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Recent Perceptions on Baking Ovens: A Review

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ABSTRACT

Improvement in heating modes of ovens and baking processes can enhance the physical qualities such as moisture content, surface colour, texture, crumb hardness, and porosity of the final baking product. While optimizing the oven characteristics such as the baking capacity, baking efficiency, weight loss, baking time, and optimum baking temperature improves the productivity and energy efficiency of the baking oven. In this review study, the history and evolution of ovens, conventional and non-conventional ovens, and a summary of some previous works carried out on different baking ovens were presented. Results showing advantages, disadvantages, and effects of existing ovens have also been reported. Literature showed that a dual-powered oven has the possibility of providing high efficiency in energy consumption, reduction in time baking process, and better quality of the baked products. However, it requires a comprehensive knowledge of baking processes with a vast understanding of the biochemical, thermal, and physical transformation of the baking materials. Despite that, there are existing oven designs, there are still some peculiar gaps needed to be filled in terms of the energy supply, capacity, and effectiveness, to optimize the performance. Therefore, the objective of this study is to review the literature on the existing oven designs with a view to identifying the areas that require improvements so that enhanced productivity and efficiency can be facilitated for food productivity and security.

Keywords: Baking process, bread, Infrared-microwave, gas oven, charcoal baking oven

1. INTRODUCTION

Long before recorded history, early man obtained his food by hunting wild game animals, fishing, and collecting edible seeds and roots of plants. With advancements in technology, man has also advanced in methods of gathering and processing of foods (Pasqualone, 2018). While some foods are eaten raw, others need to be processed. Processing of food involves a series of activities embarked upon to ensure the conversion of food from its raw state to a form that is edible and more appealing for human consumption (Hager, 2013 and Adamu et al 2021].

According to Enid, (1985) food processing methods include cooking (boiling), frying, roasting, and baking amongst others. These methods involve the application of heat from different sources such as burning of wood, coal, gas cooker, and electric cooker. Baking has been seen and analyzed from different perspectives by series of authors and researchers, although aimed at a common objective by many. Al-Nasser, et al (2021) and Reddy, et al (2020) defined baking as a way of loaf's transformation during a variety of complicated chemical, biochemical, and physical processes that occur within a product. Tong, and Lund, (1990) reported that baking is the most common and oldest form of food processing that uses sustained dry heat through convection instead of thermal radiation normally in the oven, in ashes or hot stones. It is a dynamic method of simultaneous heat and mass transfer widely used in food industries. In a different perspective,

Armando, et al (2012), Fellows, (2012) and Giz (2014) saw baking as a process "to cook by dry heat, therefore, next to cooking, which is another essential way of preparing food from raw staple crops. Usually, baking takes place in an oven hotplate, but also feasible in hot ashes or on hot stones. During baking, the heating process is done by a combination of three forms of heat such as infra-red energy that is radiated from oven walls, by circulating hot air; and by conduction, through the baking pan or tray as reported by Fellows, (2012). This implies that the efficiency of the baking process depends on the optimal use of three different parts of the device namely; the walls, the tray and the ventilation system (Emma, 2012; Stephane, 1997). Analysis and optimization of baking process and equipment have been conducted for minimizing energy consumption by Therdthai et al, (2003) while baking techniques were improved with the development of an enclosed baking utensil thus, making possible thicker baked cakes or loaves.

Mondal, and Data, (2008) reported that a baking oven is the most widely used appliance in food service industry and simply described it as a fully enclosed thermally insulated chamber used for the heating, baking or drying of a substance. Chhanwa, and Anandharamakrishnan, (2014); Vanin et al, (2009) and Weibiao Zhou and Hui (2014) referred baking as a complex and irreversible process in their studies. The experimented substance in the study was observed and the dough changes in two different parts i.e. crumb and crust, both of which have their distinct texture. The golden brown colour of bread surface was due to the non-enzymatic browning reaction initiated as a result of high surface temperature (> 120 °C) and low moisture content (< 0.05%) of the bread surface. However, in baking oven, the hot air flew over the material through natural convection or forced by a fan, convection heat transfers from air, the radiation heat transfer from the oven heating surfaces, and the conduction heat transfer across contact area between product and metal surface (Ozilgen and Heil, 1994).

