# THE THERMODYNAMIC BENEFITS OF THE INTEGRATION OF COGENERATION INSTALLATIONS IN BAKERY OVENS

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## INTRODUCTION

The bread industry is one of the main branches of the food industry in Moldova, which offer the population the vital food –the bread. The food industry has a considerable share in the entirely industrial sector - about 51,6%, according to statistics, [1].

Baking industry share in total industrial production is approx. 4% [2], and in the total food production – 8,8%, but that does not diminish its importance in the development of industrial sector. Bakery branch has been, it is and will be one of the most needed, because this branch assure the vital human needs.

Recently, prices of bakery products were increased by approx. 15%. An important argument was put forward by the bakers- to increase of tariffs in august by 39,3% for electricity and 15% for natural gas. This has increased energy share in the cost price of bread from 10% to 11,5% [3].

In the mentioned context, the increasing energy efficiency of processes in bakery ovens is a significant concern and necessary.

The continuous increase of the price of the used fuel demonstrates the need to rationalize the energy consumption.

The researches devoted to developing a method and optimal schemes of fuel utilization are very important, not only in the bakery processes but in all technological industrial processes.

In the technological process of baking, in bakeries are used practically all forms of energy: warm water – for the preparation of the dough and for cleaning of the equipment; steam - for steaming bread in ovens and for drying of pasta; natural gas – for ovens; electricity - for ovens and for different electrical equipment; compressed air and cold - in auxiliary processes.

In general, there is a detailed analysis of the bread-making process by steps made in order to highlight the energy-intensive operations. The analysis results are shown in tab. 1, [4].

As it is shown in the tab. 1, the highest consumption of energy takes place in the cooking process, practically the entire heat introduced in the process of production of bread (approx. 93,8%) is used in the cooking chamber. Therefore, the present work will approach especially the issue of the increasing energy efficiency of the process of baking the bread.

**Table 1.** The analysis of share of the energy consumption in the bread bakery process.

| *Nr.* | *The step of technological process* | *Share, %* | |
|---|---|---|---|
| | | *electricity* | *heat* |
| 1 | Reception and storage of raw materials | 1,5 | 0,3 |
| 2 | Reception and dosing of raw and auxiliary materials | 4,5 | 0,8 |
| 3 | Preparation of dough | 13,8 | 1,4 |
| 4 | Processing of dough | 23 | 2,4 |
| 5 | Final rising | 22,6 | 1 |
| 6 | Baking | 33,7 | 93,8 |
| 7 | Receive product | 0,5 | 0,2 |
| 8 | Storage | 0,4 | 0,1 |

## 1. COGENERATION – THE MEASURE TO INCREASE ENERGY EFFICIENCY OF PANIFICATION

At the moment, most bakeries in Moldova use electric bakery ovens. The main argument is simplicity of installation and their exploitation, compared with natural gas ovens, especially if it is the lack of access to a gas pipe. At the same time, in the use of electric ovens, there is no problem with the evacuation of combustion gases, because they aren't.

Actually, the country at the moment, deals with essential increase of the price of electricity, and it is absolutely necessary to pass the ovens from the electrical supply to the natural gas.

In [5] there were presented the detailed essence and benefits of implementing the measures to improve energy efficiency in the process of baking bread. A particular attention is paid to method of transition of ovens from the electric to natural gas supply and the cogeneration application in bakeries.

An electrical oven whose surface of baking is 50 $m^2$, has the average working power of 200 kW, and with the same surface and the same productivity, in the use of natural gas - the average consumption of natural gas– 23 $m^3$/h. Considering the operating schedule – 16 hours per day and 330 days per year, the ovens consume respectively 1056 MWh/year and 121,4 thousands $m^3$ of natural gas per year. For generating the indicated quantity of electrical energy, at the power plant are consumed 313 thousands $m^3$ of natural gas. The transition from electrical supply to natural gas supply of ovens will be reduced the expenses for energy resources, at the current fares [6], by over one million lei per year, or 20 thousand lei per $m^2$ per year.

