Effect of Energy Modernisation of a Steam Boiler on the Economic Efficiency

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Effect of Energy Modernisation of a Steam Boiler on the Economic Efficiency: *Increasing the efficiency of energy systems and reducing the environmental impact is one of the most important tasks for energy engineers. In this work the exergoeconomy analysis is applied to a steam boiler in order to find the most effective measure of modernisation. The analysis revealed that the largest share in formation of exergy cost of steam belongs to fuel followed by feed water, taxes for air pollution and electricity consumption. The discussed measures of modernisation aimed at use of variable speed drive for feed water pump; optimise boiler blowdown with recovery of blowdown heat and automatic control system for combustion. The most cost effective measure was found the implementation of a automatic control system for combustion.*

Key words: *Exergoeconomy, Steam boiler, Exergy cost, Pollution taxes, Boiler blowdown, Combustion optimisation, Variable speed drive.*

INTRODUCTION

In Romania about 54.5% of total power consumption in 2012 was covered by thermal power plants. About 80% of thermal power plants have been built between 1970 and 1980. Their current efficiency reaches 30 %, that means (65-70) % from efficiency of modern power plants in EU. Starting with 2014 all thermal power plants have to obey to national environmental regulation, otherwise they will be closed. Beside the environmental performance, the thermal power plants should increase their energy efficiency in order to face market competition.

The actual energy crisis is maintained due to lack of alternative energy resources and conversion technologies which are both environmentally friendly and economically competitive. Until competitive new technologies become available, increasing the economic efficiency of current energy conversion technology is the only option to reduce the impact of the crisis.

Directions of enhancement the thermodynamic efficiency of a system are well established, but no directions for economic efficiency. One of the methodologies to assess the economic efficiency of an energy system became known as thermoeconomy or exergoeconomy. Exergoeconomy, this common branch of mechanical engineering and chemical industry represents a unique combination of exergy analysis and cost analysis which provides the designer or user of energy conversion facilities information that can not be obtained through conventional energy analysis, exergy or cost, but which are crucial in the economically efficient design and operation of a facility.

A thermal energy generator typically operates with more products: electricity, heat carrier materials (water or steam) at various parameters, cooling water, compressed air at one or more pressures. In such a complex energy system, the system user is interested to know the real cost of each utility that is produced, so that later each of these costs to be related to the final product, corresponding to the type and size of utilities. Knowing the weight of individual partial costs helps identifying the processes and transactions less economically efficient, and the choice of technical options to improve the system efficiency.

In this paper, by exergoeconomic analysis that takes into account the environmental impact (the most powerful new tool) has been established the influence of energy modernization measures of a steam boiler on the cost of generated steam. Modernization measures concerned are: use of variable speed drive for feed water pump; optimise boiler blowdown with recovery of blowdown heat and automatic control system for combustion.

The exergoeconomic analysis refers to the TGM 89 steam boiler which delivers 410 t/h of steam at 130 bar and 540 °C. The steam boiler is schematically presented in Fig.1.

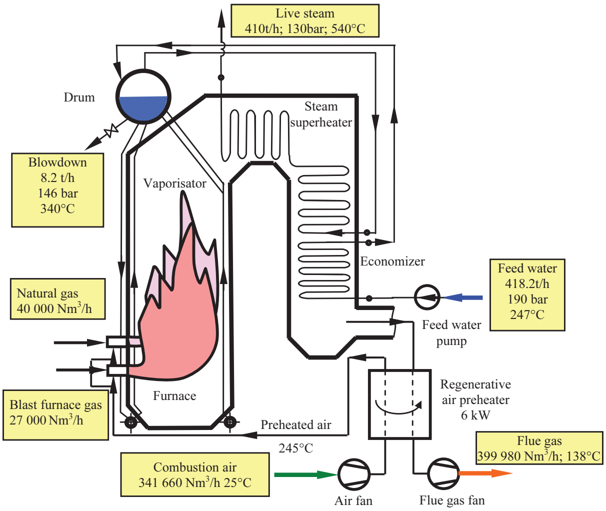

Fig.1. Scheme of the TGM 89 steam boiler

The operation parameters of steam boiler are given in Tab.1.

Table 1. Working parameters of steam boiler

Parameter	Value
Excess air in furnace	1.2
Temperature/pressure of water at economizer outlet	340°C/180 bar
Temperature/pressure inside the drum	340°C/146 bar
Power of feed water pump	3225 kW
Power of air fans	2 x 400 kW
Power of flue gas fans	2 x 440 kW
Power of regenerative air preheater	6 kW

Table 2. Properties of fuels

Fuel	Lower heating value *LHV*, kJ/Nm³	Composition, % vol.						
		C_2H_6	C_3H_8	N_2	CO	CO_2	H_2	CH_4
Natural gas	37 206	0.811	0.269	0.7	-	0,048	-	97.983
Blast furnace gas	3 431	0.21	-	51.8	25.2	13	9.76	0.03

