ACHIEVING NET ZERO FOR CLAMP KILN FIRED BRICK PRODUCTION: A CASE OF UGANDA

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Globally, the concentration of emissions in the atmosphere keeps increasing, exacerbating climate change. This study leverages the concept of net zero to examine the impact of thermal insulation (mud slurry) thickness on emissions associated with clamp kiln brick firing. The methodology involved experimental set-ups of clamp kilns and field observations. Correlation and regression analysis was used to determine the extent of influence of thermal insulation on the concentration and type of emissions. Results showed that CO2, CO, SO2 and NO were the major types of emissions, with CO2 presenting the highest concentrations. A negative correlation was identified between the mud slurry thickness and the concentration of emissions, suggesting that increasing the insulation's thickness to 150mm can mitigate emissions concentrations. It is possible to achieve net zero clamp kiln-fired brick production whereby, in addition to using optimum thickness of mud slurry, emission reduction measures such as fuel switching are employed. These initiatives do not only encourage the brick-firing industry to follow a path to net-zero emissions but also have implications towards the role of construction management in responsible material sourcing.

Keywords: bricks; emissions; mud slurry; net-zero; Uganda

INTRODUCTION

Clamp kiln-fired brick production, a method of 'baking' stacked bricks by firing under (or within) them, is one of the most common and preferred technique for manufacturing bricks in developing countries (Aniyikaiye *et al.,* 2021). This technique is favoured because it produces bricks that are easily accessible, relatively cheap, considerably durable, and easy to handle or work with (Bories *et al.,* 2015). The goal of clamp kilns is to produce fired bricks with the ideal characteristics, such as strength and water resistance, suitable for use in the building sector (Figueroa *et al.,* 2024). However, this brick-production technique is typically associated with a disorganised small-scale industry that relies on energy-inefficient traditional techniques (Aniyikaiye *et al.,* 2021). These techniques emit harmful gases such as SO2, CO, black carbon, CO2, and NOx into the atmosphere, which affect climate and pose health risks to society (Asif *et al.,* 2021). In developing contexts like Uganda, where clamp kiln wood-fired brick production is common, addressing these gaseous

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emissions is pivotal to achieving emission targets and broader sustainable construction goals, and thus, the brick production industry requires significant attention and intervention.

Although construction-related activities are essential for steering economic development, it is crucial to make deliberate attempts to reduce emissions to ensure that sustainable development is not compromised (Kibwami and Tutesigensi 2016). Uganda announced its intention to reach net-zero emissions by 2065 (IEA 2023), paving the way for the country to explore a wide variety of carbon-neutrality options across different sectors. The brick production sector offers an immense opportunity to contribute towards this ambitious target. In Uganda, clamp kiln-fired bricks, shown in Figure 1, are among the building sector's most used construction materials (Hashemi and Cruickshank 2015). According to Min *et al.,* (2022), burning these bricks accounts for approximately 39% of the global CO2 emissions each year. These statistics clearly show that while construction activities are a key driver of Uganda's fast-growing economy (Alinaitwe 2020), they are equally a significant source of emissions. Therefore, deliberate efforts are necessary to mitigate their impact and promote sustainable construction practices.

Figure 1: A double-chamber clamp kiln brick stack (Source: Authors' fieldwork)

Clamp kiln-fired bricks are formed by stacking green bricks together, as depicted in Figure 1, and firing them using fuels such as firewood (Hashemi and Cruickshank 2015). This production method is notably energy intensive (Nandipati *et al.,* 2023), and indeed, previous studies have been undertaken to understand the energy associated with these brick production techniques in Uganda (Hashemi and Cruickshank 2015). However, there remains a glaring gap in understanding the factors that influence the concentration and types of emissions associated with these brick production methods, particularly when firewood is used as a fuel source. Addressing this gap could go a long way in making Uganda's net-zero emissions targets a reality.

Net Zero for Clamp Kiln Brick Production

The concept of net zero has been variously defined. However, it can be understood as a world in balance - where carbon emissions are eliminated by removing equal amounts of emissions from the atmosphere through natural processes and other carbon removal measures, effectively leaving zero emissions in the atmosphere (Allen *et al.,* 2022; Green and Reyes 2023). While existing technologies may not fully support achieving the net-zero emissions target, efforts towards this goal must be adopted (Xu *et al.,* 2023). Given that the brick-firing process releases emissions into the atmosphere (Ukwatta *et al.,* 2018), strategies to minimise the concentration of these emissions, or adopting measures to offset them to Zero, can contribute to achieving net zero in clamp kiln-fired brick production. Achieving net zero for the brick industry may involve implementing counterbalancing measures such as using more efficient firing techniques, adopting alternative sustainably sourced firing materials, and improving the design of clamp kilns (Abbas *et al.,* 2021). However, it is crucial to understand the impact of these influencing factors to further the net-zero concept in brick production.