The bakeries operates entire year at a practically constant productivity. It slightly varies the electrical and thermal load. Therefore, an installation with cogeneration, based on piston engine on natural gas, at the same bakery can operate with a high coefficient of the use of the installed power, which would reduce the cost of the produced energy.

In the case of using the cogeneration installations result a fuel economy, in comparison with separate generation of electricity and heat, from 25% to 40 %.

## 2. THE BENEFITS OF TUNNEL OVENS WITH GASES

Lately, the tunnel ovens with gases became widespread in bakeries. The benefits of the tunnel ovens, in comparison with other types of gas ovens, are:

- mechanization of the processes of loading and unloading the products;
- continuous production process;
- uniform distribution of the heat in 4-5 areas of baking;
- more efficient automation of the baking and steaming areas;
- disappearance of the “gas” flavor of bread, because the flue gases flowing through the gas channels and don’t enter in the baking chamber of the oven;
- viewing the baking processes through special viewfinders.

These are the arguments favoring the choice of tunnel oven. But the arguments in favor of the supply option to natural gas of the ovens, comparing with the electrical supply, are:

- the electric ovens have a higher thermal inertia and an expensive function, due to higher tariff for electricity;
- the taste of the bread baked in the gas ovens is better than that obtained in electric ovens;
- the probability of the interruption of electricity supply at the factory (in case of damage or repairs to electrical networks)is much higher than for natural gas.

In addition, some researches [7], demonstrated that total equivalent emission of greenhouse gases, generated by ovens, to produce 1 kg of bakery products, is greater than 2 times in electrical ovens than in the case of gas ovens. But environmental problem is very acute today, at national and global level.

In the above context, the purpose of this paper is to analyze the efficiency of the installation of oven by integrated internal combustion engine.

Thus, this installation will produce electricity and the flue gases evacuated from the cogeneration installation, will be used to perform the technological processes baking in the oven.

## 3. EXERGETIC ANALYSIS – RELEVANT METHOD TO ASSESSMENT THE ENERGY EFFICIENCY

In baking ovens take place baking processes of bread. For this purpose, it is consumed a certain amount of energy. It is important to understand how effectively this process from the energy point of view is.

A method of analysis would be one based on balance and energy efficiency of the oven.

Energetic analysis is the classic method of assessing the energy efficiency of an installation or process. But this method does not take into account the following important factors: thermodynamic state of the system, form of energy consumption, the degree of perfection of the process (the degree of irreversibility), the state of environment. That's why, this method leads to the difficulty of interpreting the energy efficiency level.

This has caused the scientists to search the new methods, more complex, for technological processes analysis, in sequence with the second law of thermodynamics, which would allow qualitative assessment of different forms of energy. So, the exergetic analysis was developed.

In concordance with the second law of thermodynamics, energies with limited capacity of transformation, can be converted partially into mechanical work, - in exergy, the rest of these energies is anergy.

The economic value of energy is so great then the suitable energy is greater, therefore the exergy can be used to assess circulating energies, and the quality of processes which take place in the installation.

In concordance with the second law of thermodynamics, the sum of the input exergy into the ovens is equal to the sum of the output exergy plus exergy losses.

The thermodynamic perfection of the oven is expressed through the efficiency of the thermodynamic perfection of this installation $\gamma_{ex}^{cupt}$ and constitutes the report between the amount of exergy output of the oven $\sum_{i=1}^{n} E_{xi}^{e}$ and the amount of exergy input the oven $\sum_{i=1}^{n} E_{xi}^{i}$ [8]:

$$\gamma_{ex}^{cupt} = \frac{\sum_{i=1}^{n} E_{xi}^{e}}{\sum_{i=1}^{n} E_{xi}^{i}} = 1 - \frac{\sum_{i=1}^{n} P_i}{\sum_{1=1}^{n} E_{xi}^{i}}, \qquad (1)$$

in which $\sum_{i=1}^{n} P_i$ are the exergy losses of the oven.

