Brick Kiln Emission Variability and Impact in Environment and Health

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ABSTRACT

Brick manufacturing is a major global industry employing millions of workers, yet it remains heavily reliant on outdated, polluting technologies. This study aims to categorize the brick kilns according to the way each of them functions. Also, it focuses on the fuel used and its properties. Another goal of the current research is to bring out the effects brick industry has on the environment and the people who work and live near the brick kilns. Conclusively, the current study underscores the urgent necessity for improvement and for the adoption of the strategies outlined to guide the brick manufacturing field towards a more sustainable future.

Keywords-brick kiln; emission; carbon; fuel; climate change; public health

I. INTRODUCTION

Bricks have a long history as a major building material, dating back to 8000 B.C. when they had the form of sun-dried mud blocks. The brick industry is considered the oldest industry in the human history, with bricks being a manmade material that has endured for thousands years. Bricks have been widely used across various ancient civilizations, with regions like central and southern Iraq relying heavily on the former considering them their primary construction material [1-3]. Today, the global annual brick production is estimated at 1.83 trillion units and is expected to have grown to 2.76 trillion by 2027 due to the housing sector's expansion. Although traditional burnt clay bricks are widely utilized, they have significant environmental drawbacks, including depletion of fertile topsoil and CO_2 emissions. The conventional brick production process, which involves digging clay, processing it, molding the bricks, drying them, and firing them in kilns, has caused serious environmental contamination through large greenhouse gas emissions and high energy consumption [1, 4, 5]. To address these environmental and economic challenges, the brick industry is exploring renewable energy sources and innovations to improve the efficiency and sustainability of brick production [4, 6-9]. The objective of this study is to prioritize different brick kiln technologies for potential implementation, considering factors like environmental impact, product quality, fuel efficiency, labor intensity, and investment requirements.

II. MAKING PROCESS

Bricks are a common building material used to construct walls, pavements, and other masonry elements. While traditionally made of clay, the term "brick" now encompasses any rectangular units laid in mortar, including those made from concrete or other materials. The brick production process involves several key steps. First, raw clay is dug from the local area around the brick kiln. This clay is then processed for impurities like gravel or organic matter to be removed. After that, the clay is mixed with water and left to dry up and harden. Clay preparation may also involve crushing, blending, and screening to achieve the desired plasticity, drying, and firing properties. Different types of clay and sand are often combined at this stage. The prepared clay mixture is then formed into bricks, typically using molds. The freshly molded "green" bricks are left to dry in the sun for 1-2 days, with the initial batches requiring up to 25 days of drying time. Finally, the dried bricks are placed into a kiln and fired at high temperatures, typically between 700-900 °C. This firing process alters the chemical and physical structure of the bricks, rendering them durable, strong, and suitable for construction. After firing, the bricks must be allowed to cool before their removal from the kiln. Waste fuels or carbonaceous materials can be added to the clay mixture to allow the bricks to self-fire during the heating process, saving energy and making them lighter and more durable. This multi-step process, from clay digging to brick firing and cooling, is essential for producing high-quality bricks in bulk quantities, which are to be used in masonry and building projects [10].

III. BRICK KILN TYPES

There is a wide variety of kiln designs, which can be classified in several ways (Figure 1). One key distinction is based on the production process: Intermittent kiln fire bricks in discrete batches, where the fire is lit, the bricks are fired, and the kiln is subsequently emptied, reloaded, and the fire is restarted for each new batch. This batch-based process results in significant heat losses, as the hot flue gases, fired bricks, and kiln structure cool down between firings. Intermittent kilns without stacks/chimneys (e.g. clamps, scove, and scotch kilns) allow the flue gases to vent directly from the kiln, while intermittent kilns with stacks (e.g. down-draught and climbing kilns) use the chimney to create draft and release the gases at a higher point [11]. In contrast, continuous kilns maintain a constant, uninterrupted firing process. A continuous fire moves through the kiln circuit, with green bricks being continuously loaded and fired bricks being continuously unloaded. This allows the heat in the flue gases and fired bricks to be recovered and reused to preheat the incoming green bricks, making continuous kilns significantly more energy efficient. Continuous kilns can be further divided into moving-fire kilns, where the fire travels around a closed circuit, while the bricks remain stationary (e.g. fixed chimney Bull's trench, Hoffman, and zigzag kilns), and moving-ware kilns, where the bricks and air move in counter-current paths (e.g. tunnel kilns and vertical shaft brick kilns) [12]. Kilns can also be classified based on the airflow direction: up-draught (where air enters from below), down-draught (where air enters from above), and cross-draught (where air flows horizontally). Mechanical fans can drive the airflow. Alternatively, natural draft allows brick manufacturers to optimize their firing processes to enhance automation, efficiency, and fuel usage [13].