According to Basil and Blessent (2014), during baking, the driving force of heat transfer is the temperature gradient while that of mass diffusion is the concentration difference. However, both occur simultaneously within the food product from the outer part to the inner part of the food material. It was reported that during baking the moisture diffusion in the food material occurs mainly by convection and conduction, less by radiation. Whereas, Ingole and Band (2016) reported that an oven is the small electric kitchen appliance designed to heat or bakes multiple types of products. Design of oven had undergone many changes from purely mechanical to automatic forms which are accompanied by some sophistications. In the toasting systems available in market, the user can set temperature and toasting time. In some systems the temperature values are directly the function of the recipes, thus, need not to manually set the temperature. Mondal and Datta, (2008) reported that an oven can simply be described as a thermal insulated chamber used for the heating, baking, cooking, or drying of food substances.

Ovens were reported by Gourdin and Kingery (1975) as an ancient method of heat treatment in Near Eastern domestic contexts. Ovens are often used for cooking, where they can be used to heat food to a desired temperature. Ovens are also used in the manufacturing of ceramics and pottery; these ovens are sometimes referred to as kilns.

Metallurgical furnaces are ovens used in the manufacturing of metals, while glass furnaces are ovens used to produce glass. There are many methods by which different types of ovens produce heat. Some ovens heat materials using the combustion of a fuel, such as wood, coal, or natural gas, while many others employ electricity. Microwave ovens heat materials by exposing them to microwave radiation while electric ovens and electric furnaces heat materials using resistive heating. Some ovens use forced convection, the movement of gases inside the heating chamber, to enhance the heating process, or, in some cases, to change the properties of the material being heated, such as in the Bessemer method of steel production. As reported by Akinwonmi et al. [24], burners or combustion units gain application in power plants, internal combustion engines, steam plants, ovens, and furnaces.

Many of the existing baking ovens are accompanied by limitations that have posed negative effect on the substance(s) being baked as well as the process timing. Therefore, given the need for more convenient means by which baking can be carried out efficiently, review of previous studies in this area becomes necessary, thus, the conception of this study. The novelty of this study lies in the review of the use of infrared energy which is radiated from oven walls, by circulating hot air, conduction through the baking pan or tray and the airing system in order to enhance the efficiency of baking ovens and better the output/quality of baking process as well as the end products.

2. HISTORY AND EVOLUTION OF OVENS

History showed that by 2600 before the common era, BCE, the Egyptians, credited with the first intentional use of leavening, were making bread by methods similar in principle to those of today. The Egyptians developed the first ovens. The earliest known examples are cylindrical vessels made of baked Nile clay, tapered at the top to give a cone shape and divided inside by a horizontal shelf like partition. The lower section is the firebox while the upper section is the baking chamber. The pieces of dough were placed in the baking chamber through a hole provided in the top. In the first two or three centuries after the 7 founding of Rome, baking remained a domestic skill with few changes in equipment or processing methods. According to Pliny the Elder, there were no bakers in Rome until the middle of the 2nd century BCE. As well-to-do families increased, women wishing to avoid frequent and tedious bread making began to patronize professional bakers, usually freed slaves. Loaves molded by hand into a spheroidal shape, generally weighing about a pound, were baked in a beehive-shaped oven fired by wood.

Panis artopticius was a variety cooked on a spit, *panis testuatis* in an earthen vessel. The earliest ovens were found in Central Europe, and date back to 29,000 BC. They were roasting and boiling pits inside yurts used to cook mammoth (Viegas, 2009). In Ukraine from 20,000 BC they used pits with hot coals covered in ashes. The food was wrapped in leaves and set on top, then covered with earth (Peter, *et al.,* 1995). In camps found in Mezhirich, (2011) each mammoth bone house had a hearth used for heating and cooking. Ovens were used by cultures who lived in the Indus Valley and in pre-dynastic Egypt. By 3200 BC, each mud-brick house had an oven in settlements across the Indus Valley (Dales, 1974). Ovens were used to cook food and to make bricks. While pre-dynastic civilizations in Egypt used kilns around 5000–4000 BC to make pottery.