That's why, knowing and the calculation need of the losses of exergy have considerable importance to determine the methods to reduce the irreversibility of the processes which take place in the studied oven.

To calculate these losses it can be used the entropy method, which requires the calculation of exergy losses in each process separately using Guy-Stodola theorem::

$$P_{ex} = T_o \cdot \Delta S, \qquad (2)$$

where: $T_0$ is the thermodynamic temperature of the environment; $\Delta S$ - increase of entropy in examined process because of the irreversibility.

From the last relationship it follows that the question of exergetic losses calculation in any process is reduced to calculation of variation of entropy.

## 4. WHY DO WE NEED OF THE INSTALLATION OF OVENS WITH INTEGRATED COGENERATION?

That's why the real processes from the oven are irreversible; in this processes take place destruction of exergy. The improvement of the processes, ie reducing their irreversibility, can be achieved by improving of ovens in order to reduce losses of exergy, which may lead to a decrease of operating costs (due to the reduction of primary energy consumption).

One of the most irreversible processes resulting in the oven is the process of mixing of the gases to the combustion chamber with the recirculated gases.

For example, the oven *PPP 3 54 211ST* is equipped with combustion chamber with the gas burner. Gas temperature in the combustion chamber is approx. 1630 °C, while necessary temperature of the gases in the channels of oven is about 450 °C (fig. 1).

There is a huge difference between the gas temperature in the combustion chamber and the required temperature in the channels of baking chamber. The reduction of the gas temperature in the combustion chamber is achieved after mixing of hot gases with the cold gases recycled from the channels of the baking chamber, whose temperature is 268 °C.

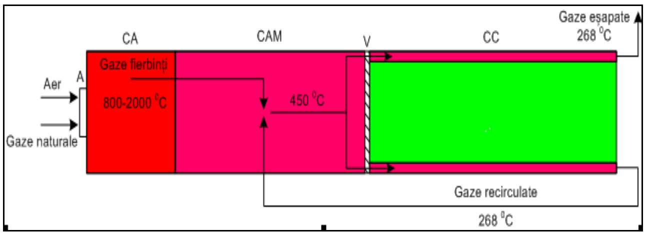


**Figure 1.** Heat flow diagram of the oven: *A – burner; CA – combustion chamber; CAM – mixing chamber; V – fan; CC – baking chamber.*

In case when currents, which are mixed, are the same ideal gas, with the same constant of gas $R$, and the same specific heat capacity $c_p$, is valid the following relationship for calculating entropy variation (were the term 1 refer to the parameters of the hot combustion gas in the combustion chamber, 2 – the parameters of the recirculated exhaust gases in the oven and 3 – the parameters of the gas mixture resulting from the mixing of the first two), [9]:

$$\frac{\Delta \dot{S}}{\dot{m}_3} \approx x(1-x)\left(\frac{T_1 - T_2}{T_1}\right)^2 + x\frac{R}{c_p}\left(\frac{p_1 - p_3}{p_3}\right) + (1-x)Rc_p\left(\frac{p_2 - p_3}{p_3}\right) \geq 0 \qquad (3)$$

where $x = \dot{m}_1 / \dot{m}_3$ is the ratio between the flow rate of the hot flue gas in the combustion chamber and the flow rate of the gas mixture.

As it is shown in the equation (3), thermal irreversibility, increase of entropy and losses associated of mixing processes increase with the square of difference of the two gases mix of mixing temperature difference of the two mixed gases.

A measure to increase the energy efficiency of the process of baking bread would be the reducing the irreversibility of the process by replacing the process of mixing by a heat transfer process, which is less irreversible.

The essence of this technology involves „integrating" a cogeneration installation (based on the internal combustion engine, or a gas turbine installations) in an ovens installation.

The flue gases after expansion in internal combustion engine will be debited in a heat exchanger for the heating of the air taken from the environment and its subsequent circulation in baking channels of the oven (fig. 2).

