Eco-Friendly, Energy Generating Brick Kiln

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Islamabad, Pakistan

(2024)

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Project submitted in partial fulfillment of the requirements for the degree of BE Civil Engineering.

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This is to Certify that the final copy of BE Civil Engineering's Final year project

" Eco-Friendly, Energy Generating Brick Kilns "

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List of Acronyms

FCBTK	Fixed Chimney Bull Trench Kiln
ID ZZK	Induced Drought Zig Zag Kiln
PM	Particulate Matter
WHRS	Waste Heat Recovery System
PAH	Polycyclic Aromatic Hydrocarbons
BC	Brick Clay
FA	Fly Ash
WG	Waste Glass
CB	Cigarette butts
ORC	Organic Rankine Cycle

DEDICATION

We want to dedicate our work to our parents, who have been our unwavering source of love, support, and encouragement. We express our heartfelt appreciation. Their sacrifices, guidance, and belief in our abilities have been instrumental in shaping our lives and empowering us to pursue our dreams. This project is a testament to the values and lessons they have instilled in us.

We would also love to dedicate our work to the construction laborers of Pakistan, who toil tirelessly under challenging conditions, we extend our utmost respect and gratitude to them.

ACKNOWLEDGEMENTS

We would like to express our heartfelt gratitude and dedication to the successful completion of this project, which would not have been possible without the combined efforts, collaboration, and unwavering support of many individuals.

First and foremost, we extend our deepest appreciation to Maj. Wajeeh Ul Hassan, our esteemed supervisor, for his exceptional guidance, invaluable expertise, and continuous encouragement throughout this project. His mentorship has been instrumental in shaping our ideas and driving us towards excellence.

We would like to extend our sincere thanks to our fellow project group members, whose dedication, perseverance, and hard work have been the driving force behind our success. The synergy and teamwork displayed by each member have been invaluable, and we are grateful for the diverse skills and perspectives that have contributed to the project's outcomes.

Our profound gratitude goes to our families and friends who have been a source of constant support, understanding, and motivation. Their encouragement and belief in us have played a crucial role in our journey, and we are truly grateful for their unwavering support.

ABSTRACT

Pakistan holds the 3^{rd} *largest* share of brick production in the world, producing over *70 billion* clay bricks per year which accounts for ***3%*** of the global production. Half of the total coal extracted from Pakistan is used as fuel to burn bricks in highly inefficient Fixed Chimney Bull Trench kilns. These kilns are highly energy inefficient as they consume a lot of fuel but have low production, and at the same time, the quality of the bricks produced is generally not satisfactory. Moreover, they also release millions of tons of carbon emissions, extremely dangerous $PM_{2.5}$, carbon black, Sulphur oxides, nitrogen oxides, and heavy metals into the atmosphere. The problem not only lies in kiln design, the composition of the clay bricks also plays a huge role in adding to the inefficiency of the whole brick manufacturing process. This project adopts a comprehensive approach to address these challenges by designing and implementing mechanisms to make the whole clay brick manufacturing process eco-friendly, energy-efficient, and an economically viable source of energy production. In this project the traditional all-clay material composition of clay bricks was altered by adding 3 different waste materials; i.e. Fly Ash, Waste Glass Powder, and waste Cigarette Butts, to enhance their performance, manage the solid waste and minimize environmental impact. The bricks prepared by making these additions in the clay composition were baked quicker, were lighter in weight, had better insulation due to superior thermal conductivity, and had nearly a 10% lesser thermal mass relative to the conventional clay bricks. The strength and weather resistance capability of the bricks prepared were no less than the 1^{st} class conventional clay bricks. Moreover, an efficient 3D kiln design equipped with a modern Waste Heat Recovery System is proposed. An elaborative 3D animation of the whole operational procedure of the proposed design is also made for a clearer explanation. The approach applied properly can lead to the production of up to *1 MW* of electricity through a single kiln while protecting the environment as well. Additionally, the presented model of the kiln also includes a robust mechanism to further filter the highly toxic gases by directing the flue gases leaving the waste heat recovery system into a microalgae pond.

This project aims to transform the clay brick manufacturing industry by developing sustainable and energy-efficient alternatives. The adoption of these cutting-edging strategies will not only improve the air quality and lessen the environmental footprint of brick production but also solve the energy crisis of Pakistan.

CHAPTER 1

INTRODUCTION

1.1 Scope

The scope of this research is to revolutionize the traditional brick manufacturing industry of Pakistan by developing and implementing innovative technologies that not only reduce environmental impact but also generate sustainable energy. The research will be conducted through a literature review of existing studies and case studies of different techniques used in manufacturing brick kilns and experiments will be performed to get desired results.

1.2 Background

The brick industry is a fundamental part of the construction sector. Pakistan holds the *third-largest* share of brick production in the world, producing over *70 billion* clay bricks per year, accounting for *3%* of global production. There are two types of brick manufacturing kilns in Pakistan: *Fixed Chimney Bull Trench Kiln (FCBTK)* and *Zig-Zag Kiln*. Out of the *16,000* brick kilns, nearly *99%* are *(FCBTKs),* and only *1%* are *Zig-Zag Kilns*.

The primary difference between FCBTK and Zig-Zag kilns lies in the arrangement of bricks on the brick kiln car, which affects the kiln's insulation through airflow *(Fig. 1.1).* The brick kiln car is the part of the kiln where the bricks are placed for baking. In FCBTK, bricks are arranged in a straight manner, leading to significant heat loss. According to workers at *Pabbi FCBTK* in *Nowshera*, it takes *1.5 tons* of coal to bake *3800* bricks and we noticed a huge amount of heat waste there due to poor insulation of brick kiln. FCBTK is the oldest type of brick kiln and is the least eco-friendly, with the highest emissions of hazardous gases. In contrast, Zig-Zag Kilns arrange bricks in a zig-zag manner, resulting in fewer emissions of hazardous gases due to better heat insulation.

