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Exergetic Analisys of a Recovery Boiler from Siderurgycal Industry

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Abstract

This work presents the exergetic method of thermodynamic analyses applied generating steam in power plants. Using the result of the exergetic method, we emphasize the factors that reduce conversion capacity fuel-steam. [3]

Key words: *exergy, energy, heat transfer, efficiency*.

General Appreciation

The definition of exergy was given by Zoran Rant, as "that part of the energy that can be extract, the part that can produce mechanical work"[5]. Exergy not only can be destroyed through a irreversibility of processes, but can be also transferred to and from a system as a heat transfer loss in athmosphere. The improvement of the energetic resources utilization could be accomplished by reducing the exergy losses and destructions.

The purpose of this paper is to introduce the exergetical analyses, as a method which uses the mass and energy conservation (First principle of thermodynamics), together with the second principle of thermodynamics for the analysis, modelation and the functioning updating (optimization) of the thermic systems. The importance of the upgraded thermic systems that are using not recovered energetic resources, as fuels (oil and oil products), natural gases and carbon, is obvious"[6]. For a better utilization of a those energetic resources, the method of exergetic analysis offer the possibilities to locate and identify the loss and the real dimension of these. This information is useful for designing the thermic systems, and for the existing systems to be a model of reducing inefficient sources, this information could be used in economical evaluation of the thermic systems. Through the exergetic analysis of the processes it can be identified the place and the way where the transformation of exergy in anergy takes place and take measure for reducing this loss. As a thermo dynamical method of analyses, it operates with different forms of energy quantity, ignoring the quality characteristics of it. This classical way leads to wrong appreciations of the thermo dynamical efficiency ratio , with all the negative consequences that came from it.

The first step in the exergetic analysis is the establishment of the sum borders and references parameters.[3] Another step that is necessary for making the exergetic sum is the identification of the consumption and the exergetic product which is adherent to each element that is part of the analyzed system. The right establishing of the exergetic flows of the elements that enter in the process and of the products that came out will lead ,by sum, at finding the lost and destroyed exergetic flows on each analyzed component, a very important indicator in the irreversibility influence of the estimation of the analyzed process.

The analyzed system is a exhaust- heat steam boiler.

Boiler Description

The components of the exhaust - heat steam boiler are: boiler drum; hood; radiation tower; water cooled elbow; gases cooler; exhauster; smoke stack; cooling gases installations.

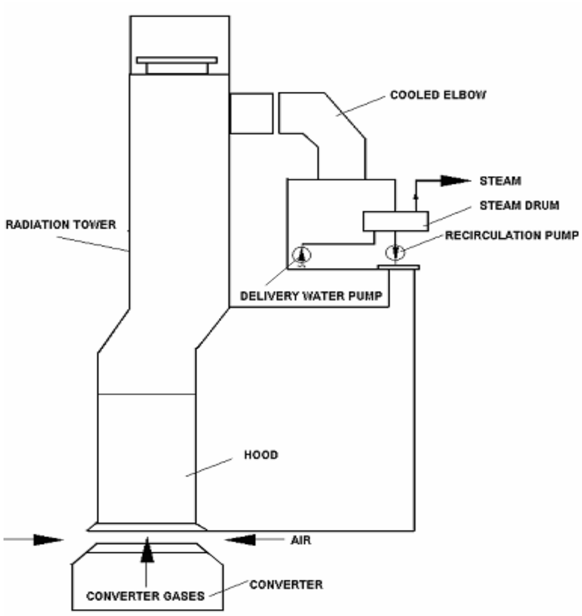

Fig. 1. Installation chart

At 105^{0}C the delivery water of the boiler is sent by pumps in boiler drum. The circulation in boiling system of the boiler is provided by re-circulation pumps through an exterior ducts system ad to water distributor of each element (hood, radiation tower and cooled elbow). The water running through the steamer system absorbs the heat from burned gas, resulting a water - steam emulsion which from the collectors of each element of the boiler ,by exterior ducts system , get to boiler drum. The steam flow measurement is done by a diaphragm mounted on the main steam duct, making in this way an recording registration . The rest of water is completed with delivery water, starts from the beginning at the oxygen blast ending in converter, one of the 3 recirculation pumps in use, stops till the beginning of a new charge.