Bellis, (2017) also reported that an oven made entirely of bricks and tile was built in 1490, in Alsace, France. During the middle ages, instead of earth and ceramic ovens, Europeans used fireplaces in conjunction with large cauldrons. These were similar to the Dutch oven. Following the Middle-Ages, ovens underwent many changes over time from wood, iron, coal, gas, and even electric. Each design had its own motivation and purpose. The wood-burning stoves saw improvement through the addition of fire chambers that allowed better containment and release of smoke. Another recognizable oven would be the cast-iron stove. These were first used around the early 1700s when they themselves underwent several variations including the Stewart Oberlin iron stove that was smaller and had its own chimney (Bellis, 2018). In the early part of the 19th century, the coal oven was developed. It was cylindrical in shape and made of heavy cast iron. The gas oven saw its first use as early as the beginning of the 19th century as well.

Gas stoves became very common household ovens once gas lines were available to most houses and neighborhoods. James Sharp patented one of the first gas stoves in 1826. Other various improvements to the gas stove included the AGA cooker invented in 1922 by Gustaf Dalén. The first electric ovens were invented in the very late 19th century, however, like many electrical inventions designed for commercial use, mass ownership of electrical ovens could not be a reality until better and more efficient use of electricity was available (Bellis, 2018). It is reported that more recently, ovens have become slightly more high-tech in terms of cooking strategy. The microwave as a cooking tool was discovered by Percy Spencer in 1946, and with the help from engineers, the microwave oven was patented. The microwave oven uses microwave radiation to excite the water molecules in food causing friction, thus producing heat. (Gallawa, 2018). It was recorded that domed ovens were found in Turkey and Iraq c. 7000 B.C.E., but there is no evidence that these populations ate bread (Martin and Nerissa, 2000). Others have suggested that early bread-baking methods in the region included preheated ceramic trays or moulds (Chazan and Mark 1990).

The *tannur* is the most commonly reported domestic bread oven in the Near East. Tannur are found in Southwest Asia, Turkey, Afghanistan, India, and Pakistan (Wulff 1966; Pomeranz and Shellenberger 1971; Tannahill 1973). These ovens first appeared in domestic and monumental buildings in Mesopotamian cities by 3100 B.C.E., and later in Bronze Age Jordan (1550 B.C.E.) and New Kingdom Egypt (1550-1070 B.C.E.) (McQuitty 1984; Van de Mieroop 1997; Samuel 2000; Ochsenschlager 1974). Tannur are cylinders or cones of mud plaster or brick, lined with clay. They are either freestanding or, more frequently, set into benches or floors (Kramer 1982; Serjeant and Lewcock 1983; Samuel 1989; Pomeranz and Shellenberger 1971; Ochsenschlager 1974).

Oven sizes vary but all have an opening near the top to insert bread and a smaller opening at the base for draft, fueling, and ash removal. Fuels include animal dung; mixtures of dung, reeds, and wood; or chopped straw (Sweet 1960; Kramer 1982; Samuel 1989; Weinstein 1973; Ochsenschlager 1974). Count Rumford (also known as; Benjamin Thompson) invented a working iron kitchen stove that was designed for very large working kitchens (Rumford, 1928). One of the successful and compact cast iron design was Stewart's Oberlin iron stove, patented in 1834. The evolution of gas stoves was delayed until gas lines that could furnish gas to households became common (Bellis, 2017). The microwave ovens were a byproduct of another technology (Bellis, 2017).

3. TYPES OF BAKING OVENS

According to Phillips (2011) double oven is a built-in oven fixture that has either two ovens, or one oven and one microwave oven built into the kitchen cabinet. Dering, (1999) reported that an earth oven is a pit dug into the ground and then heated, usually by rocks or smoldering debris. Historically, these have been used by many cultures for cooking. Cooking times are usually long, and the process is usually cooking by slow roasting of the food. Earth ovens are among the most common things archaeologists look for at an anthropological dig, as they are one of the key indicators of human civilization and static society. Clay oven is described as the ceramic oven constructed of clay or any other ceramic material and takes different forms depending on the culture. The Indians referred to it as a tandoor, and use it for cooking dated back as far as 3,000 BC. Forno, (2011) described brick ovens as another ceramic type oven.