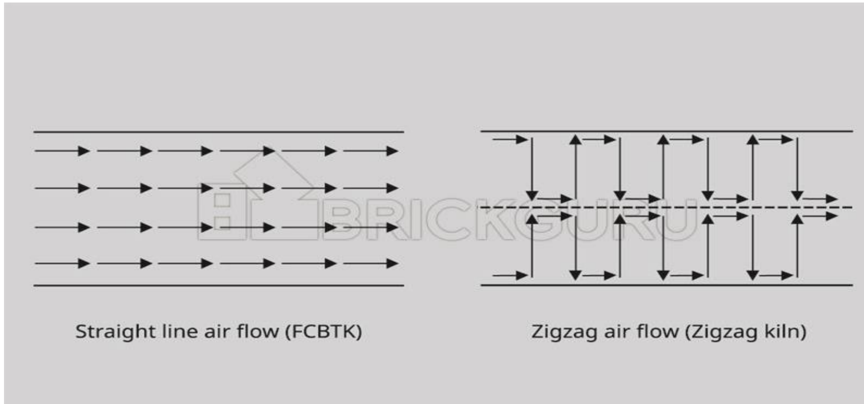

Figure 1 Heat flow in brick kilns

1.3 Problem statement

Among 16000 working clay brick kilns in Pakistan, 99% of them are FCBTK. These FCBTKs are highly energy in-efficient, consume half of the total coal extracted from the whole country, and emit millions of tons of carbon footprint, extremely hazardous gases (Sox, NOx, and methane), heavy metals (cadmium, arsenic, zinc, chromium, and lead) and particulate matter (PM2.5) that poses adversarial effect on human health and air quality. Due to the incomplete combustion of coal in these old-designed FCBTKs, carbon black and Polycyclic Aromatic Hydrocarbons are also released to the environment unfiltered, causing lung cancer and epidermal skin diseases. The pollutants and the hot flue gasses emitted from the brick kilns' chimneys are identified as the major causes behind Smog in winter and Global Warming by the Environment Protection Authority.

1.4 Objectives

This project aims to transform the clay brick manufacturing industry by following techniques:

- To modify the material composition by adding certain percentages of waste materials like Fly Ash, Waste Glass Powder, and Cigarette Butts to bake bricks quicker and at lower temperatures, with lower thermal mass and better insulation.
- To design a Waste Heat Recovery System to produce thermal energy.
- To Filter the toxic gasses and $PM_{2.5}$ before releasing them into the atmosphere.

CHAPTER 2

LITERATURE REVIEW

The brick kiln industry is one of the largest and most highly unregulated industrial sectors in developing countries. Most of the kilns use low-quality coal as primary fuel along with small quantities of bagasse, rice husk, and wooden chips. As a result of inefficient methods of combustion in conventional brick kilns, such as fixed chimney Bull's trench kilns (FCBTKs), harmful pollutants are emitted in high quantities, which ultimately deteriorate the environment and are widely in operation in Pakistan (Bashir Z, Amjad et. al, 2023). The burning of clay bricks by FCBTK requires coal and wood combustion which produce greenhouse gases like CO_2, CO, SOx and NOx and various pollutants among them PAHs are very common and most dangerous. This emission deteriorates environmental quality *(Nazrul Islam, 2017).*

2.1 Fly Ash

Energy efficiency can be achieved through the utilization of fly ash, leading to a reduction in both fuel consumption and pollution levels. Compared to traditional clay brick composition, the use of fly ash results in a 30 percent reduction in fuel consumption during firing. This translates to a cost saving of 0.75 rupees per brick, which is significant. Furthermore, fly ash is readily available in large quantities within brick kilns, making it a readily accessible and sustainable resource for industry. Adding 15-20% fly ash into the composition of brick clay is the best practice to achieve energy efficiency without affecting the brick strength required by ACI standards *(Jayant L. Patil and Arun K. Dwivedi, 2017).*

2.2 Waste Glass Powder

In 2014, approximately 128 million metric tons of glass were manufactured worldwide, of which 21% (27 million metric tons) were recycled. Despite this, a substantial amount of waste glass continues to be deposited in landfills, posing significant environmental and health concerns. This issue has been identified as a major challenge in waste governance in several nations. One innovative solution is the use of waste glass dust bricks, which enable a reduction in firing temperatures by up to 50 degrees Celsius. This not only contributes to environmental sustainability but also helps in reducing the cost of brick production *(N. Phonphuak, S. Kanyakam, and P. Chindaprasirt, 2015).*

2.3 Cigarette Butts

Reducing the cigarette butt content in bricks to just 1% can result in a 10% reduction in the energy required for firing them. In Pakistan, an alarming 64.5 billion cigarettes are smoked annually, contributing to both water pollution and the risk of lung cancer due to discarded cigarette butts. By recycling and incorporating these cigarette butts into the brick-making process, we have the potential to significantly mitigate pollution and its adverse health effects (*A. Mohajerani, 2020).*

2.4 Microalgae pond

Biological CO_2 capture through fast-growing microalgae from point sources is one of the critical aspects that can ultimately help decarbonize and, hence, ameliorate global warming. Significant carbon dioxide emissions emanate from power generation, combustion of fuels, and process industries. As an antidote, we can leverage microalgae's ability to capture CO2 and lock them into their organelles. Unlike the conventional carbon capture techniques mostly applicable to power plants, this approach is suitable for carbon emission from the transportation sector and, at the same time, a source of biofuel for the sector resulting in carbon neutrality *(Onyeaka et al. ,2021).*

2.5 Waste heat from brick kilns

This study investigates the efficient utilization of heat in brick firing zones, where currently, 37% is used, and the remaining 63% is wasted. The research focuses on harnessing waste heat from the brick kiln industry to generate electricity. Each brick kiln has the potential to produce 1MW per day. The study discusses methods for recovering and using waste heat to generate power, particularly given the high temperatures of flue and exhaust gases (around 850°C and above 200°C, respectively). One proposed approach is the implementation of Rankine or Organic Rankine Cycles. The research demonstrates that utilizing 40% of flue gas, along with 60% for burning green bricks in the firing zone, and capturing up to 70% of waste heat, is sufficient for steam production at rated pressure and temperature *(S.h.Labib, Md.R.Habib, D.Ahmad, 2019).*

CHAPTER 3

METHODOLOGY

3.1 Composition of bricks

The composition of the clay bricks plays a vital role in the brick kiln industry. Currently, clay bricks' material composition comprises all clay. No other additive is being added to them, besides a minuscule amount of sand being used while casting bricks to avoid sticking clay with the steel molds.