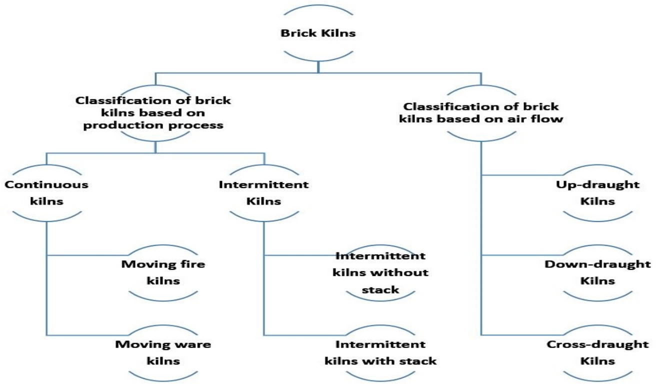

Fig. 1. Classification of brick kilns.

IV. FUEL IN BRICK INDUSTRIES

A. Used Fuel

The fuel utilized in the brick industries is often of poor quality, characterized by the following issues [14, 15]:

- Lack of uniform particle size: The fuel does not have a consistent particle size distribution, leading to uneven burning and inefficient combustion.
- Fluctuating humidity: The moisture content of the fuel varies, which can affect its burning characteristics and energy output.
- Presence of organic matter: The fuel contains organic impurities, which can introduce unwanted emissions and byproducts during the burning process.
- Supplementation with domestic solid waste: Brick industries sometimes supplement their fuel with household waste, further compromising the quality and consistency of the fuel.

Brick industries around the world utilize a variety of fuels for their operations, including firewood, bagasse (sugarcane waste), rice husk, and coal. In some cases, a mixture of these fuels is deployed. Even though coal is often described as the traditional fuel for brick firing, other options are also common [16]. The method of fuel application varies as well. In some cases, the fuels are added separately, while in others, they are pre-mixed. Additionally, low-calorific fuels, such as ash, may be incorporated into the clay during the preparation process. In the Latin American brick manufacturing industry, the primary source of fuel is biomass. For instance, in Chile, waste wood or "lampazo" is commonly used as a fuel [17]. The brick industry's reliance on fuels of a varying quality and the diverse fuel sources employed across different regions highlight the need for more sustainable and efficient fuel management practices to improve the environmental performance of brick production [18].

B. Future Fuel Trends

The brick industry is undergoing a fuel switch process driven by three key factors: the lower combustion costs, the availability of organic waste near production sites, and the desire to reduce pollutant emissions. The organic waste with the greatest energy potential is the agricultural waste [19]. One notable example to highlight this point is the transition from firewood to chestnut shells in Bolivia's artisan brick industry, where 70% of the world's chestnut production occurs. This shift helps to stop the deforestation of the Amazon rainforest. The use of chestnut shells, combined with fans, has resulted in a 32% reduction in fuel consumption [20]. Similarly, in Mexico's artisan brick sector in Guerrero, a mixture of coconut shells and firewood is used, leveraging the characteristics of the local vegetation [21]. The global trend moves towards the utilization of solid organic fuels that undergo torrefaction and densification into pellets. This approach is considered a viable energy option for artisan brick producers, as it can contribute to community development through new employment opportunities. Additionally, the use of pellets promotes the utilization of non-polluting energy sources and the recycling of organic waste [22]. Authors in [23] stress the potential of both carbonized (charcoal) and non-carbonized (pellets) biomass briquettes as renewable energy resources for the artisan brick industry.

