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# THE PERFORMANCE CRITERIA OF THE COMBUSTION CHAMBERS

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***Abstract:*** *In order to establish the optimum parameters of combustion chambers, it is necessary to define the most adequate performance criteria of thermoenergetic processes developed iniside this chamber. Thus, in the paper classical thermodynamic performance parameters (adiabatic combustion temperature and combustion thermal efficiency) are firstly analysed and secondly they define exergoeconomic criteria like: exergy destroies and exergetic efficiency, accordingly to parameters of processes.*

***Key words:*** *combustion chambers, exergetic analysis, exergetic efficiency.*

## 1. Introduction

The thermoenergetic systems and equipment performances depend on the combustion chambers performances where the fuels chemical energy is transformed into heat. This is why it is necessary to define the most adequate performance criteria of thermoenergetic processes developed in combustion chambers, in order to establish their optimum working parameters.

According to the second principle of thermodynamics, all real processes from the thermoenergetic machines and equipments are irreversible processes. This means that the real processes determine an entropy increase or generation, according to the general relation of the second principle of thermodynamics [1], [2], [3], [4].

Hence, if we consider the exergy basic relation, it appears that the difference between the heat exergy that has been exchanged with the environment by a thermodynamic system and the sum between the system exergy variation and the exchanged mechanical work, represents the sum of the exergy losses and the exergy destruction due to the internal irreversibility of processes [6]:

$$e_q - \left(\Delta e + l_t\right) = \sum e_P + e_D \tag{1}$$

In this relation, we make the difference between the exergy losses, marked with $e_P$ and the exergy destruction $e_D$. Thus, the exergy loss displays as an exergetic flow that leaves the thermoenergetic system taken into account, joining a material flow or a heat transfer, but which does not represent a useful product in regard to the objectives of the system. The exergy destruction represents the difference between the exergetic flows that come into the system and the exergetic flows that leave the system, difference without which the exergetic balance cannot be closed.

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The magnitude of the exergy destructions produced during a thermoenergetic process defines the perfection of that process [1], [5].

That's why the evaluation of these exergy destructions is absolutely necessary; we should analyze its causes in order to find the reduction technical solutions and increase the thermodynamic efficiency of the analyzed process.

If we analyze the real processes, characteristic for the thermoenergetic machines and equipments, we find out that the internal and external irreversibilities can be associated to some specific processes, typically irreversible: the heat transfer process at a finite temperature difference, the lamination process, the compression and extension processes, the burning process, the mixture process [7], [8].

The real complex processes can be divided into these simple processes, typically irreversible, for which we can evaluate the exergy destructions.

Therefore, the processes from the combustion chambers are typically irreversible processes and should be studied in this context.

## 2. The Exergetic Analysis of the Combustion Processes

The combustion of a combustible implies chemical reactions; the chemical exergy is transferred as physical exergy of the combustion products. This implies a finite temperature increase from the value of the flows before combustion, to the final value of the combustion products. Further to this finite temperature difference, combustion processes are always irreversible. However, not all the combustible chemical exergy is to be found in the exergy of the combustion products because the exergy destruction caused by the combustion irreversibility.

In order to display this exergy destruction, we consider a combustion chamber (Fig. 1), in which the process develops in an isobaric manner, in order to avoid the exergy destructions caused by the pressure variations.

Because the combustion chamber is fix, it doesn't exchange any mechanical work with the environment, and heat losses through the external walls are considered to be insignificant.

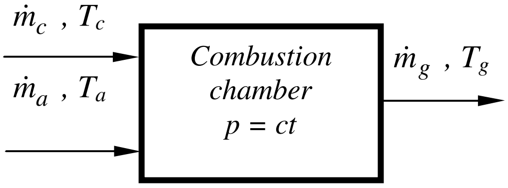

Fig. 1

Therefore, the fundamental exergy equation will be :

$$\Delta\dot{E} + \dot{E}_{D,ar} = 0 \tag{2}$$

It means that the exergy destruction caused by the combustion irreversibility will be equal to the exergy variation from the inlet and the outlet flows.

As the exergy destruction is always considered to be positive, the exergy variation will be negative.

This exergy variation can be expressed by an exergetic balance equation on the combustion chamber:

$$\Delta\dot{E} = \dot{E}_g - \left(\dot{E}_{ch} + \dot{E}_a + \dot{E}_c\right) \tag{3}$$

Where: $\dot{E}_{ch}$ is the chemical exergy flow of the massic flow $\dot{m}_c$ of combustible introduced in the combustion chamber; $\dot{E}_g$ - the physical exergy flow of the massic flow $\dot{m}_g$ of combustion gases, at the final temperature $T_g$ ; $\dot{E}_a$ - the physical exergy flow of the flow $\dot{m}_a$ of air, at the initial temperature $T_a$; $\dot{E}_c$ - the physical exergy flow of the flow $\dot{m}_c$ of combustible, at the initial temperature $T_c$.

Relations (2) and (3) have been expressed in total exergy flows and not in specific exergies, because the massic flows are different.