Fly ash is a leftover waste material left after the burning of coal. Since coal is the primary fuel used in clay brick kilns, and on average 15 to 20 tons of coal is burnt every day on an average-sized kiln, which leaves a humongous amount of Fly ash as waste material. This waste is being poorly managed by the kiln owners and mostly Fly ash heaps are found in kilns' vicinities.

Fly ash can be added to bricks since it gives a better compressive strength and the overall temperature required to bake bricks drops to 850-900 degrees Celsius. Fly ash entails a *30%* saving in fuel in firing as compared to traditional clay brick technology.

Then comes the Waste Glass Powder, which is a harmful solid waste of the glass industry. Waste glass dust bricks allow firing temperature reduction by 50 C. Nearly 65 billion cigarettes are smoked in Pakistan every year. We will utilize this waste, and add cigarette butts to the composition of brick clay. Cigarette butts content would reduce the energy required to fire bricks and will decrease the thermal mass and gives superior thermal conductivity resulting in better insulation ability of bricks.

3.1.1 Materials collection

Fly ash was meticulously gathered from a reputable fly ash brick manufacturing factory situated in *Hassanabdal*. The procurement of waste glass powder involved a visit to the esteemed *Gunj Glass Factory*, where it was systematically acquired. The sourcing of waste glass extended to the collection of discarded glass shards from *NUST-Cafe*. Additionally, the acquisition of waste cigarette butts was methodically executed through strategically positioned receptacles in various locations across *Nowshera* and *Risalpur Cantt*, reflecting a systematic approach to waste collection in these areas.

3.1.2 Preparation of samples

The fly ash was ready to be added to the brick clay in its current state and requires no further modification. The waste glass powder, obtained from Gunj Glass Factory, and the waste glass collected from NUST-Cafe were initially in solid form. They underwent a crushing process using an apparatus known as a *Los Angeles ball mill*, followed by passage through a *No. 100 sieve* to attain a refined state suitable for mixing with clay, as illustrated in the accompanying *Figure 3.1.2.* The collected cigarette butts were shredded using a blender to facilitate their seamless integration with the brick clay. All three materials were dried in the oven at *105 C for 24 hours* to remove the water content before adding them to the brick clay composition. Based on various research findings, a total of *18 brick samples* were prepared, each featuring distinct ratios of fly ash, cigarette butts, and waste glass powder. *Three bricks* were made for each ratio for testing purposes, with materials being added according to their respective weights. The prepared ratios are as follows:

- **Sample A: 0.5% CB + 15% FA + 10% WG + 74.5% BC**
- **Sample B: 0.8% CB + 18% FA + 15% WG + 66.2% BC**
- **Sample C: 1% CB + 20% FA + 15% WG + 64% BC**

Figure 2 Waste glass crushed into powder form

Figure 3 Mixing of waste materials with clay

Figure 4 Prepared Brick samples before baking

Once the brick samples were ready, they were baked in an IDZZK Brick kiln and brought back to the laboratory for testing purposes.

Figure 5 Baked bricks being extracted from Kiln

3.1.3 Performed Tests

The following tests were performed on the baked brick samples and based on the results the best sample was chosen:

1. Water absorption test
2. Compressive strength test
3. Modulus of Rupture
4. Porosity test
5. Hardness test
6. Soundness test
7. Light-Weight test
8. Efflorescence Test

3.2 Waste heat recovery system

A 3D model of the kiln is prepared that includes a waste heat recovery system. The waste gases that leave the kiln chimneys have a temperature between 200-300 degrees Celsius. In the proposed model a pipe is fixed at the very start of the chimney, from where these hot waste gases are channeled into the WHRS. Firstly the flue gases moving in a pipe will enter the evaporator and then the pipe containing the flue gases exits the WHRS after further spiraling from the preheater. In the evaporator and preheater, these high-temperature gasses will heat and superheat the working fluid into steam and that steam will then be directed to a turbine wheel. Steam will hit the turbine wheel with pressure, rotating at high speed and generating electricity. That electricity will either be stored in batteries, used by the kiln owners to run a parallel electricity-based brick kiln, or add the electricity to the national grid and earn revenue from it. This whole system is called a waste heat recovery system. On average, brick kilns in Pakistan produce 40000-120000 bricks per day. Installation of this waste heat recovery system at a brick kiln with a capacity of 100,000 bricks per day can generate 1 MW of electricity.

The mathematical proof of this logic can be given as follows:

The term “specific energy consumption” (SEC) refers to the amount of energy in MJ needed to produce 1 kg of fired brick. SEC is a parameter for comparing the energy performance of brick kilns.

According to the information collected by various sources that include 25 brick kiln owners and workers, we came to know that 1.5 to 2 tonnes of coal is currently being used to bake ONE SANTAR of clay bricks. SANTAR is a locally used word by the brick kiln fraternity which means a stack of 3600 bricks. Usually, clay brick kilns in Pakistan produce 25 to 30 santars of clay bricks per day. Considering an average clay brick kiln that produces 27 santars of clay bricks per day and consumes 1.75 tonnes of coal per santar, its electricity generation potential is measured theoretically.

In general:

Weight of green brick = 3 kg

Weight of fired brick = 2.6 kg

The average specific energy consumption (SEC) ranging from 0.95MJ/kg to 1.15 MJ/kg of fired brick

For calculation, let's assume the SEC of Fired brick = 1.05 MJ/kg

Number of bricks in 27 santars= 3600x27= 97200 bricks

For the production of 100,000 bricks, the weight of total bricks = (97200x3) kg = 291,600 kg

Total Specific Consumption of Energy = (291,600 kg×1.05 MJ/kg of fired brick) = 306,180MJ

Coal For Medium Volatile Bituminous Coal,

Lower heating value = 32.247 MJ/kg

Required amount of coal = 306180/32.247 = 9494.8 kg

For the production of 97,200 (27 santars) bricks coal consumption is:

(27x1.75)=47.25 tonnes coal.

