At pressure p^*_{iz} can be the velocity in core of the stream equal as sound velocity. But the velocity of flow can be subsonic on the periphery of the flow area due to boundary layer at the wall of the nozzle. Therefore the mean velocity at the throat of the nozzle is smaller than sound velocity respective the mean kinetic energy of the stream is smaller than kinetic energy for case sound velocity[18]. The mean velocity stream is equal the sound velocity at the pressure p^* see chapter viz kapitola 38. Flow of gas through channel with constant flow area.

[18]*Remark*
If the heat capacity ratio κ is not the same as at isentropic expansion, then konetic energy of speed sound is not the same as isentropic expansion (see speed of sound formula). It means, enthalpy is changed $i^*\neq i^*_{iz}$.

Efficiency of nozzle

The nozzle loss is can calculated through energy parameters of the nozzle as a **velocity coefficient φ** and a **nozzle efficiency η**:

$$\varphi=\frac{c_e}{c_{e,iz}};\quad \eta=\frac{i_{ic}-i_e}{i_{ic}-i_{e,iz}}=\frac{c_e^2}{c_{e,iz}^2}=\varphi^2$$

20.569 *The energy parameters of the nozzle.*
φ [-] velocity coefficient; **η** [-] nozzle efficiency. The values of the velocity coefficients φ are shown in [4, p. 328] (for convergent nozzle including the cone nozzles) a [4, p. 348] (for Laval nozzles).

The description of the static state profile inside the nozzle or comparing two different nozzles cam be through a **polytropic index**. Mean value of the polytropic index can be derived from equation for difference of specific enthalpy between two states of the gas:

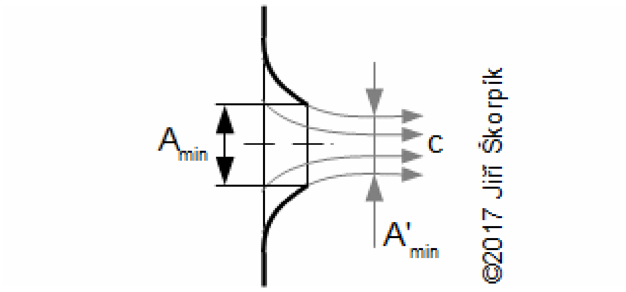
$$n=\frac{\log\varepsilon}{\log\varepsilon-\log K};\quad K=1-\frac{(i_i-i_e)(\kappa-1)}{\kappa\cdot r\cdot T_i}$$

21.883 *The equation for calculation mean value of polytropic index between two state of gas.*
n [-] polytropic index.

Calculate the throat area and the exit area of the de Laval nozzle and its efficiency. Through the de Laval nozzle flows the water steam saturation. The mass flow rate is $0,2\ kg\cdot s^{-1}$. The stagnation pressure at the inlet of the nozzle is $200\ kPa$ and back-pressure is $20\ kPa$. The velocity coefficient of the nozzle is $0,95$. The solution of this problem is shown in the Appendix 109.
Problem 5.109

Contraction of flow and mass flow coefficient

The mass flow is increased not only under internal friction of fluid but also under a **contraction** of flow behind narrowest area of the nozzle [15 p. 14]. The contraction of flow is caused by inertia flow and it has the same impact as an decreasing flow area of the nozzle:



22.761 *Contraction of flow inside the nozzle.*
A'$_{min}$ [m^2] flow area of nozzle at contraction. The contraction for cases perfectly made nozzles is very small (A_{min}≈A'_{min}), it is the bigger for case orfice plates.

Real mass flow of the nozzle is calculated by **mass flow coefficient** (discharge coefficient), which takes into account influence of internal losses and the contraction of flow. The mass flow coefficient is ratio the real mass flow of the nozzle and isentropic mass flow without any contraction:

$$\mu=\frac{\dot{m}}{\dot{m}_{iz}}$$

23.478 *Mass flow coefficient.*
μ [-] mass flow coefficient.; **m$^\bullet_{iz}$** [kg·s^{-1}] mass flow rate at flow without loss (isentropic expansion).

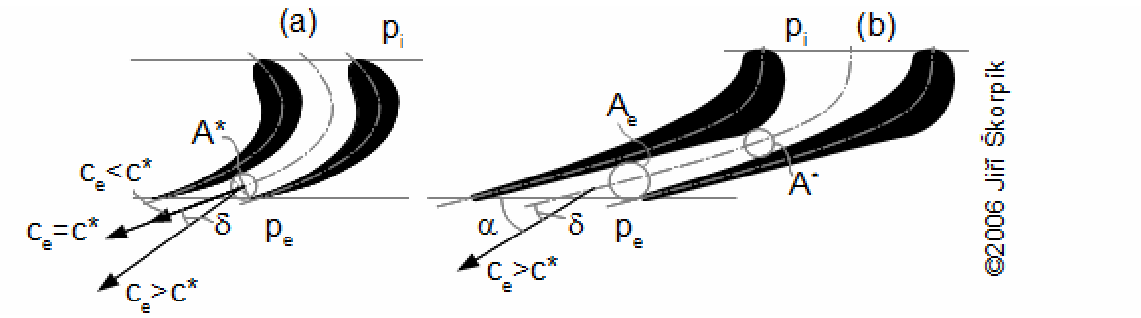
Values of the mass flow coefficients any types of the nozzles and the orffice plates are shown in [4], [15].

Some applications of nozzle theory

The theory of the nozzles can be aplicated on various type of flow devices. Through theory of the nozzles be can descripted complicated flow system.

Nozzle as blade passage

The blade passage can have same shape as convergent nozzle or de Laval nozzle. The blade passage with de Laval profile is used for case supersonic velocity of working gas at the exit (decreasing of enthalpy between the inlet and the exit is under critical enthalpy $i*$). This type of blade passage has properties as oblique cut CD nozzle:



24.111 *The supersconic flow at the exit of blade passage.*
(a) convergent blade passage; **(b)** blade passge for supersonic flow. **A** [m^2] flow area; **δ** [°] deflection of supersonic flow from axis of passage. The procedure of calculation of angle δ is shown in [3, Equation 3.6-10] or be can use Prandtl-Meyer equation. Photos of high velocity flow of gas through blade rows are shown in chapter 16. Aerodynamics of airfoils and blade rows at compressible flow.