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Application Of Economizer For Waste Heat Recovery From Exhaust Flue Gas In Steam Boiler: A Case Study In A Biscuit Factory

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Abstract

In the present work, the useful concept of energy utilization is analyzed and implemented to the steam boiler system. Energy flows in the steam boiler system have been shown in this work. Energy efficiency and losses have been determined as well. Energy losses are found to be 18.88%. 7.37 % of the total losses is emitted by a waste heat of exhaust flue gas. This work also presents a case study of recovering the waste heat of exhaust flue gas by applying a condensing economizer. From the analysis results, it reveals that energy saving amount as natural gas is 21724,8 m^3/year. Thus, applying of the condensing economizer in a profit of about 7760 $/year and a reduction of 27,13 tons CO_2 emission per year. As a result, calculated energy saving amount for the investment cost of the economizer corresponds to about 1,13 year according to the payback period analysis method.

Key words: Waste heat recovery, Economizer, Steam Boiler, CO_2 emission

1. Introduction

Nowadays, waste heat is considered to be an important energy source It is produced in a process by way of fuel combustion or chemical reaction, and then “emitted” into the environment even though it could still be reused for some useful and economic object. The main quality of the heat is not the amount but rather its “value”. The strategy of how to recover this heat partially depends on the temperature of the waste heat gases and the economics involved.

Large quantity of hot flue gases is commonly generated from boilers, kilns, ovens and furnaces. If some of this waste heat could be recovered, a considerable amount of major fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and the loss could be minimized by realizing required applications [1].

In a boiler system, an economizer can be ensured to evaluate the flue gas heat for pre-heating the boiler feed water. In addition, the waste heat can be used to heat combustion air with an air pre-heater. In both the cases, there is a corresponding reduction in the fuel requirements of the boiler. According to the researchers, for every 60 ^{0}C rise in feed water temperature through an economizer or 200 ^{0}C rise in combustion air temperature through an air pre-heater, 1% saving of fuel occurs in the boiler [2].

This work presents that a condensing economizer is planned to obtain high heat recovery from the exhaust gas of the steam boiler as a case study in the biscuit factory. Since the heat loss by exhaust flue gas is a determinative factor in energy efficiency of the steam boiler, the reuptake of

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sensible heat and condensation of the exhaust flue gas, which means total heat recovery, will be beneficial for both the environment and economy.

2. Materials and Method

Ambient temperature (T_a) of the steam boiler room was determined and surface temperature of the steam boiler (Ts) was measured by multifunctional measuring instrument and thermal camera (TESTO 870X2i), respectively. Besides, the components (temperature, CO, O_2, CO_2 etc.) of the exhaust flue gas were identified by flue gas analyzer. The steam boiler made by stainless steel has 5.5 m length and 2.7 m diameter. The natural gas is used as a fuel in the steam boiler with 60 m^3/hour consumption. Physical properties and recent analysis of the natural gas are given in Table 1.

Table 1. Physical properties and ultimate analysis of natural gas. (All the data is provided by fuel supplier)

C1 (Methane)	91,22
C2 (Ethane)	3,39
C3 (Propane)	1,17
I-C4 (I-Butane)	0,18
N-C4 (N-Butane)	0,24
I-C5 (I-Penthane)	0,07
N-C5 (N-Penthane)	0,05
C6+ (Hexane)	0,06
N_2 (Nitrogen)	3,16
CO_2 (Carbon dioxide)	0,45
HHV (Kcal/Sm^3)	9233,97
LHV (Kcal/Sm^3)	8364,26
Specific weight	0,61
Density (kg/Sm^3)	0,75
Atmospheric Pressure (bar)	0,90

2.1. Energy Losses in the Steam Boiler

The steam boiler efficiency has a great effect on heating which is related energy savings. It is therefore significant to maximize the heat transfer to the water and minimize the heat losses in the steam boiler. Heat can be lost from steam boilers by a kinds of methods such as hot exhaust flue gas losses, radiation losses and, blow-down losses etc. To optimize the operation of a steam boiler plant, it is essential to specify where energy waste is likely to occur. An important amount of the energy is lost through exhaust flue gases as all the heat generated by the burning fuel cannot be transferred to steam in the boiler. As the temperature of the exhaust flue gas removing the steam boiler typically ranges from 150 to 250 °C, about 10–30% of the heat energy is lost through it. Since most of the heat losses from the steam boiler transpire as heat in the flue gas, the recovery of this heat can result in substantial energy savings. This demonstrates that there is huge savings potentials of the steam boiler energy savings by minimizing its losses [3]. The calculated heat balance in the steam boiler is shown in Figure 1.

