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Boiler blowdown recovery

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Abstract
One way to reduce the heat loss of the steam boiler is to reduce the blowdown rate and recover the heat from the purged water. Purging the boiler, although necessary, represents a loss of treated water and a loss of heat because the purged water is water brought to saturation. Blowdown recovery must be done according to the available users/consumers. The paper analyses the recovery of blowdown of a steam boiler of 420 t/h capacity by using a flash separator and a makeup water preheater. The flash steam is used for the feed water deaeration. The heat recovered from the blowdown can reach 97%, and the recovered water can reach 43%.

Keywords: blowdown, steam boiler, heat recovery, flash tank.

1. INTRODUCTION

One of the heat losses of the steam boiler is the blowdown. This can represent between 1% and 3% of the energy introduced with the fuel in the boiler. It consists in discharging a quantity of water from the boiler area where the water accumulates suspended and dissolved solids. Dissolved and suspended solids must be removed from the boiler because they form adherent deposits on the surfaces of the heat exchangers, reducing the heat exchange rate, causing surface corrosion and steam contamination. Blowdown rate can represent 1% of the feedwater when it is of higher quality, and up to 20% when it is of poor quality [1, 2, 3].

The flow rate of the blowdown for a certain boiler depends on the design of the boiler, the operation conditions, and the level of total dissolved and suspended solids in the feedwater. In many steam boilers, the blowdown rate is determined by measuring the concentration of the total dissolved solids. In some steam boilers, the blowdown rate is determined according to the level of alkalinity, sand, or suspended solids concentration.

The minimum possible rate for blowdown can only be determined experimentally [2]. The effect of feedwater characteristics on steam quality can be verified by testing the purity of the steam. However, the effects on internal conditions must be determined by the results of long-term observations of a boiler.

This paper analyses from a thermal and economic point of view the recovery of the blowdown of a steam boiler from a thermal power plant, by using the flashing of blowdown and the use of flash steam for feedwater degassing. The water exiting the flash separator is used to preheat the makeup water.

2. BOILER BLOWDOWN RECOVERY

The blowdown recovery is performed by flashing of water blown out of the boiler in a flash tank/separator, where due to the decrease of pressure, the water partially evaporates, the resulting flash steam being sent to the deaerator, and the water is used to preheat the makeup water (Fig. 1). The pressure in the flash separator was chosen equal to the pressure in the deaerator.

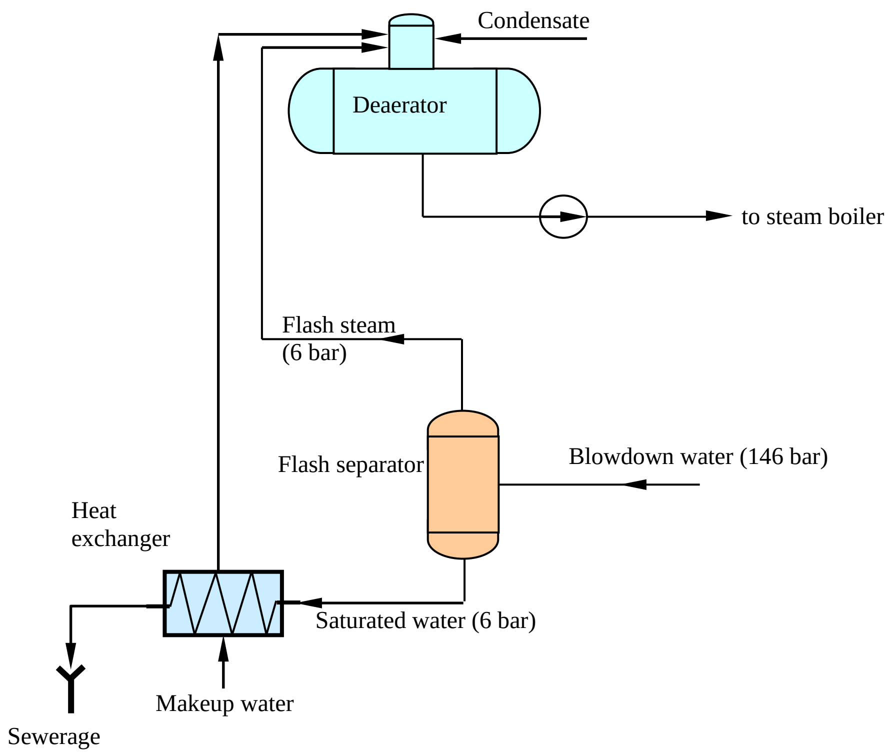

Fig. 1. Blowdown recovery with flash separator and heat recuperator.

