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SOME ENGINEERING FACTORS AFFECTING THE PERFORMANCE OF A SMALL ROTARY BAKING OVEN

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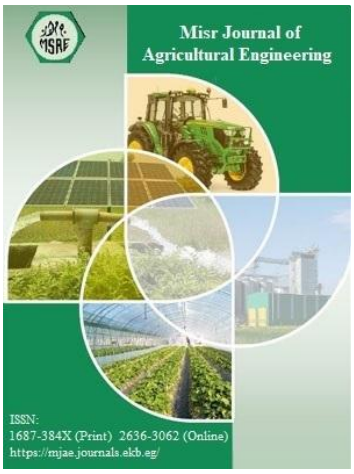


Keywords:
Rotary, baking, oven.

ABSTRACT

This research was carried out to study some engineering factors affecting on the performance of a small rotary baking oven to select the optimum design factors suitable for baking loaves. The aim of this study was to achieve maximum of the thermal efficiency for baking and better quality specification of the baked loaves (loaf color percentage, loaf maturity percentage and loaf height). Baking oven tray with variable thicknesses of 2, 3, 4 and 5 mm, baking oven chamber heights of 15, 20, 25 and 30 cm and the baking oven walls insulation density of 40, 50 and 60 kg/m³ were studied. The optimum design factors of the baking oven which achieve best quality of the baked loaf and optimum thermal specification were obtained at baking chamber height of 15 cm, baking oven walls insulation density of 60 kg/m³ and 3mm baking oven tray thickness for optimum thermal specification of the oven and 2mm for the best quality of the loaves.

1. INTRODUCTION

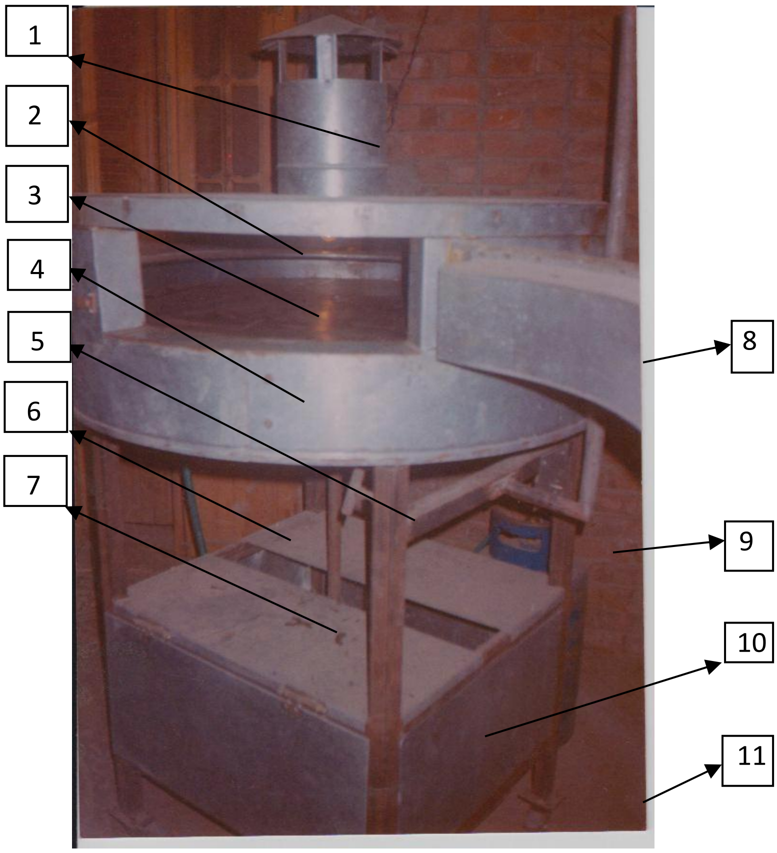
Bread industry is the most important human food industries, especially in Egypt. About 270 million – balady bread are produces in Egypt. 20% of the bread produced is not intended for eating, due to rapid staling after baking and poor quality specifications after baking this makes it unacceptable to consumers *(*M.S.T. 2020)**.** Due to this problem, it was important to think of the reasons of this big huge amount of balady bread waste, by improving its quality and baking specifications (**Islam et al., 2016).** Small size rotary ovens which use gas are now wide spread in Egypt. These ovens are made in small workshops with different specifications from one workshop to another, in terms of the height of the baking chamber, the thickness of the baking tray, or the degree of insulation of the oven walls. This research focused on studying those engineering specifications to achieve the most suitable for baking, and operation of ovens of this type. There are many common practices in the baking process which affect the quality of the produced bread

