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IMPROVING FURNACE PERFORMANCE BY WASTE HEAT RECOVERY-ECONOMIC ANALYSIS

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ABSTRACT

Combustion type furnaces used to melt metals for casting or to heat materials for change of shape or change of properties have low energy efficiency due to energy losses in different areas and forms, especially in the form of exhaust gases. There are many ways to recover the waste heat of exhaust gases. Most of them use the sensible heat in flue gases for combustion air preheating, charge preheating and to generate steam or hot water. In this study economic analysis is applied to a furnace for forging equipped with combustion air preheater. The thermal efficiency increases from 14.86% to 21.87% and the yearly total running cost decreases from 720542 € to 716532 €, that means an economy of 4010 € per year. This analysis provides information on investment cost and the economic and environmental benefit by using the waste heat for combustion air preheating.

KEYWORDS: furnace, efficiency, capital costs, environmental cost, heat recovery

1. INTRODUCTION

The purpose of a heating process is to rise the product temperature by introducing a certain amount of heat into product. The product heating in furnace is accompanied by heat losses in different areas and forms such as: stored heat in furnace structure; heat losses through furnace walls; material handling losses; cooling media losses; radiation (opening) losses; lose due to air infiltration and wasted heat in exhaust gases. Thermal efficiency of furnaces used as heating equipments, is the ratio of heat delivered to a material and heat supplied to the heating equipment. Most furnaces have lower thermal efficiency than boilers, typically in the range 5% to 35%. This is mainly because the generated heat is in great extent wasted. To increase the furnace thermal efficiency one can proceed to the following techniques: combustion enhancement that leads to reduced fuel consumption and reduced pollutant emission; furnace thermal insulation to reduce the heat loss through the furnace walls and heat recovery contained in exhausted gases.

In an energy system the user is interested to know the true cost of utility is produced in order to identify processes that less economically efficient, and the choice of technical options to improve system efficiency. This analysis uses flows of energy, costs and flows of other resources and flows of pollutants. The environmental degradation is taken into consideration by considering the taxes on pollution.

A large number of different techniques for waste heat recovery have been investigated by numerous researchers. The main task of researchers is designing efficient and cost effective systems that also meet lower capital and running costs and environmental conditions.

This paper applies economic analysis to a combustion forging furnace that will be equipped with a heat recuperator to preheat combustion air by using waste heat in exhausted gases. The analysis provides information of the financial effort to equip the furnace in order to increase the energy efficiency of furnace.

2. SYSTEM PRESENTATION

Physical model of a fuel fired forging furnace equipped with heat exchanger for air preheater by using heat in exhausted gases is shown in Figure 1.

The furnace uses natural gas with the following composition: CH_4=97.9%, C_2H_4=0.8%, N_2=1.2%, CO_2=0.1% and lower heating value of 35420 kJ/Nm^3. The natural gas is burnt with excess air of 10%.

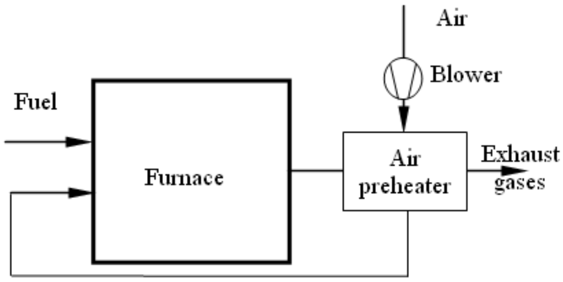

Fig. 1. Furnace scheme.

The furnace introduces heat in metal bars with dimensions 70x70x400 mm, made of steel carbon. The furnace capacity is 315 kg per charge and the total time of heating is 1.7 hours.

Inside furnace temperature is 1169°C and surface temperature of metal parts is 850°C. Exhaust temperature of flue gas decreases from 1054°C to 120°C (lower limit to avoid dew point) and combustion air temperature increases from 20°C to 772°C by using heat recovery. Higher combustion air temperature leads to increased adiabatic temperature. To maintain constant heat flow introduced in metal parts it is necessary to reduce fuel flow rate to balance the higher adiabatic temperature. A lower fuel flow rate means a lower combustion air flow rate. This means the combustion air fan has the same power since the gazodinamic resistances supplementary introduced by combustion air preheater are balanced by lower air flow rate through furnace and air preheater. The furnace operation parameters are shown in Table 1.

Table 1. Operation data for forging furnace (metal bars heating).