Consequently, the exergy destruction due to the combustion's irreversibility can be expressed by:

$$\dot{E}_{D,ar} = \dot{E}_{ch} - \Delta\dot{E}_f \tag{4}$$

If $I_g$ , $I_a$ , $I_c$ , [kJ/kg comb.], represent the gases' enthalpy, air enthalpy, respectively combustible enthalpy, and the entropies of these gases are $S_g$, $S_a$, $S_c$, [kJ/K.kg.comb.], then we have the combustion heat $Q_{ar}$, equal to the inferior heating value $H_i$ ,

$$Q_{ar} = I_g - (I_a + I_c) = H_i \tag{5}$$

and the entropy generation,

$$\Delta S_{ar} = S_g - (S_a - S_c) \tag{6}$$

In order we are the physical exergy increase:

$$\Delta\dot{E}_f = \dot{m}_c (Q_{ar} - T_0 \Delta S_{ar}) = \dot{m}_c E_{Q_{ar}} \tag{7}$$

But the combustion heat exergy can be expressed with the help of average exergetic factor,

$$E_{Q_{ar}} = \theta_{Em} Q_{ar} = \left(1 - \frac{T_0}{T_{m,ar}}\right) H_i \tag{8}$$

Now we can to express the exergy distruction on the combustion chamber:

$$\dot{E}_{D,ar} = \dot{m}_c e_{ch} - \dot{m}_c \left(1 - \frac{T_0}{T_{m,ar}}\right) H_i \tag{9}$$

or,

$$e_{D,ar} = e_{ch} - \left(1 - \frac{T_0}{T_{m,ar}}\right) H_i \tag{10}$$

where $e_{ch}$ and $e_{D,ar}$, [kJ/kg.comb.], represents the chemical exergy, respectively the exergy destruction on the combustion chamber, related to the combustible mass unit.

Taking into account that in a combustion chamber we consume the chemical exergy of the combustible, in order to increase the gases exergy, the exergetic efficiency of the combustion process will be defined as:

$$\eta_{ex,ar} = \frac{\Delta\dot{E}_f}{\dot{E}_{ch}} = \frac{E_{Q_{ar}}}{e_{ch}} = \frac{\left(1 - \frac{T_0}{T_{m,ar}}\right) H_i}{e_{ch}} \tag{11}$$

or,

$$\eta_{ex,ar} = 1 - \frac{e_{D,ar}}{e_{ch}} \tag{12}$$

In order to express the average temperature for the isobaric process, we must consider the definition relation:

$$T_{m,ar} = \frac{Q_{ar}}{\Delta S_{ar}} \tag{13}$$

But,

$$\Delta S_{ar} = \lambda L_0 \bar{c}_{p1} \ln\frac{T_g}{T_a} + \bar{c}_{p2} \ln\frac{T_g}{T_c} \tag{14}$$

In these relations we have considered two massic separate flows: one with the $\lambda L_0$ [kg / kg comb.] that corresponds to the air flow heating from $T_a$ to $T_g$ and one with the 1 [kg / kg comb.] that corresponds to the combustible unitary flow, that heats from $T_c$ to $T_g$.

If in the case of relation (14) we consider $T_c = T_a$, then replacing in Rel. (13) we obtain:

$$T_{m,ar} = \frac{T_g - T_a}{\ln \frac{T_g}{T_a}} \tag{15}$$

We would have obtained the same relation, if we had considered that the combustible unitary flow has no importance in keeping with the air flow, because,

$$\frac{1}{\lambda L_0} = 0{,}07...0{,}03$$

The gas temperature at the outflow from the combustion chamber can be determined by particularizing the energetic balance equation, expressed by Rel. (5).

Hence, it results:

$$T_g = \frac{H_i + \lambda L_0 c_{pa} T_a + c_c T_c}{(1 + \lambda L_0) c_{pg}} \tag{16}$$

In fact, if we reconsider relation (15), we find out that it expresses the average temperature for the isobaric heating process 1-2, represented in T-S coordinates in fig. 2. For this process, the heat exergy is proportional to the area until the environment temperature $T_0$ . That is: $E_{Q_{ar}} \cong aria_{TS}(1'122')$.

According to relation (11) it comes out that the combustion exergetic efficiency is increased by the growth of the $aria_{TS}(1'122')$, implying the augmentation of the air temperature introduced into the combustion chamber and the augmentation of the final temperature of the combustion gases.

The air temperature $T_a$ can be increased by the air preheating before being introduced into the combustion chamber, a frequently used method.

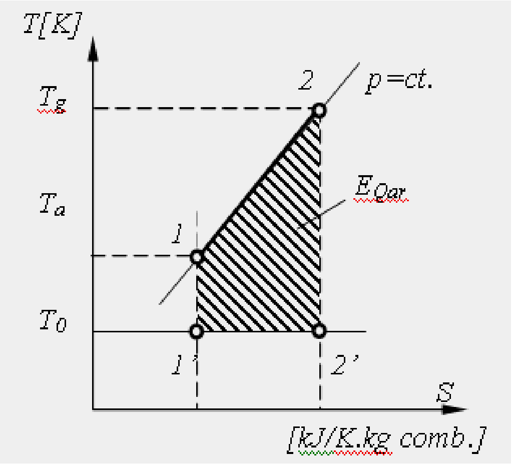

Fig.2.