Exergy losses after irreversibility of heat transfer will be determined by the relation, [9]:

$$P_{ex} = E_x^g - E_x^a = Q\frac{T_o}{T_{med}^a} \cdot \frac{1}{\left(1 + \left(T_{med}^a / \Delta T\right)\right)}, \qquad (4)$$

where: $T^a_{med}$ is the average thermodynamic temperature of the air in the heat exchanger;

$\Delta T$ - mean difference of the ambient temperature which environment are cooled and heated;

$Q$ - the flow of heat exchanged in the heat exchanger, between the two fluids.

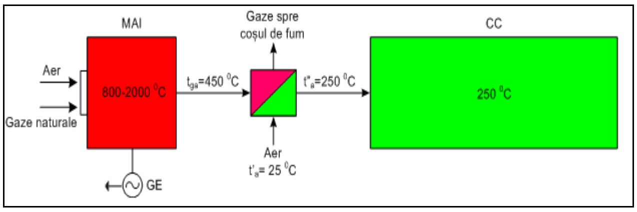


**Figure 2.** Schematic diagram of integrated cogeneration installation with heat exchanger:
*MAI - internal combustion engine;*
*GE – electric generator; CC – cooking chamber.*

As it is shown in equation (4), the loss of exergy is increased by the increase of the difference, but not square as in the case of mixing processes.

Applying this technology, the working agent for heating the baking chamber will be the air heated in the heat exchanger. This solution is welcome for ovens in which thermal agent is debited directly in the baking compartment, as the exhaust gas from the engine can contain drops of oil used to lubricate the engine and cannot be debited in the baking chamber because it can contaminate the bread.

In the exposed technology, are diminished the irreversibility of the process for the preparation of the heat by replacing the mixing process to heat transfer process, with a lower degree of irreversibility. The disadvantage of this solution lies in the fact that the heat exchanger can be larger, leading to an increase in the massiveness in the entire installation.

In case of the ovens tunnel, the thermal agent is not charged directly to the baking chamber, but circulates through the channels made in the walls of the chamber (so they have no contact with the bread), the flue gases discharged from internal combustion engine can be handled the cannels. Thus, are totally exhausted the losses of exergy associate with the made process of the heat (fig.3).

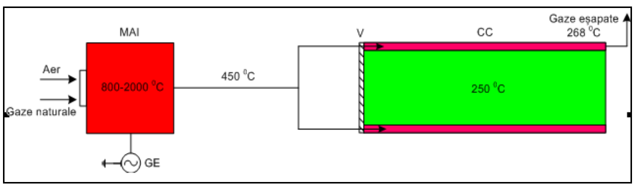


**Figure 3.** Schematic diagram of integrated cogeneration installation without heat exchanger

At the same time, it will significantly simplifies the installation by excluding the heat exchanger from its composition, in comparison with the solution described above.

Even if the combustion of fuel in the combustion chamber of the internal combustion engine, anyway there will be irreversibility and respective loss of exergy, they will be associated to the process of producing electricity (as the main product) and the exhaust gas evacuated from the internal combustion engine and subsequently used for the process of baking, they will result, in effect, as a waste.

The internal combustion engine is chosen depending on the thermal capacity of the baking chamber of the oven so that the oven heat load – $Q$, must correspond to the flow of the exhausted gases of internal combustion engine. Also, the combustion gas flow out of the internal combustion engine must provide the necessary flue gas- $V_{gt}$ in baking channels of the oven.

In tab. 2, are presented the basic parameters of the ovens PPP required for selecting the type of internal combustion engine.