Electric oven produces their heat electrically, often via resistive heating. In microwave oven, food is cooked by means of microwave radiation instead of infrared radiation obtained from a source of fire. Conceptualized in 1946, Dr. Percy Spencer discovered the heating properties of microwaves while studying the magnetron. By 1947, the first commercial microwave was in use in Boston, Mass. Wall ovens make it easier to work with large roasting pans than Dutch ovens. The width of the microwave is typically 24, 27, or 30 inches. Mounted at waist or eye level, a wall oven eliminates bending. However, it can be nested under a countertop to save space. This feature enhances the ergonomic principles as it relates to the anthropometric characteristics of the user, therefore enhances comfort of use. Although, separate wall oven is expensive compared with a range. One of the first recorded uses of a gas stove and oven referenced a dinner party in 1802 hosted by Zachaus Winzler, where all the food was prepared either on a gas stove or in its oven compartment. In 1834, British inventor James Sharp began to commercially produce gas ovens after installing one in his own house.

In 1851, the Bower's Registered Gas Stove was displayed at the Great Exhibition. This stove set the standard and basis for the modern gas oven. Notable improvements to the gas stove since included the addition of the thermostat which assisted in temperature regulation; also an enamel coating was added to the production of gas stoves and ovens to help with easier cleaning. It further revealed that Masonry ovens consist of a baking chamber made of fireproof brick, concrete, stone, or clay. Though traditionally wood-fired, coal-fired ovens were common in the 19th century. Modern masonry ovens are often fired with natural gas or even electricity, and are closely associated with artisanal bread and pizza. In the past, however, they were also used for any cooking task that required baking while steam oven is an oven that can cook food using steam to provide heat. The schematic diagram of a gas fired oven is shown in Figure 1.

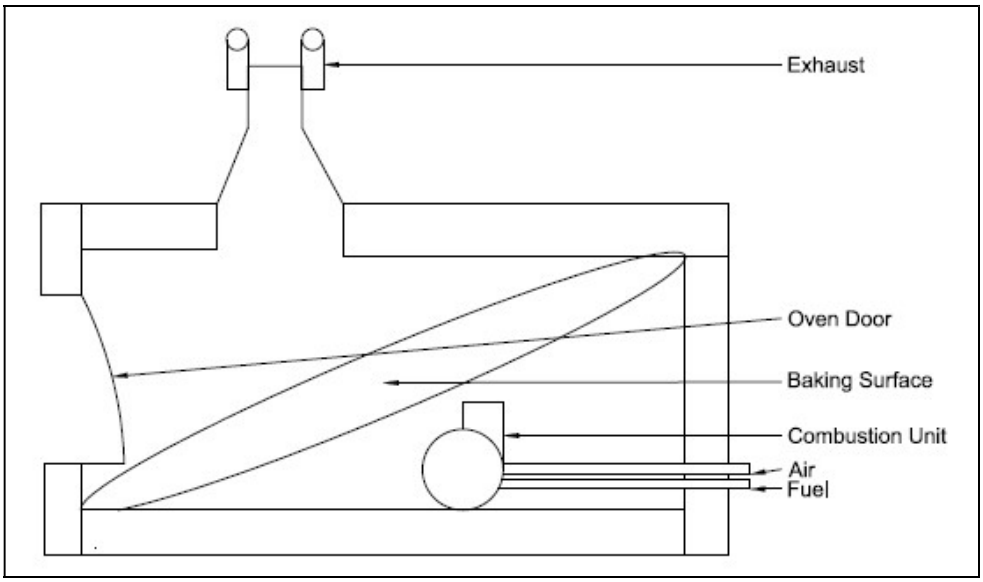

Figure 1: A Typical Gas Fired Oven (Sadripour Et Al., 2018)

4. PREVIOUS WORKS DONE ON BAKING OVENS AND THEIR EFFECTS

According to Chhanwal, *et al.,* (2018) several works have been carried out by researchers on some non-conventional ovens and this requires review in other to identify the knowledge contiobuted as well as the research. Li and Walker (1996) worked on impingement and hybrid baking ovens for baking cakes. The research found out that as compared to convection oven, impinging jet oven increases heat transfer rate by four-time and decreases bake time by half. The integrated oven also gives similar results for baking time as an impinging oven with less volume and firmest texture. Wählby *et al.,* (2000) also used impingement jet oven for buns. It is reported that medium air temperature was required to achieve desired bun quality.

