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Analysis of energy efficiency improvement of boiler-houses in oil and gas industry using method for deep chilling flue gases

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Analysis of energy efficiency improvement of boiler-houses in oil and gas industry using method for deep chilling flue gases

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Abstract. The article is devoted to the methods of increasing boiler-house efficiency. This current problem is considered in the article by two reasons: big part of volume flue gases enter the atmosphere, utilization of this gases is difficult process. The scope includes a description of the sample of heat exchanger. The analysis method for deep chilling flue gases for increasing the energy efficiency of the boiler- house was carried out. This method can be used in enterprises with big energy consumption, also boiler- house with small capability. The calculation of a boiler-houses with different was given, as an example. Average increasing energy efficiency of boiler-houses was found.

1. Introduction

The improvement of the energy efficiency of energy equipment is of paramount importance for most branches. The reason for this is the reduction of reserves of fossil fuels. Designing new energy equipment with high-energy efficiency is an important task. However, the most important task is increasing the energy efficiency of existing equipment. To increase energy efficiency of boiler- house need to analyze using equipments. Main factor influencing on energy efficiency is efficiency of boiler.

The heat balance of the boiler was considered [1]. The studies of technical literature showed that in a modern boiler, it was possible to minimize heat loss due to dry flue gases, incomplete combustion and unburnt flue. For example, E A Biryuzova [2] considers the heat loss value from external cooling of the boiler unit surface. The authors obtained dependence for determining the value of this loses. The article [3] presents the analysis of the boiler performance thermal and technical indicators, and depending boiler energy efficiency of exhaust gases temperature, and furnace volume thermal stress. However, heat carried away by flue gases stay the main losses of heat in the boiler. Flue gas losses account for 5-10 percent. For comparison, other losses (Q_3, Q_4, Q_5, Q_6) are no more than 5 percent [4, 5, 6]. Flue gases have high temperature around 100-200ºC. High temperature helps to avoid condensation moisture in fuel gases on the inner area of exhausted tube. It means that hidden heat and sensible heat are lost. A number of methods for reducing losses heat carried away by flue gases are listed in [7, 8, 9]. In article [7] presented concept of heat recovery from exhaust gases use it to prepare hot water. This solution is relevant for the industry with a large load and coal boilers. The authors of article [8] also consider the possibility of using heat recovery from flue gases. However, they also estimate limit of heat power of the heat exchanger. The method deep chilling of the flue gases was chosen of offered process engineering solution. It is because efficiency of this method can be reached and set up in the boiler-house. The literature [10] also was presented calculation methods for determining the effectiveness. The basis of the method is to install a recuperative heat exchanger at the flue gas outlet. This technical solution has shown well in other areas. For example, the authors of article [11] consider installing a recuperative heat exchanger in a ventilation system to increase efficiency. Also to achieve increasing efficiency can use other method, for example by water regime boiler [12], and other presented in [13, 14, 15, 16, 17].

The problem of this article is the improvement of efficiency of low power boiler by deep chilling the temperature of the flue gases with the return of part of the heat for secondary using. The idea of reusing the heat of flue gases was developed for a long time, but there is no basic research in this area. To achieve improving energy efficiency can by installing condensing recovery unit of surface heat.

2. Principle of operation of condensing surface heat recovery unit

There are several options for the design of heat exchangers to reduce the flue gas temperature. They can be divided into two groups. The first group is contact type heat exchangers were widely used in the past. The second group is condensing surface heat exchangers [18, 19].

Condensing surface heat exchanger is better than contact heat exchanger. They possess the improved technical characteristic. The using contact heat exchanger is complicated by the absorption by water of carbon dioxide and oxygen. In this case, the water acquired corrosive and aggressive properties. The use of the condensing surface of the heat exchangers allows avoiding this [20].

Figure 1 shows scheme of reusing the heat of flue gases in condensing surface heat exchanger. Flue gases enter from the economizer to the distributive valve. The valve divides flue gases flow into two flows. The main flow passes through the mesh filter into the heat exchanger. The second stream goes along the bypass line to the gas duct.