The Ecokiln is a semi-artisanal kiln designed from rural brick-makers, offering improved efficiency over traditional kilns. Its design allows for better fluid dynamics, resulting in lower fuel consumption, shorter operating durations, higher brick processing capacity, and reduced losses of burnt bricks. It is worth mentioning that the Ecokiln also delivers significant environmental benefits. It emits fewer polluting gases, enhancing the quality of life for brick-makers and their communities. Compared to the traditional brick industry, the Ecokiln exhibits substantially lower emissions: 25% less CO, 83% less SO_2, 58% less NO_x, and 74.3% less PM_{10}. These remarkable reductions in pollutant emissions underscore the Ecokiln's environmental advantages over conventional brick firing methods in the region. Its innovative design and improved efficiency make it a promising solution for sustainable brick production in rural areas [24].

In [25] authors assessed the carbon, water, and land use impacts of the brick sector in Bangladesh. Their findings provided several key insights: Fuelwood consumption was a major factor of the carbon and water footprints, contributing around 40% of the carbon footprint and over 90% of the water footprint for single brick production. This is concerning, as fuelwood harvesting from natural forests is often illegal, suggesting a potential link between brick production and deforestation. Promoting green brick technologies could help, but may not substantially reduce clay consumption, which constitutes a substantial environmental and social issue. An alternative solution could be the use of concrete bricks, which could reduce both environmental footprints and clay consumption.

Shifting among fuel sources, namely transitioning from fuelwood and coal to natural gas could also help lower carbon emissions and water use. However, the infrastructure of each country is currently not prepared for this. The use of renewable energy sources, such as solar, wind, and hydropower, can effectively reduce the depletion of fossil resources and encourage sustainable development. These clean, pollution-free, and renewable energy sources can help raise development rates without causing climate problems. The increasing concerns about natural resource depletion and environmental degradation have led to the development of "green" products and the adoption of sustainable manufacturing processes. The production of natural resources, such as crops, forests, and livestock, can actually absorb harmful gases like CO_2 from the air, heat from the sun, and excess water from the soil, contributing to a more balanced climate [6].

V. BRICK INDUSTRY ENVIRONMENTAL IMPACT

A. Impact on Air

The brick kiln industry is one of the major contributors to air pollution, emitting various harmful pollutants like particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides NO_x, and carbon monoxide (CO), with far-reaching consequences, including climate change, acid rain, respiratory diseases, and other public health impacts. Therefore, addressing these environmental and health concerns is crucial.

Coal is the primary fuel used in conventional brick kilns, and its combustion releases large amounts of carbon dioxide (CO_2) into the atmosphere, exacerbating climate change. The retrofitting brick kilns combined with zigzag technology offer an effective solution, since they improve combustion efficiency and lower coal requirements, and thereby emissions from production and transportation. Also, increasing the thermal efficiency reduces the overall energy consumption and associated emissions. The zigzag kiln design creates a longer air path, improving heat transfer to bricks and enhancing firing efficiency compared to straight-line kilns. Studies have demonstrated that zigzag retrofits can achieve a significant decrease in CO_2 emissions of up to 37% compared to traditional kilns, while also reducing CO emissions by around 40% and improving thermal efficiency and particulate matter transitioning. Thus, the former present a promising solution to address the substantial air pollution and climate change impacts of the brick kiln industry, contributing to improved environmental and public health outcomes as well as enhanced economic sustainability, with the added benefits of reduced fuel consumption and lower operating costs making the brick-making process more sustainable and economically viable [7, 12, 26-28]. Table I illustrates the concentrations of gas emissions in some cities in Iraq.

TABLE I. GAS EMISSIONS AND TYPE OF FUEL USED IN IRAQ BRIK INDUSTRIES

District		Units	Fuel	SO_2	NO_2	CO	Reference
1	Baghdad	ppm	Fossil	0.76	0.83	-	[26]
2	Babylon	ppm	Oil	0.45		10.42	[27]
3	Basrah	ppm	Wood	0.6	1.7	10.6	[28]
4	Basrah	ppm	Kerosene	2.18	0.9	15.3	[29]
5	Al-Diwaneyha	ppm	Gas-liquid	9	1.15	3	[30]
6	Baghdad	molecules (cm^{-2})	oil	0.73	9	2.63	[31]