An important feature of this exhaust- heat boiler is the cyclic working ,with 1 cycle/hour frequency, that leads to a permanent fluctuation of the main parameters of the boiler (pressure, temperature, flow).

“Converter gases” or burned gas are the resulting gases after the oxygen blast by lance in steel ladle, that came as a result of carbon burning from cast iron in reaction with blast oxygen. “Converter gases” or burned gas exits from exhaust - heat boiler at 1085 C after that enter in gases cooler , by humectation with water fog are chilled at 700 C and separated from converter dust , after that with an exhauster are released in atmosphere. For an exergetic analysis of the exhaust - heat boiler will make a balance according with the following basic data:

o Boiler model – recovery boiler with multi-forced circulation ;

- Combustible : gas converter;
- Maximum steam flow produce: 254 t/h
- Maximum pressure of the steam at drum steam exit: 52bari
- Steam temperature :2600 C
- Delivery water temperature : 1050 C
- Converter gases maximum temperature at the boiler admission :1700 C
- Converter gases maximum temperature at the boiler exit :1085 C
- Burning efficiency: 0,7

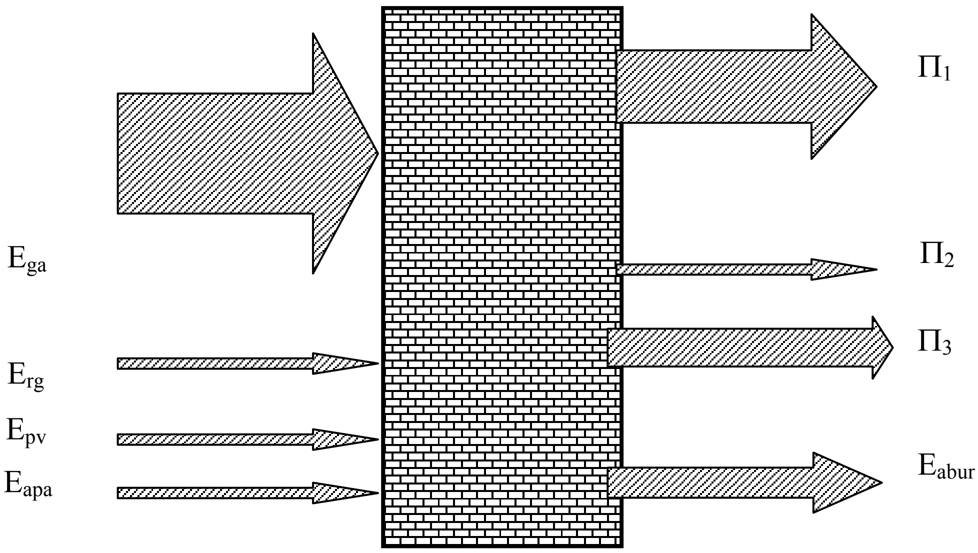

Fig. 2 – Exergetical flows chart

E_{ga} - physical exergy of burned gas (converter gases) at the boiler admission;
E_{apa} - physical exergy of delivery water;
E_{rg} - physical exergy of gases break out;
E_{pv} - physical exergy of flyer dust;
Π_1 - exergy loss by burned gas heat waste;
Π_2 - exergy loss by external surfaces boiler cooling ;
Π_3 - exergy loss by irreversibility heat exchange;
E_{abur} - steam exergy produce in boiler.

$$E_u = E_{ga} + E_{rg} + E_{pv} + E_{apa} \tag{1}$$

$$E_u - \sum_{i=1}^{3} \Pi = E_{abur} \tag{2}$$

Physical exergy of delivery water:

$$E_{apa} = \left(1 - \frac{T_0}{T_{apa}}\right) \cdot D_{apa} \cdot i_{apa} \ \text{[kW]} , \tag{3}$$

where: T_{apa} =378 [K] – delivery water temperature [K];

