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Energy and Exergy Analysis of Traditional Flatbread Bakeries

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ABSTRACT: In this study by experimental measurements and mathematical methods, the energy and exergy efficiencies, wasting energies and fuel consumptions of different traditional flatbreads bakeries are obtained. The knowledge about these parameters can pave the way to find useful solutions for reducing energy consumptions in bakeries. Based on obtained results, the energy efficiencies of Sangak, Barbari and Taftun bakeries are about 21%, 12% and 5%, respectively. On the other side, the exergy analyzes for these bakeries illustrate that thermo-dynamical quality of wasted energy of flue gases is low for Sangak and Barbari bakeries. According to results, usage of insulator for side-walls and roof of oven and reducing excess air in combustion reaction, are useful solutions to decease wasting fuel in bakeries. By using insulator for walls and roof of oven the wasted energy of walls can reduce about 65%. Also by controlling the combustion reaction to perform with 5% excess air the wasted energy of excess air decreases about 90%. Finally, it was cleared that above solutions can increase the energy and exergy efficiencies of bakeries and also their can reduce the annual energy consumption of Sangak, Barbari and Taftun bakeries about 58%, 66% and 82%, respectively.

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1- Introduction

Traditional bread is the most favorable and popular type of bread in Iran and the predominant contribution of bread consumption belongs to this type of bread [1]. Traditional bakeries are not energy efficient because of their old structures and low price of fuel in Iran. Improving energy efficiency in traditional bakeries can play an important role in reducing fuel consumption in such small industries. There is no study on the energy audit of flatbreads bakeries as opposed to some popular industrial processes on which several studies are carried out [2-5].

In this study, based on experimental measurements and theoretical methods, energy and exergy analysis are performed on flatbreads bakeries. According to this analysis, the main elements of losses were known and some strategies were proposed for reducing energy consumptions in these bakeries.

2- Experimental Methodology

An IR thermometer ST-9861 is used to measure the wall temperature of the oven. In addition, Testo M/XL350 analyzer is used to analyze flue gases and calculate combustion efficiency. The analyzer calculates combustion efficiency with the following relation [6 and 7]:

$$\eta_{comb} = 100 - \left[(FT - AT) \cdot \left(\frac{0.66}{0.21 - O_2\%} + 0.009 \right) \right] \qquad (1)$$

Where FT, AT are flue and ambient temperatures respectively.

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3- Energy Analysis

Considering natural gas as 91% methane and 9% ethane, the combustion reaction for natural gas with ex percent excess air is as follow [8]:

$$0.91CH_4 + 0.09C_2H_6 + 2.135(1+e_x)(O_2 + 3.76N_2) \longrightarrow 1.09\ CO_2 + 2.09\ H_2O + 2.135\ e_xO_2 + 8.0276(1+e_x)N_2 \qquad (2)$$

Following relation calculates the energy efficiency of oven based on the energy of fuel and the energy needed for baking [8,9]:

$$\eta = \frac{1.1 n_B \left[\frac{m_d \cdot c_{p,d} \Delta T + (m_d - m_B) h_{fg}}{\Delta t} \right]}{\dot{m}_F \cdot h_F} \qquad (3)$$

Where m_d and m_b are mass of dough cake and mass of water content of dough cake respectively. n_B is the number of bread is baked in Δt. h_{fg} is latent heat of water evaporation. $\dot{m}_f$ and h_f are flow rate and heating value of fuel.

4- Exergy Analysis

Following relation calculates the exergy efficiency of oven based on the exergy of fuel and the exergy needed for baking [8, 9]:

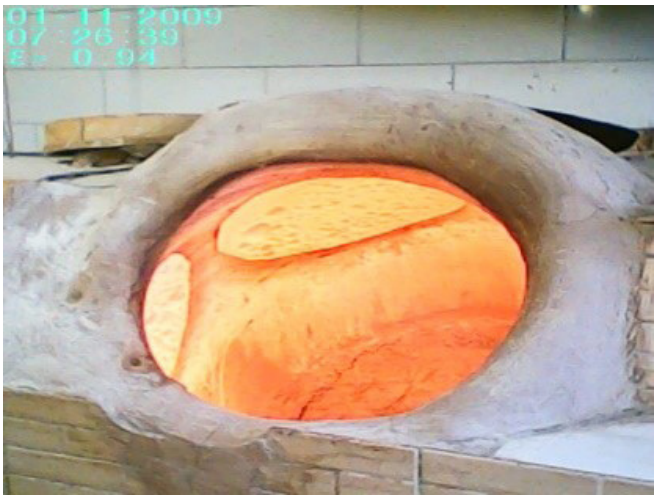
$$\varepsilon = \frac{1.1 n_B \frac{m_d \cdot c_{p,d} \cdot \Delta T + (m_d - m_B) h_{fg}}{\Delta t} \cdot \left(1 - \frac{T_0}{T_B}\right)}{\dot{m}_F \cdot \left(\sum_i N_{F,i} \cdot \psi_{F,ch,i} \right)} \qquad (4)$$

5- Results and Discussion

Fig. 1 shows Sangak, Barbari and Taftun bakeries.