The data presented in Table I reveal significant variations in the emissions from brick kilns across different cities in Iraq, likely influenced by the type of fuel used and other operational factors. Notably, some brick kilns exhibit particularly high levels of nitrogen dioxide, sulfur dioxide, and carbon monoxide, indicating the need to improve environmental performance in these regions. The choice of fuel is a crucial factor in determining the environmental impact of brick production. Additionally, Table I highlights the geographical variations in the emissions across the different Iraqi cities. Brick kilns in Al-Diwaneyha, for instance, show much higher SO_2 and NO_2 emissions than those evidenced in other locations, potentially owing to factors like production scale, kiln age/condition, or local environmental conditions. The observed variations in the emissions underscore the importance of having a robust regulatory framework and effective enforcement mechanisms to ensure consistent environmental compliance in the brick-making industry [29-31].

B. Impact on Land, Crop Yields, and Soil Fertility

The excessive exploitation of fertile topsoil for brick production is a major concern for agricultural sustainability. On average, 3 kilograms of soil are required to make a single brick, with an estimated 150 billion kilograms of soil annually used to create 50 billion bricks worldwide [32]. This massive soil depletion is problematic, as topsoil is essential for sustainable agriculture. The use of topsoil for brick production leads to land degradation and reduced crop yields, while air pollution from brick kilns further hinders agricultural productivity [33]. Chemical analysis has revealed declining soil fertility, with lower levels of key nutrients, directly affecting agricultural production, water availability, and sustainable development

[34]. Although some countries have restricted the use of topsoil for brick-making, the particular practice remains widespread and more comprehensive solutions are needed to address this pressing environmental and agricultural challenge [35].

C. Impact on Water

The brick production industry has a significant influence on water consumption and resource utilization. The results of this study show that the largest share of water consumption, nearly 98.39%, is attributed to the use of fuelwood as a fuel. This is due to the high water consumption intensity associated with fuelwood. The total water consumption to produce a single brick is approximately 0.003 m³, with the indirect water consumption being twice the direct water consumption. This demonstrates the importance of considering the supply chain's water footprint in addition to the direct water use during brick production [36]. The estimated total water consumption for brick production in Bangladesh rose from around 49.70 Mm³ in 2006 to 115.54 Mm³ in 2020. This accounts for a significant portion, approximately one-third, of the total industrial water consumption in the country during the period 2003-2007. The brick sector in Bangladesh contributes around 1% to the country's Gross domestic product, yet its water footprint is substantial. If the current trend continues, the water footprint of brick production is projected to have reached 189.47 Mm³ by 2030, with the majority of this water consumption originating from fuelwood use [37]. These findings stress the need to address the water sustainability challenges in the brick production industry. Strategies to reduce fuelwood consumption, promote water-efficient technologies, and improve the overall sustainability of the brick sector should be prioritized to ensure the responsible management of water resources and the long-term viability of the industry.

D. Influence of Brick Industries on Global Warming and Climate Change

The brick kiln industry is a significant contributor to GreenHouse Gas (GHG) emissions, primarily through the combustion of fossil fuels. These GHG emissions, including carbon dioxide, nitrogen oxides, nitrous oxide, nitric oxide, and methane, are partly responsible for the observed changes in the global climate conditions [38]. Globally, around 70% of the total GHG emissions are attributed to the burning of fossil fuels in the industrial sectors [39]. In 2016, CO_2 was identified as the key player, contributing 74.4% of the total global GHG emissions, while methane, nitrous oxide, and fluorinated compounds accounted for 17.3%, 6.2%, and 2.1%, respectively [40]. The continuous increase in anthropogenic GHG emissions is dynamically modifying climatic conditions at both an international and local level.

Climate change has become a global issue due to its multifaceted and interconnected adverse effects. The impacts on meteorological processes and environmental events are well documented [41]. Extreme weather events, such as water scarcity, severe drought, elevated precipitation, and tropical cyclones, have resulted in increased instability in food production in many regions. These effects have become progressively more intense, leading to injuries, serious communicable diseases, and increased mortality rates [42]. Therefore, the brick kiln industry's significant contribution to GHG emissions, especially CO_2, is a major factor of climate change. This has far-reaching consequences on the environment, food security, and public health. Addressing the industry's GHG emissions is crucial to mitigate the impacts of climate change and ensure a more sustainable future [43].