Converting tonnes into kilograms:

47.25X1000=47,250 kg

Total Heat Input= 47250× 32.247

MJ/kg = 1523670MJ

Heat loss= (1523670– 306180) MJ =

1217490 MJ

Percentage of heat loss = (1217490/1523670)

×100 = 79.9%

This calculation shows that nearly 80% percent of the energy is wasted in the conventional IDZZK in Pakistan.

Whatever material or design is proposed, there will always be some energy loss due to the heating of the kiln walls, kiln car, etc. However, it can vary depending on the quality of material used in building the kiln and the overall insulation of the system. The temperature in the firing zone of the brick kilns is 900 to 1000 degrees Celsius. The temperature of the flue gasses at the start of the chimney is said to be about 400 degrees Celsius, which eventually drops to 300 degrees when it travels through the chimney and reaches its tip, it is feasible to suggest that nearly 6 Hundred Thousand MJ of energy can be pumped into the Waste Heat Recovery System in a day to generate electricity. 6 hundred thousand MJ in a day translates to 25000 MJ of energy per hour. There are many different WHRH capacities in the market, producing steam at a rate of 5 tons per hour requires approximately 14129 MJ per hour. The steam is then sent to a turbine with a 1 MW capacity and a generator attached to generate around 1 MW of power.

Although our calculations on the very safer side still suggest installing nearly 1.75 times bigger WHRS with a 1.75MW capacity, considering the on-ground and unforeseen challenges and energy losses, generating 1MW of electricity from a single brick kiln is ostensibly very much practical and possible.

3.3 Organic rankine cycle (ORC)

An Organic Rankine Cycle (ORC) system *(shown in Figure 3.5)* is a closed thermodynamic cycle used for power production from low to medium-high temperature heat sources ranging from 80 to 400°C and for small-medium applications at any temperature level.

Unlike traditional Rankine cycles that use water as the working fluid, ORCs utilize organic working fluids. These organic fluids have lower boiling points than steam/water at the same pressure, allowing them to be driven by low-grade waste heat. ORCs are particularly useful for capturing energy from sources that would otherwise go to waste.

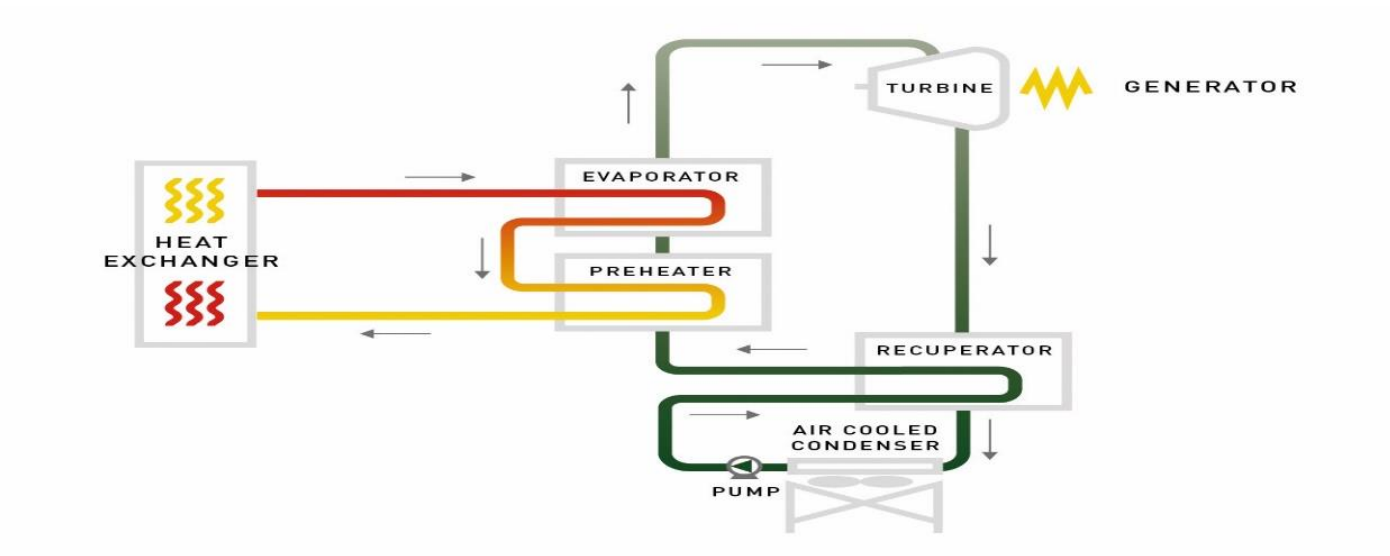

Figure 6 Organic Rankine Cycle (ORC)

3.4 Filtration of flue gases

After heating the fluid in the evaporator and preheater of the waste recovery system, the toxic gases can be seen directed to the microalgae pond to remove their toxicity and particulate matter by microbial reactions. These ponds can be used for fishery and other micro-organism growth purposes, Hence, either these gases will be utilized in ponds for microbial growth and filtered there. In addition to the filtration of hazardous gases, some valuable products such as biofuels (e.g. bio-diesel), bioplastics, Omega-3 Fatty Acids, etc. can be obtained from the microalgae pond.

3.5 Proposed model of the brick kiln with WHRS and microalgae pond

This is the 3D model of the proposed brick kiln. The flue gasses entering the chimney are being directed towards the WHRS with a capacity of 1MW electricity generation. Firstly the flue gases moving in a pipe will enter the evaporator and then the pipe containing the flue gases exits the WHRS after further spiraling from the preheater. In the evaporator and preheater, these high-temperature gasses will heat and superheat the working fluid into steam and that steam will then be directed to a turbine wheel. Steam will hit the turbine wheel with pressure, rotating at high speed and generating electricity. After exiting the WHRS, the flue gases are taken to the micro-algae pond where Particulate matter and other harmful materials are filtered from them through the water.