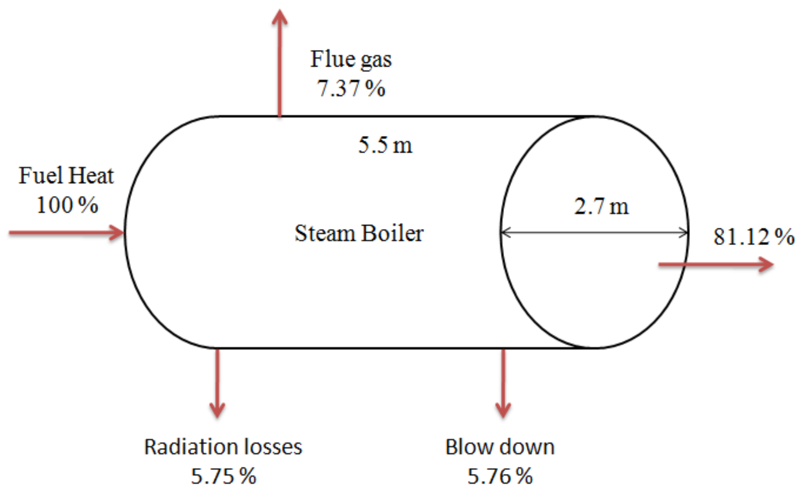

Figure 1. Heat balance of the steam boiler

2.2. A Condensing Economizer

Boilers bedecked with condensing economizers can have an overall efficiency that surpasses 90%. A condensing economizer can enhance total heat recovery and steam system efficiency by up to 10% by decreasing the exhaust flue gas temperature below its dew point, resulting in improved effectiveness of the waste heat recovery. According to initial measurements, the temperature of the exhaust flue gas of the steam boiler (T_{EG}) is 214.4 °C and it can be reduced as 70 °C by installing a condensing economizer.

3. Results and Discussion

3.1. Energy saving calculations

Energy balances are fulfilled around the control volume, determined by the external surface of the steam boiler. The energy balances are acquired by combination of both average measurement values and calculations based on the following assumptions:

1. The steam boiler works at steady state conditions.

2. The composition of the natural gas, given in Table 1, and the average inlet of natural gas at ambient temperature do not change over time.

3. Although surface temperature changes along the steam boiler, it is accepted that the average surface temperature of steam boiler (T_M) does not change in time.

4. The average ambient temperature (T_0) 22 °C is constant throughout the study.

5. All gas streams are assumed to be ideal gases. The average specific heat capacities at constant pressure and fractions of the gas species that compose the exhaust gas, as well as its temperature and enthalpy are shown in Table 2.

Table 2. Energy balance data of the steam boiler

Fuel Consumption	44,86 kg/hour
Exhaust Gas Flow	423,22 m^3/hour
n_{EG}	15,27 kmol/hour
T_{EG}	214,4 °C
T_0	22 °C
T_M	118,2 °C
LHV	57381,088 kJ/ kg
C_{pM}	31,93 kJ/kmol K
h_{fg}	2015 kJ/kg

Energy losses before and after installing the condensing economizer was calculated by following heat transfer formulas by using data which obtained from the measurements:

Energy of the fuel was;

$$E_{fuel} = m_{fuel} X\ LHV$$

$$E_{fuel} = 44{,}86\ m^3/hour\ X\ 57381{,}088\ kJ/m^3 = 2574115{,}6\ kJ/hour$$

Where E_{fuel} is energy obtained from combustion of the fuel (kJ/s), m_{fuel} is consumption of the fuel (kg/s) and LHV is low heat value of the fuel (kJ/ kg).