EXERGOECONOMIC MODEL

In exergoeconomic analysis, the balance of cost formulated for boiler operating in steady state is:

$$\dot{C}_{steam} = \dot{C}_{fuel} + \dot{C}_{fw} + \dot{C}_{el} + \dot{Z}^{OM}_{boiler} + \dot{Z}_{pen} + \dot{Z}^{CI}_{boiler} \quad [€/s] \qquad (1)$$

where: $\dot{C}_{steam}$ - exergy cost flow rate of steam:

$$\dot{C}_{steam} = c_{e,steam}\dot{E}_{steam}$$

$c_{e,steam}$ – specific exergy cost of steam, €/kW

$\dot{E}_{steam}$ – exergy flow rate of live steam:

$$\dot{E}_{steam} = \dot{m}_{steam}(1 + k_{bd})e_{steam} \quad [kW] \qquad (2)$$

e_{steam} – specific exergy of steam, kJ/kg;

$\dot{m}_{steam}$ – mass flow rate of steam, kg/s;

k_{bd} – percent of blowdown: k_{bd} =0.03;

$\dot{C}_{fuel}$ - exergy cost flow rate of fuel:

$$\dot{C}_{fuel} = c_{e,fuel}\dot{E}_{fuel} \tag{3}$$

$\dot{E}_{fuel}$ –exergy flow rate of fuel, kW:

$$\dot{E}_{fuel} = \dot{m}_{fuel} \cdot e_{fuel} \tag{4}$$

e_{fuel} – specific exergy of fuel, kJ/
$c_{e,fuel}$ – specific exergy cost of fuel, €/kW;
$\dot{m}_{fuel}$ - mass flow rate of fuel, kg/s;

$\dot{C}_{fw}$ - exergy cost flow rate of feed water:

$$\dot{C}_{fw} = c_{e,fw}\dot{E}_{fw} \tag{5}$$

$\dot{E}_{fw}$ – exergy flow rate of feed water, kW:

$$\dot{E}_{fw} = \dot{m}_{steam}(1 + k_{bd})e_{fw} \tag{6}$$

e_{fw} – specific exergy of feedwater, kJ/kg;

$\dot{C}_{el}$ - exergy cost flow rate of electricity necessary to electrical engines to drive the feed water, air preheater, flue gas fans and air fans:

$$\dot{C}_{el} = c_{el}W_{tot} \tag{7}$$

c_{el} – specific exergy cost of electricity, €/kJ;
W_{tot} – overall electricity consumption, kW;
$\dot{Z}_{pen}$ - cost flow rate of taxes paid for air pollution:

$$\dot{Z}_{pen} = P_{CO_2}\dot{m}_{CO_2} + P_{NO_x}\dot{m}_{NO_x} \tag{8}$$

P_{CO_2}, P_{NO_x} – penalties (taxes) paid for air pollution, €/kg (Tab. III);

$\dot{m}_{CO_2}$, $\dot{m}_{NO_x}$ – CO_2 and NO_x emissions, kg/s;

$$\dot{m}_{NO_x} = \dot{m}_f \cdot LHV \cdot e_{NO_x} \tag{9}$$

e_{NO_x} – NO_x emission factor (Tab.4);

Table 3. Taxes paid for emitted pollutants into atmosphere [2]

Pollutant	Tax
CO_2	5.3 €/t CO_2
NO_x	10 €/t NO_x

Table 4. NO_x Emission factor, e_{NO_x} [4]

Fuel	**NO_x emission factor, e_{NO_x}, kg/kJ**		
	Thermal power of steam boiler, MWt		
	50-100	100-300	>300
Oil	$1.9\cdot10^{-7}$	$2.1\cdot10^{-7}$	$2.8\cdot10^{-7}$
Natural gas	$1.3\cdot10^{-7}$	$1.5\cdot10^{-7}$	$1.7\cdot10^{-7}$

$\dot{Z}^{OM}_{boiler}$ - cost rate associated with boiler operation and maintenance, €/s;
$\dot{Z}^{CI}_{boiler}$ - cost rate associated with capital investment, €/s.

RESULTS AND DISCUSSIONS

By applying equations (1) to (9) is obtained the exergetic cost of steam generated at 130 bar and 540°C of $1.453\cdot10^{-5}$ €/kJ. Taxes paid for CO_2 emission (0.107 €/s) are higher than taxes paid for NO_x emission (0.0005 €/s).

The weights of different costs in the exergetic cost of steam at 130 bars and 540°C are shown in Fig. 2. It can be seen that the fuel cost has the highest weight (71.633%) and also the taxes for pollution represent an important component of steam cost (3.804%).

If the costs associated with feed water and capital investment, operation and maintenance of steam boiler can not be much reduced, the largest reduction could be achieved in fuel and electricity costs and pollution taxes. By reducing the fuel consumption and optimising the combustion process the pollution taxes are reduced as well.