D_{apa} =50t/h=13,88kg/s – delivery water flow[kg/s];

I_{apa} =429kJ/kg – delivery water enthalpy [kJ/kg]

T_0 =298 [K] – reference temperature [K].

$$E_{apa} = \left(1 - \frac{298}{378}\right) \cdot 13{,}88 \cdot 429 = 1256{,}4 kW \tag{4}$$

Physical exergy of flyer dust:

Flyer dust is the dust that enter along with converter gases in the boiler. The flyer dust amount that enter in the boiler is 1,5 [%] of burned gases. The dust temperature at admission is 1700 [^{0}C]. Normal charge is lasting 16 [min].

c_p=0,016(Kcal/kgC) x4,187=0,669 [kJ/kgK] – dust specific heat;
T_{aer} – dust temperature inlet [K];

B – dust flow=2800 [m_N^3/s];
c_p – dust specific heat [kJ/kg grad];

$$Q_{pv}\text{=160000 x 0,015 x 0,016x0,7x1700x16/60=0,17 x106[Kcal/h]=197,38kJ/s} \tag{5}$$

$$E_{praf} = \left(1 - \frac{T_0}{T_{praf}}\right) \cdot B \cdot c_{pc} \cdot t_{aer} \ \text{[kW]} \tag{6}$$

$$E_{praf} = \left(1 - \frac{298}{1973}\right) \cdot \frac{2800}{3600} \cdot 0{,}92 \cdot 1700 = 1031{,}544 \ \text{[kW]} \tag{7}$$

Physical exergy of gases break out: The gases break out flow is minor and the exergy is zero.

Physical exergy of burned gas (converter gases) at the boiler admission;

$$E_{ga} = \left(1 - \frac{T_0}{T_{ga}}\right) \cdot B \cdot c_{pc} \cdot t_{aer} \ \text{[kW]} \tag{8}$$

where: T_{ga} –temperature of burned gas (converter gases) at the boiler admission – [K];

c_{ga} – gases specific heat [kJ/kg grad];

$$E_{ga} = \left(1 - \frac{298}{1973}\right) \cdot \frac{33314}{3600} \cdot 2{,}53 \cdot 1700 = 33751{,}22 \ \text{[kW]} \tag{9}$$

Exergy loss by burned gas heat waste:

$$\Pi_1 = \left(1 - \frac{T_0}{T_{ga}}\right) \cdot B \cdot \left[I_{ga}(t_{ga}, \lambda_f) - I_{ga}(t_0, \lambda_{ev})\right] \ \text{[kW]} \tag{10}$$

where: T_{ga} –burned gas heat waste temperature [K]; T_{ga} = 1085 ^{0}K; B – gas flow [kg/s];

$I_{ga}(t_{ga}, \lambda_{ev})$ - burned gas enthalpy stands on burned gas heat waste temperature and air excess factor;

$I_{ga}(t_0, \lambda_{ev})$ - burned gas enthalpy stands on reference temperature;

I_{ga}(100; 1,3)= 2781,47 [kJ/kg];I_{ga}(20; 1,3)= 211,88 [kJ/kg]

Exergy loss by external surfaces boiler cooling:

$$\Pi_2 = \Phi_2 \cdot \left(1 - \frac{T_0}{T_p}\right) \text{ [kW]} \tag{11}$$

$$\Phi_2 = \varphi \cdot S \text{ [kW]} \tag{12}$$

where: φ - heat flux lost on the external surface boiler's aria [W/m^2]

φ = 350 [W/m^2] = 0,35 [kW/m^2]

S – external surface boiler's [m^2]

T_p- boiler surface temperature;

$$S = \pi \text{ x D x h} = 3{,}14\text{x}4{,}5\text{x}28 = 395{,}64 \text{ m}^2 \tag{13}$$

$$\Pi_2 = 0{,}35 \cdot 395{,}64 \cdot \left(1 - \frac{298}{573}\right) = 66{,}289[kW] \tag{14}$$

