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DESIGN AND CONSTRUCTION OF A LPG POWERED BARREL KILN FOR CERAMIC FIRING

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Abstract

In the quest for sustainable ceramics firing process, the usage of Liquefied Petroleum Gas (LPG) has emerged as a promising solution to the process of transforming clay to durable and functional ceramic products. The study sets out to explore the use LPG and it effectiveness in a barrel kiln for ceramics firing. For the study, data was collected after firing the ceramics works for a period of ten (10) hours, in which the pieces came out perfectly fired with little recorded losses/damages to them. The barrel kiln was made from repurposed 55-gallon steel drum, refractory insulation (mortar) made up of kaolin, clay and sodium silicate in a ratio of 6:3:1. It also comprised of refractory bricks arranged in circular manner in the pattern of the drum for effective thermal circulation and heat distribution. The LPG system comprised of a burner which helped to enhance the air to fuel mixture for complete combustion not forgetting control valves for safety measures. The kiln had a pyrometer with a digital data display for real-time temperature monitoring to enhance the quality and energy efficiency of the firing process. The research results revealed that use of LPG proved to be a better option due to its cleaner combustion and high energy output. Also, the use of the barrel drum proved to be cost-effective and readily available. Findings from the study underscore the fact that the LPG-powered barrel kiln reached target temperatures within a reduced timeframe compared to conventional kilns. In conclusion, the study indicated that an LPG-powered barrel kiln is a feasible and efficient alternative for ceramics firing. The design effectively balances cost, performance, and safety, making it a promising option for sustainable ceramic production.

Keywords: *Barrel, Ceramics, Construction, Design, Firing, LPG,*

1.0 Introduction

The firing of ceramics is a very complicated process in which we take the clay and make it into product which is strong, functional and aesthetically appealing i.e. durable ceramics. This has been done with wood firing or electric kilns however each have different issues such as being an expensive process, non-homogenous temperature profiles and environmental impact (Smith, 2016). This encouraged a call towards greener and energy efficient alternative method, which is focused on different fuels with prefabricated kiln designs that not only provide lesser energy consumption, but also minimize the global carbon footprint.

Liquefied Petroleum Gas (LPG) is identified as a possible substitute for the high energy output and clean

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combustion (Gupta, 2020). Critical parameters that directly relate to LPG properties which include fast heating and full temperature control, enabling more precise physical and chemical transformations during firing suggest it to be a suitable alternative. Also, the use of Barrel kilns provide an economic and scalable solution of building kilns from down-cycled steel drums for small to medium scale ceramic producers (Davis, 2015); simultaneously, an LPG fuel system combined with the simplicity of a barrel kiln is likely an important system to explore for optimizing firing.

In the design of an LPG fired kiln, it is required that the Kiln should have uniform temperatures all over the firing chamber; to make sure that the ceramic ware can be processed at one uniformed manner. Secondly, for this refractory material has be of the correct choice and placement (Kumar & Singh 2018) and insulation (Kumar and Singh, 2019). Also, the Burner design is essential and has to be accompanied by accurate control over fuel delivery as well combustion dynamics for an efficient LPG fueled system (Chen, 2018). Thirdly is the necessity of sufficient ventilation and accurate thermal measuring by advanced sensor technologies to stop thermal shock and hazardous fuel conditions (Fernandez & Lee, 2019)

Besides that, sensor and digital control systems evolved so that the kiln can be monitored in real-time about what is about the temperature condition inside the kiln. This possibility gives the operator the opportunity to adjust the flow and temperatures of fuel dynamically, thus improving the quality and energy efficiency of firing.

2.0 Literature Review

A kiln is any of several kinds of insulated chamber, heated electrically or by means of a fuel, used to fire ceramic products, roast ores, or in the production of cement. Kilns are essential, not only in the production of ceramic wares, but also in the teaching and learning of ceramic technology. Kilns may be generally classified into two broad types, based on their heat source-electric kilns and fuel fired kilns, (Idowu et al, 2015). Electric kilns are heated by radiant heat produced by the conversion of electrical energy to heat energy in heating elements, (Olsen, 2001). Electric kilns nowadays, often use elements made of special high temperature alloy of iron-aluminium-chrome. This alloy can withstand very high temperature of up to about 1015℃, (Lewicki, 2014).