(a)

(b)



(c)

Fig. 1. Bakery of (a) Sangak, (b) Barbari and (c) Taftun

Table 1 shows the energy and exergy efficiencies of traditional flatbreads bakeries.

Table 1. Energy and exergy efficiencies of bakeries

Efficiency (%)	Bakery		
	Sangak	Barbari	Taftun
Energy	20.50	11.50	5.35
Exergy	4.44	2.60	1.14

According to the results shown in Table 1, it is observed that wasted energy and exergy in bakeries in Iran is too high. Thus, it is important to find some solutions to improve the efficiency of these bakeries. There are three useful solutions for reducing energy consumption:

- Using insulator in order to reduce wasted energy from the walls and roof of the oven.
- Reducing excess air in the combustion reaction.
- Heat recovery of hot flue gases.

Table 2 shows the energy balance in each bakery. $\dot{Q}_F$, $\dot{Q}_B$, $\dot{Q}_{Exh}$ and $\dot{Q}_{loss}$ are input energy of the fuel, the energy needed for bread baking, heat wasted from exhaust and heat loss from the wall. Total loss is ($\dot{Q}_{Exh} + \dot{Q}_{loss}$). $\dot{Q}_{Exh}$ consists of excess air and hot products losses. In sangak and barbri bakeries $\dot{Q}_{loss}$ is larger than $\dot{Q}_{Exh}$ and this shows that insulating the wall is a priority. In taftun bakery $\dot{Q}_{Exh}$ is larger.

Table 2. Energy balance in bakeries

quantity bakery	$\dot{Q}_F$ (kW)	$\dot{Q}_B$ (kW)	$\dot{Q}_{Exh}$ (kW)	$\dot{Q}_{loss}$ (kW)
sangak	60.0	12.3	18.7	28.9
barbari	82.8	9.6	27.0	46.2
taftun	200.	10.7	114.0	75.3

The equivalent fuel saving corresponding to each loss is calculated and is shown in Table 3. Insulation is carried out with a 5 cm rock wool and 5cm glass wool and excess air is adjusted to 5 percent.

Table 3. Equivalent natural gas fuel saving related to each type of heat losses in bakeries

$\dot{V}_F$ (%)	Bakery		
	sangak	barbari	taftun
Excess air control	18.1	24.8	50.3
Exhaust gas recovery	9.3	5.1	7.7
insulation	31.1	36	24.3
total	**58.4**	**65.9**	**82.3**

Table 4 reports the annual saving fuel in different bakeries by using energy-saving solutions. Table 5 reports energy and exergy efficiencies of bakeries by using energy-saving solutions.

Table 4. Annual saving fuel in different bakeries by using energy saving solutions

Annual saving fuel	Bakery		
	Sangak	Barbari	Taftun
Volume (m^3)	19633	17400	68664
Percentage (%)	58	65	82

Table 5. Energy and exergy efficiencies of bakeries after using energy saving solutions

Efficiency (%)	Bakery		
	Sangak	Barbari	Taftun
Energy	35.34	17.84	6.50
Exergy	7.70	4.02	1.40

6- Conclusions

Energy and exergy efficiencies and fuel consumptions of different traditional flatbreads bakeries (Sangak, Barbari, and Taftun) are studied. According to the results, use of insulator for walls of the oven, reducing excess air in combustion reaction and heat recovery of flue gases, are useful solutions to decrease wasting fuel in bakeries. By using insulator for walls and roof of the oven the wasted energy of walls can reduce about 65%. Also by controlling the combustion reaction to perform with 5% excess air the wasted energy of excess air decreases about 90%. Retrieving the energy of flue gases reduces the wasted energy of exhausted gases of Sangak, Barbari and Taftun bakeries about 71%, 61%, and 65%, respectively. Finally, it is obvious that above solutions can reduce the annual energy consumption of Sangak, Barbari and Taftun bakeries about 58%, 65%, and 82%, respectively.

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