and increase energy consumption such as low or high internal temperature of the oven, fast heating at the beginning of baking, irregular temperature distribution inside baking chamber, unequal distribution of loaves inside baking chamber **(Jado., 2019)**. The objective of this research was to study some design factors that affect the performance of a small rotary baking oven. These factors mostly include chamber height, tray thickness and insulation density. With the following evaluation factors: loaf color, loaf height, loaf maturity, baking temperature rise in the baking chamber ambient and baking thermal efficiency. The high temperature immediately causes the dough to rise, more from steam formation than from carbon dioxide production. This research was to study some design factors that affect the performance of a small rotary baking oven. These factors mostly include chamber height, tray thickness and insulation density. With the following evaluation factors: loaf color, loaf height, loaf maturity, baking temperature rise in the baking chamber ambient and baking thermal efficiency. The high temperature immediately causes the dough to rise, more from steam formation than from carbon dioxide production.

Baking theory: Baking is done by conduction, radiation and convection. The sides and sole of an oven give up their heat by conduction, the sides and the crown assist in the baking by radiating heat so that when a cool substance is introduced into the oven, all parts of the hot interior surface radiate towards it. Convection plays its part in baking by setting up convection currents between loaves. When cool bodies are placed in an oven, any moisture of the oven atmosphere tends to condense upon them and, by giving up the latent heat of evaporation, warms them very quickly **(Bennion 1970)**. The dough temperature increases in the oven, carbon dioxide in the gaseous phase expands according to the general Charles gas law, V = kt, where the volume (v) is proportional (by a constant, k) to the temperature (t) of the gas at a constant weight and pressure of the gas **(Kulp 1988).** The dough is put in the oven after fermentation, a considerable increase in volume occurs. The increase in temperature directly influences the dough in several ways, including yeast activity, solubility of gases, and volume expansion of evaporated gases. The flour constituents are also affected, the starch gelatinizes, and the protein undergoes certain changes. As a result of the physical changes related to the included gas, an enormous increase in volume occurs, and this increase in volume has some indirect effect on the dough. The low thermal conductivity of foods causes low rates of conductive heat transfer and is an important influence on baking time. The size of the pieces of bread determines the distance that heat must travel to bake the center of the bread adequately. When a food is placed in an oven, moisture at the surface is evaporated and removed by the hot air. The low humidity of air in the oven establishes moist vapor pressure gradients, which cause movement of moisture from the interior of the food to the surface. When the rate of moisture loss exceeds the rate of movement from the interior, the zone of evaporation moves inside the food, the surface dries out, its temperature rises to the temperature of the hot air and a crust is formed (**Larsson 1993)**. The crust and color formation are the key parameters that identify the acceptability of the baked products by consumers. The formation of crust and increase in surface temperature beyond the evaporation temperature result in color development and they need higher temperatures (**Servet et al., 2008).** At the end of the baking period, which averages 60 sec, the bread is 7-10 cm high at the center of the loaf. High oven temperatures reduce the baking time and, consequently, increase the moisture content and softness of the bread (**Faridi 1988)**. Improvement the ovens are using energy at the optimum efficiency, more effective refractories and insulation materials, improved preventive maintenance and rebuilding practices and reduced infiltration of outside air **(Anonymous, 1992)**. The main purpose of baking is to change the eating quality of staple food stuffs and to add variety to the diet. However, the baking process is also a preservation process. Baking exposes the product to high temperatures which will destroy most micro-organisms present in the product **(George, 2000)**.