The gas temperature $T_g$ , according to relation (16) can increase if we use air excess coefficients with as low as possible values.

The combustible chemical exergy is often approximated with the inferior heating value and therefore the combustion chamber exergetic efficiency becomes equal to the efficiency of the Carnot cycle, developing between the $T_{m,ar}$ and $T_0$ temperatures.

## 3. Conclusion

In order to display the influence of the combustion parameters upon the exergetic performances previously defined, we have presented a numerical application. We have taken into account a liquid combustible with a known composition and caloric power. The air excess coefficient has been modified in the λ=1...4 limits, and for the air temperature at the entrance of the combustion chamber, we have considered two different values ($T_a$=565K şi $T_a$=765K).

Based on the Rels. (11), (15), (16) relations, in Fig. 3 and Fig. 4, we have temperatures $T_g$, the average temperature

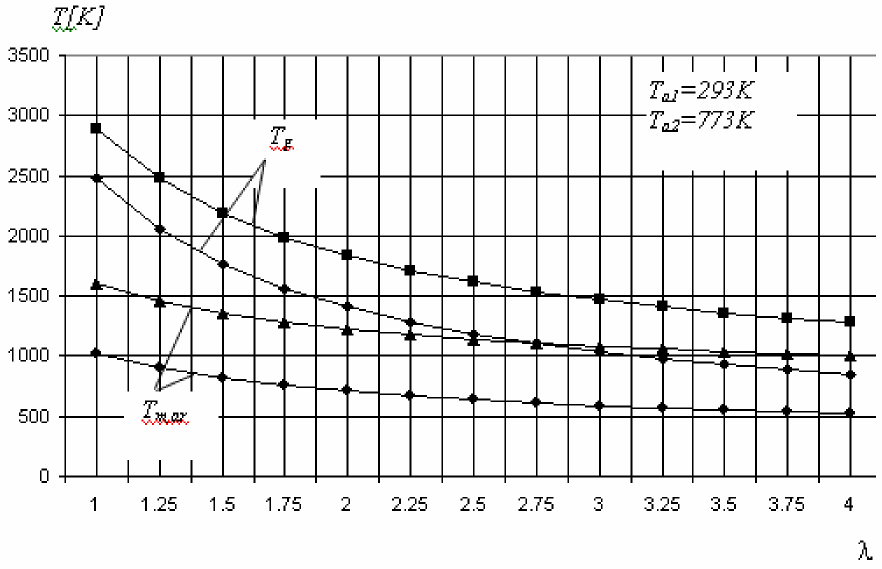

Fig. .3.

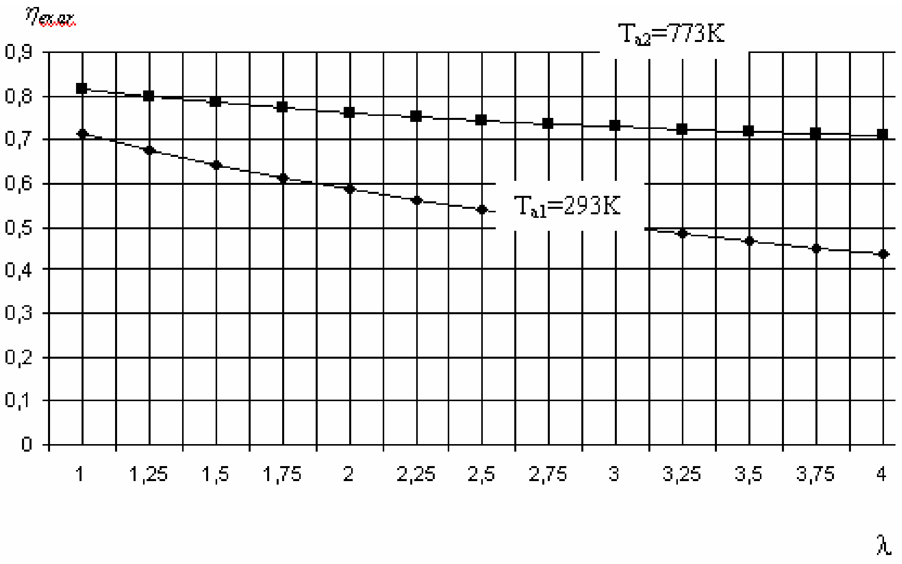

Fig. 4.

for the isobaric combustion process $T_{m,ar}$ and the exergetic combustion efficiency $\eta_{ex,ar}$, all according to the air excess coefficient λ.

First of all we notice that the gas combustion temperature, and the average temperature for the combustion process are continuously lowering with the increase of the air excess coefficient.

We can also notice that the combustion exergetic efficiency lowers as the air excess coefficient increases, meaning that the exergy destructions increase.

Secondly, if the air temperature increases at the combustion room admission, the combustion process efficiency increases, too.

The choice of the values for the air excess coefficient and of the air temperature at the combustion room admission depend on the structural and functional conditions of the installation. This means that we need an optimisation study for the entire installation.

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