Parameter	Without combustion air preheating	With combustion air preheating
Capacity (kg of metal parts) (steel with 0.5% carbon)	315 kg	315 kg
Total time for heating	1.7 hours	1.7 hours
Natural gas flow rate, B	20.14 Nm^3/h	13.68 Nm^3/h
Combustion air flow rate	227 Nm^3/h	154.17 Nm^3/h
Air fan power, W_A	250W	
Initial temperature of metal parts	20°C	
Final temperature of metal parts	850°C	
Specific heat of steel	$c_p(20°C) = 0.42$ kJ/(kg·grd) $c_p(850°C) = 0.685$ kJ/(kg·grd)	
Initial temperature of combustion air	20°C	
Temperature of preheated air	-	772.7°C
Exhaust gases temperature	1054°C	120°C

3. ECONOMIC MODEL

For the given system, the total yearly running cost, considering the environmental costs is expressed by the following equation:

$$C_t = C_{mpi} + C_f + C_{el} + C_{env} + Z_F^{CI} + Z_F^{OM} \quad [€] \qquad (1)$$

where:

C_{mpi} - cost of metal parts introduced in furnace:

$$C_{mpi} = \dot{m}_{mp} \cdot c_{mpi} \cdot \tau_{op} \quad [€] \qquad (2)$$

$\dot{m}_{mp}$ - flow rate of heated metal parts, kg/s;

c_{mpi} – specific cost of raw metal parts, €/kg;

τ_o - yearly operation period (s);

C_f – fuel cost:

$$C_f = B \cdot c_f \cdot LHV \cdot \tau_{op} \quad [€] \qquad (3)$$

B - fuel flow rate, Nm^3/s;

c_f – specific cost of fuel, €/ kJ;

LHV – lower heating value of the fuel, kJ/Nm^3.

C_{el} - cost of electricity consumed by air blower:

$$C_{el} = \frac{c_{el} \cdot W_A \cdot \tau_{op}}{3600} \qquad (4)$$

c_{el} – electricity cost, €/kWh;

W_{AF} – power of air fan, kW;

$\dot{C}_{env}$ – cost rate connected to taxation applicable to fuels for industrial or commercial use established by the Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity:

$$C_{env} = B \cdot LHV \cdot \tau_{op} \cdot c_{ng} \; [€] \qquad (5)$$

c_{ng} –current taxation applicable to natural gas for industrial or commercial use (Table 2).

Table 2. The minimum levels of taxation applicable to fuels for industrial or commercial use [1].

Fuel	Current minimum excise rates
Diesel	21 €/1000 l
Kerosene	21 €/1000 l
LPG	41 €/1000 kg
Natural gas	0.3 €/GJ

Z_F^{CI} - capital cost of furnace:

$$Z_b^{CI} = CA \cdot \varphi \ [€] \quad (6)$$

φ =1.06 is maintenance factor
CA - annual capital cost:

$$CA = PW \cdot CRF(i,n) \ [€] \quad (7)$$

PW - present worth of furnace:

$$PW = C_k - S \cdot PWF(i,n) \ [€] \quad (8)$$

i =10% is annual rate of return;
n =25 years is furnace life period;
C_k – furnace capitalized cost (€);
S - salvage venue:

$$S = C_k \cdot j \quad (9)$$

j =12% is effective rate of return
PWF - present value:

$$PWF = \frac{1}{(1+i)^n} \quad (10)$$

CRF - capital recovery factor:

$$CRF = \frac{i(i+1)^n}{(i+1)^n - 1} \quad (11)$$

The total annual capital cost of furnace becomes:

$$Z_F^{CI} = C_k \cdot \varphi \cdot i \cdot \frac{(1+i)^n - j}{(1+i)^n - 1} \ [€] \quad (12)$$

The capital cost of tubular air preheater was estimated using the following equation [2]:

$$C_k = 5910.69 + 303.98 \cdot S^{0.8} \ [€] \quad (13)$$

where S is heat transfer surface, m^2.

Z_F^{OM} - operation and maintenance cost rate of the furnace, €.

From equation (1) we can find the specific cost of heated metal bars:

$$c_{mpo} - c_{mpi} = \frac{C_f + C_{el} + C_{env} + Z_F^{CI} + Z_F^{OP}}{\dot{m}_{mp} \cdot \tau_{op}} \ [€/kg] \quad (14)$$

Using data from Table 1 the following costs were obtained:

- specific cost of heated metal bars without waste heat recovery:

$$c_{mpo}\text{-}c_{mpi} = 0.055 \ €/kg$$

- specific cost of heated metal bars with waste heat recovery for combustion air preheating:

$$c_{mpo}\text{-}c_{mpi} = 0.046 \ €/kg$$

The contribution of each cost component to the cost of heated metal bars is shown in Figure 2. It can be seen that the fuel cost has the highest weight (59%), followed by the operation and maintenance cost (33%), capital cost recovery (4%), environmental cost (2%) and electricity cost (2%). The environmental cost represents 2% of the specific cost of heating metal bars when the tax of energy products and electricity are paid.

