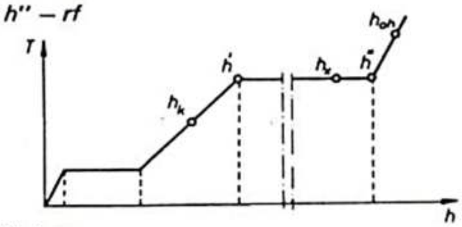
STEAM

Enthalpy

$$h_x = h'' - rf$$



$$h_x = h' + rx$$

h_x	specific enthalpy for wet steam	J/kg
h''	specific enthalpy for dry saturated steam	J/kg
r	evaporation heat	J/kg
f	humidity	1
h'	specific enthalpy for boiling water	J/kg
x	dryness	1

$$h_{oh} = h'' + c_{oh}\,\Delta T$$

h_{oh}	specific enthalpy for superheated vapor	J/kg
c_{oh}	specific heat capacity for super-heated vapor/steam	J/kg · K
ΔT	temperature difference	K

Specific heat capacity for superheated steam

$$c_{oh} = \frac{\Delta h_{oh}}{\Delta T_{oh}}$$

Δh_{oh}	enthalpy increase	J/kg
ΔT_{oh}	temperature increase	K

Steam density

$$\rho = \frac{1}{v}$$

ρ	density	kg/m^3
v	specific volume	m^3/kg

Specific volume of wet steam

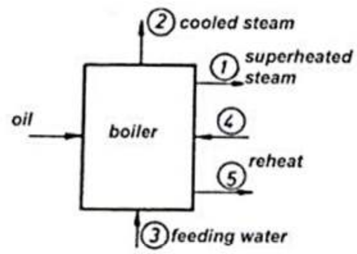
$$v_x = v'(1 - x) + v''x$$

v_x	specific volume of wet steam	m^3/kg
v'	water volume	m^3/kg
x	dryness	1
v''	steam volume	m^3/kg

Efficiency

Boiler efficiency

$$\eta_k = \frac{\dot{m}_1 h_1 + \dot{m}_2 h_2 + \dot{m}_5 h_5 - \dot{m}_3 h_3 - \dot{m}_4 h_4}{\dot{m}_B h_g}$$



η_k	boiler efficiency	1
$\dot{m}_1$	flow of super-heated steam	kg/s
h_1	enthalpy of super-heated steam	J/kg
$\dot{m}_2$	flow of cooled steam	kg/s
h_2	enthalpy of cooled steam	J/kg
$\dot{m}_3$	flow of feeder water	kg/s
h_3	enthalpy of feeder water	J/kg
$\dot{m}_4$	flow of reheated steam	kg/s
h_4	enthalpy in reheated steam to the boiler	J/kg
$\dot{m}_5$	flow of reheated steam	kg/s
h_5	enthalpy in reheated steam from the boiler	J/kg
$\dot{m}_B$	fuel consumption	kg/s
h_g	gross calorific value	J/kg

Turbine inner efficiency

$$\eta_i = \frac{H_i}{H_A} = \frac{h_{oh} - h_2}{h_{oh} - h_1}$$

η_i	inner efficiency of turbine	1
H_i	indicated decreased enthalpy	J/kg
H_A	adiabatic enthalpy fall	J/kg
h_{oh}	superheated steam enthalpy	J/kg
h_2	enthalpy of steam at real end condition, before condenser	J/kg
h_1	enthalpy of steam after adiabatic expansion	J/kg

Mechanical efficiency

$$\eta_m = \frac{P_s}{P_i}$$

η_m	mechanical efficiency	1
P_S	shaft effect	W
P_i	indicated effect	W

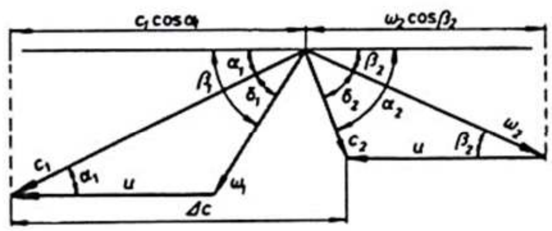
Thermo efficiency of turbine and condenser (without drain off and pre-heating	$\eta_{tp} = \frac{h_{oh} - h_2}{h_{oh} - h_k}$	η_{tp}	thermo efficiency of the process	1
		h_2	enthalpy at leaving turbine	J/kg
		h_k	enthalpy of condensate	J/kg
Thermo efficiency of plant (without drain off and pre-heating)	$\eta_{ta} = \frac{\dot{m}_D (h_{oh} - h_2)}{\dot{m}_B h_g} = \eta_{tp} \eta_k$	η_{ta}	thermo efficiency of the plant	1
		$\dot{m}_D$	steam production	kg/s
		η_k	boiler efficiency	1
Flow in narrow pipes	$c_o = \sqrt{2(h_1 - h_2) + c^2}$	c_o	theoretic flow velocity	m/s
		c	velocity before "narrow pipe"	m/s
		h_1	specific enthalpy (before)	J/kg
		h_2	specific enthalpy (after)	J/kg
	$c_o = 44.72 \sqrt{(h_1 - h_2)}$	h_1 and h_2 are in kJ/kg		
	$c_1 = c_o \phi$	c_1	real flow velocity	m/s
		ϕ	velocity factor	1
Critical pressure	$p_c = 0.577\, p_1$	p_c	critical pressure	Pa
		p_1	pressure before "narrow pipe"	Pa
	$p_c = 0.546\, p_1$	0.577 factor for saturated steam 0.546 factor for superheated steam		
Steam flow	$\dot{m}_D = \frac{A_c c_k}{v}$	$\dot{m}_D$	flow of steam	kg/s
		A_c	critical cross section (area)	m^2
		c_k	critical velocity	m/s
		v	specific volume	m^3/kg

