ESF II project of the University of West Bohemia in Pilsen

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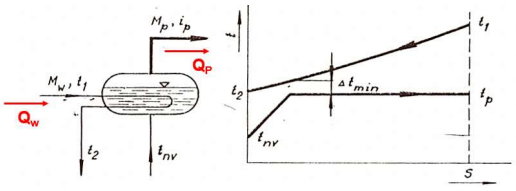
Energy calculation of steam generators

Exercises 6 (KEE/TTE)

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

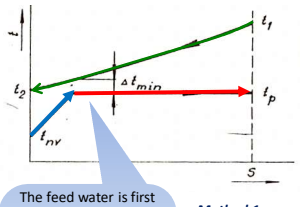
Example 1

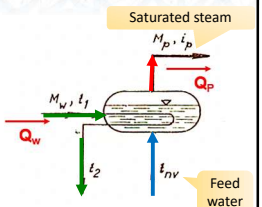
- Determine the required mass and volume flow of cooling water for the nuclear power plant steam generator, if the required mass flow of saturated steam of the secondary circuit (thermal cycle) is M_p = **470 t/h** at pressure p_p= **4.6 MPa** and feed water temperature t_{nv} = **222 °C**. Refrigerant temperatures are t_1 = **301 °C** and t_2 = **268 °C**. The minimum temperature drop between heat transfer media is t_{min} = **10 °C**.



Example 1 - Solution

- **Energy balance**





The feed water is first heated to boiling point (its temperature changes) and then evaporated (temperature does not change). The liquid refrigerant transfers its liquid heat.

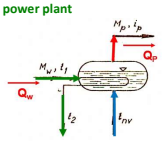
Method 1 $Q_w = Q_p$ → M_w

Method 2 $INPUT = OUTPUT$ → M_w

Example 1 - Solution

Specified parameters: $t_1 = 301\ °C$ $t_2 = 268\ °C$

- **Enthalpy and specific volume of cooling water of the primary circuit of a nuclear power plant**

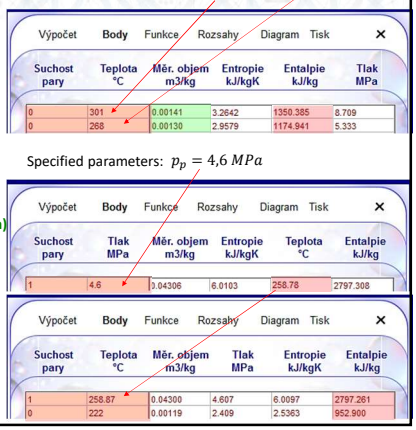


- **Feedwater and saturated steam parameters (dry steam)**

The saturated steam temperature is determined according to the saturated steam pressure.

Specified parameter:

$t_{nv} = 222\ °C$



Example 1 - Solution

$i_1 = 1\,350\ kJ/kg$ $i_p = 2\,797\ kJ/kg$
$i_2 = 1\,175\ kJ/kg$ $i_{nv} = 953\ kJ/kg$

- **Mass flow rate of primary circuit cooling water**

$M_w =$

- **Volume flow of cooling water of the primary circuit**

$v_1 = 0.00141\ m^3/kg$ $v_2 = 0.00130\ m^3/kg$

Attention, here Q_w does not mean heat, but volume flow !!!

$$M_w = \frac{dm}{dt} = \rho_w \cdot \frac{dV}{dt} = \rho_w \cdot Q_w$$

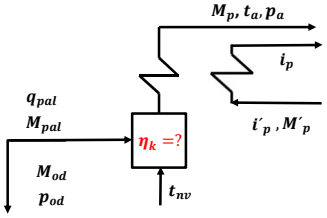
$$v = \frac{V}{m} = \frac{1}{\rho}$$

$$\rho_w = \frac{\rho_1 + \rho_2}{2} = \frac{1}{2} \cdot \left(\frac{1}{v_1} + \frac{1}{v_2}\right) =$$