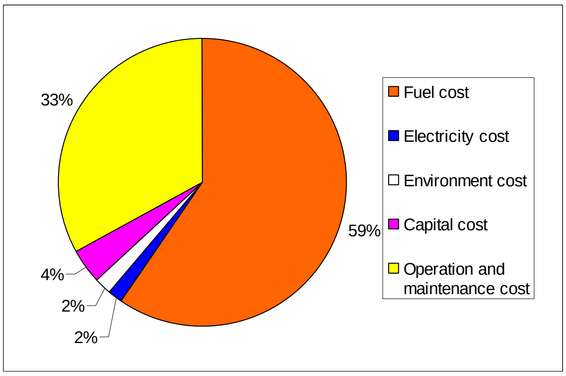

Fig. 2. The weights of different costs in the specific cost of heating metal bars (without waste heat recovery).

Comparative contribution of different costs in total cost of furnace running is shown in Figure 3.

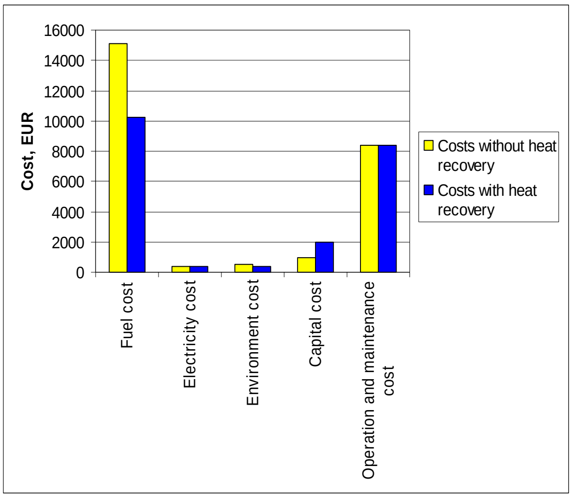

Fig. 3. Contributions of different costs in total cost of furnace running.

Though the recovery cost of capital expenditures increased by purchasing and installing tubular air preheater with heat exchange area of 16m^2 and an overall heat exchange coefficient U=20 kW/(m^2·degree) the total yearly cost of furnace running decreased from 720542€ to 716532€ leading to an economy of 4010 € due to reduction of fuel cost from 15091 € to 10250 €.

4. CONCLUSIONS

Industrial combustion type furnaces have low thermal efficiency due to heat losses. There are many researches on techniques for heat recovery. The engineer's interest is designing efficient and cost effective systems that also meet lower capital and running costs and environmental conditions.

By installing a tube air preheater with heat exchange area of $16m^2$ and an overall heat exchange coefficient U=20 kW/(m^2·degree) the total yearly cost of furnace running decreased from 720542€ to 716532€ leading to an economy of 4010 € due to reduction of fuel cost from 15091 € to 10250 € and reduction cost related to tax of energy products and electricity established by the Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity.

The capital cost 8704 € of air preheater can be recovered in less than 3 years.

The furnace thermal efficiency increases from 14.86% to 21.87%.

REFERENCES

[1] ****, Emission Factor Documentation for AP-42 Section 1.4—Natural Gas Combustion*, Technical Support Division, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1997.

[2] Rakonjac, I.M., Budimir, S.J., Jari, M.S., Budimir, N.J., *Manufacturing cost of Shell and Tube Heat Exchangers with paralel Helical Tube Coils*, Proceedings of the 2nd International Conference on Manufacturing Engineering & Management, ICMEM 2012, pp. 151-154.

[3] Bejan, A., Tsatsaronis, G., Moran, M., *Thermal Design and Optimization*, Wiley, New York, 1996.

[4] Trinks, W., Mawhinney, M. H., Shannon, R. A., Reed, R. J., Garvey, J. R., *Industrial Furnaces,* Sixth Edition John Wiley & Sons, 2004.

[5] ***, Bureau of Energy Efficiency, Ministry of Power, India. *Energy Efficiency in Thermal Utilities*. 2005.

[6] Mullinger, P., Jenkins, B., *Industrial and Process Furnaces. Principles, Design and Operation*, Butterworth-Heinemann, 2008.

[7] Saunders, E.A.D., Heat exchangers: selection, design & construction, Longman Scientific & Technical, 1988.

[8] Valero, A., Lozano, M.A., Serra, L., Tsatsaronis, G., Pisa, J., Frangopoulos, C., von Spakovsky, M., *CGAM problem: Definition and conventional solution***,** Energy 03/1994; 19, pp. 279-286.

[9] Ion, V.I, Pană, D., Bălan, G., *Exergoeconomic analysis of a furnace for heat treatment*, Proceedings of the 8th International Conference on Industrial Power Engineering, CIEI 2011, "Vasile Alecsandri" University of Bacau, Alma Mater Publishing House, pp. 185-189.

[10] Ion, V.I., Bălan, M., Popa, V., *The influence of the environmental impact on the thermoeconomic performance of a steam boiler*, Technical University of Cluj-Napoca Acta Technica Napocensis, Series: Applied Mathematics and Mechanics, No. 52, Vol. II, 2009, pp. 177-180.