Similarly, Ozmutlu et al. (2001) used microwave oven for bread, in their experiment. The researchers found out that bread formulation having low gluten content shows high quality, with a softer texture and higher volume. Compared conventionally baked products, the firmness of microwave baked product was more in quantity. Also, Keskin *et al.,* (2004) in their experimental study of halogen lamp-microwave to bake bread, found out that bread baked in halogen lamp-microwave combination oven shows desired browning and volume. And the enzyme shows a positive effect on the specific volume of bread. Weight loss and firmness of bread were higher as compared to conventionally baked ones. Furthermore, Patel *et al.,* (2005) used impingement and microwave to bake bread. They discovered that the heating rate affected the product quality and storage stability. Olsson et al. (2005) used impinging jet oven and infrared oven for bread. It was found out that infrared heating showed higher colour development than impingement heating. In another study on optimizing baking parameters for cake, Sevimli *et al.,* (2005) also found out that baking time and upper halogen lamp showed significant effect on product quality. Keskin *et al.,* (2007) also discovered that in infrared-microwave oven, bread product quality increased in specific volume and bread porosity and decreased its hardness by the addition of xanthan-guar gum into the bread formulation.

To quantify the works carried out on ovens, Ozge *et al.,* (2009) while evaluating the physical properties of bread baked in different ovens reported that bread baked in infrared-microwave combination oven showed similar staling degrees as in a conventional. Demirkesen *et al.,* (2011) also reported that in infrared-microwave oven, bread optimization of gluten-free bread that contained chestnut-rice flour bread is possible. The bread containing 46.5% chestnut flour with 40% infrared and 30% microwave power for 9 min of baking time yielded bread comparable to conventional one. Purlis (2014) used infrared-conventional oven for bread optimization of baking process based on critical and quality time involving conventional and infrared heating. It was discovered that the use of infrared heating would obtain the desired browning index and other optimum parameters.

However, Chhanwa and Anandharamakrishnan, (2014) reported that in infrared-electrical oven, bread baked in hybrid heating mode showed higher volume and softness. 28% energy saved was observed with the use of hybrid heating mode compared to electrical heating. Genitha et al., (2014) designed, fabricated and carried out the performance evaluation of domestic gas oven. The effectiveness was analyzed by baking cake, cookies and muffins. Results showed that the cake was baked in 28 min at a temperature of 180˚C depending on the size of the cake, cookies took 10 min at a temperature of 150˚C and the muffins were baked in 13min at a temperature of 180˚C. These showed higher energy efficiency by reduced energy, cost and the time of baking observed in the study. They also concluded that gas oven can be better used for the baking of the cakes, cookies and all the bakery products with good quality parameters such as color, texture and the taste and good volume in the fermented products. Also, the pre heating time of the gas oven was also reduced which resulted in very less energy consumption, reduced time of the baking and reduced overall working cost. This can be used for small entrepreneurs and can be popularized in areas where power cuts are more frequent and power is available for limited hours.

This gas oven has the disadvantage of controlling the temperature inside the baking chamber. In another experiment by Akinnuli and Basil (2019), it is reported that when the gas baking oven was tested, high efficiency was obtained. The findings of the study are consistent with those obtained by Genitha et al, (2014). The performance test gave oven efficiency of 90.7 per cent. They also concluded that the oven can be used for the baking of the cakes, cookies and all the bakery products with good quality parameters such as color, texture and the taste and good volume in the fermented products and also the pre heating time of the gas oven was also reduced this in turn consumes very less energy and the time of the baking and reduces the overall working cost. Ilesanmi and Akinnuli (2019) worked to improve on the already existing gas baking oven through the incorporation of a vent/chimney for removal of humid air and roller (wheels) for easy movement. Cooking gas is supplied to the burner located in the lower chamber of the oven via a pipe connection to the gas cylinder.

The researchers found out that perforations allowed for heat dissipation within the lower chamber, capacity of the baking oven is 12 loaves of bread of 0.5 kg per bread per tray (batch), using a temperature regulator and from practical determination, the maximum temperature of 210°C was recorded and the performance test on the oven showed that the efficiency of the oven is of 90.7 percent. Morakinyo *et al.,* 2020 evaluated the oven characteristics of a gas-fired baking oven and found that the baking capacity (12.5 kg/hr), baking efficiency (87.8%), weight loss (12.5 g) and optimum baking temperature (200-220°C) were feasible. The physical properties of baked bread dough were found to correspond with the imported product (i.e., the control sample). They concluded that the developed gas-fired baking oven can be adopted for baking of bread at domestic and commercial levels.

