

**FACULTAD DE INGENIERÍA**

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Tesis

**MK4 Kiln in Brick Manufacturing in Peru:  
Reduction of Pollutants and Maximum Energy  
Efficiency for Sustainable Production**

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# Mk4 Kiln In Brick Manufacturing In Peru: Reduction Of Pollutants And Maximum Energy Efficiency For Sustainable Production

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**Abstract.** The study of the MK4 kiln reveals notable results, highlighting its efficiency in firing bricks through convection heat exchange, avoiding heat losses in kilns (1) and (2), achieving a final firing temperature of 995.6 °C in 160 minutes, this system not only accelerates the cooking process, but also contributes significantly to the overall efficiency, benefiting comprehensive operational efficiency not only improves the quality of the final product, but also promotes sustainability and profitability in the manufacture of bricks, indicating a faster and more uniform firing. Likewise, it demonstrates optimal results in its cogeneration system, having an energy efficiency of 60% in 160 minutes of cooking, generating a heat recovery temperature of 596.5 °C in each oven (3) and (4). In addition, the pollutants PM2.5 and PM10, through the gravitational force, the particles settle during the cooking process and remain within the environmental quality standards, registering 23  $\mu\text{g}/\text{m}^3$  and 60  $\mu\text{g}/\text{m}^3$ , respectively. Finally, the MK4 oven is presented as an effective and sustainable solution, surpassing inefficient and polluting artisanal ovens. marking a milestone in the search for environmental sustainability and efficiency in the brick production industry, allowing an impact on the firing time and, therefore, on the quality of the final product that allows improving the quality of life of the society and environment.

**Keywords:** Convection heat exchange, Cogeneration system, heat recovery, PM2.5, PM10, energy efficiency, gravitational force and particle sedimentation.

## 1. Introduction

The artisanal manufacture of bricks on a global level, as Asians lead the production of bricks, generating 20% of them with modern mechanized technology, becoming an important challenge from an environmental perspective on a global level. In 2019, the World Health Organization (WHO) documented an alarming situation: nearly 99% of the global population experienced the influence of PM2.5 and PM10 particle pollution, causing approximately 6 million premature deaths each year [1]. The pollutants released by this brick industry, such as carbon dioxide and PM2.5 and PM10, contribute significantly and account for a quarter of global emissions [2]. Additionally, research has confirmed that the traditional brick manufacturing process releases pollutants into the environment, thereby contributing to the rise in global pollution levels [3]. This situation presents significant challenges regarding energy efficiency and environmental sustainability within the brick manufacturing industry. In this context, it is crucial to investigate strategies and approaches aimed at enhancing energy efficiency while minimizing the environmental impact of this essential sector [4]. The increasing focus on environmental impact and the high consumption of thermal energy have become critical factors in the pursuit of more sustainable industrial practices [5]. The production of artisanal bricks in traditional kilns is a common practice in the construction industry; however, it has a significant negative environmental impact due to the pollution produced during the firing process. These kilns are energy inefficient, as they rely on natural resources as fuel, leading to the release of particulate matter into the environment [6]. It is essential to highlight that the firing temperature varies greatly depending on the type of bricks being produced. For instance, standard bricks require a firing temperature between 900 and 1050°C, whereas basic bricks demand significantly higher temperatures, ranging from 1400 to 1800°C [7].

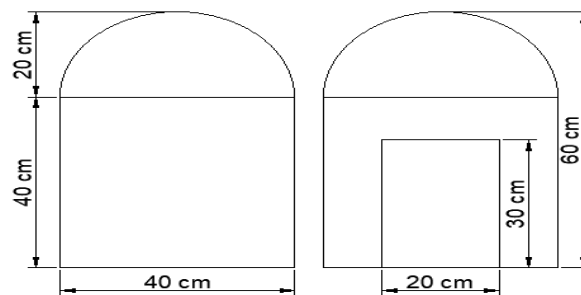
In Nepal, air quality has been continuously deteriorating, primarily due to the rise of informal artisanal brick factories that contribute to pollution and struggle to improve energy efficiency. This issue has raised serious concerns regarding public health and the quality of life for residents in the affected regions [8]. Currently, artisanal brick factories are responsible for large-scale production, relying heavily on coal for combustion. This process releases pollutants that negatively affect the health of brick producers and significantly deteriorates air quality [9]. Furthermore, the manufacturing process of these bricks requires a substantial energy input, as it involves subjecting earth blocks to extremely high temperatures, reaching up to 1,100 degrees Celsius, for a duration of 10 to 40 hours [10].