WORK OF STEAM (STEAM ENERGY)

Turbine without loss	$W = \frac{1}{2} mc^2$	work m mass c velocity	J kg m/s
	$W_n = \frac{1}{2} m\,(c_0^2 - c_1^2)$	W_n loss at narrow Pipe c_0 theoretic velocity c_1 real velocity	J m/s m/s
	$W_\upsilon = \frac{1}{2} m\,(\omega_1^2 - \omega_2^2)$	W_υ blade/vane loss ω_1 relative in-velocity of steam ω_2 relative out-velocity of steam	J m/s m/s
	$W_\sigma = \frac{1}{2} m\, c_2^2$	W_σ discharge flow (outward flow loss) c_2 velocity from blades (vanes)	J m/s
Real turbine	$W_e = W - W_n - W_\upsilon - W_\sigma$	W_e real work	J

$$W_e = \frac{1}{2} m\,[c_0^2 - (c_0^2 - c_1^2) - (\omega_1^2 - \omega_2^2) - c_2^2]$$

Trigonometric calculations of velocities	$\omega_1^2 = c_1^2 + u^2 - 2c_1 u \cos \alpha_1$	ω_1 relative in-velocity of steam c_1 velocity into narrow pipes u rotation velocity of vanes α_1 angle of "narrow pipe"	m/s m/s m/s rad



$$\frac{\sin \delta_1}{u} = \frac{\sin \alpha_1}{\omega_1}$$

$$\angle\beta_1 = \angle\alpha_1 + \angle\delta_1$$

β_1 in-angle of vanes — rad

$$c_2^2 - \omega_2^2 + u^2 - 2\omega_2 u \cos\beta_2$$

c_2	absolute velocity outward from vanes	m/s
ω_2	relative out-velocity of steam	m/s
β_2	out-angle of vanes	rad

$$\frac{\sin\delta_2}{u} = \frac{\sin\beta_2}{c_2}$$

$$\angle\alpha_2 = \angle\delta_2 + \angle\beta_2$$

α_2	out-angle of steam-jet	rad

$$\Delta c = c_1 \cos\alpha_1 + \omega_2 \cos\beta_2 - u$$

Δc	change of velocity	m/s

$$\Delta c = \omega_1 \cos\beta_1 + \omega_2 \cos\beta_2$$

Effect

$$P = \dot{m}_0 u \,\Delta c$$

P	effect	W
$\dot{m}_0$	steam flow	kg/s

Degree of reaction

$$\rho = \frac{(\omega_2^2 - \omega_1^2)}{(c_1^2 - c_2^2) + (\omega_2^2 - \omega_1^2)}$$

ρ	degree of reaction	1

Twisted blades/vanes

$$\delta = \beta'_1 - \beta_1$$

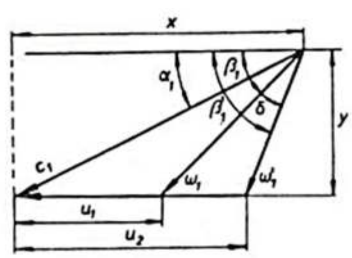
δ	angular twist	rad
β'_1	in-angle of steam at end of vanes	m/s
β_1	in-angle of steam at root of vanes	m/s

$$t_g\,\beta_1 = \frac{y}{x - u_1}$$

u_1	peripheral velocity at root	m/s

$$t_g\,\beta'_1 = \frac{y}{x - u_2}$$

u_2	peripheral velocity at end	m/s

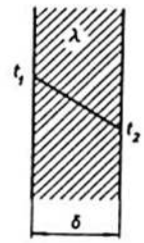


ω_1	relative-velocity of steam at vane root	m/s
ω'_1	relative-velocity of steam at vane end	m/s
c^1	in-velocity of steam	m/s
α_1	in-angle of steam-jet	rad

HEAT TRANSFER IN BOILERS

Heat conduction

$$P = \frac{\lambda}{\delta} A \; (T_1 - T_2)$$



P	effect	W
λ	thermal conductivity	W/m · K
δ	thickness of material	m
A	area	m^2
$T_1 - T_2$	temperature difference	K

Convection

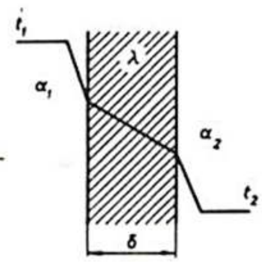
$$P = \alpha A \; (T_1 - T_2)$$

P	effect	W
α	heat transfer coefficient	$W/m^2 \cdot K$

Simultaneous conduction and convection

$$P = k A \; (T_1 - T_2)$$

$$k = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}}$$



P	effect	W
k	heat transfer (through) coefficient	$W/m^2 \cdot K$
α_1	heat transition coefficient gas – wall/material	W/m^2
α_2	heat transition coefficient water – wall/ material	W/m^2
λ	thermal conductivity	W/m · K
δ	thickness of material	m