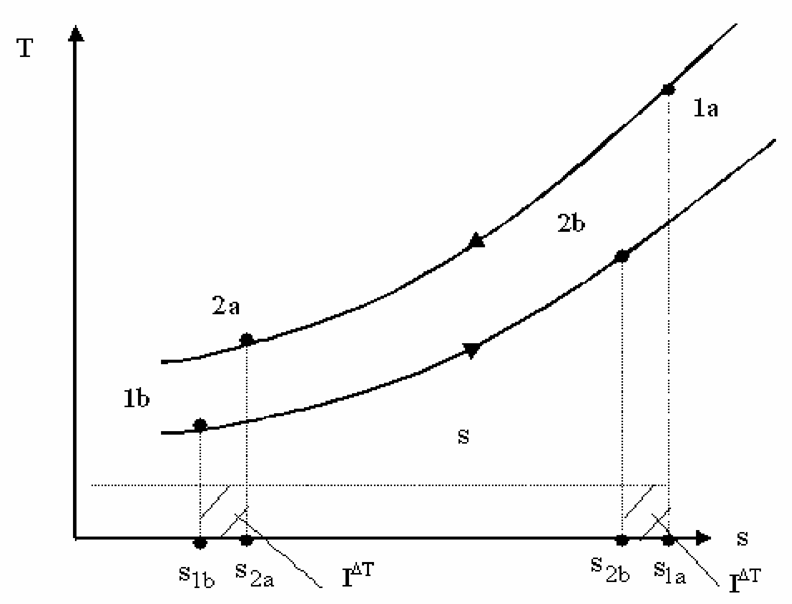

Fig. 3 Exergetical loss by irreversibility heat exchange:
1a – burned gas state at burning temperature;
2a – burned gas state at evacuation temperature;
1b – delivery water state; 2b – steam state.

s_{1a} - burned gas entropy at burning temperature [kJ/kg grad];

s_{2a} - burned gas entropy at evacuation temperature [kJ/kg grad];

s_{1b} - delivery water entropy[kJ/kg grad];

$\dot{s}_{2b}$ - steam entropy [kJ/kg grad].

$I^{\Delta T}$ - irreversibility stands on finite temperature difference of heat transfer:

$$I^{\Delta T} = T_0 \cdot [(\dot{s}_{2a} - \dot{s}_{1b}) + (\dot{s}_{1a} - \dot{s}_{2b})] = T_0 \cdot [(\dot{s}_{1a} + \dot{s}_{2a}) - (\dot{s}_{1b} + \dot{s}_{2b})] \text{ [kJ/kg]} \tag{15}$$

For burned gases , the entropy formula is:

$$\Delta s = s - s_0 = \bar{c}_m \cdot \ln \frac{T}{T_0} \text{ [kJ/kgK]} \quad (16)$$

where: $\bar{c}_m$ - medium specific heat;

$$s_{1a} = \frac{1{,}48 + 1{,}042}{2} \cdot \ln \frac{2173}{293} = 2{,}52 \text{ [kJ/kgK]} \quad (17)$$

$$s_{2a} = \frac{1{,}06 + 1{,}042}{2} \cdot \ln \frac{373}{293} = 0{,}25 \text{ [kJ/kgK]} \quad (18)$$