In Peru, artisanal brick factories are defined by outdated infrastructure and inefficient energy systems used for firing bricks. A key issue lies in the emissions produced by traditional kilns, which rely on firewood, eucalyptus

branches, and solid waste as fuel sources. This practice not only deteriorates air quality and poses risks to human health but also negatively impacts the environment and threatens the economic sustainability of these artisanal operations.

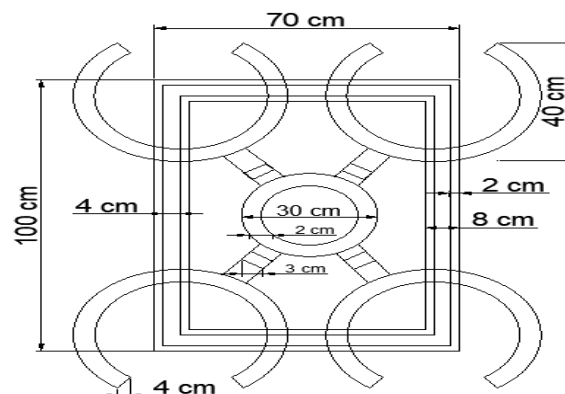
## 2. Materials and methods

To initiate the experimental process, data was collected, and the construction of the MK4 Oven was undertaken to prepare the kiln for firing artisanal bricks. The primary objective is to reduce pollutants, evaluate the energy efficiency and production performance of the bricks, and, based on this analysis, develop an economical alternative that minimizes environmental impact, reduces energy consumption, and protects human health.



**Fig. 1.** Front view of the MK4 oven. Source: self made.

### 2.1. MK4 oven design features



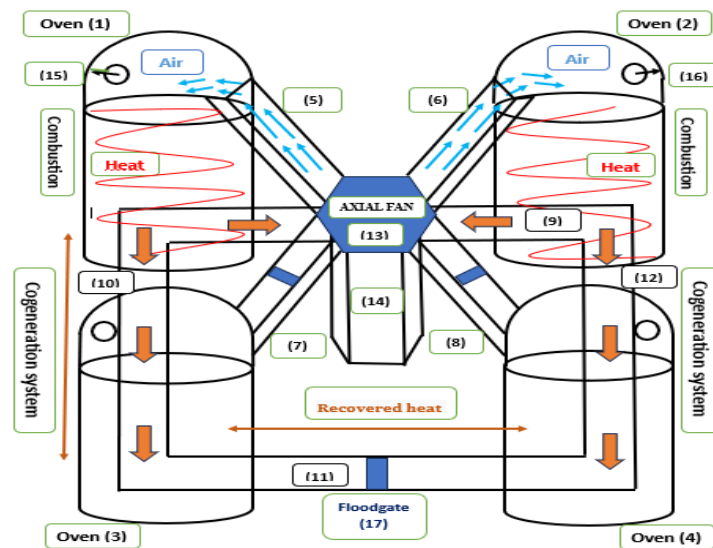
**Fig. 2.** Plan view of the MK4 Oven Source: self made.

As shown in Figure 1, the design of the MK4 oven presents a structure made up of four ovens, with a height of 60 cm and a width of 40 cm. The walls of each oven have dimensions of 40 cm high and 4 cm wide, contributing significantly to thermal insulation and heat resistance, ensuring efficient performance. As shown in figure 2, To facilitate heat transfer, lower ducts with a width of 8 cm are incorporated. These ducts play an important role in evenly distributing heat inside the ovens and ensuring ideal conditions. The chimney has a diameter of 30 cm and a height of 40 cm, it plays a key role in the system. Connected to the ovens through upper ducts, it facilitates air flow and helps start the cooking process.

### 2.2. Brick firing process in the MK4 kiln

As shown in Figure 3, the brick firing process in the ovens (1) and (2) begins with two industrial copper torches (15) and (16), of 2050 BTU/h (approximately 0.60 kW), fed with propane gas. which are connected to the holes designed in the upper part of the oven, so that the nozzle of the torch can enter. These torches trigger the combustion essential for firing the brick. To do this, it is necessary to have a 220V axial fan, located in the chimney (14), with a maximum wind speed of 6.4 m/s, generating air flow in the system. This fan directs the air through the upper ducts (5), (6), (7) and (8), according to the ovens that will begin the brick firing process. The air supply

to the ovens (1) and (2) is carried out through the upper ducts (5) and (6), to start combustion in the ovens, starting the brick firing process.