2. MATERIAL AND METHODS

The experimental small rotary baking oven was consisted of an oven frame, a baking chamber oven, oven tray and bottom flame chamber, a motor and a motion transfer unit, (Figs. (1) and (2)). The oven frame was constructed of hollow steel section form two rectangular parallel soldered rods, the cross section of this rod is square hollow 4x4 cm, the dimensions of the upper rectangular bar is 70 cm length , 65 cm width and 44 cm height. The baking oven chamber rests on upper surface of motion transfer motor unit, and it is higher than the motor and its lower surface is insulated to separate the baking chamber heat from motion transfer motor. The bottom rectangular parallel use for fixing the motion motor and gear pox on its bottom surface, The dimensions of this rectangular parallel are 70 cm length, 65 cm width and 34 cm height, The standing rods of this rectangular parallel expanded in bottom with length of 19 cm and moving on the ground by four wheels with a diameter of 10 cm and supplied with brake in order to fixing the baking oven on the ground.



1. Exhaust duct
2. Upper flame tube
3. Baking oven tray
4. Bottom flame chamber
5. Drive shaft
6. Gas tube
7. A.C motor unit
8. Baking oven door
9. Gas tube resource
10. Oven frame rods
11. Oven wheel

Fig. (1): The experimental small rotary baking oven.

The baking oven chamber has cylindrical form and is constructed of laminar galvanized steel of two layers. Each layer of the galvanized steel has a thickness of 0.7 mm and an insulation layer of fiberglass wool with thickness 7cm and asbestos with thickness of 3 mm, four densities of the fiberglass wool were used 30, 40, 50 and 60 kg/m^3. The dimension of the cylindrical baking chamber was 94 cm for inner diameter and 102 cm for outer diameter. In the middle of the cover cylinder upper there is the exhaust duct hole which has a diameter of 20cm and height of 32 cm. There is another hole in the sidewall of the baking cylindrical chamber which is inserted in it the upper flame tube with diameter 2cm. This tube has a form of non-completed cycle. The upper flame tube is perforated with holes of 0.2 mm diameters. The same materials and diameter have four heights of 15, 20, 25 and 30 cm.