In addition, Chukwuneke *et al.,* (2018) designed and fabricated a dual powered baking oven which is mainly made up of the electric coil, the lagging material, temperature control and the gas burner. It has an internal volume of 0.140m^3, and outside surface area of 0.142 m^2, with a double tray for baking and drying of food items. The oven was constructed in such a way that the electric coil heater and the gas burner are in one chamber. Using the electrical coil heater and a temperature regulator, they found out that the maximum temperature of 220˚C was recorded and the oven can bake maximum of 12 loaves of bread (area of 0.022 m^2per loaf). Olugbade and Ojo (2018) conducted an experiment on development and performance evaluation of an improved electric baking oven. The performance evaluation test revealed the moisture content of 67.7%, and resistance of the heating element, 0.64 Ω. It was also established that the heating element could supply a minimum of 1,797.6 KJ of heat energy to the oven chamber in 80 minutes. An entrepreneurial skill development study was carried out by Asibeluo *et al.,* (2015).

The case study was focused on the design and construction of charcoal baking oven. The study found out that the oven is capable of generating 1488 KJ of heat energy and the maximum temperature attainable with the oven is about 500^oC. The authors further concluded that the construction of charcoal baking oven has proved a reliable in way of baking. Asides from baking, the oven can also be used to dry farm products like maize, groundnuts and warm food. The charcoal baking oven was designed in a manner such that heat loss is reduced to the barest minimum as well as allow for even distribution of heat for optimal baking performances. Kulla *et al.,* (2014) designed and constructed a small-scale charcoal baking oven, however, it was reported that the epileptic nature of power supply in the urban centers as well as lack of electricity in the rural settlements crippled the functionality of the oven. Because, the operation of the oven is largely electricity dependent. In this connection, the need for baking oven that is not electricity dependent arises. Charcoal oven which is one of such ovens, is cheap and efficient and can be used both in the rural and urban settlements for domestic consumption and small-scale business. When further made sophisticated can be applied for industrial purposes because this oven uses little quantity of charcoal but with high energy intensity which makes it bake within a short time possible.

Furthermore, Kulla *et al.,* (2014) found out that an optimum charcoal of 0.2kg was used for the baking of bread, taking 25 minutes time at baking temperature 140^oC. In a similar manner, Babajide *et al.,* (2021) modified the existing baking oven to a dual powered baking oven and evaluated it by considering the baking oven characteristics such as baking capacity, baking efficiency, weight loss and optimum baking temperature and physical properties. It was established that the average baking efficiency of wood-fired and gas-fired were 46.44% and 70.34%, respectively. This is an indication that compared to wood-fired, energy was efficiently used in gas-fired. The surface area and volume of baked bread with wood-fired oven compared with gas-fired oven were significantly different from each other at level of $p < 0.05$ and 95% confidence level. On the other hand, the effect of the factors was not significant for the density and specific volume, but optimum baking temperature was found to be between 145˚C - 150˚C. It is therefore concluded that the modified oven can be used for the baking of dough at domestic, small and medium scale bakery.

Critical Issues with Baking Ovens

Some of the critical issues that have been identified in the design, fabrication and utilization of baking ovens are presented in Table 1. The issues include; the quality of the baked product, health impact of flue gas from oven assembly, energy loss and optimization, waste heat recovery, control of baking temperature and other process parameters, and optimization of oven design such as the use of rotating trolley racks to ensure uniformity during baking process.