$Q_w =$

Example 2

- Determine the energy efficiency of the steam boiler and perform its energy balance if it has a mass output ***M_p = 75 t/h*** with steam parameters ***p_a = 9 MPa***, ***t_a = 480 °C*** with steam reheating ***M'_p = 60 t/h*** with parameters ***i_p = 3 420 kJ/kg*** and ***i'_p = 3 047 kJ/kg***. The steam generator is of the drum type and the mass flow of blowdown ***M_{od} = 600 kg/h*** at a pressure ***p_{od} = 10 Mpa*** is extracted from it. The mass flow of fuel with calorific value ***q_{pal} = 11 MJ/kg*** is ***M_{pal} = 22 t/h***. Feedwater temperature ***t_{nv} = 225 °C.***



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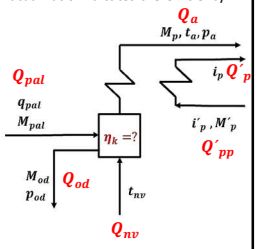
Example 2 - Solution

- **Boiler efficiency**

➢ Losses in the boiler represent the difference between the heat that enters the boiler in the form of the calorific value of the fuel and the heat that is supplied to the heat circuit and removed by blow-off and sludge. Their mutual ratio indicates the efficiency of the boiler.

Boiler energy balance

$$Q_{pal} \cdot \eta_k + Q_{nv} + Q'_{pp} = Q_{od} + Q_a + Q'_p$$

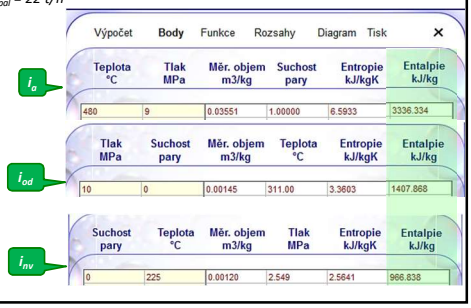


Example 2 - Solution

- **Boiler energy balance**

Specified parameters:

- M_p = 75 t/h, p_a = 9 MPa, t_a = 480 °C
- M'_p = 60 t/h, i_p = 3 420 kJ/kg, i'_p = 3 047 kJ/kg
- M_{od} = 600 kg/h, p_{od} = 10 MPa
- q_{pal} = 11 MJ/kg, M_{pal} = 22 t/h
- t_{nv} = 225 °C



Example 2 - Solution

- **Boiler energy balance**

Specified parameters:

- M_p = 75 t/h, M'_p = 60 t/h, i_p = 3 420 kJ/kg, i'_p = 3 047 kJ/kg
- M_{od} = 600 kg/h, q_{pal} = 11 MJ/kg, M_{pal} = 22 t/h
- ***Values from steam tables:***

$i_a = 3\,336\ kJ/kg$ $\quad i_{od} = 1\,408\ kJ/kg$ $\quad i_{nv} = 967\ kJ/kg$

$\eta_k =$

$\eta_k =$

$\boldsymbol{\eta_k =}$

Example 2 - Solution

- **Boiler energy balance**

Specified parameters:
- M_p = 75 t/h, M'_p = 60 t/h, i_p = 3 420 kJ/kg, i'_p = 3 047 kJ/kg
- M_{od} = 600 kg/h, q_{pal} = 11 MJ/kg, M_{pal} = 22 t/h
- ***Values from steam tables:***

$i_a = 3\,336\ kJ/kg$ $\quad i_{od} = 1\,408\ kJ/kg$ $\quad i_{nv} = 967\ kJ/kg$

- ***Heat supplied = contained in the fuel***

$Q_d = Q_{pal} = M_{pal} \cdot q_{pal}$

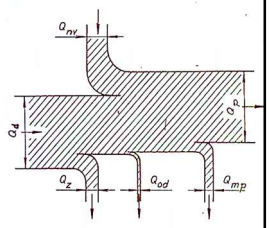
$\boldsymbol{Q_{pal}} =$

- ***Feed water heat***

$\boldsymbol{Q_{nv}} = M_{nv} \cdot i_{nv} =$

- ***Heat of superheated steam***

$\boldsymbol{Q_p} = \boldsymbol{Q_a} = M_p \cdot i_a =$



Example 2 - Solution

- **Boiler energy balance**

Specified parameters:
- M_p = 75 t/h, M'_p = 60 t/h, i_p = 3 420 kJ/kg, i'_p = 3 047 kJ/kg
- M_{od} = 600 kg/h, q_{pal} = 11 MJ/kg, M_{pal} = 22 t/h
- ***Values from steam tables:***