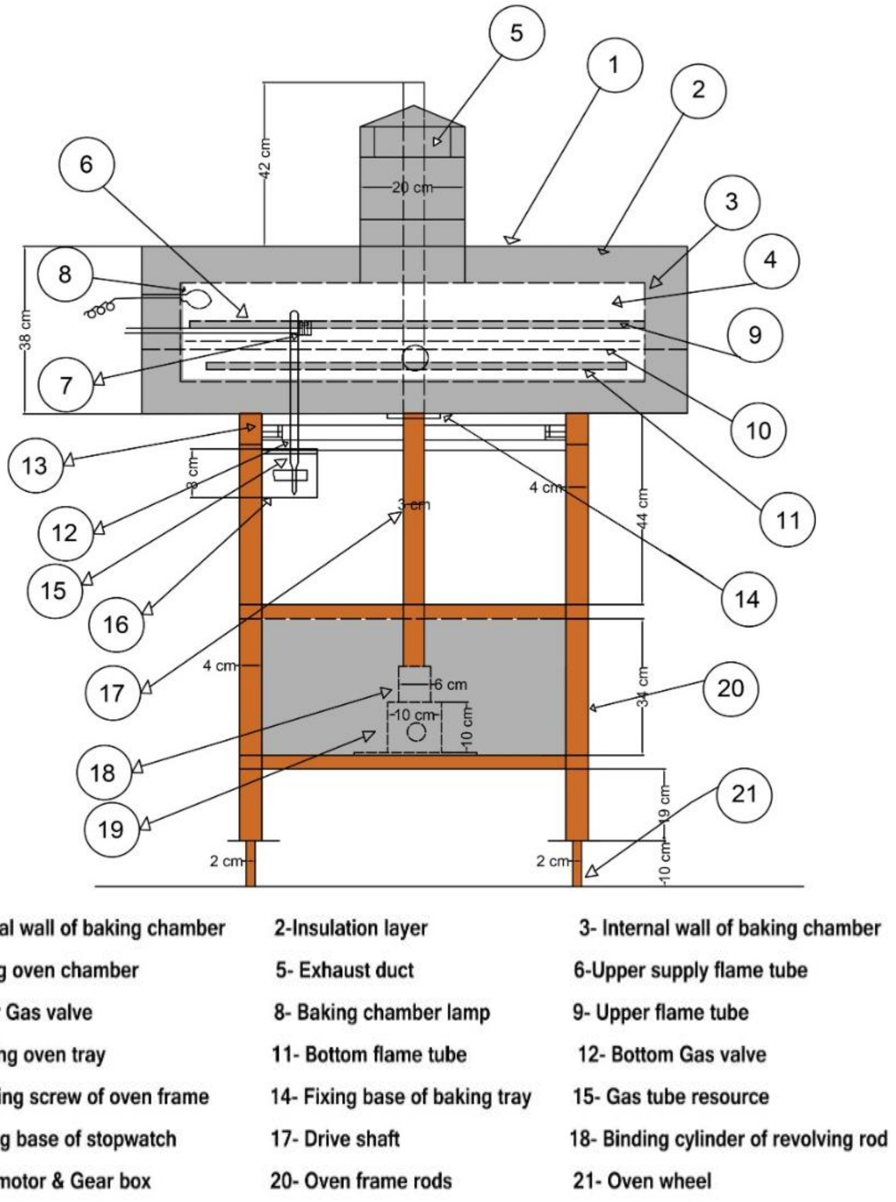


Fig. (2): Diagrammatic sketch of the experimental small rotary baking oven.

The oven door is in front of the baking chamber, and was made from the materials used for chamber walls. The side bottom of the cylindrical baking chamber is without cover. The baking oven tray was made from steel with a diameter of 82 cm and thickness of 3 mm. This tray was placed on iron rod with diameter of 3 cm and length of 58 cm which is connected by gear box of the motion motor. This tray is rotated at a rate of 2 cycles/ min. The bottom flame chamber has the same dimensions and the same components as the baking chamber. The bottom flame cylinder is perforated with 8 holes of diameter of 3 cm, as placed on the upper frame of the oven. Four types of tray were made with variable thicknesses 2, 3, 4 and 5 mm. The motion motor was fixed on the steel frame and placed into galvanized steel box. The energy source in this oven is gas fuel, which is preserved pump of 12.5 kg weight. It is connected with two gas valves on this small steel tube for supplying the upper and bottom flame tubes by gas. Digital thermometer was used to measure the internal air temperature in the baking chamber ambient inside the oven. The tri-Sense Hygrometer \ Anemometer\ Thermometer used to measure the air velocity and the temperature of the entry air to the baking chamber ambient.

Methods: In this study the independent variables that affect loaf quality were considered as follows:

1- Tray thickness "TTH" (2, 3, 4and 5 mm)
2- Baking chamber height "BCH" (15, 20, 25 and 30 cm)
3- Insulation density "ID" (40, 50 and 60 kg/m³)

While the dependent variables were considered as follows to express the loaf quality:

1- Baking chamber temperature rise "TR"   2- Loaf color "LC"

3- Loaf height "LH"   4- Loaf maturity "LM"

The loaves color and loaves maturity were measured by team work from 10 person in the Food Technology Research Institute (F. Tech. Inst. Re). And they estimate a collective estimate of the percentage of color and maturity. Effect of change TTH, Bch and Id on the baking thermal efficiency (η_{th}) at fixed others design factors, baking period (BP) at 90 s. The baking thermal efficiency was calculated as the following equations:-

$$\eta_{th} = Q_o / Q_f \quad .... \quad (1)$$ **(Chernov and Bessrebrennikov, 1969)**

Where:

Q_o = the consumed thermal power of the oven (Watt).