Sensible heat (E_{SH}) and latent of the exhaust flue gas (E_{LH}) were;

$$E_{SH} = n_{EG}\ x\ C_{PM}\ x\ (T_{EG} - T_O)$$

$$E_{SH} = 15{,}27 \frac{kmol}{hour}\ x\ 31{,}93\ \frac{kJ}{kmol\ K}\ x\ (487{,}4 - 295)K = 93808{,}68\ kJ/hour$$

$$E_{LH} = (n_{EG}\ x\ x_{H2O}) x\ h_{fg}\ x\ Ma_{H2O}$$

$$E_{LH} = \left(15{,}27 \frac{kmol}{hour}\ x\ 0{,}173\right) x\ 2015\ \frac{kJ}{kg} x\ 18\ \frac{kg}{kmol} = 95814{,}82\ kJ/hour$$

$$E_{TOTAL} = E_{SH} + E_{LH}$$

$$E_{TOTAL} = 93808{,}68 \frac{kJ}{hour} + 95814{,}82 \frac{kJ}{hour} = 189623{,}5\ \frac{kJ}{hour}$$

Heat loss from the exhaust flue gas was;

$$\%\ Heat\ losses\ from\ EG = \frac{E_{TOTAL}}{E_{fuel}}\ x\ 100$$

$$\%\ Heat\ losses\ from\ EG = \frac{189623{,}5\ kJ/hour}{2574115{,}6\ kJ/hour}\ x\ 100 = \%\ 7{,}37$$

Dew point temperature in Karaman is between 50-60 °C. Therefore, the reduced temperature by the condensing economizer of the exhaust gas was determined as 70 °C. At this temperature, recovered energy (E_{RE}) was;

$$E_{RE} = n_{EG}\ x\ C_{PM}\ x\ (T_{EG} - T)$$

$$E_{RE} = 15{,}27 \frac{kmol}{hour}\ x\ 31{,}93\ \frac{kJ}{kmol\ K}\ x\ (487{,}4 - 343)K = 70405{,}27\ kJ/hour$$

And heat loss from the exhaust flue gas after installing the condensing economizer was;

$$\%\ Heat\ losses\ from\ EG = \frac{189623{,}5\ \frac{kJ}{saat} - 70405{,}27 \frac{kJ}{saat}}{44{,}86\ \frac{kg}{saat}\ x\ 57381{,}088\ \frac{kJ}{kg}}\ x\ 100 = \%\ 4{,}6$$

Natural gas savings were;

$$\text{Natural gas savings/hour} = \frac{E_{RE}}{LHV x\ n_{boiler}}$$

$$\text{Natural gas savings/hour} = \frac{70405{,}27\ \frac{kJ}{hour}}{(8364{,}26\ x\ 4{,}186) \frac{kJ}{m^3} x\ 0{,}81} = 2{,}48\ \frac{m^3}{hour}$$

The biscuit factory is working 24 hours in day and 365 days in a year. Therefore;

$$\text{Natural gas savings/year} = 2{,}48\ \frac{m^3}{hour} x\ \frac{24\ hour}{day} x\ \frac{365\ day}{year} = 21724{,}8\ \frac{m^3}{year}$$

Savings cost was;

$$Savings\ cost = \frac{\text{Natural gas savings}}{\text{year}} \text{x unit cost of fuel}$$

$$Savings\ cost = 21724{,}8\ \frac{m^3}{year} \text{x } 0{,}36\ \$ = 7821 \frac{\$}{\text{year}}$$

Finally, payback period was calculated by the following equation;

$$Payback\ period = \frac{Investment\ cost}{Savings\ cost} = \frac{8872\ \$}{7821\,\frac{\$}{\text{year}}} = 1{,}13\ year$$

Conclusions

Following conclusions can be drawn from this study:

- The exhaust flue gas is the main part of the contributed energy losses.
- The method of heat recovery by installing a condensing economizer from flue gas is one of the effective ways to save energy in a steam boiler.
- From the calculations it has been found that 70405,27 kJ/hour of energy can be saved by using a condensing economizer in the steam boiler.
- According to the results, it isestimated that 21724,8 m^3/year fuel can be saved for a maximum 3,3 % energy savings.
- The payback period for heat recovery system in the steam boiler found to be 1,13 year is economically very viable.

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