TABLE 1: CHALLENGES WITH BAKING OVENS

Authors	Oven type/design	Heat transfer mode	Challenge	Major findings	Study Area
Genitha et al (2014)	Domestic gas oven	Convection	Difficulty in controlling baking chamber temperature	Preheating of the gas reduces energy consumption and overall cost of operation	India
Sugar et al (2017)	Electrical resistance	Conduction	Achieving balance between dough weight and intensity of heat	Use of electric resistance ensures that the temperature within the baking unit can be controlled	Romania
Pinelli and Suman (2017)	Compressed Air	Convection	The study attempted to solve the problem of uniformity of baked products by simulation but encountered a major challenge of stability of the simulation process due to fluctuations in the mass flow rate	The use of rotating trolley racks in baking ovens will ensure uniform cooking of baked products.	Italy
Sadripour et al (2018)	Natural gas fired oven	Convection and conduction	Energy losses in flue gas up to 68% inspite of improvement in convection mechanism and volume radiation	Efforts to maximize energy utilization through improving surface radiation and conduction technics should be investigated	Iran

Authors	Oven type/design	Heat transfer mode	Challenge	Major findings	Study Area
Mukherjee et al (2019)	Gas fired oven	Conduction, convection, radiation	Managing heat losses and heat recovery through process re-engineering	Heating parameters optimization and heat recovery processes will reduce the cost of energy consumption in Baking ovens	United Kingdom
Tadevosyan et al (2019)	Open fire oven	Conduction, convection, radiation	Carbon monoxide pollution	High carboxyhaemoglobin levels among vulnerable population living around oven location	Armenia
Saberi et al (2021)	Indirect radiation-cyclotherm (IRC) Indirect convection (IC) Hybrid and industrial tunnel (HIT)	Radiation Convection Hybrid of radiation and convection	IC producing the highest amount of heat flux, the baked product still had high moisture content and lowest hardness	The amount of heat flux generated in an oven has a significant impact on the product quality. The quality of baked products can be modified by using different oven arrangements	Iran
Sprengel et al., (2021)	Gas Ovens	convection	Transfer of chlorinated paraffins from oven doors to baking product	Using ovens that contain chlorinated paraffins for baking increases the chances of CP intake by consumers	Germany

Authors	Oven type/design	Heat transfer mode	Challenge	Major findings	Study Area
Hatou et al., (2021)	Solid fuel fired oven	Radiation	Optimizing process parameters for locally constructed oven in developing countries	The efficiency of the simulated solid fuel oven without the dough is 0.49. Efforts to improve oven efficiency should be sustained.	Cameroon
Utazi et al (2021)	Solar powered oven	Radiation and convection	Baking temperature was limited to 98^{o}C	The fabricated oven is ecofriendly, useful in homes and cities where wood resources for open fire ovens are scarce.	Nigeria
Akinwonmi (2024)	Firewood/Charcoal	Convection, Radiation and conduction	Difficulty in controlling baking chamber temperature	the maximum temperature of the installed oven is 700°C which is good enough for annealing treatment of steel and possibility of melting aluminum	Nigeria

Some Experimental Results

The impact of oven type on the bake product has been examined (Sadripour et al., 2018). One method of determining the quality of oven products is by carrying out hardness test. Sugar et al (2017) who proposed the use of electrical resistance oven compared the crust hardness of the product of the oven with those of the traditional oven by means of Hardnell Brinell test. The results presented in Figure 2 showed that Hardnell Brinell Number (HBN) increased with increase in baking time and the HBN for electrical oven product were lower than those of the traditional oven. The advantage of using electrical resistance oven is that the oven temperature can easily be controlled.