Q_f = the consumed fuel power for air heating (Watt)

$$Q_o = V_a \; A_h \; \rho_a \; \Delta t_a \; Cp_a \quad .... \quad (2)$$

Where:

V_a = the air velocity entering the baking chamber (m/s)

A_h = the cross section area of the air entry holes of baking chamber m²

ρ_a = the air density *at the mean temperature* (kg/m³)

Δta = the temperature difference of air out and in the baking chamber (̊k).

CPa = the specific heat of the air at the mean temperature of air (J/kg.̊k).

$$Q_f = M_f \; C.V \quad .... \quad (3)$$ **(El Bahadly, 1991)**

Where.

M_f = the actual fuel consumed (kg/s).

$C.V$ = the calorific value of the used fuel (J/kg)

3. RESULTS AND DISCUSSION

The effect of baking oven tray thickness (TTH), baking chamber height (BCH) and baking oven walls insulation density (ID) was studied as engineering design factors in order to select the optimum design for the small rotary baking oven under test.

1 - Effect of baking oven tray thickness.

Fig (3) Shows the loaf quality specification loaf color percentage (LC), loaf height (LH) and loaf maturity percentage (LM), were affected as the following:

a - Increasing baking tray thickness from 2 to5 mm lead to an decreasing in LC percentage.

b- Loaf height LH and loaf maturity LM were increased with increasing of baking tray thickness from 2 to 3 mm and decreased with increasing TTH from3 to 5 mm.