Previous studies have examined the emissions associated with the production of clamp kiln-fired bricks. For example, Asif *et al.,* (2021) identified pollutant emissions from brick kilns, including SOx, NOx, CO2, CO, unburnt hydrocarbons, particulate matter, heavy metals, and other compounds. The study recommended installing proper technology to reduce pollutants in brick kilns. Similarly, Khan *et al.,* (2019) highlighted that clamp kilns, a rather rudimentary traditional method of firing bricks, necessitate the adoption of new technologies to minimise emissions. However, in developing countries, adopting new technologies in the building sector takes due to the lack of financial capacity, among other reasons. Therefore, to achieve net zero for clamp kiln-fired bricks, pursuing measures that can counterbalance or offset emission concentration is worthwhile. This study examines the impact of thermal insulation, precisely the thickness of mud slurry, on the concentration of emissions associated with the clamp kiln brick firing technique. The specific objectives are as follows:

1. To measure emissions associated with the production of clamp kiln-fired bricks with varying thicknesses of mud slurry insulation.
2. To determine the optimal mud slurry thickness for achieving net zero clamp kiln-fired bricks.

METHOD

The experimental setup involved a single-chamber Clamp Brick Kiln (CBK) containing 500 clay bricks fired using firewood placed in the chamber, in a real-world environment with natural airflow. A circular emission collection unit/hood was placed atop the CBK to collect emissions. The collection unit featured a 100mm diameter chimney pipe made of clay material with a 10mm probe hole. A flue gas analyser customised with sensors for various gases was inserted into the probe hole to monitor and measure emissions during the firing process. Each round of firing lasted approximately 14 hours. During this firing period, emissions data were recorded for 10minute durations at 1-hour intervals. Six different mud slurry thicknesses, ranging from 0 to 250mm, were considered. Three trials or firings were conducted for each thickness, and the results were recorded as an average value. The emissions monitored and measured by the flue gas analyser included Carbon monoxide (CO), Carbon dioxide (CO2), Sulfur dioxide (SO2), and Nitric oxide (NO). Thus, the focus of emissions in this study was on Scope 1: direct emissions, according to the Greenhouse Gas protocol classification terminology. Other parameters considered are summarised in Table 1.

Correlation and linear regression analyses were conducted to assess the relationship between mud slurry thickness and the quantity of emissions measured. The correlation between the mud slurry thickness and emissions was determined using the Pearson product-moment correlation coefficient (γ) in Stata software version 13, and the calculated values of γ were obtained. Scatter graphs were produced using Stata software to visualise the linear regression between the two variables (mud slurry thickness and emissions). The results, including correlation coefficients and graphs, were used to evaluate the extent of the influence of mud slurry thickness on the emissions. Based on these findings, options for offsetting the associated concentration of emissions to net zero were presented.

Table 1: Summary of key parameters used

Parameter	Specification
Number of bricks per kiln	500
Brick making process	Manual moulding, sun drying
Material used for Bricks	Mud
Nature of Fuel	Firewood
Temperature range considered	200 - 1060 °C
Measurement unit of emissions	Concentration in parts per million (ppm)

FINDINGS

Influence of Varying Mud Slurry Thickness on Emissions Concentration

The results obtained from recording emissions associated with various mud slurry thicknesses are presented in Table 2. Notably, the highest concentration of emissions was observed from CO2, reaching 21,978 ppm at a mud slurry thickness of 0mm. These findings align with expectations since CO2 is most prevalent during the combustion of firewood (Lacoma 2018). Given that the average concentration of CO2 in the atmosphere is about 400ppm (NOAA 2022), the findings of this study underscore the importance of minimising emissions associated with the clamp kiln brick-firing technologies in the developing world. If left unchecked, the concentration of emissions in the atmosphere will continue, albeit with global consequences.