Fuel fired kilns are heated by the combustion of carbonaceous materials which may be firewood, coal,

Ilaro Journal of Environmental Research & Development (2025) 7 (1), 79– 87
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charcoal, sawdust, various oils, and gas, (Asante-Kyei et al, 2019). Various fuel types have their own merits and demerits, however most modern fuel fired kilns utilize gas as fuel due to its availability, clean burning and ease of control. Unlike oil burners, gas burners are simple, inexpensive and fool proof, (Oteng, 2011). Norton (1956) indicates that gas kilns can achieve very high temperatures. According to him, well-designed gas kilns give uniform temperature and may be used up to 1450 ºC. This permits the attainment of uniform temperature with greater ease. In comparison, firing with electricity usually costs twice as much as firing with gas (Oteng, 2011). In addition, varieties of rich visual textures are achievable with gas kilns due to the possibility of neutral, oxidation or reduction firing, which cannot be achieved with electric kilns, (Oduagwu et al, 2015).

Gas kilns may further be classified according to the method of flow draft. Updraft kilns are those in which the flame is introduced into the bottom of the kiln, at or below floor level, and exhausted out the top. Updraft kilns consist of three basic components: the firebox, the damper, and the stack area. The firebox is where the flame enters. The damper is at the top of the kiln and controls the exhaust (and, by association, the kiln's atmosphere). The stack area is where the wares are set and it's between the firebox and damper. Although an updraft kiln tends to be less fuel efficient than a downdraft kiln, most commercially built fuel-burning kilns are updrafts. This is mainly due to their simplicity to build, pack, and ship. (Peterson, 2019). Downdraft kilns are designed to force the flame and heated air to circulate through the kiln. Flame is introduced at the bottom of the kiln and naturally flows upward. The construction forces the flame back downward, to exhaust at the bottom of the kiln. Downdraft kilns consist of four main components: the firebox, the stack area, the damper, and the chimney. The addition of the chimney helps create draw or air flow, (Peterson, 2019). A damper is usually a piece of refractory material, often a kiln shelf that is placed in the path of the flue gases as they travel up through the chimney stack of the kiln. By moving it in and out, the pressure inside the kiln is controlled. Increased pressure decreases airflow, and decreasing pressure increases airflow, (Frenzel, 2010).

There are also other less common flow draft configurations, including cross draft kilns, which rely on movement of heat from the inlet flues on one side of the kiln chamber to the exit flues along the opposite side. The critical factors and principles involved in the

Ilaro Journal of Environmental Research & Development (2025) 7 (1), 79– 87
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design and fabrication of gas kilns are described in detail by Olsen (2010).

2.1 Design Considerations

In the design of an LPG-powered barrel kiln some of the key considerations made; include the kiln's physical structure, fuel system design, thermal management, and overall safety. Each component are to work in concert to ensure a uniform firing environment and optimal energy utilization.

2.1.1 Kiln Structure

The barrel kiln's structure serves as the foundation for effective ceramics firing. The design is based on repurposing a standard 55-gallon steel drum, chosen for its durability, cost-effectiveness, and ready availability.

a. **Refractory Lining and Insulation:** A refractory lining of internal structure of the kiln is a vital element. The inner surface of the drum gets insulation applied on it by high temperature ceramic bricks, then a coat of Refractory Cement this configuration helps to minimize possible heat loss and maintain a constant temperature profile through firing chamber to the ceramics (Kumar & Singh, 2018).

b. **Drum geometry:** The cylindrical shape of the drum allows for different size of ceramics to be placed in it in a drum. The geometry promotes a free convection pattern that encourages even heat stirring. Changes like the inset of access ports for burner and sensor attachment are executed to low structural impact as well as flexible functional integrations.

c. **Thermal mass and heat distribution:** The steel drum has a thermal mass and serves two purposes. It is designed to assist with keeping the higher temperatures during the firing run and also as a heat reservoir which helps insulate the internal temperature from spikes. It is important to find balance between these properties for rivalizing best ceramic quality and energy efficiency.