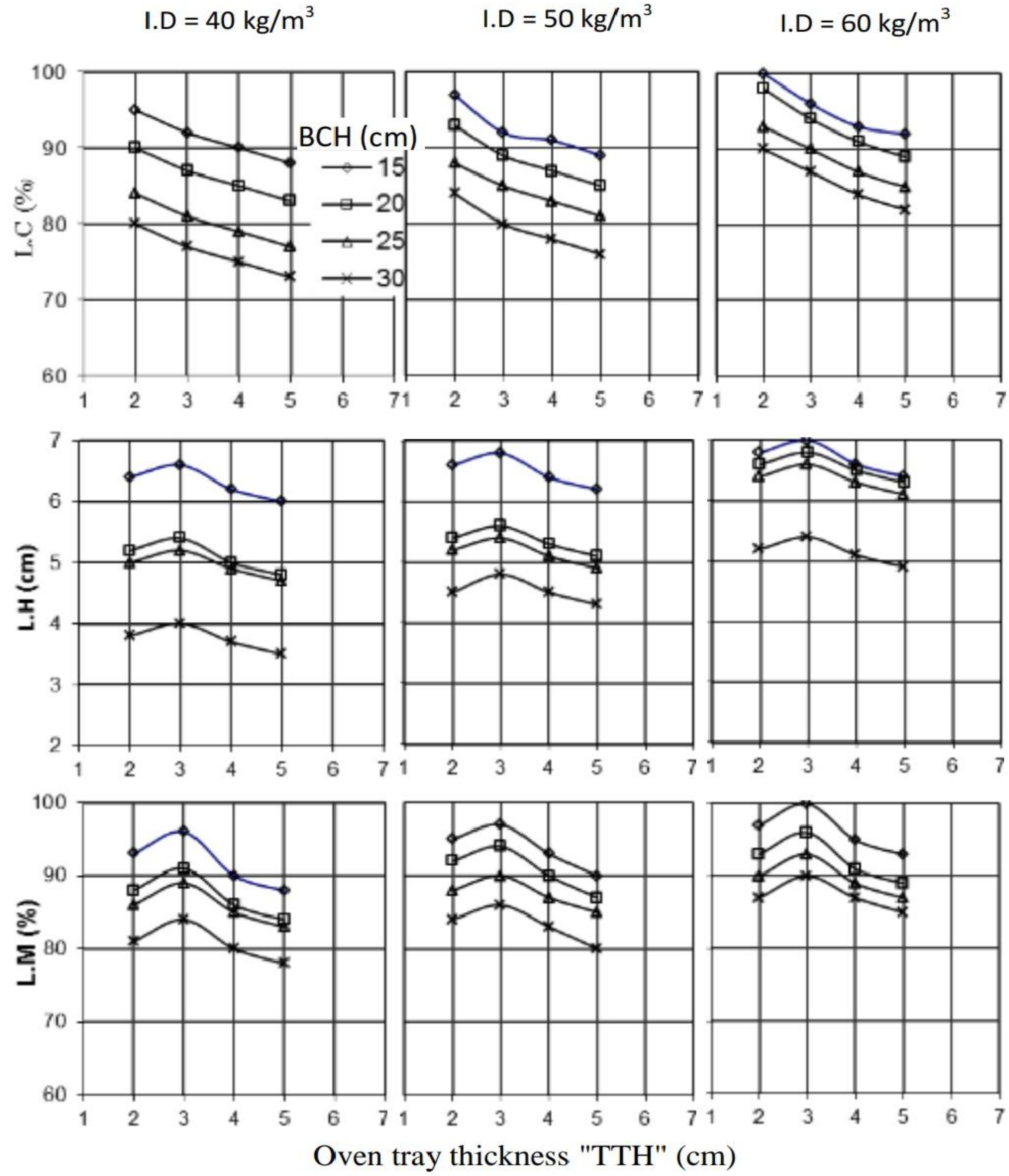


Fig.(3): Effect of oven tray thickness (TTH) and baking chamber height (BCH) on Loaf color percentage (LC), Loaf height (LH) and Loaf maturity percentage (LM) at difference oven walls insulation density (ID)

2- Effect of baking oven walls insulation density (I.D).

Fig. (3) show that the increasing ID from 40 to 60 kg/m³ lead to increasing TR and all loaf quality specification LC, LH and LM

3- Effect of baking chamber height (BCH).

LC, LH and LM were decreased with increasing BCH from 15 to 30 cm. Fig. (3) show that the increasing BCH from 15 to 30 cm lead to decreasing all loaf quality specification LC, LH and LM.

4- Effect of temperature rise (TR) in baking chamber.

The baking temperature rise (TR) was increased with decreasing both the baking chamber height (BCH) from 30 to 15 cm and the baking oven tray thickness (TTH) from 5 to 2 mm, subsequently the loaf quality specification LC, LH and LM were affected by TR. Fig. (4) Show that the increasing TR up to 470 ^{o}C lade to increasing LC, LM percentage and LH. These effects of baking oven tray thickness (TTH), baking chamber height (BCH) and baking oven walls insulation density (ID) on the loaf quality specification may be attributing to effecting of temperature rise (TR) inside the baking chamber. Fig. (5) Shows affected of temperature in baking chamber by oven tray thickness (TTH) and baking chamber height (BCH) at difference oven walls insulation density (ID).

5 - The thermal efficiency of the oven.

When the produced loaves have the same properties (weight and moisture content and the same components) the temperature rise in the baking chamber oven can be considered an indicator of the thermal performance of the baking oven and the quality characteristics can be considered as indicator of the thermal performance of the baking oven. Fig. (6) Show that the thermal efficiency (equations 1,2,3) was increased with decreasing both the baking chamber height (B.C.H) from 30 to 15 cm and the baking oven tray thickness (T.TH) from 5 to 2 mm, and was increased with increasing oven walls insulation density (ID).