$$s_{2b} = 1{,}85 \text{ [kJ/kgK]} \quad (19)$$

$$s_{1b} = 0{,}16 \text{ [kJ/kgK]} \quad (20)$$

$$\Pi_3 = B \cdot I^{\Delta T} = 9895{,}89 \text{ [kW]} \quad (21)$$

$$E_u = E - (\Pi_1 + \Pi_2 + \Pi_3) \quad (22)$$

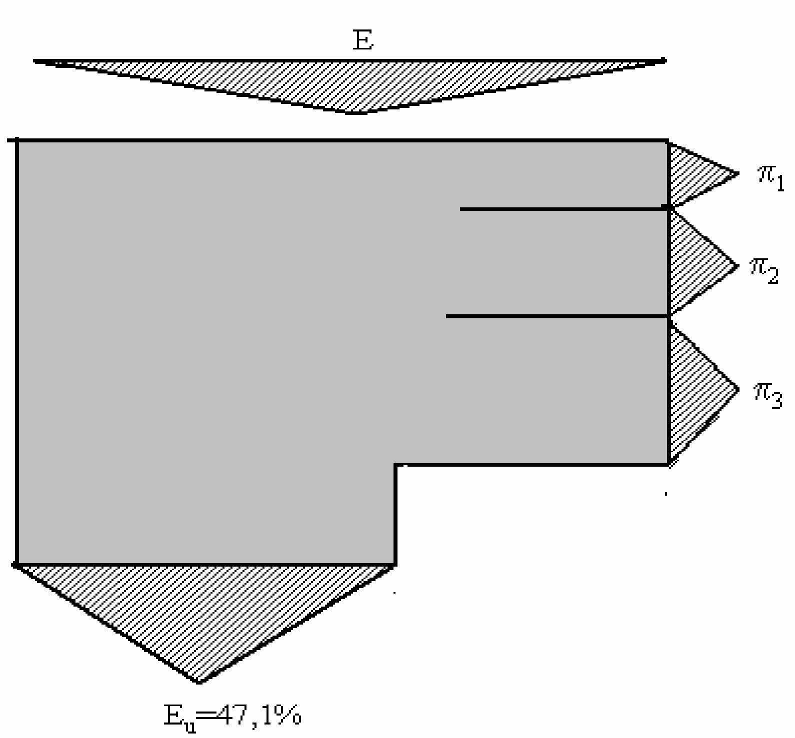

Fig. 4. Sankey chart of exergetic efficiency

The exergetic efficiency is:

$$\eta_{ex} = \frac{E_u - \sum \pi_{ex}}{E_u} \cdot 100 = \frac{E_{ga} + E_{rg} + E_{nv} + E_{apa} - (\Pi_1 + \Pi_2 + \Pi_3)}{E_u} \cdot 100 = 47{,}1\% \quad (21)$$

Conclusions

Exergy loss, according to boiler exergetic flows chart , is conditioned by the processes irreversibility such as: burning, burned gas and water (steam), heat exchange between burned gases and air, and combining process. It is well known the fact that irreversibility of burning demonstrate that in the moment of making burning gases, a part of elements exergy involved in burning process won't no longer exists in burned gases.

A solution could be the modification of the CO_2/CO proportion from burned gas, using the heat from other metallurgical processes in converter, in this way making a cast iron discount per tone of steel and increasing the amount of scrap iron in converter. Another solution can be the modification of the construction of exhaust-heat boiler after the modification of the CO_2/CO proportion from burned gas, as at the outlet the temperature of the gases will be 50-60^{0}C maximum but is very expensive solution .

Another solution that I propose and it is my these, is the heat recover that now is losing in the atmosphere, by introduction another exchange heater in exhaust-heat boiler installations . With this solution the temperature of the gases will be 50-60^{0}C maximum. The quantity of heat regained estimated will be enough for the heating of a residential district during winter.

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Analiza exergetică a unui cazan recuperator din siderurgie

Rezumat

Obiectivul acestei lucrări este de a introduce analiza exergetică, ca pe o metodă care foloseşte conservarea masei şi a energiei (Principiul I al Termodinamicii), impreună cu Principiul al II lea al Termodinamicii pentru analizarea, modelarea, şi imbunătățirea functionarii (optimizarea) sistemelor termice. Importanța îmbunătățirii sistemelor termice care folosesc efectiv resurse energetice nerecuperabile, cum ar fi carburanții (petrolul si produsele petroliere), gazele naturale şi cărbunele, este evidentă. Pentru o mai bună utilizare a acestor resurse energetice metoda analizei exergetice dă posibilitatea să localizeze şi să se identifice pierderile şi adevărata dimensiune a acestora.[4].