$i_a = 3\,336\ kJ/kg$ $\quad i_{od} = 1\,408\ kJ/kg$ $\quad i_{nv} = 967\ kJ/kg$

- ***Heat needed to reheat the steam***

$Q_{mp} = M'_p \cdot (i_p - i'_p)$

$\boldsymbol{Q_{mp}} =$

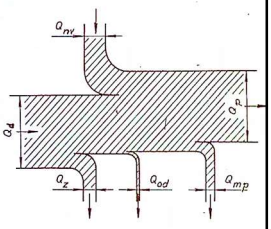
- ***Removed heat by mass flow of blowdown***

$\boldsymbol{Q_{od}} = M_{od} \cdot i_{od} =$

- ***Losses***

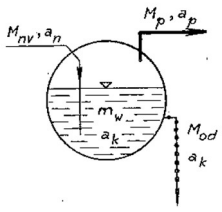
$\boldsymbol{Q_z} = Q_d + Q_{nv} - Q_p - Q_{od} - Q_{mp} =$

$\boldsymbol{Q_z} = Q_d \cdot (1 - \eta_k) =$



Example 3

- Determine the mass flow of blowdown of a steam boiler with an output of ***M_p = 100 t/h***. The permissible salt concentration in steam is ***a_p = 0 mg/kg***. The permissible concentration in the feed water is given by the value $\mathbf{a_n}$ and the concentration of the boiler water (i.e. the ratio of salts in the boiler water ($\mathbf{a_k}$) to the ratio of salts in the feed water) is ***Z = 125.***



Example 3 - Solution

- Salt concentration balance

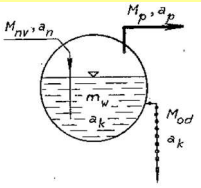
Specified parameters:

- $a_p = 0$ mg/kg, $Z = 125$

$$Z = \frac{a_k}{a_n} = 125$$

$$M_{nv} \cdot a_n = M_p \cdot a_p + M_{od} \cdot a_k$$

- The solution is based on the balance equation of the allowed concentration of salts in the system, ie the amount of salts inputting must be equal to the amount of salts outputting:



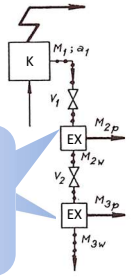
- Mass flow of blowdown

$M_{od} =$

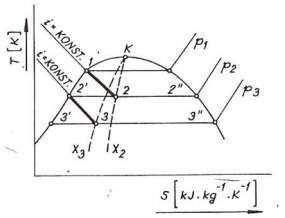
$\boldsymbol{M_{od}} =$

Example 4

- From the drum of the steam boiler, in which the pressure $\mathbf{p_1}$ **= 10 MPa**, the exhaust with the mass flow $\mathbf{M_1}$ **= 3 t/h** is discharged. Exhaust heat recovery is performed by a two-stage exhaust expander. In the first expander the pressure is $\mathbf{p_2}$ **= 5 MPa** and in the second $\mathbf{p_3}$ **= 1 MPa**. The permitted salt concentration in the effluent (boiler water) is $\mathbf{a_1}$ **= 120 mg/kg**. Calculate the heat and mass balance.



In EXPANDERS, the water pressure decreases, whereby part of the water (blowdown) evaporates in the form of saturated steam.



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Used and recommended literature

- Dvorsky, Emil; Hejtmankova, Pavla; Kocmich, Martin. Elektrarny : zaklady vyroby elektricke energie : priklady. 1. vyd. Pilsen : UWB, 1994. ISBN 80-7082-133-7.
- Dvorsky, Emil; Hejtmankova, Pavla. Elektrarny : zvysovani ucinnosti premen energie v tepelnych elektrarnach : priklady. 1. vyd. Pilsen : UWB, 1999. ISBN 80-7082-523-5.
- ..... and other literature listed in the course syllabus on the website Portal of the UWB in Pilsen

Next exercise

Combined heat and power generation – CHP (Cogeneration)

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