Turbine Cycle with up to Four Feedwater Heaters: Heat Balance

Extraction flows for up to four closed feedwater heaters from shell pressures, TTD and DCA, then turbine power, final feedwater temperature and cycle heat rate.

Input parameters

Unit system: SI

Parameter	Value	Unit
Throttle steam flow (= feedwater flow)	200.00	t/h
Throttle pressure (absolute)	130.00	bar
Throttle temperature	535.00	°C
Feedwater pressure through the heaters (absolute)	160.00	bar
Condenser pressure (absolute)	0.10000	bar
Expansion-line (section) isentropic efficiency	82.000	%
Heater 1	Closed heater, drains cascaded down	
Heater 1: extraction (shell) pressure, absolute	40.000	bar
Heater 1: terminal temperature difference	2.0000	K
Heater 1: drain cooler approach	6.0000	K
Heater 2	Closed heater, drains cascaded down	
Heater 2: extraction (shell) pressure, absolute	18.000	bar
Heater 2: terminal temperature difference	2.0000	K
Heater 2: drain cooler approach	6.0000	K
Heater 3	Closed heater, drains cascaded down	
Heater 3: extraction (shell) pressure, absolute	2.5000	bar
Heater 3: terminal temperature difference	2.5000	K
Heater 3: drain cooler approach	5.5000	K
Heater 4	Closed heater, drains cascaded down	
Heater 4: extraction (shell) pressure, absolute	0.70000	bar
Heater 4: terminal temperature difference	3.0000	K
Heater 4: drain cooler approach	5.5000	K
Gearbox and generator efficiency	97.000	%

Calculated results

Parameter	Value	Unit
Heater 1: extraction steam flow	17.614	t/h
Heater 1: extraction enthalpy	3,142.0	kJ/kg
Heater 1: feedwater outlet temperature	248.36	°C
Heater 1: drain outlet temperature	211.12	°C

Parameter	Value	Unit
Heater 2: extraction steam flow	25.947	t/h
Heater 2: extraction enthalpy	2,975.9	kJ/kg
Heater 2: feedwater outlet temperature	205.12	°C
Heater 2: drain outlet temperature	130.91	°C
Heater 3: extraction steam flow	10.877	t/h
Heater 3: extraction enthalpy	2,656.8	kJ/kg
Heater 3: feedwater outlet temperature	124.91	°C
Heater 3: drain outlet temperature	92.432	°C
Heater 4: extraction steam flow	10.900	t/h
Heater 4: extraction enthalpy	2,487.6	kJ/kg
Heater 4: feedwater outlet temperature	86.932	°C
Heater 4: drain outlet temperature	51.308	°C
Steam to the condenser	134.66	t/h
Exhaust dryness	0.86775	
Final feedwater temperature	248.36	°C
Generator output	51,851	kW
Heat added in the boiler	130,745	kW
Turbine cycle heat rate	9,077.6	kJ/kWh
Cycle efficiency	39.658	%
Generator output with no heaters	59,860	kW
Heat rate with no heaters	10,779	kJ/kWh
Heat-rate improvement from the heaters	15.783	%

Notes for this case

• All heaters are closed with drains cascaded to the next lower heater and the last drain to the condenser; feedwater flow equals throttle flow (no make-up, no reheat). Pump work and pressure losses in extraction lines are neglected. The no-heater case expands along one line of the same efficiency, which is slightly different from the sectioned line.

Formula and method

$$\dot{m}_j(h_j - h_{d,j}) + D_{j-1}(h_{d,j-1} - h_{d,j}) = \dot{m}_{fw}(h_{fw,j} - h_{fw,j+1}), \quad T_{fw,j} = T_{sat}(p_j) - TTD_j, \quad T_{d,j} = T_{fw,j+1} + DCA_j$$

$$P_{el} = \eta_g \sum_j (\dot{m}_0 - \sum_{k<j} \dot{m}_k)(h_{j-1} - h_j), \quad HR = \frac{\dot{m}_0(h_0 - h_{fw})}{P_{el}}$$

Variables

$\dot{m}_0$	Throttle steam flow (= feedwater flow)	kg/s
p_0	Throttle pressure (absolute)	Pa
T_0	Throttle temperature	K
p_{fw}	Feedwater pressure through the heaters (absolute)	Pa
p_c	Condenser pressure (absolute)	Pa
η_t	Expansion-line (section) isentropic efficiency	-
use_1	Heater 1	-
p_1	Heater 1: extraction (shell) pressure, absolute	Pa

TTD_1	Heater 1: terminal temperature difference	K
DCA_1	Heater 1: drain cooler approach	K
use_2	Heater 2	-
p_2	Heater 2: extraction (shell) pressure, absolute	Pa
TTD_2	Heater 2: terminal temperature difference	K
DCA_2	Heater 2: drain cooler approach	K
use_3	Heater 3	-
p_3	Heater 3: extraction (shell) pressure, absolute	Pa
TTD_3	Heater 3: terminal temperature difference	K
DCA_3	Heater 3: drain cooler approach	K
use_4	Heater 4	-
p_4	Heater 4: extraction (shell) pressure, absolute	Pa
TTD_4	Heater 4: terminal temperature difference	K
DCA_4	Heater 4: drain cooler approach	K
η_g	Gearbox and generator efficiency	-
$\dot{m}_1$	Heater 1: extraction steam flow	kg/s
h_1	Heater 1: extraction enthalpy	J/kg
$T_{fw,1}$	Heater 1: feedwater outlet temperature	K
$T_{d,1}$	Heater 1: drain outlet temperature	K
$\dot{m}_2$	Heater 2: extraction steam flow	kg/s
h_2	Heater 2: extraction enthalpy	J/kg
$T_{fw,2}$	Heater 2: feedwater outlet temperature	K
$T_{d,2}$	Heater 2: drain outlet temperature	K
$\dot{m}_3$	Heater 3: extraction steam flow	kg/s
h_3	Heater 3: extraction enthalpy	J/kg
$T_{fw,3}$	Heater 3: feedwater outlet temperature	K
$T_{d,3}$	Heater 3: drain outlet temperature	K
$\dot{m}_4$	Heater 4: extraction steam flow	kg/s
h_4	Heater 4: extraction enthalpy	J/kg
$T_{fw,4}$	Heater 4: feedwater outlet temperature	K
$T_{d,4}$	Heater 4: drain outlet temperature	K
$\dot{m}_c$	Steam to the condenser	kg/s
x_c	Exhaust dryness	-
T_{fw}	Final feedwater temperature	K
P_{el}	Generator output	W
Q	Heat added in the boiler	W
HR	Turbine cycle heat rate	J/J
η_{cyc}	Cycle efficiency	-
$P_{el,0}$	Generator output with no heaters	W
HR_0	Heat rate with no heaters	J/J
ΔHR	Heat-rate improvement from the heaters	-

Method and standards

Regenerative feed heating heat balance with IAPWS-IF97.

Assumptions and limits

- Closed heaters only; no deaerator, reheat or make-up; pump work neglected.

Report details

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Reopens the calculator with the inputs of this report.