Worldwide annual clay brick production is estimated to exceed 1.5 trillion bricks, with the majority of them being produced in developing countries using inefficient and highly polluting kiln technologies. These traditional brick kilns have a devastating environmental impact, accounting for over 750 million tons of carbon dioxide emissions into the atmosphere every year, burning 315 million tons of fossil fuels annually, plus millions of tons of highly-polluting scavenged fuels, creating hazardous working conditions for workers, and producing sub-standard bricks by using outdated technology. Although many developing countries have banned the use of the most polluting kiln technologies, such as the Bull's Trench Kiln and Clamp Kiln, these banned practices continue to operate with impunity in many regions. The brick industry's outsized contribution to global greenhouse gas emissions and environmental degradation is a pressing concern that requires urgent action. Transitioning to more efficient, cleaner, and environmentally responsible brick manufacturing methods is crucial for mitigating the industry's impact on the climate change and protecting the health and safety of the workers and surrounding communities [44].

E. Black Carbon and Impact on Health and Surrounding Communities

Black Carbon (BC) is a dangerous air pollutant that results from the incomplete combustion of fossil fuels, wood, and other biomass types. Its sources are primarily human activities like transportation, shipping, agricultural burning, diesel engines, and residential cooking and heating. BC is a major component of particulate matter, and the World Health Organization (WHO) estimates that it is responsible for 865,000 premature deaths globally each year [45]. It has significant health impacts, as it is linked to heart attacks, cancer, and respiratory illness. Beyond health, BC also contributes to atmospheric and environmental phenomena, like tropical rains and the Asian monsoon, melting snow and ice in the Arctic and Himalayas, and damaging agriculture through its effects on soil quality and crop yields. The BC has negative effects for the poor in developing countries, severely affecting their living standards, health, and working conditions [45, 46].

The traditional brick-burning process has significant short-term and long-term environmental and health impacts. In the short-run, it may cause severe air, soil, and water pollution, harming vegetation and aquatic life. In the long-run, surrounding communities, and especially vulnerable groups, may suffer from respiratory and skin diseases. The influence on brick kiln workers is even more severe. Those inside the kilns face intense smoke, heat, and particulate matter exposure, leading to respiratory problems, dizziness, and debilitating "black lung" disease. External workers, who transport raw materials, also experience respiratory issues. Many workers suffer from headaches, dizziness, fatigue, and decreased fitness during the brick manufacturing season due to prolonged exposure. Nearby communities also experience high incidences of respiratory, cardiovascular, and other health problems, which residents often accept as normal due to a lack of awareness about the harmful effects of pollution [15].

VI. HEALTH CONSEQUENCES FOR BRICK KILN WORKERS

Brick kiln work exposes workers to hazardous conditions with severe health impacts. Comprehensive reviews showed that Brick Kiln Workers (BKWs) have a significantly lower lung function, with smoking exacerbating this effect. BKWs also experience higher prevalence of respiratory symptoms like chronic cough, asthma, and bronchitis, especially the ones who live near kilns. Studies have further discussed the elevated risks of respiratory infections like pneumonia and upper respiratory infections associated with exposure to brick kiln pollution. With consistent evidence of impaired lung function and higher incidence of respiratory ailments of the BKWs compared to the control populations, the detrimental impact on respiratory health is a primary concern [47, 48].

Even though the aforementioned relationship was not entirely consistent across all studies, longer durations of brick kiln work were generally associated with greater respiratory health impacts. Certain worker roles, such as brick bakers and carriers, appeared to bear a disproportionate burden of respiratory problems compared to other brick kiln occupations. Beyond the respiratory system, the available evidence suggests concerning impacts on gastrointestinal and reproductive health as well. Limited data indicated elevated liver enzymes and other markers of liver dysfunction among silica-exposed BKWs. Studies also reported higher rates of general gastrointestinal disorders in this population. Nevertheless, the direct link to kiln exposures was unclear [48, 49]. Similarly to the control groups, in the realm of reproductive health, menarche at younger ages, increased pregnancy complications, and hormonal changes (lower testosterone, higher FSH/LH) were observed among female and male BKWs, relative to control groups, with these reproductive impacts appearing to be associated with brick kiln exposure [48]. Musculoskeletal disorders were another area of concern, with several studies documenting higher prevalence of pain and musculoskeletal issues in BKWs compared to the control groups [48, 50]. Although not directly linked to the cardiovascular disease prevalence, some research did find elevated heart rate and blood pressure levels, particularly after a work shift, with one study noting hypertension in a percentage of 25.5% among Mexican BKWs [50]. Across the different health outcome categories, the quality of the available evidence was generally rated as low, with methodological heterogeneity making it challenging to draw firm conclusions. However, the existing literature clearly indicates that brick kiln workers face heightened risks of adverse health effects, especially in the respiratory domain, while there are also some indications of impacts on their reproductive, gastrointestinal, and cardiovascular health [50-52].

