Regenerative Rankine Cycle (Open Feed Heater)

Thermal efficiency of a Rankine cycle with one open feedwater heater (deaerator), the bled-steam fraction and net work, from the steam and heater conditions (IAPWS-IF97).

Method: IAPWS R7-97(2012) IF97; first and second laws of thermodynamics

Input parameters

Unit system: SI

Parameter	Value	Unit
Inlet steam pressure (absolute)	66.000	bar
Inlet steam condition	Superheated at the temperature below	
Inlet steam temperature (superheated only)	485.00	°C
Feedwater heater (bleed) pressure (absolute)	4.0000	bar
Condenser pressure (absolute)	10.000	kPa
Turbine isentropic efficiency (each section)	85.000	%
Pump isentropic efficiency (condensate and feed pumps)	75.000	%

Calculated results

Parameter	Value	Unit
Cycle thermal efficiency	35.507	%
Steam bled to the heater, per kg of main steam	15.845	%
Net work per kg of main steam	982.15	kJ/kg
Specific steam consumption (per kWh of net shaft work)	3.6654	kg/kWh
Heat added in the boiler	2,766.1	kJ/kg
Turbine exhaust dryness	88.618	%

Formula and method

$$y = \frac{h_f(p_h) - h_{p1}}{h_x - h_{p1}} \qquad w_t = (h_1 - h_x) + (1 - y)(h_x - h_4)$$

$$h_x = h_1 - \eta_t \left[h_1 - h(p_h, s_1)\right] \qquad h_4 = h_x - \eta_t \left[h_x - h(p_2, s_x)\right]$$

$$h_{p1} = h_f(p_2) + w_{p1},\ w_{p1} = \frac{h(p_h, s_f) - h_f(p_2)}{\eta_p} \qquad h_{p2} = h_f(p_h) + w_{p2},\ w_{p2} = \frac{h(p_1, s_f) - h_f(p_h)}{\eta_p}$$

$$w_p = (1 - y)\, w_{p1} + w_{p2} \qquad q_{in} = h_1 - h_{p2} \qquad \eta_{th} = \frac{w_t - w_p}{q_{in}} \qquad SSC = \frac{1}{w_t - w_p}$$

Variables

p_1	main steam pressure, absolute	Pa
state	dry saturated or superheated steam	–
T_1	main steam temperature	K
p_h	feed heater (bleed) pressure, absolute	Pa
p_2	condenser pressure, absolute	Pa
η_t	turbine isentropic efficiency, each section	–
η_p	pump isentropic efficiency (condensate and feed pumps)	–

η_{th}	cycle thermal efficiency	–
y	bled steam per kg of main steam	–
w_{net}	net work per kg of main steam	J/kg
SSC	specific steam consumption	kg/J
q_{in}	heat added in the boiler	J/kg
x_4	turbine exhaust dryness	–
$w_t\$, \$w_p$	turbine and pump work	J/kg
$w_{p1}\$, \$w_{p2}$	condensate pump and feed pump work	J/kg
$h_1\$, \$h_x\$, \$h_4$	main steam, bleed and exhaust enthalpies	J/kg
$h_{p1}\$, \$h_{p2}$	enthalpy after condensate pump and after feed pump	J/kg
h_f	saturated liquid enthalpy at heater pressure	J/kg
$s_x\$, \$s_f$	entropy at the bleed point, and of the saturated liquid entering each pump	J/(kg·K)

Method and standards

Rankine cycle with one open (mixing) feedwater heater leaving saturated liquid at heater pressure; isentropic efficiencies on both turbine sections and both pumps; states by FireCAD's IAPWS-IF97.

Assumptions and limits

- One open heater, no closed heaters, no reheat; no pressure drops; heater outlet saturated.
- The same η_t is applied to each turbine section, the LP section starting from the actual bleed state. Because of the reheat-factor effect the whole turbine is then slightly more efficient than η_t, so this cycle is not exactly like for like with the simple Rankine page at the same η_t.
- SSC is per kWh of net shaft work, before generator losses.

References

• IAPWS R7-97(2012) IF97
• first and second laws of thermodynamics

Report details

Report reference	FCC-SY0H-M68P (the same inputs always give the same reference)
Generated	17 November 2026, 19:46 UTC
Calculator	Regenerative Rankine Cycle (Open Feed Heater)
Method last reviewed	11 November 2026
Software release	FireCAD Calc, release of 17 November 2026
Release checks	3 reference cases of this calculator, computed independently, are checked on every release

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/regenerative-cycle-efficiency

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Reopens the calculator with the inputs of this report.