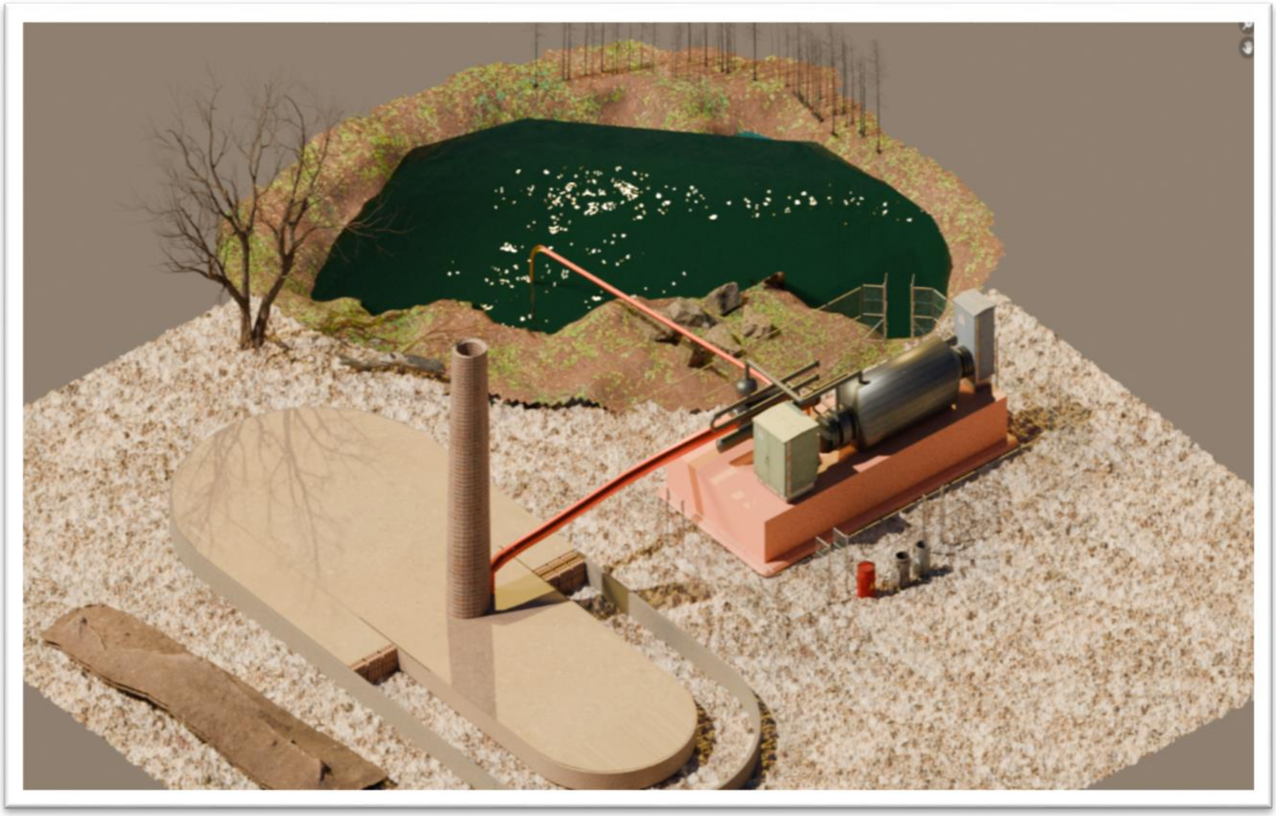

Figure 7 3D Model of the proposed brick kiln with waste heat recovery system and microalgae pond

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Experiments and Results

The following tests are performed on the baked brick samples and based on the results the best sample is chosen.

4.1.1 Compressive strength test

The test was conducted on prepared samples of three different ratios of the same dimensions *(228.6 mm X 114.3 mm X 76.2 mm)* using the Digital Compressive Testing Machine at the structural lab of MCE. This machine assesses the compressive strength of any material using a standard static load and a standard deformation rate. The load was applied to each sample at a rate of 1.3 kN per second, and the deformation was observed.

According to the Planning and Development Department Government of Pakistan, the Bricks shall be classified based on their minimum compressive strength specified and summarised in the figure below:

Designation	Average compressive strength (lbs/Sq.inch)
First Class	2000
Second Class	1500
Third Class	1000
Fourth Class	725

Figure 8 Average compressive strength of bricks according to P&DDGP

Sample A sustained a maximum load of *356.213 kN*, ensuring a maximum strength of *13.705 MPa or 1987.742 psi*. Similarly, the performance of samples B and C was also evaluated. It was found that sample C ensures a maximum strength of 13.91 MPa and sample B exhibited the best behavior, yielding the following results:

Maximum load: 370.852 kN

Maximum strength: 14.268 MPa or 2069.398 psi

Deform. 1: 4.712 mm

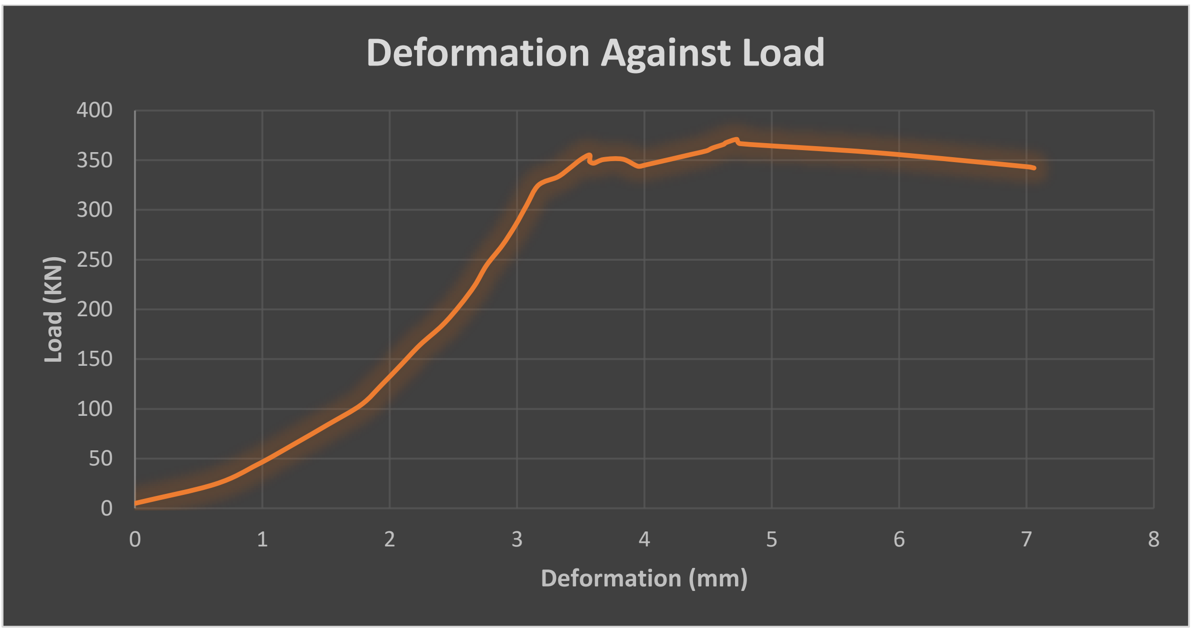

Figure 9 Graph showing the deformation of sample B against load

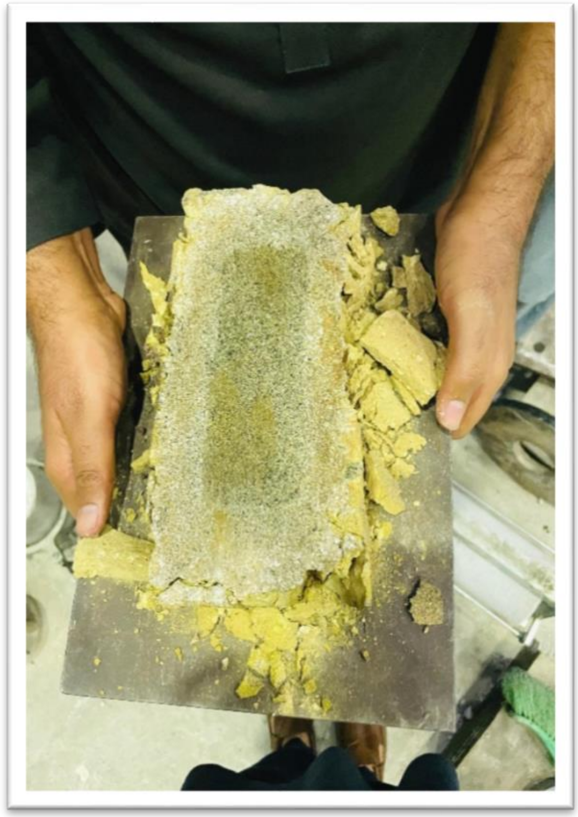

Figure 10 Performing compressive test on brick samples

4.1.2 Flexural strength test/ Modulus of rupture

The flexural strength test determines the ability of bricks to withstand bending forces. It involves applying a load to the center of a brick supported at its ends and measuring the maximum load it can withstand without failure. This test is especially relevant for bricks used in arches and other curved structures.

The test was conducted on prepared samples of three different ratios of the same dimensions *(228.6 mm X 114.3 mm X 76.2 mm)* using the Universal Testing Machine at the structural lab of MCE. The sample was placed in the UTM as shown in the figure below and load was applied until the sample failed.

According to the building code of Pakistan, the standard flexural or rapture strength is given in the figure.

2109.2.1.2 Modulus of rupture.

Adobe units shall have an average modulus of rupture of 50 psi (345 kPa) when tested in accordance with the following procedure. Five samples shall be tested and individual units shall not have a modulus of rupture of less than 35 psi (241 kPa).

Figure 10 average modulus of rapture of bricks according to the building code of Pakistan

Sample A sustained a maximum load of *9.487 kN*, ensuring a flexural strength of *3.267 MPa or 473.83 psi*. Similarly, the performance of samples B and C was also evaluated. It was found that sample C ensured a flexural strength of 3.4 MPa and sample B exhibited the best behavior, yielding the following results:

Maximum Load: 10.618 KN

Maximum Stroke: 1.68mm

Flexural strength = F = PL/bd^2

F = (10.618x1000)x228.6/114.3x(76.2)^2 = 3.657 MPa or 530.40 psi

The behavior of the brick sample is observed by the stroke against the applied load shown in the graph below.