The widespread reliance on brick kilns, particularly in low- and middle-income countries, necessitates urgent action to improve the working conditions and reduce exposure to protect the health of this vulnerable population. Strengthening occupational safety regulations, implementing engineering controls, and providing personal protective equipment are potential strategies to achieve this goal. Further high-quality research is needed to fully understand the scope and underlying mechanisms of health impacts among BKWs. While the main review did not identify studies on cancer risk, some modeling assessments brought out elevated risks emerging from kiln emissions, particularly from those of Polycyclic Aromatic Hydrocarbons (PAHs), metals, and radionuclides. Biomarker studies also provided evidence of heightened oxidative stress, inflammation, and DNA damage in BKWs compared to the control groups. Additionally, a few studies examined the impact of brick kiln pollution on child linear growth, with mixed findings. Some research found lower height-for-age and higher stunting prevalence in children living near kilns, especially in those with multiple migration episodes, while another study did not observe differences in stunting. The cumulative evidence paints a troubling picture of the wide-ranging health consequences faced by BKWs. Immediate action is required to address this critical occupational health challenge, including the strengthening of regulations, implementation of exposure controls, and provision of protective equipment. Further high-quality research is crucial to fully elucidate the scope and mechanisms of these health impacts, informing targeted interventions to safeguard the wellbeing of BKWs [48].

VII. CONCLUSIONS, FUTURE PROSPECTIVE, AND SUGGESTIONS

Brick making is an ancient technology that has changed a little over thousands of years. The core of brick production process - manufacturing, drying, firing, and cooling - has remained largely unchanged since ancient times. However, the brick kiln technology used in developing countries has evolved to some degree. Early brick kilns were simple pits, but the addition of walls and chimneys helped improve airflow and fuel efficiency. Over time, various kiln designs have been invented, offering differing levels of efficiency and cost. The brick manufacturing industry shows significant geographical disparities in emissions, with some regions exhibiting alarmingly high levels of pollutants, such as nitrogen dioxide, SO_2, and CO. These variations are likely influenced by factors such as the type of fuel used and other operational conditions.

The brick industry contributes a high percentage in the environmental pollution. The usage of brick kilns increases the greenhouse effect due to gas emissions, the water footprint, and it reduces soil fertility. Also it has negative effects on the health of workers and generally of the people living near the brick kilns.

Although brick making skills have improved in recent years, the industry still faces several persistent challenges:

- Resistance to changing traditional business practices.
- Lack of knowledge about innovative brick-making operations and their costs.
- Lengthy environmental impact assessment processes.
- Limited access to financing for green technology investments.

- Volatile financial climate.

The promotion of Sustainable Brick Production (SBP) through state policies was proposed. SBP should balance social, economic, and environmental sustainability, which could be achieved through:

- Tax reductions for brick makers implementing emissions/fuel-reducing innovations.
- Educational programs on sustainable development and project management.
- Government-funded innovation projects with artisans and researchers.
- Media campaigns to raise awareness of SBP.

However, brick firing also generates unavoidable CO_2 emissions, suggesting the need for a forest area to offset them. Using organic waste pellets can improve the fuel density and energy content for more efficient combustion. Thermal insulation and proper brick arrangement in kilns can also enable energy savings.

Looking to the future, certain key trends focus on improving combustion efficiency to reduce costs and emissions. Factors like proper combustion chamber sizing, continuous fuel feeding, and air injection fans can decrease the burning time, fuel use, and improve product quality. Future research should adapt technologies to the needs of small-scale producers, as the large part of the advancements has targeted larger operations.

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