**Table 2.** The total volume of flow gases and heat load of the ovens PPP.

| **Oven type,** [10] | **Capacity,** kg/h | $V_{gt}$, $m^3/s$ | **Q,** kW |
|---|---|---|---|
| PPP 2,1 18,9 | 342 | 0,56 | 163 |
| PPP 2,1 25,2 | 450 | 0,74 | 216 |
| PPP 2,1 31,5 | 558 | 0,84 | 245 |
| PPP 2,1 37,8 | 684 | 1,02 | 297 |
| PPP 2,1 44,1 | 792 | 1,21 | 353 |
| PPP 2,1 50,4 | 900 | 1,40 | 408 |
| PPP 2,1 56,7 | 1008 | 1,58 | 461 |
| PPP 2,5 30,0 | 540 | 0,84 | 245 |
| PPP 2,5 37,5 | 684 | 1,02 | 297 |
| PPP 2,5 45,0 | 810 | 1,30 | 379 |
| PPP 2,5 52,5 | 954 | 1,49 | 435 |
| PPP 2,5 60.0 | 1080 | 1,67 | 487 |
| PPP 3,0 54,0 | 972 | 1,49 | 435 |
| PPP 3,0 63,0 | 1134 | 1,76 | 513 |
| PPP 3,0 72,0 | 1296 | 2,05 | 598 |
| PPP 3,0 81,0 | 1458 | 2,23 | 650 |
| PPP 3,0 99,0 | 1782 | 2,79 | 814 |
| PPP 3,0 108 | 1944 | 3,07 | 895 |

## CONCLUSIONS

In the above article, we can conclude that the technology of integrated cogeneration installation in ovens is very relevant from the thermodynamic point of view, respectively, in terms of energy efficiency.

This measure allows the minimization of the exergetic losses associated to the process of securing the necessary temperature of thermal agent (by mixing), by replacing it with a heat transfer process, which is less irreversible than the mixing process (solution shown in Fig.2) or total avoidance of these exergy losses (the solution shown in Fig. 3).

The production of two forms of energy, after retrofitting of installation, will contribute to the increase of the amount of the flow exergy from the modernized installation (because the exergy work is equal to the work done and exergy of electricity also is equal to the value of produced electricity), by increasing the thermodynamic efficiency of the installation calculated the equation (1).

It should be noted that the proposed technology can be implemented in any enterprise equipped with natural gas oven, it doesn't matter with the type of products cooked, especially in cases where the required temperature of the flue gas for performing the processes is much lower compared with the temperature of combustion natural gas.

However, the result of implementing the cogeneration installations at the enterprise, it will be ensured with the electricity needed to carry out other processes or utilities, and coolants agents can be then used to require thermal energy consumption for preparing blanks or cleaning the equipment.

### *References*


***1.*** *Statistical yearbook of the Republic of Moldova 2013. Biroul Naţional de statistică al R. Moldova. Chişinău, 2013.*

***2. Steclaru D., Mamaliga V.*** *Analiza volumelor de producere şi desfacere în industria de panificaţie. Meridian Ingineresc Nr. 3, Chișinău, pag. 70-74, 2009.*

***3***. *http://ziarulnational.md/decis-painea-se-va-scumpi-din-15-august-cu-aproximativ-15-explicatia-brutarilor-din-r-moldova/*

***4. Alexandru R. et al.*** *Economia de energie în industria alimentară// Bucureşti: Editura Tehnică, 1991, 354 p.*

***5. Chelmenciuc C., Guţu C.*** *Sporirea eficienţei energetice în brutării// Conferinţa Tehnico-ştiinţifică a Colaboratorilor, Doctoranzilor şi Studenţilor UTM, Chișinău, pag. 320-323, 2011.*

***6.*** *Hotărâre privind tarifele la gazele naturale. Nr. 425 din 29 septembrie 2011// Monitorul Oficial al Republicii Moldova, 30.09.2011, nr. 160-163/1459.*

***7. Shevchenko R. i. d.*** *Sravnitel'ny'j e'kologicheskij analiz hlebopekarnyh pechej// Harchova nauka i tehnologiya Nr. 1(14), pp. 80-84, 2011.*

***8. Musteaţă V.*** *Termodinamica tehnică şi procese tehnologice// Chişinău: Editura UTM, 2006, 88 p.*

***9. Bejan A.*** *Termodinamica tehnică avansată// Bucureşti: Editura Tehnică, 1996, 848 p.*

***10.****http://www.j4.cz/RJ/html/pekarskepece.htm#standard*


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