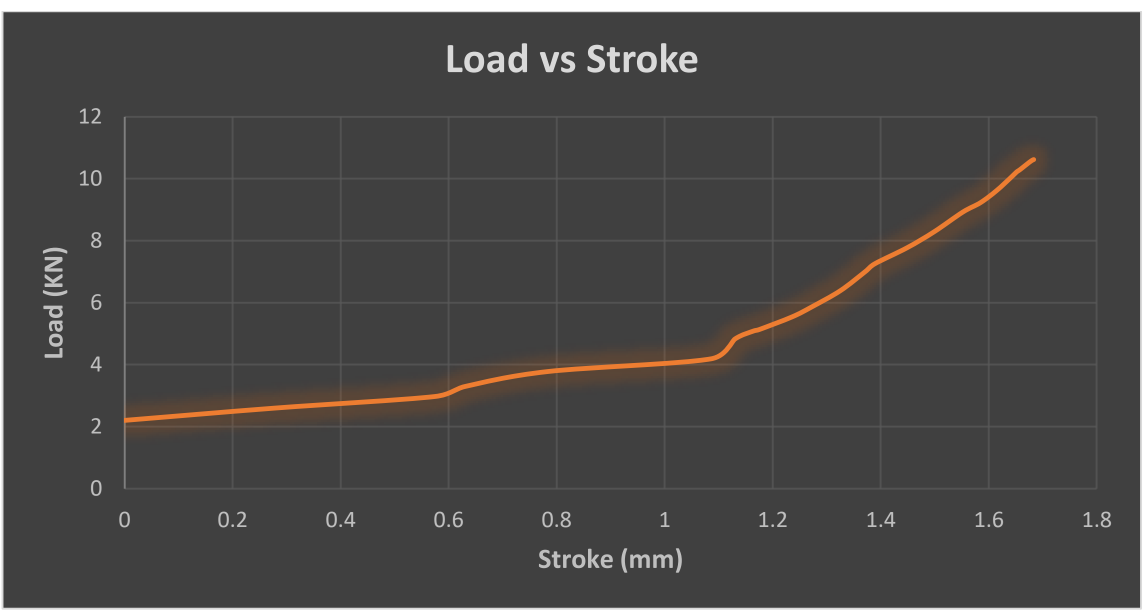

Figure 11 Graph showing the stroke of sample B against load

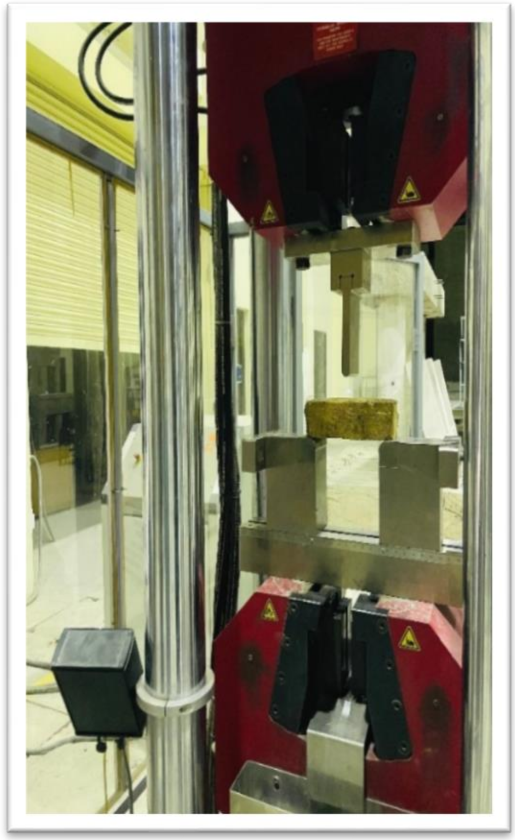

Figure 12 Performing flexural test on brick samples

4.1.3 Hardness Test

The Schmidt Rebound Hammer test was performed on the brick samples to check the hardness. The Schmidt hammer has a scale that measures and displays the rebound value. This value is typically recorded as a numerical index. Higher rebound values correspond to stronger and more durable materials, while lower values indicate weaker and less durable materials.

A total of three samples were tested using the Schmidt rebound hammer and the results were analyzed to determine the best sample. The average of five readings recorded for a particular sample was calculated. Following the studies, if some reading lie at a distance of 5 units or more the reading was disregarded and the average was revised excluding the distant reading. The same procedure was done for all three samples.

Table Calculation of the average rebound number for the three samples

Samples	Observed rebound number (RN)					Average RN	Mean RN
	1	**2**	**3**	**4**	**5**		
A	28	30	27	32	31	29.6	30.93
B	31	30	33	31	34	31.8	
C	29	31	30	34	33	31.4	

The mean rebound number was used to check the strength of the bricks using the rebound hammer test graph shown below.

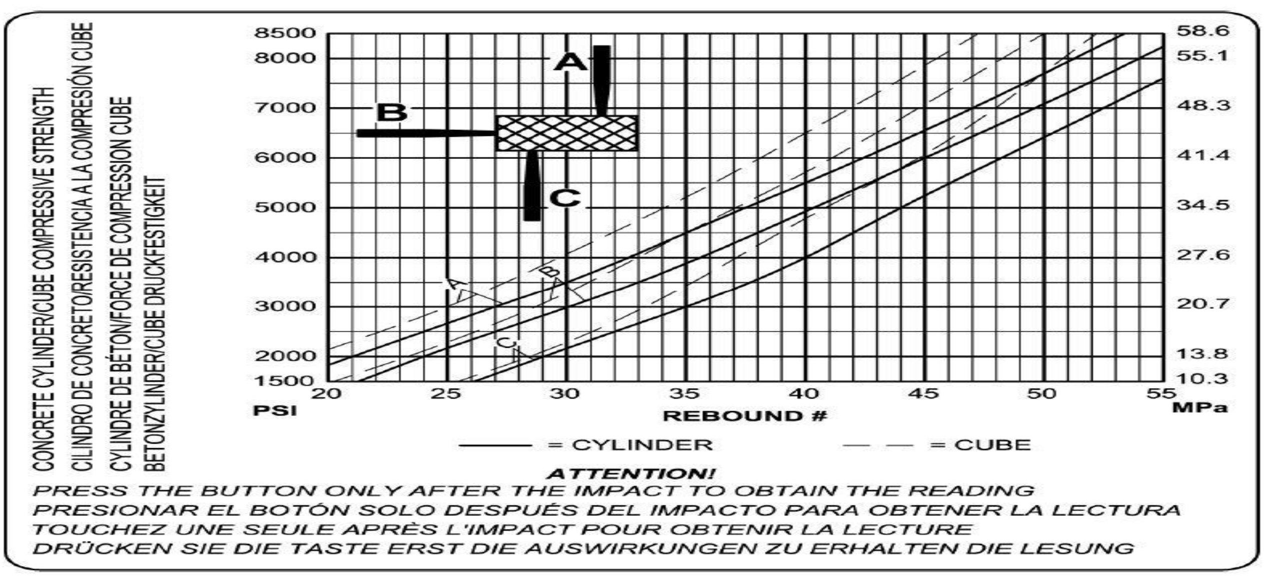

Figure 13 Schmidt Rebound Hammer test graph for determining the strength of sample

The strength of the sample from the graph using the mean rebound number of 30.93 is determined as 3500 psi which shows that the strength of the brick sample is good enough to be used in construction.

