Steam Nozzle Exit Velocity, Critical Pressure and Areas

Exit velocity of steam from a nozzle from the enthalpy drop, the critical (choked) pressure and throat mass flux found on the IF97 isentrope, and throat and exit areas for a flow.

Method: IAPWS-IF97 (water and steam); Isentropic nozzle flow (textbook)

Input parameters

Unit system: SI

Parameter	Value	Unit
Inlet pressure (absolute)	10.000	bar
Inlet steam	Superheated at the temperature below	
Inlet temperature (superheated)	250.00	°C
Exit pressure (absolute)	2.0000	bar
Nozzle efficiency	95.000	%
Approach velocity	0	m/s
Steam flow	3,600.0	kg/h

Calculated results

Parameter	Value	Unit
Isentropic enthalpy drop to the exit	315.75	kJ/kg
Actual enthalpy drop η Δh_s	299.96	kJ/kg
Exit velocity √(2 Δh + V₁²)	774.54	m/s
Critical (throat) pressure	5.4468	bar
Critical pressure ratio	0.54468	
Throat velocity	513.59	m/s
Throat area for the flow	722.35	mm²
Exit area for the flow	1,110.9	mm²
Dryness at the exit (1 when superheated)	97.139	%

Notes for this case

- The exit pressure is below the critical pressure: the nozzle must be convergent–divergent.
- The expansion enters the wet region: equilibrium expansion on the IF97 isentrope is assumed; real nozzles supersaturate and pass slightly more flow.

Formula and method

$$V_2 = \sqrt{2\,\eta_n\,\Delta h_s + V_1^2} = 44.72\sqrt{\eta_n\,\Delta h_s\ [\mathrm{kJ/kg}]}\quad (V_1 = 0)$$

$$G = \rho\sqrt{2(h_0 - h)}\ \text{ on }\ s = s_1,\quad p_c : G = G_{max}$$

$$A_t = \frac{\dot m\, v_t}{V_t},\quad A_2 = \frac{\dot m\, v_2}{V_2}$$

Variables

p_1	Inlet pressure (absolute)	Pa
inlet	Inlet steam	-

T_1	Inlet temperature (superheated)	K
p_2	Exit pressure (absolute)	Pa
η_n	Nozzle efficiency	-
V_1	Approach velocity	m/s
$\dot{m}$	Steam flow	kg/s
Δh_s	Isentropic enthalpy drop to the exit	J/kg
Δh	Actual enthalpy drop η Δh_s	J/kg
V_2	Exit velocity √(2 Δh + V_1^2)	m/s
p_c	Critical (throat) pressure	Pa
p_c/p_1	Critical pressure ratio	-
V_t	Throat velocity	m/s
A_t	Throat area for the flow	m²
A_2	Exit area for the flow	m²
x_2	Dryness at the exit (1 when superheated)	-

Method and standards

Steady adiabatic flow: kinetic energy gained equals enthalpy lost. The critical (choked) pressure is where the mass flux on the IF97 isentrope is greatest.

Assumptions and limits

- Equilibrium expansion; supersaturation not modelled.
- Nozzle efficiency applied to the whole drop. For a convergent nozzle (exit above the critical pressure) the throat is the exit, so the throat values equal the exit values at the actual state.
- With an approach velocity the flux uses the stagnation enthalpy h_0, while the critical pressure ratio is referred to the static inlet pressure, not the stagnation pressure used in some textbooks.
- The critical pressure is searched between 0.2 and 0.999 p_1; a result at the edge is flagged.

References

- IAPWS-IF97 (water and steam)
- Isentropic nozzle flow (textbook)

Report details

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Results are for engineering estimation. Verify critical designs against the referenced standards and your own data.

This calculator online

https://calc.firecad.com/boilers-power-plant/turbines-cycles/steam-nozzle-velocity

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Reopens the calculator with the inputs of this report.