APPENDIX 102: Fluid dynamics, Flow of gases and steam through nozzles, Calculation of nozzle mass flow

The calculation here is based on the nozzle equations derived for ideal gas and lossless flow. This is a methodical problem, where the calculation of the required quantities can be done in the order as given in the entered parameters, i.e. first we decide whether critical flow occurs, then we calculate the outlet velocity and finally we calculate the mass flow through the nozzle.

Entered parameters of the problem are:

V_i	p_i	t_i	p_e	A_e	c_p	r	κ
250	1	350	0,25	15	1,01	287	1,4

V [m·s^{-1}]; p [MPa]; t [°C]; A [cm²]; c_p [kJ·kg^{-1}·K^{-1}]; r [J·kg^{-1}·K^{-1}]; κ [1]

A102/2: To determine if the flow in the nozzle is critical, compare the stagnation nozzle pressure ratio ε_s with the critical pressure ratio for dry air ε^*_s. The nozzle static pressure ratio ε can also be used. If the static pressure ratio ε is less than the pressure ratio ε^*_s, it is certain that critical flow will occur.

The critical pressure for dry air can be calculated using FORMULA 515, (p. 5):

ε^*_s	ε
0,5283	0,25

[1]

If $\varepsilon<\varepsilon^*_s$ is valid, it means that critical conditions will occur, therefore the quantities at the nozzle outlet will be indexed* to show that this is a critical condition at this point.

A102/3: The calculation of the outlet velocity V_e can be based on EQUATION 101b, (p. 4) In this case the total absolute temperature T_{is}, must be determined, the pressure ratio in the nozzle throat will be critical.

We calculate the total temperature t_{is} using the definition equation of the total enthalpy h_s (see also FIGURE 101, p. 4) equation to calculate the enthalpy as a function of heat capacity temperature at constant pressure [Škorpík, 2024]:

$$h_{is}=h_i+\frac{V_i^2}{2},\ C_p\cdot t_{is}=C_p\cdot t_i+\frac{V_i^2}{2},\ t_{is}=t_i+\frac{V_i^2}{C_p\cdot 2}.$$

t_{is}	T_{is}	V^*_e
380,94	654,09	467,97

t [°C]; T [K]; V [m·s^{-1}]

A102/4: If the critical state is reached in the nozzle, then EQUATION 515, (p. 5) can be used for the mass flow through the nozzle.

The stagnation pressure at the nozzle inlet p_{is} can be calculated from the isentropy equation and the ideal gas equation of state [Škorpík, 2024]:

$$p_{is} \cdot v_{is}^{\kappa} = p_i \cdot v_i^{\kappa},\ v = \frac{r \cdot T}{p} \Rightarrow p_{is} = p_i \left(\frac{T_{is}}{T_i} \right)^{\frac{\kappa}{1-\kappa}}.$$

The equation of state of an ideal gas can also be used to calculate the specific volume v_{is}:

χ_{max}	p_{is}	v_{is}	m^*
0,6847	1,1848	158,44	2,8086

p [MPa]; v [$dm^3 \cdot kg^{-1}$]; m [$kg \cdot s^{-1}$]