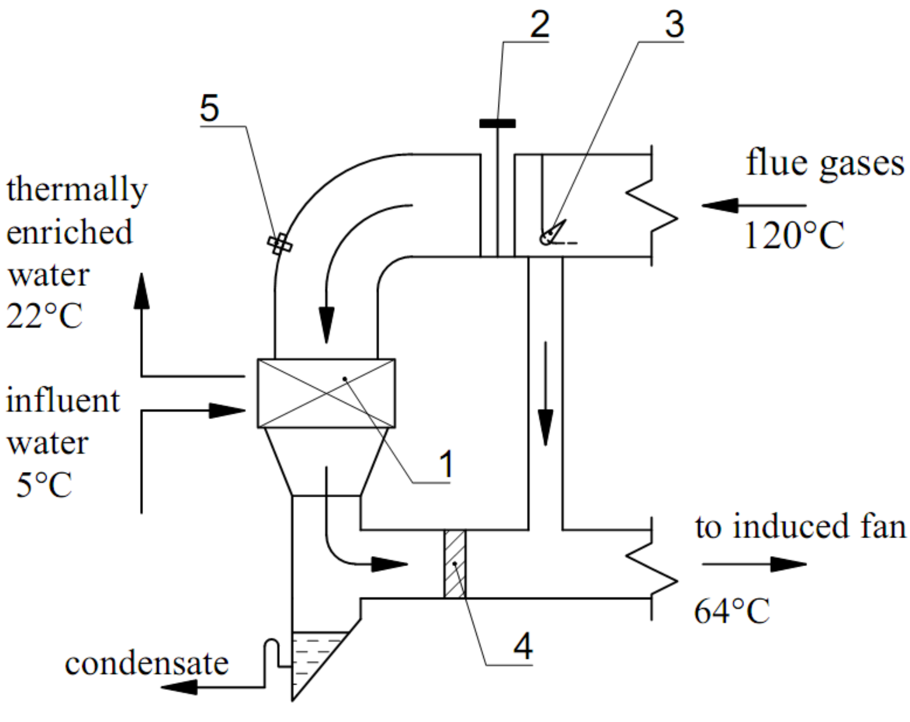

Figure 1. Scheme of reusing the heat of flue gases in condensing surface heat exchanger: 1- condensing surface of heat exchanger; 2 – mesh filter; 3 – distributive valve; 4 – drip collector; 5 – hydro-pneumatic blower [10].

The heat exchange has been reducing the moisture content of combustion products and condensate. After mixing, temperature of flue gases maintain at higher then condensing point. Accordingly, condensation in the gas duct is excluded.

Condensate is collected in a pan. Then it goes to the decarbonised water tank, bypassing the water treating plant. Pumps are fed water (condensate) from the tank into the deaerator when heat supply system is closed type [10].

3. Methodology of the calculation method increasing efficiency boilers

Several options for hot-water boilers of different capacities were considered. Each boiler house has two Logano sk755 boilers of different capacities. Calculation data was taken from the technical dossier of the boiler. The main characteristics of the boiler are presented in Table 1.

Table 1. Technical characteristics of boilers and boiler- houses

Characteristic	Boiler- house		
	1	2	3
Boiler-houses power, kW	1200	2080	3700
Boiler power, kW	600	1040	1850
Unit efficiency,%	90	90	92
Temperature of flue gases, ^oC	200	200	200
High heat value of heating agency(QHV), kJ/m^3	8867		

Natural gas is used as fuel of Urengoy field. The calculation of the condensation surface heat exchanger was made by the method given in [10]. The presented technique was helped to evaluate the efficiency of the installation of a condensing heat exchanger.

Calculate volume of flue gases of the inlet heat exchanger under standard conditions, V_N(m^3/s):

$$V_N = (1.135 + 1.32 \cdot \alpha_{FG}) \cdot Q_B \cdot 10^{-3} \cdot \eta_{LB}^{-1} \quad (1)$$

α_{FG}– the excess air factor of the flue gases; Q_B –heating capacity of boiler (MW); η_{LB} – efficiency of boiler under lower heating value.

Actual volume of flue gases of the outlet heat exchanger under field conditions,V_{1t}=V_{FG}(m^3/s) is:

$$V_{1t} = V_{FG} = V_N \cdot (t_{FG} + 273) \cdot 273^{-1} \quad (2)$$

t_{FG} – flue gases temperature of the outlet heat exchanger (^oC).

Average volumetric flow of flue gases of the outlet heat exchanger V_{AVG} (m^3/s):

$$V_{AVG} = (V_{1t} + V_{FG}) \cdot 2^{-1} \cdot 3600^{-1} \quad (3)$$

Mass flow rate of flue gases, G_{FG}(kg/s) is:

$$G_{FG} = V_N \cdot \rho_N \quad (4)$$

ρ_N – density of the flue gases average composition under standard conditions, (1,295 kg/m^3).

Enthalpy gases of the inlet heat exchanger I_1 (kJ/kg) is:

$$I_1 = (C_{CP} + C_{WV} \cdot \chi_{CP}) \cdot t_{CP} + 2491 \cdot \chi_{CP} \quad (5)$$

C_{CP} – heat capacitance dry combustion products (kJ/(kg·^oC);C_{WV} – heat capacitance of combustion water vapour (kJ/(kg·^oC); t_{CP} – combustion products temperature of the outlet heat exchanger (^oC); χ_{CP} – water content combustion products of the outlet heat exchanger(kg/kg$_{CP}$).