**Fig. 3.** MK4 furnace cogeneration system. Source: self made.

### 2.3. Sedimentation of particulate matter through gravitational forces

As shown in Figure 3, these negative impacts affect throughout the manufacturing process. To address this, a channeling system was implemented that directs contaminants through lower conduits (9), (10), (11) and (12), which adhere particles to the raw bricks and conduits. through the gravitational forces that sediment the particles. This system seeks to significantly reduce the emission of pollutants, mitigating the environmental impacts associated with brick manufacturing. The strategy focuses on sedimenting pollutants by gravitational force before their release, effectively reducing particles.

### 2.4. Energy Efficiency through the Cogeneration System

As shown in Figure 3, during the cooking phase, the heat produced by ovens (1) and (2) is directed through the lower duct (9), initiating a convection heat exchange system that positively impacts both cooking time and temperature uniformity during the brick manufacturing process. This system not only enhances thermal performance but also ensures a more consistent temperature distribution, which is crucial for producing high-quality final products. Energy efficiency is a key focus in this process, as all heat generated by ovens (1) and (2) is directed through the lower ducts (10) and (12) as part of a cogeneration system. This design ensures more effective use of thermal energy, improving sustainability and reducing environmental impact. Meanwhile, kilns (3) and (4) operate in parallel, loaded with raw bricks. Once the cooking cycle in ovens (1) and (2) is complete, the system resets, and the process continues with ovens (3) and (4).

## 3. Result

### 3.1. Firing brick in the MK4 kiln

As shown in Figure 4, temperature measurements during the firing process in ovens (1) and (2) provide valuable insights. In the first 20 minutes, the temperature reached 500.6°C, marking the start of the thermal process. Even more notable is the rapid increase, with the temperature peaking at 698.4°C after 80 minutes, indicating exponential heat growth. This suggests an efficient heating and thermal insulation system, which helps conserve heat. After 160 minutes, the temperature reached 995.6°C, underscoring the effectiveness of thermal insulation and the importance of energy efficiency in the kiln. Lastly, the role of heat exchange through convection is crucial for achieving a more uniform heat distribution inside the oven.

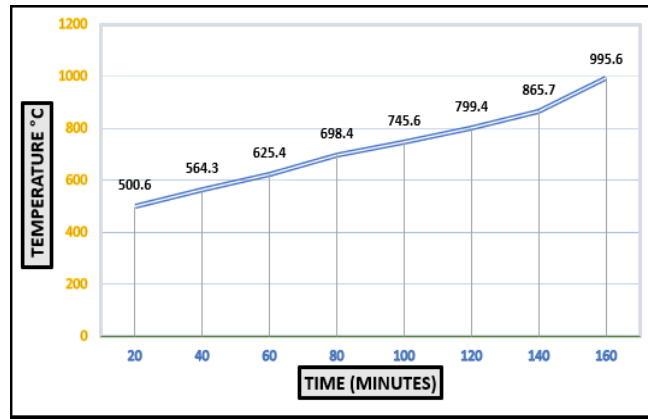


Fig. 4. Result of oven temperature and cooking time. Source: self made.

### 3.2. Increase in Energy Efficiency through the Cogeneration System

As shown in Figure 5, the brick firing process in kilns (1) and (2) of the MK4 kiln utilizes an innovative cogeneration system to optimize energy efficiency. After 20 minutes, the second kiln reaches a temperature of 66.2°C, achieving an efficiency of 13%, demonstrating the system's effectiveness. After 80 minutes, the temperature increases to 254.6°C, with an energy efficiency of 36%, showcasing the second kiln's efficiency in comparison to total heat generation. At the completion of 160 minutes of firing, the temperature reaches 596.5°C, with an energy efficiency of 60%, facilitating a continuous process between the four kilns.