The recovered flash steam is calculated from the mass and heat balance equations written for the flash separator.

$$\dot{m}_b = \dot{m}_l + \dot{m}_s \tag{1}$$

$$\dot{m}_b h_b = \dot{m}_l h_l + \dot{m}_s h_s \tag{2}$$

$$\text{Flash steam percentage} = \frac{\dot{m}_s}{\dot{m}_b}100 = \frac{h_b - h_l}{h_s - h_l}100\ [\%] \tag{3}$$

where: $\dot{m}_b, \dot{m}_l, \dot{m}_s$ are the blowdown rate, saturated water mass flow rate and flash steam mass flow rate, respectively, kg/s;

h_b, h_l, h_s are the enthalpy of blowdown, saturated water and flash steam, respectively, kJ/kg. The enthalpy of saturated water and flash steam are calculated by using the following equations [5]:

$$h_l = -3{,}153399\cdot 10^3 + 2{,}913765\cdot 10^4 y_s - 1{,}224973\cdot 10^5 y_s^2 + 2{,}984568\cdot 10^5 y_s^3 - \\ -3{,}632168\cdot 10^5 y_s^4 + 1{,}785296\cdot 10^5 y_s^5,\ \text{kJ/kg} \tag{4}$$

$$y_s = \frac{T_s}{1000}$$

$$T_s = 1000 / \left[2{,}20732 - 2{,}117187 \cdot 10^{-1} \ln m - 2{,}166605 \cdot 10^{-3} (\ln m)^2 + \right.$$
$$\left. + 1{,}619692 \cdot 10^{-4} (\ln m)^3 + 4{,}8998 \cdot 10^{-5} (\ln m)^4 + 3{,}691725 \cdot 10^{-6} (\ln m)^5 \right], \text{ K} \tag{5}$$

$$m = \frac{p_s}{10}$$

$$h_s = 6{,}010277 \cdot 10^3 - 4{,}7493 \cdot 10^4 y_s + 2{,}388416 \cdot 10^5 y_s^2 - 5{,}704046 \cdot 10^5 y_s^3 +$$
$$+ 6{,}772865 \cdot 10^5 y_s^4 - 3{,}264862 \cdot 10^5 y_s^5, \text{ kJ/kg} \tag{6}$$

To determine the flash steam percentage, the diagram in Fig. 2 built by using the equations (1-6) for a blowdown at 146 bar, can be used. The pressure of the water entering the flash separator is located on the y-axis and is followed horizontally until it meets the curve corresponding to the pressure in the flash tank, after which it descends vertically to find the flash steam percentage on the x-axis. It can be seen that the percentage of flash steam is approximately the same when flashing occurs in one or two stages. For economic reasons, the flashing was chosen in one stage.

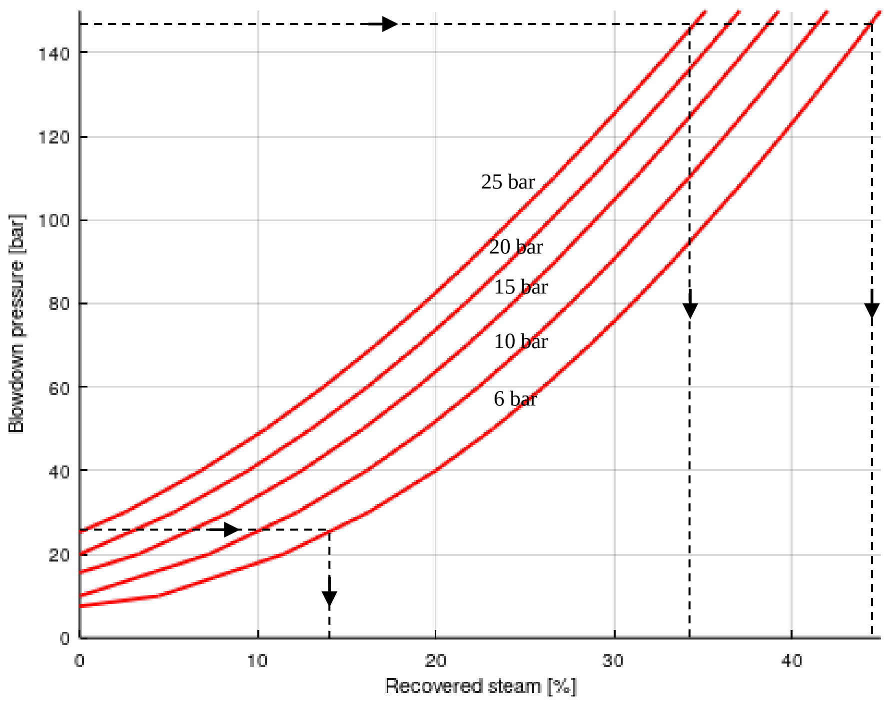

Fig. 2. Diagram for determining the percentage of flash steam.