Table 2: Mud slurry insulation thickness Vs emissions from the firing process

Mud slurry thickness (mm)	CO2 (ppm)	CO (ppm)	SO2 (ppm)	NO (ppm
0	21,978	704	33.710	14.394
50	12,518	434	16.619	7.296
100	10,231	415	14.007	4.951
150	7,977	404	13.009	4.033
200	11,977	471	14.156	5.493
250	12,655	469	15.592	6.178

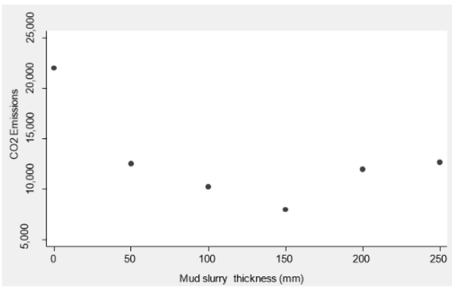
As shown in Table 2, there was a noticeable decrease in the concentration of emissions for all gases as the thickness of the mud slurry increased. This observation aligns with the findings of Valdes *et al.,* (2020), who highlighted that thermal insulation, achieved by adequately sealing the CBK walls, can significantly increase their efficiency and subsequently lower emissions. Figueroa *et al.,* (2024b) also argue that greater energy savings during the firing of bricks significantly reduce the emissions associated with brick kilns. Therefore, applying mud slurry reduces emissions associated with brick firing and could serve as a potential avenue for promoting net-zero kilns.

The correlation results between the mud slurry thickness and emissions are presented in Table 3. The Pearson product-moment correlation coefficient (γ) between emissions and varying mud slurry thickness was found to be highly negatively correlated for CO2 (-0.5632), CO (-0.5127), SO2 (-0.6719), and NO (-0.6739). These values indicate strong negative correlations, suggesting that the concentration of emissions tends to decrease as the mud slurry thickness increases. However, it was also noted that beyond the 200mm thickness of the mud slurry, emissions began to increase, indicating a shift to a positive correlation. This implies that emissions increased with further increases in the mud slurry thickness. Overall, these coefficients demonstrate the existence of a significant and meaningful relationship between mud slurry thickness and emission concentration. This surprising observation could be attributed to several factors. Firstly, field observations revealed that as the mud slurry becomes thicker and heavier, it is prone to cracking under heat and falling off the clamp kiln, exposing gaps between bricks and potentially causing increased emissions. Additionally, poor application of the mud slurry on the kiln surfaces and the material composition of mud slurry may also contribute to these observed factors, as previously reported by Beamish and Donovan (1993).

Table 3: Correlation between mud slurry thickness and emissions

	Mud slurry	CO2 emissions	CO emissions	SO2 emissions	NO emissions
Mud slurry	1.0000				
CO2 emissions	-0.5632	1.0000			
CO emissions	-0.5142	0.9746	1.0000		
SO2 emissions	-0.6719	0.9673	0.9739	1.0000	
NO emissions	-0.6739	0.9843	0.9628	0.9901	1.0000

The influence of mud slurry thickness was further examined, and Figures 2, 3, 4 and 5 relationships between the mud slurry thickness and the various gaseous emissions (CO2, CO, SO2 and NO). The data suggests that each increase in mud slurry thickness is associated with a decrease of 28.853 ppm for CO2, 0.614 ppm for CO, 0.057 ppm for SO2, and 0.0271 for NO emissions, respectively. From the findings, it is evident that the optimal mud slurry thickness that can minimise the concentration of emissions to the lowest possible amounts was between 150 and 200mm thick.



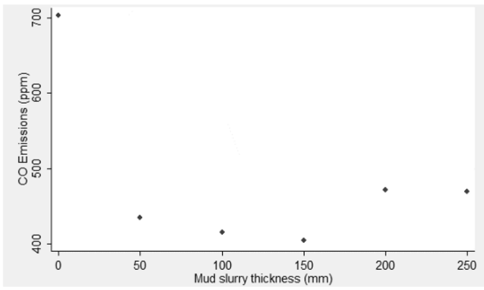
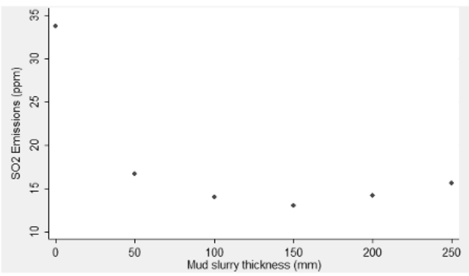