Figure 14 Figure 14 Performing Rebound Hammer test at MCE Structural Lab

4.1.4 Soundness Test

A soundness test on the bricks is performed to check the soundness of the prepared brick. Random two bricks were picked from the 18 prepared samples and they were struck against each other. The bricks neither cracked nor broke and a clear, sharp, and bell-ringing sound was heard contrary to second or third-class bricks that either crack/break or produce a dull sound upon collision. This shows that the chosen composition produces bricks equivalent to 1st class conventional clay bricks when it comes to soundness.

4.1.5 Water Absorption Test

Water absorption tests on bricks are conducted to determine the durability properties of bricks such as degree of burning, quality, and behavior of bricks in weathering. A first-class brick should absorb water not more than 20% weight of the brick.

A total of three water absorption tests were conducted on the three samples (A, B, C). First of all these three samples were placed in the oven at 105º C for 24 hours to ensure no water content was left in the brick samples. After 24 hours, the bricks were taken out from the oven and the weight $\mathbf{W_1}$ of the brick samples was observed using a weight machine as shown in fig. The three samples were weighed W_1 as 2531.8g, 2674.4g, and 2623.3g respectively. After weighting the samples were placed in a water tub for 24 hours so that they can absorb water as much as the availability of pores in brick (fig.).

Figure 15 sample bricks placed in water tub

The brick samples were taken out of the water tub after 24 hours and weighed after wiping with a piece of cloth to remove the water on the surface of the bricks (fig.). They were weighed as 3051.1g, 3079.8g, and 3115.8g respectively.

Figure 16 ***Weighing dry brick sample***

Figure 17 ***Weighing wet brick sample***

The water absorption percentage was calculated using the formula:

$(W_2 - W_1 / W_1) \times 100$

Table 3 Water absorption of all three samples

Samples	**W_1 (grams)**	**W_2 (grams)**	**$(W_2 - W_1 / W_1) \times 100$**	**Water Absorption %**
A	2531.8	3051.1	(3051.1 – 2531.8 / 2531.1) x 100	20.51%
B	2674.4	3079.8	(3079.8 – 2674.4/2674.4) x 100	15.15%
C	2623.3	3115.8	(3115.8 – 2623.3 / 2623.3) x 100	18.77%

The water absorption percentage for sample B is the lowest, so sample B performed the best. Also, the water absorption percentage is less than 20% which means the sample brick is an alternative to first-class bricks.

4.1.6 Porosity test

Bricks are made out of clay particles of different types and sizes. The space between particles is called pore space. Pore space is used to determine the amount of water absorption that gives the volume of brick sample can hold. Porosity is the percentage of the total volume of brick samples that consist of pore space.

The measurements of porosity values of brick samples are used to identify the quality of bricks. International Journal of Modern Research has reported that the porosity values for bricks generally lie in the range between 19.13% and 25.06%.

A porosity test was performed on the sample B. The total dry volume of sample B was:

V_1 = 9x4.5x3= 121.5 cubic inches

Convert cubic inches to cubic meters:

$V_1 = 121.5 \times 1.639 \times 10^{-5} = 0.00199$ cubic meter

It was noticed in the water absorption test that sample B's weight increased by 405.4g after it had been placed in water for 24 hours. It means that the weight of water in the pores of bricks is 405.4g.

Convert grams into cubic meters:

$V_2 = 405.4 \times 0.000001 = 0.000405$ cubic meters

So, the porosity % of the sample is:

$V_2 / V_1 \times 100 = 0.000405/0.00199 \times 100 = 20.35$ %

Since the porosity % lies between the normal range of 19-25 %, therefore the porosity test for the sample has passed and the brick is fine to used in construction.

4.2 Weight of brick

Two bricks were taken, one was a sample brick and the other was a first-class brick. A weight machine was used to check their weight to confirm that has the addition of waste materials had lightened the weight of the brick or not.

It was observed that the standard brick which was first-class brick weight was 2869.2g where whereas the sample brick which had waste materials added in the composition weighed 2531.8g. This means that by adding the waste materials (Fly ash, waste glass powder, and cigarette butts), the brick can be also made lightweight.

Figure 18 **Weight of standard first class brick**

Figure 19 **Weight of sample brick**

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Project outcomes

- A faster process of baking bricks at lower temperatures.
- Reduced fuel consumption.
- Improved air quality by filtering hazardous gases through microalgae pond.
- Waste management of fly ash, waste glass, and waste cigarette butts.
- Generation of electricity as a thermal energy using a waste heat recovery system.
- Production of bio-diesel and other useful substances using biomass from microalgae pond.

5.2 Significance

There are more than 16000 clay brick kilns in Pakistan. if the proposed approach is adapted at the commercial level, it can add thousands of MWs of electricity to the national grid and potentially solve the energy crisis of Pakistan. along with this, the quality of the construction might be enhanced and its cost lowered at the same time. the reduction in the spread of environmentally hazardous substances in the atmosphere might improve air quality and address the smog issue in winter.

5.3 Conclusions and Recommendations

After performing various tests and analyzing the results, the brick sample with 0.8% waste cigarette butts, 18 % fly ash, and 15% waste glass powder proves to be the most feasible composition. Moreover, it is suggested to install a 1 MW capacity Waste Heat Recovery System which works on the principle of an Organic Rankine Cycle instead of a conventional Rankine Cycle. The recommended working fluid for an ORC WHRS at a clay brick kiln is R245fa as it can work at temperatures as low as 153.86 degrees Celsius. Adding a microalgae pond at the site and directing the waste flue gasses leaving the WHRS into it can be beneficial in reducing the carbon footprint and spread of toxic materials in the atmosphere. Moreover, the proposed micro-algae pond has the potential to produce biodiesel, biomass, proteins, and some other useful substances. This research proposes a comprehensive model for an eco-friendly, energy-efficient, and energy-generating clay brick manufacturing unit which aims to reduce the cost, improve efficiency, produce electricity, exploit all resources present at the clay brick manufacturing site, and reduce the environmental footprint of the process.

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