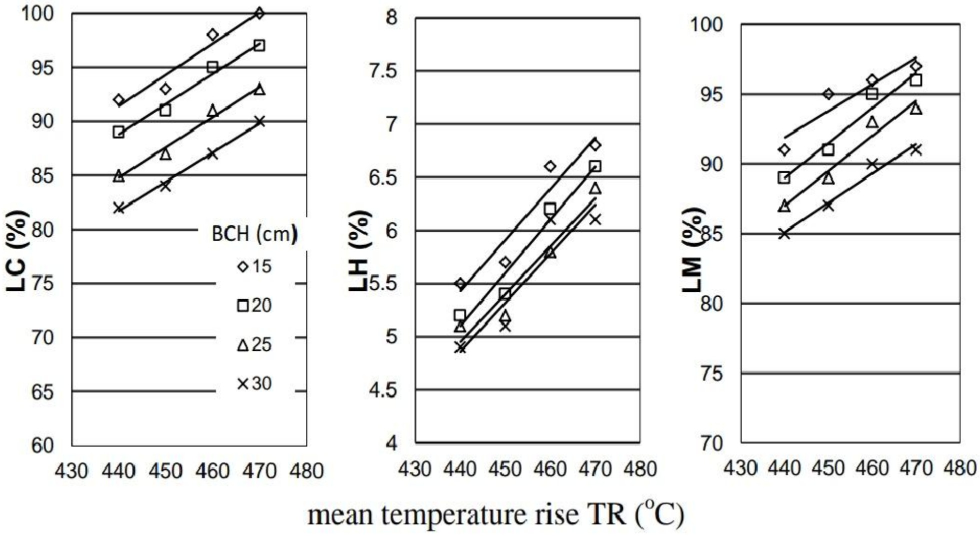


Fig.(4): Effect of mean temperature rise (TR) on Loaf color percentage (LC), Loaf height (LH) and Loaf maturity percentage (LM) at difference baking chamber height (BCH) and constant baking period 90 s.

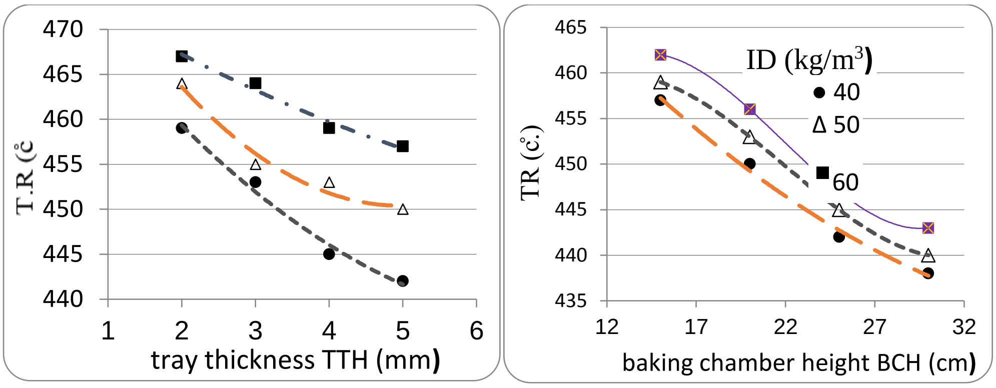


Fig. (5): Effect of oven tray thickness (TTH) and baking chamber height (BCH) on baking temperature rise (TR) at various oven walls insulation density (.ID).

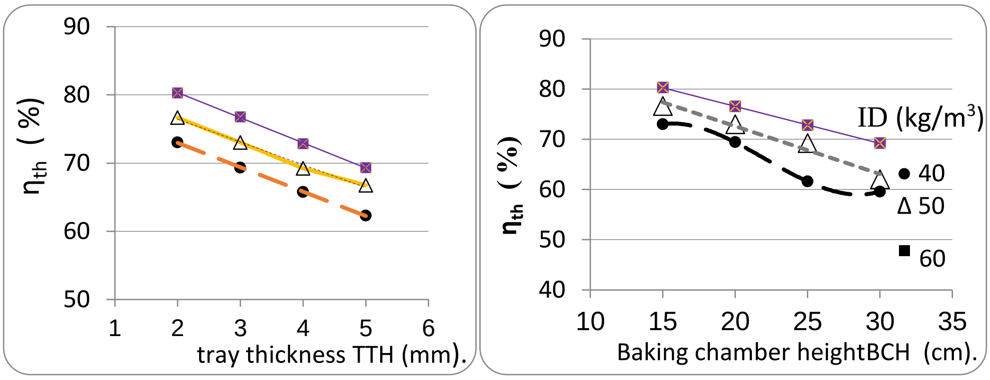


Fig. (6): Effect of Baking Oven tray thickness (TTH) and Baking chamber height (BCH) on baking thermal efficiency (η_{th}) at various oven walls insulation density (ID).