The heat recovered from the water leaving the flash separator is calculated with the following equations:

$$\dot{Q} = \dot{m}_l \left(h_{l1} - h_{l2} \right) = \dot{m}_{mw} \left(h_2 - h_1 \right), \text{ kW} \tag{7}$$

$$\dot{Q} = U \times A \times \Delta t, \text{ kW} \tag{8}$$

where: $\dot{m}_l, \dot{m}_{mw}$ are the mass flow rate of water leaving the flash separator and mass flow rate of makeup water, respectively, kg/s; A is the heat exchange area, m^2; U is the overall heat transfer coefficient, kW/m^2/K; Δt is logarithmic mean temperature difference, K.

The purchase cost of a flash separator and heat recuperator can be calculated by using the following equations:

- the cost of the heat exchanger as a function of heat exchange area, *A* [4, 6]:

$$Z_{HE} = 10000 + 324 \times A^{0.91}, \text{€} \tag{9}$$

- the cost of the flash separator as a function of capacity, *Q* [7]:

$$C_{FS} = C_B \left(\frac{Q}{Q_B} \right)^M, \text{€} \tag{10}$$

where: C_B is the base cost, €; *M* is the cost exponent (M=0.82); *Q* is the flash separator capacity, tone; Q_B is the base size, ton (Q_B = 6). The flash separator capacity is determined by the condition that the water has a residence time in the flash separator of 5 minutes [8, 9];

- total capital cost corresponding to year 2021:

$$Z_{tot} = \left(Z_{HE} + Z_{FS} \right) \frac{CEPCI_{2021}}{CEPCI_{2001}}, \text{€} \tag{11}$$

where $CEPCI_{2001}$ and $CEPCI_{2021}$ are the Chemical Engineering Plant Cost Index values required to convert the purchase cost from 2001 to 2021 [10, 11];

- capital recovery cost:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{12}$$

where *i* is the annual interest rate (i=0.1) and *n* is plant lifetime (n=25 years);

The payback period is:

$$PP = \frac{Z_{tot}}{N \times \dot{Q}_{rec} \times C_f - C_{OM}}, \text{years} \tag{13}$$

where $\dot{Q}_{rec}$ is heat recovered from blowdown, kW; Cf is fuel cost, €/kWh; C_{OM} is the annual cost of plant operation and maintenance, € ($C_{OM} = 0.3 \cdot Z_{tot}$), *N* is annual hours of operation (N = 8000 hours).

3. RESULTS AND DISCUSSION

Applying the thermal and economic models described above to the 8.2 t/h blowdown of a boiler that produces 420 t/h superheated steam and taking into account the characteristics in Tab. 1 resulted: the recovered heat flow of 3511 kW, the cost of the flash separator of 16900 €, the cost of heat recuperator of 91000 € and the payback period of about 2 months.

Tab. 1. Characteristics of the blowdown recovery system.

Parameter	Value
Pressure of blowdown	146 bar
Blowdown rate	2.27 kg/s
Flash separator capacity, *Q*	0.5 ton
Recuperator heat exchange area, *A*	431 m^2
Overall heat transfer of recuperator, *U*	0.2 $kW/m^2/K$
Natural gas cost	0.064 €/kWh
CE Plant Cost Index (CEPCI) for September 2021	750
CE Plant Cost Index (CEPCI) for September 2009	521.9

4. CONCLUSIONS

Heat loss by boiler blowdown, seemingly insignificant, can increase the boiler's thermal and economic performance when its heat is recovered.

Integrating a flash separator and a heat recuperator to a 420 t/h superheated steam boiler with a financial effort of 107900 € can make annual savings of 1797000 €. The recovered heat represents 97% of the blowdown heat, and the recovered water represents 43%. The investment can be recovered in about 2 months. In addition, heat recovery from boiler blowdown reduces the CO_2 emissions by 5115 tons/year.

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