Figure 2: Mud slurry thickness and CO2 Figure 3: Mud slurry thickness and CO



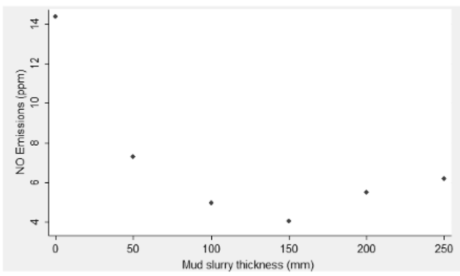


Figure 4: Mud slurry thickness and SO2. Figure 5: Mud slurry thickness and NO

However, since it was observed that beyond 200mm thickness, the insulation tends to crack and fall off, leading to increased emissions, implementing measures to stabilise the mud slurry thickness beyond 200mm thick could potentially achieve further emission reductions. Based on the results obtained, adequate insulation of brick kilns is crucial for reducing emission concentrations during brick production. Essentially, proper insulation minimises heat loss through conduction, thereby decreasing the amount of fuel required for firing the bricks and subsequently, lowering emissions. In contrast, poor insulation results in significant heat losses, necessitating more fuel to maintain the desired firing temperature inside the kiln, which leads to increased firewood consumption and higher emissions. This relationship is underscored by Son *et al.,* (2023), who argue that minimising heat losses through proper insulation significantly enhances the overall thermal efficiency of brick kilns. Additionally, Makrygiannis and Karalis (2023) observe that better insulation reduces the energy required to produce a unit of fired bricks by 20-30%. Therefore, adequate insulation of brick kilns is crucial for minimising heat losses, reducing fuel consumption, improving energy efficiency, and lowering associated emissions in the brick industry.

Potential CO2 Emission Removal Measures

Construction materials contribute significantly to building emissions, making them critical enablers for the net-zero transition journey. This work potentially contributes to making a meaningful realisation of the net-zero concept and how it can be fitted into various aspects of construction delivery, in this case, material production. Although this study focussed on a single influencing factor of emissions from clamp kilns, it is apparent that achieving net zero in the brick manufacturing industry requires balancing a combination of emission removal techniques alongside other measures to offset any remaining emissions. These could include: 1) afforestation to restore the forests surrounding brick production sites, which are usually cut down for firewood. These restored forests act as carbon sinks that absorb CO2 from the atmosphere; 2) switching to renewable energy sources, such as hydrogen, has proven to reduce up to 84% of the CO2 emissions in clamp kilns using 100% green hydrogen (Net Zero Association 2023). This aligns with the findings of several other scholars who recommend fuel switching and energy-efficient measures, such as increasing the slurry thickness, as readily applicable and effective strategies for curbing emissions during brick production (Asif *et al.,* 2021; Bories *et al.,* 2015; Net Zero Association 2023) ; and 3) carbon capture and storage, although this may present challenges, particularly for small-scale clamp kiln operators in developing countries like Uganda. However, this dual approach (i.e. varying mud slurry thickness coupled with emission removal measures) could foster the achievement of net-zero emissions in clamp kilns by ensuring that the net amount of emissions in the atmosphere remains at zero.

Construction Management Implications

This study presents an opportunity for material suppliers, particularly in the brick industry, to consider options that can accelerate their net-zero journey. By leveraging the findings of this study, construction managers and regulatory bodies can also play a significant role in driving the adoption of net-zero materials in the construction industry through: 1) responsible material sourcing through the standardisation of mud slurry thickness requiring that brick suppliers source bricks from producers who use optimal mud slurry thicknesses of 150 to 200mm, especially for upstream stages like construction, 2) creation of regulations that promote the use of these optimum thicknesses that could be enforced through inspections or issuance of conformity certificates, and 3) awareness creation and education of local manufacturers to improve brick production techniques, such as the appropriate application of mud slurry, in order to minimise emissions. However, these management and regulatory decisions must be intentional towards the promotion of zero material production and supply to reduce emissions and advance the net-zero targets.

CONCLUSIONS

Scientific evidence indicates that the concentration of emissions in the atmosphere keeps increasing annually, posing an increasing danger of climate change. Therefore, reducing these concentrations to the lowest possible levels should be a collective goal. This study, conducted in Uganda, examined the impact of thermal insulation (i.e. mud slurry) thickness on the concentration of emissions associated with the clamp kiln brick firing technique. The findings revealed that CO2, CO, SO2 and NO were the major emissions, with CO2 being the most prevalent. The thickness of the mud slurry insulation significantly influenced the concentration of emissions, with thicker applications presenting lower emissions, demonstrating a negative correlation. However, the negative relationship held up to a certain thickness (150mm). Beyond this point, the mud slurry could collapse, leaving the kiln uninsulated. Poor application of the mud slurry affected its stability beyond a specific thickness and subsequently affected the emission concentration. In addition, the study revealed that an optimal mud slurry thickness between 150mm and 200mm could achieve minimal emissions and further emission removal measures were necessary to achieve net-zero clamp kilns. However, this conclusion assumes that other influencing factors remained constant. Future research is needed to gain a broader understanding of how a host of other factors, such as the nature of the insulating material and the design of the kiln, influence emissions.

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