4. CONCLUSION

The measured and calculated values indicated that the optimum design factors of the baking oven which achieve useful maximum from the energy consumed in baking and best quality of the baked loaf and optimum thermal specifications were at baking tray thickness (TTH) 3 mm. The worst design factors of the baking oven which lead to poor loaf quality were not acceptable to consumers due to the loss in profitability and increase the cost of baking were at baking oven walls insulation density (Id) 30 kg\m³, baking chamber height of 30 cm and baking oven tray thickness 2 mm & 5 mm, where loaf color percentage (LC)& loaf maturity (LM) less to 75% and loaf height (LH) less to 4 cm.

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بعض العوامل الهندسية المؤثرة على اداء فرن خبيز دوار صغير

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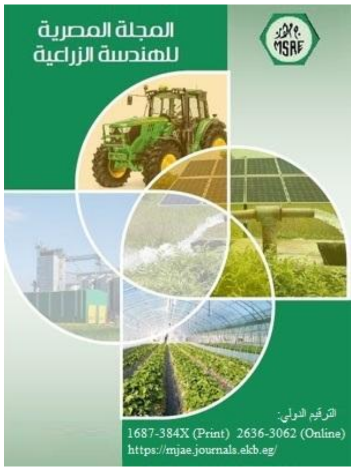

الملخص العربي

تم إجراء هذا البحث من أجل دراسة تأثير تغيير بعض العوامل الهندسية على أداء فرن الخبيز الدوار ومواصفات الجودة للعيش البلدي المخبوز به من أجل انتقاء أفضل العوامل التصميمية الملائمة لخبيز العيش بتحقيق درجة الحرارة المثلى للخبيز وأعلى كفاءة حرارية للخبيز والوصول لأفضل مواصفات جودة للعيش المخبوز والتي تتمثل فى مستوى النضج ونسبة التلون وارتفاع الرغيف. تم تصميم فرن خبيز دوار صغير واستخدام أربع ارتفاعات لغرفة الخبيز عند ١٥و٢٠و٢٥ و٣٠ سم مع كثافات عزل لجدران فرن الخبيز ٤٠ و٥٠ و ٦٠ كجم\م٣ واربعة صاجات للخبيز بسماكات مختلفة ٢و٣و٤ و٥ مم.

وكانت نتائج هذا البحث كالآتي: -

درجة حرارة غرفة الخبيز تتزايد بزيادة كثافة العزل بينما تناقصت بتزايد كلا من سمك صينية الخبيز وارتفاع غرفة الخبيز. زيادة سمك صينية الخبيز أدى الى تناقص نسبة تلون الرغيف وتزايد نسبة نضج الرغيف وأيضا تزايد ارتفاع الرغيف عند سمك صينية الخبيز ما بين ٢ إلى ٣ مم بينما تناقص ارتفاع الرغيف بزيادة سمك الصينية ما بين ٣ إلى ٥ مم. زادت كل مواصفات جودة العيش المخبوز بزيادة كثافة العزل بينما تناقصت بزيادة ارتفاع غرفة الخبيز، كما زادت الكفاءة الحرارية للخبيز بتزايد كثافة عزل جدران فرن الخبيز وتناقصت بتزايد كل من سمك صينية الخبيز وارتفاع غرفة الخبيز. وبينت النتائج ان العوامل التصميمية المثلى لفرن الخبيز والتي تحقق أفضل جودة للرغيف المخبوز ومواصفات حرارية مثلى كانت عند ارتفاع غرفة الخبيز ١٥ سم وكثافة عزل لجدران الفرن ٦٠ كجم\م^3 وسمك صاجة الخبيز ٣ مللي لأفضل جودة للرغيف و ٢ مللي لأفضل مواصفات حرارية.

الكلمات المفتاحية:
فرن، خبيز، دوار.