A_w}\right)\left(\frac{b}{r_c}\right)$$

or from figure below



Pressure loss coefficiens

K, K_o – coefficients depend on edge of outlet pipe

K=4,4 for sharp edge of outlet pipe

K=3,4 for blunt edge of outlet pipe

K_o=2,0 for sharp edge of outlet pipe

K_o=1,1 for blunt edge of outlet pipe

Loss of pressure

$$\Delta p \leq \Delta p_{perm}$$

where

Δp_{perm} = 0,8-1,2 kPa (2,5 kPa)