# APPENDIX 109: Fluid dynamics, Flow of gases and steam through nozzles, Calculation of Laval nozzle dimensions in flow with losses

*The thermodynamic data of $H_2O$ and the h-s diagram describing the expansion with losses in FIGURE 108, (p. 14) can be used in the calculation.*

Entered parameters of the problem are:

| $m$ | $p_{i,s}$ | $p_e$ | $\varphi$ |
|---|---|---|---|
| 0,2 | 200 | 20 | 0,95 |

$m$ [kg·s$^{-1}$]; $p$ [kPa]; $\varphi$ [1]

**A109/2:** The nozzle efficiency can be calculated using EQUATION 369, p. 15:

| $\eta$ |
|---|
| 0,9025 |

[1]

**A109/3:** The individual steam states in the *h-s* diagram can be read off from the $H_2O$ tables or calculated, for example, in the following order:

| $h_{i,s}$ | $s_i$ | $h_{e,is}$ |
|---|---|---|
| 2706,2 | 7,1269 | 2348,9 |

$h$ [kJ·kg$^{-1}$]; $s$ [kJ·kg$^{-1}$·K$^{-1}$]

Calculation:

| $V_{e,is}$ | $h_e$ | $V_e$ |
|---|---|---|
| 845,35 | 2383,8 | 803,08 |

$V$ [m·s$^{-1}$]; $h$ [kJ·kg$^{-1}$]

Read off:

| $v_e$ | $\varepsilon^*_s$ |
|---|---|
| 6,9176 | 0,577 |

$v$ [m$^3$·kg$^{-1}$]; $\varepsilon$ [1]

Calculation of critical pressure $p_{is}$ according to EQUATION 515, p. 4.4:

| $p^*_{is}$ |
|---|
| 115,40 |

[kPa]

The critical enthalpy can be read off from the intersection of the isentropy $s_i$ and the pressure $p^*_{is}$:

| $h^*_{is}=h^*$ |
|---|
| 2612,0 |

[kJ·kg$^{-1}$]

Calculation of $V^*$ and $h^*_L$ assuming constant efficiency in the nozzle according to FORMULA 369, (p. 15):

$$\eta = \frac{h_{i,s} - h^*}{h_{i,s} - h^*_L}.$$

| $V^*$ | $h^*_L$ |
|---|---|
| 434,07 | 2601,8 |

$V$ [m·s$^{-1}$]; $h$ [kJ·kg$^{-1}$]

Pressure $p^*$ as the intersection of isentropy $s_i$ and enthalpy $h^*_L$ and specific volume $v^*$ as the intersection of $p^*$ and $h^*$:

| $p^*$ | $v^*$ |
|---|---|
| 108,5 | 1,5231 |

$p$ [kPa]; $v$ [m$^3$·kg$^{-1}$]

**A109/4:** The nozzle outlet flow area $A_e$ can be calculated from the nozzle continuity equation (EQUATION 334, p. 4):

| $A^*$ | $A_e$ |
|---|---|
| 7,0178 | 17,227 |

[cm$^2$]

**A109/5:** From the flow areas and EQUATIONS 993, (p. 9), 703, (p. 10), the individual dimensions for the nozzle design can be calculated. For the calculation, the nozzle angle must be designed. The design of this angle shall be carried out within the recommended range:

| $\alpha$ |
|---|
| 10 |

[°]

| r* | $r_e$ | $r_r$ | t | $r_t$ | l |
|---|---|---|---|---|---|
| 1,4946 | 2,3417 | 0,5709 | 0,0498 | 1,4968 | 9,7075 |

[cm]