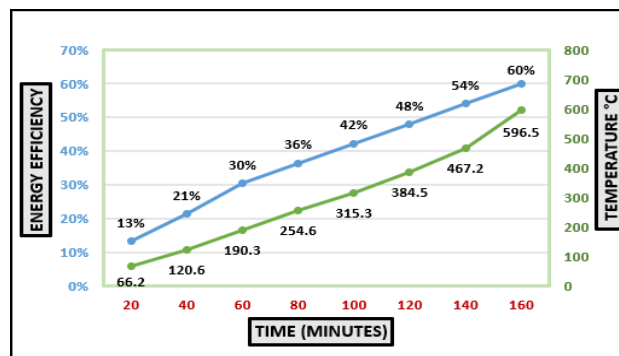


Fig. 5. Result of energy efficiency in the MK4 oven. Source: self made.

### 3.3. Particulate matter during brick firing

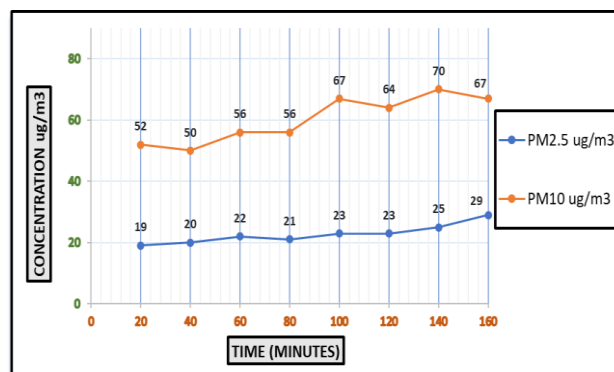


Fig. 6. Results of PM 2.5 and PM10 emissions from the MK4 oven. Source: self made.

**Table 1.** Environmental Quality Standards for Air

PARAMETERS	PERIOD	WORTH ( $\text{mg}/\text{m}^3$ )
Material Particles with diameter less than 2.5 microns (PM2.5)	24 hours Annual	50 25
Material Particles with diameter less than 10 microns (PM10)	24 hours Annual	100 50

**Fountain: Supreme Decree No. 003-2017-MINAM is approved in Peru, establishing the Environmental Quality Standards (ECA) for Air [11]**

As shown in Figure 6, the analysis of the emissions generated during the firing of the brick in the MK4 kiln reveals results in terms of air quality. The levels of suspended particles (PM 2.5 and PM10) obtained, with  $23 \mu\text{g}/\text{m}^3$  and  $60 \mu\text{g}/\text{m}^3$  respectively, are below the limits established in table 1, environmental regulations which establish a maximum of  $50 \mu\text{g}/\text{m}^3$  for PM2. 5 and  $100 \mu\text{g}/\text{m}^3$  for PM10. This compliance indicates that the MK4 furnace system is efficient and meets environmental quality standards. It is important to highlight that these results were obtained through specific monitoring designed to measure various atmospheric pollutants, using portable and versatile equipment such as the AEROQUAL SERIE 500.

#### 4. Discussion

Artisanal brickyards, in contrast to modern facilities, lack advanced control systems to mitigate polluting emissions and have significantly lower levels of efficiency in brick production. As a result, a source of environmental concern of considerable magnitude arises that significantly affects the ecosystem. The low energy efficiency in artisanal brickyards translates into an inefficient use of resources, such as the wood used to bake the bricks. Burning wood in primitive kilns entails high fuel consumption and consequently emits large amounts of greenhouse gases, contributing to climate change and air pollution [12].

#### 5. Conclusion

In conclusion, the MK4 oven is an innovative system that consists of heat exchange by convection, this is because the air inside the ovens becomes hotter, and therefore less dense, in the cooking process. of handmade bricks. Ovens (1) and (2) reached  $995.6 \text{ }^\circ\text{C}$  in 160 minutes, showing faster and more uniform cooking, essential for the quality of the product. An energy efficiency of 60% was also obtained through the cogeneration system in 160 minutes. These results reduce fuel consumption, reducing operating costs and greenhouse gas emissions. Likewise, heat recovery at  $596.5 \text{ }^\circ\text{C}$  in furnaces (3) and (4) underlines the effectiveness of the design in maximizing thermal utilization. Additionally, Measurements of PM2.5 and PM10 register  $23 \mu\text{g}/\text{m}^3$  and  $60 \mu\text{g}/\text{m}^3$ , respectively remained within environmental quality standards during the brick firing process. Finally, the MK4 oven offers an efficient alternative for environmental sustainability and marks a path towards a more responsible future in the use of natural resources and the reduction of environmental impacts.

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