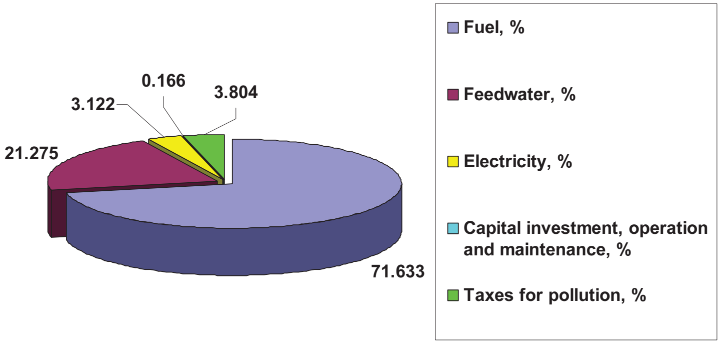

Figure 2. The weights of different costs in the steam cost

To reduce the cost of steam generated by boiler the following approaches are taken into consideration:

1) use of variable speed drive for feed water pump. There is significant potential to reduce electricity consumption of pumping systems through appropriate design, upgrading and operating techniques. The actual adjustment of feed water pump (centrifugal pump) operation is achieved by changing the network characteristic using throttling valve and bypass line. The control system of water supply of the boiler has to provide feed water flow control with boiler load and to maintain a constant steam pressure. The most efficient means of controlling pump flow consist in pump speed adjustment by using multiple-speed pump motors or variable speed drives. The level of energy saving depends on the time the boiler operates under partial load. The frequency converters can reduce energy consumption of feed water pump by (30-50)%;

2) optimisation of boiler blowdown (automatic blowdown control) with recovery of blowdown heat. In the open condensate blowdown system, vapours escape unused resulting in a heat loss. The waste heat arising in the boiler blow -down may be recovered by using a flash tank in combination with a heat exchanger and used for pre - heating the feed water;

3) optimisation of combustion process. The burners are operated with higher excess air as a safety measure. This leads to heat loss by heating the air surplus which is ejected into atmosphere. This loss may be reduced by using O_2 and CO controllers to adjust the air supply. In this way the combustion efficiency may be increased up to 3%.

If the steam boiler TGM 89 is equipped with variable speed drive for feed water pump the pump power decreases with 20% from 3225 kW to 2580 kW. System implementation requires additional investment cost of 247500 € and reduces exergetic cost of steam from $1.453\cdot10^{-5}$ €/kJ to $1.450\cdot10^{-5}$ €/kJ. The economy that can be achieved is 46640 €/year.

Implementation of automatic blowdown control with recovery of blowdown heat leads to the increase of boiler thermodynamic efficiency from 88.84% to 89.2%. Investment cost is 20292 €. In these circumstances, the exergetic cost of steam decreases from $1.453\cdot10^{-5}$ €/kJ to $1.451\cdot10^{-5}$ lei / kJ. The yearly saving can reach 162720 €.

By applying an automatic control system of combustion process, which implies an investment cost of 306000 €, provides a 2% reduction of fuel consumption (reduction from

27000 Nm^3/h to 26460 Nm^3/h of natural gas flow rate and reduction from 40000 Nm^3/h to 39200 Nm^3/h for blast furnace gas flow rate).This leads to reduction of exergetic cost of steam from $1.453 \cdot 10^{-5}$ €/kJ to $1.434 \cdot 10^{-5}$ €/kJ. The money saving that can be achieved in a year by implementation of combustion automatic control system will be 1154880 €.

The contribution of the different solutions proposed in this work to reduce the cost of steam generated by the TGM 89 steam boiler is shown in Fig. 3. It can be seen that the highest reduction of steam exergetic cost is obtained by applying automatic combustion control, even if this solution requires the largest additional investment. Implementations of automatic blowdown control with recovery of blowdown heat and use of variable speed drive for feed water pump have almost the same effect on exergy cost of steam.

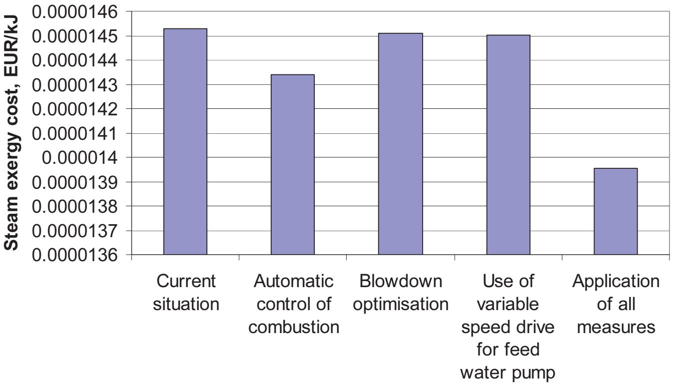

Figure 3. Exergy cost of steam

It can be noted that the combined application of all proposed solutions leads to a lower cost than costs obtained by individual application of each solution. This happens due to the individual reductions which at the combined application are summed.

CONCLUSION

A mathematical model for calculating the exergy cost of steam produced by a steam boiler that takes into consideration the costs due to environmental pollution has been developed. Applying the model to the TGM 89 steam boiler the contribution of each component to formation of steam exergy cost has found. By steam boiler modernisation (retrofit) which consist in combustion optimisation, blowdown optimisation and use of variable speed drive for feed water pump can certainly reduce the cost of steam from 0.0240 €/kg as it is in present to 0.0233 €/kg, taking into account all investment expenditures, maintenance and operation - incurred by this modernization.

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