Find water content combustion products of the outlet heat exchanger χ_{CP} (kg/kg$_{CP}$):

$$\chi_{CP} = (0.13 + \chi_{AIR} \cdot \alpha_{FG}) \cdot (\alpha_{FG} - 0.058)^{-1} \quad (6)$$

χ_{AIR} – water content air (kg/kg).

Enthalpy gases of the inlet heat exchanger I_{FG} (kJ/kg) is:

$$I_{FG} = (C_{CP} + C_W \cdot \chi_{FG}) \cdot t_{FG} + 2491 \cdot \chi_{FG} \tag{7}$$

χ_{FG} – water content flue gases of the outlet heat exchanger(kg/kg).

Find water content flue gases of the outlet heat exchanger χ_{FG} (kg/kg$_{CP}$):

$$\chi_{FG} = (0.0006382 + 0.004 \cdot \alpha_{FG}) \cdot (0.199 + \alpha_{FG})^{-1} \cdot \exp(0.062 \cdot \alpha_{FG}) \tag{8}$$

Heating capacity of heat recovery unit Q_U (kJ/s) is:

$$Q_U = G_{FG} \cdot (I_1 - I_{FG}) \tag{9}$$

The amount heated water G_W (kg/s) is:

$$G_W = Q_U \cdot [C_W \cdot (t_{W2} - t_{W1})]^{-1} \tag{10}$$

C_W – heat capacitance water under average temperature (kJ/(kg·^{o}C); t_{W2}, t_{W1} – temperature of heated water (^{o}C).

Average temperature drop Δt is:

$$\Delta t = (\Delta t_{\max} - \Delta t_{\min}) \cdot \ln^{-1}\left(\frac{\Delta t_{\max}}{\Delta t_{\min}}\right) \tag{11}$$

Δt_{max} – difference between t_{FG1}, t_{W1}; Δt_{max} – difference between t_{FG2}, t_{W1}.

Heat transfer characteristic of heat exchanger K (W/(m^{2}·^{o}C) is:

$$K = (\alpha_{FG}'^{-1} + \delta \cdot \lambda^{-1} + \alpha_{IN}^{-1})^{-1} \tag{12}$$

α'_{FG} – reduced heat transfer coefficient from the flue gases to the outer surface of the condensation heat exchanger (35, W/(m^{2}·^{o}C));δ – wall thickness (m); λ – thermal conductivity of the material (W/(m·^{o}C); α_{IN} – heat transfer coefficient from the inner surface of the pipe to the heated water(1000, W/(m^{2}·^{o}C)).

Heat transfer surface of heat recovery unit F(m^2) is:

$$F = Q_U \cdot K^{-1} \cdot \Delta t^{-1} \tag{13}$$

Number of tube of heat recovery unit N is:

$$N = F \cdot f_i^{-1} \tag{14}$$

f_i – heat transfer surface of one tube(0.0025m^2).

Number of bank of tubes z is:

$$z = N \cdot n_i \tag{15}$$

n_i – number of tube in one bank(50).

High of heat recovery unit H(m) is:

$$H = d_{OD} \cdot z \tag{16}$$

d_{OD} – outside diameter of tubes (m).

The amount of useful heat exchanger's heat Q_{UU} (kJ/s) is

$$Q_{UU} = G_W \cdot C_W \cdot (t_{W2} - t_{W1}) \tag{17}$$

Find boiler efficiency without heat recovery unit under high heat value:

$$\eta_B = Q_B \cdot B^{-1} \cdot Q_{HV}^{-1} \cdot 100\% \tag{18}$$

B – fuel burn(m^3/s).

Increasing boiler efficiency with heat recovery unit $\Delta\eta$ is

$$\Delta\eta = Q_B \cdot B^{-1} \cdot Q_{HV}^{-1} \tag{19}$$

Total efficiency of one boiler η_T (%) is:

$$\eta_T = \eta_B + \Delta\eta \tag{20}$$

Calculations are presented in table 2.

Table 2. Result of calculation increasing efficiency boiler- houses.

Characteristic	Boiler- house		
	1	2	3
Boiler-houses power, kW	1200	2080	3700
Boiler actual efficiency without heat exchanger, η_B%	84.45	91.68	85.43
Increasing boiler efficiency, $\Delta\eta$	1.17	1.27	1.2
Total boiler efficiency, η_T%	85.62	92.95	86.63

4. Conclusion

Thus, the general range of increasing of boiler efficiency maximum values calculated by the proposed method is possible to be pointed out. The obtained calculations showed that the power of the boiler does not affect the increase of boiler efficiency. Average value of increasing boiler efficiency is 1.2 percent. Installing a heat exchanger is one of the most affordable methods for improving the efficiency of a boiler room that is especially important now with high demand for high efficiency equipment. This method of improving energy efficiency can be considered for low power boilers, for example, for boiler rooms located near residential areas. As a result, the installation of the heat exchanger was increased the boiler efficiency and reduced the amount of pollutants in the flue gases.

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