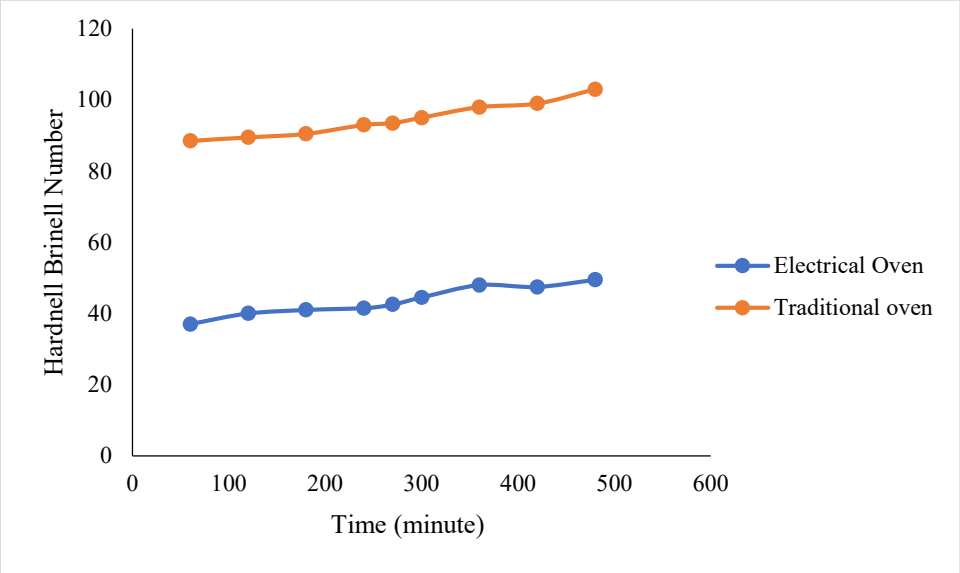

Figure 2: Comparison of Electrical and Traditional Ovens Products (Sugar et al., 2017)

Future Directions in the Design of Baking Oven

Energy Optimization: Energy losses is one of the critical challenges in the construction and use of ovens. Several research has begun to consider how energy losses can be minimized, and oven efficiency optimized. One way to achieve energy optimization is by preheating. Sugar et al. (2017) proposed steaming irradiation, Genitha et al., (2014) posited the reduction of preheating time of a gas oven to minimize the baking time and the fuel consumption.

Oven Design Optimization: The design of the oven itself is critical to maximizing economic potentials of baking oven. Over the last couple of years there have been sustained innovations and inventions in this regard, which shows that going forward there will be more inventions and innovations in oven design. For instance, McKee et al., (2016) invented an oven with H-shaped rotating door. The door which is rotated by a motor has two loading sections and also serves as a cover that would prevent heat loss from the cavity through the opening. Delrue et al. (2019) designed and fabricated a novel electric oven with an air flow. The apparatus was designed such that, there is an air flow inlet, the air is then heated by radiation from an electric circuit (heater), the heated air is then heats the food positioned along the ventilation sleeve by convection. This way, a greater portion of the food is heated per time due to the convection movement of the air.

Oven Waste Heat Recovery: This is another aspect of oven research that is gaining momentum. Efforts are on to channel the heat generated from the exhaust back into the process. This has double benefit of reducing environmental pollution and minimizing fuel consumption. It has been established in the review that over 60% of the heat generated in ovens are wasted in the flue gas. This became the bane of the study by Mukherjee et al., (2019) who developed a waste recovery unit to heat up the primary combustion air before entering the combustion unit. The outcome of the study showed a 4% reduction in fuel consumption and the probability of avoiding up to 43 tonnes of CO_2 emission per year.

Simulation Studies: the use of simulation studies is gaining wide applications in all fields of science, as it affords researchers the opportunity to vary process parameters in a virtual environment and monitor the impact on the process without incurring extra costs. Several researchers have conducted oven numerical and simulation studies (Mukherjee et al., 2019; Pinelli & Suman, 2017; Hatou et al., 2021). Going forward, this is one area that will gain prominence especially in the aspect of design of baking ovens.

Use of Renewable Energy: In developing countries with pulsating electric power supply, the use of open fire ovens is common. These ovens are fired with wood or charcoal generating a lot of CO_2 and CO in the process. This also places a huge demand on forest resources. With the use of renewable energy alternatives such solid biofuels made from biowastes and solar energy, the identified issues can be addressed. Utazi et al., (2021) developed a miniatured solar powered baking oven with a maximum temperature of 98^{o}C. Although the study shows the prospect of using solar energy in baking, more needs to be done in upscaling the innovation in terms of the size and maximum baking temperature.

5. CONCLUSIONS AND FUTURE DIRECTIONS

Baking remains a relevant technique for food processing as it involves the combination of heat and mass transfer within an oven environment with wide application in food industries from ancient time till date. It has been established that the type of oven used in baking and the process parameters such as air flow velocity, baking time, and temperature have an impact on the quality of baked product. Also, there is the tendency for food poisoning resulting from transfer of chlorofluorocarbon from baking apparatus to the product, as well as other health issues resulting from environmental pollution generated by the flue gas. These challenges can be resolved by design optimization, use of renewable energy, and waste recovery. Although, a lot has been done in this regard, findings from studies revealed that more can still be done to enhance the productivity and efficiency of baking ovens.

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