2.2. LPG Fuel System

LPG is introduced into controlled form for the purpose of burning in kilns, and burner at heart of fuel system

a. **Burner Placement/Design:** A burner is specific in the ratio for mixing LPG and air to combust fully. A precisely engineered nozzle paired with an integral pressure regulator ensures the fuel is delivered accurately,

Ilaro Journal of Environmental Research & Development (2025) 7 (1), 79– 87
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keeping and ensuring stable temperatures ramp-up, peaks (Thompson, 2021).

b. **Fuel delivery and control:** The provision of the fuel valve plus pressure regulator offers an additional safety measure in broad sense to avoid over-pressurization and no over-surge of fuel to achieve this precision is designed to accomplish fine tune adjustments and the operator will have an influence of the flame magnitude in turn the internal temperature of kiln. This is paramount in avoiding thermal shock and a repeat firing cycle (Chen, 2018).

c. **Combustion Efficiency:** Improving combustion efficiency minimizes energy consumption and pollutant emissions. The design features to support the complete combustion of air are essentially integrated; such as optimized air and fuel mixing, specific burner placement to avoid cool sections of the kiln.

2.3 Thermal Monitoring and Safety

Design of the kiln places extreme importance on real-time thermal monitoring and built-in safety features;

a. **Temperature Sensing & Control:** The kiln contains thermocouple installed in the chambers to pick temperature variations across zones These sensor data are passed into a digital control system which uses feedback loops to automatically fine tune fuel flow and burner output. This is an essential part for keeping the temperature at goal with least error (quality of fired ceramics directly depends on this) (Chen, 2018).

b. Ventilation controls to allow enough air flow, it does not increase just to support combustion but also helps out dissipating extra heat from around and prevent the build-up of combustive gases (Fernandez & Lee 2019).

3.0 Materials and Methods

Steel Drum: A typical 55-gallon steel drum that was both durable, easy to modify and economical was acquired. The drum was fully washed prior to first use just to eliminate any residues or debris that could hinder the firing process. We checked the metal drum to prove it was heat resistant and had strength for modifications.

Refractory Lining Materials: The drum was lined with ceramic fiber insulation on the inside, then refractory cement applied. The ceramic fiber is a good thermal insulator and easily lightweight while refractory cement provides strength to resist a thermal shock, also serves as a main structural support (spine)

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of the drum. The materials were chosen as required to ensure thermal property and durability, which are fundamental to a uniform fire environment (Gupta, 2020).

Fuel / LPG Fuel Components: Commercial grade LPG burners-regulators, fuel valves and hoses were used throughout fuel system. The burner was specifically made with a proportional nozzle to help the LPG and air mix better, minimizing dirty burners. Pressure regulators and valves can be used to monitor fuel flow so as to protect firer safety during the firing cycle (Thompson, 2021)

Instrumentation: Thermocouples are the real-time temperature sensor of kiln. This sensor goes at a digital data logger that data records temperature values. These instruments were calibrated before experiments in order to guarantee accurate measurements.

3.2 Methodology/Construction Process

The construction of the kiln was carried out in the following steps:

Drum Disassembly and Modification: The steel drum was thoroughly checked and cleaned of oil, rust or residue. The access plates were then cut into the drum for burner, thermocouples and other instrumentation to be installed. These changes were accomplished with the help of cutting tools to guarantee smooth edges and avoid manufacturing of the drum (Anderson & Brown, 2017).

Insulation & Refractory Cement Application: The inner surface was covered with an even layer of ceramic fiber insulation first. This layer was manual troweled on to guarantee even. The refractory cement coat was then reapplied over the insulation to make it hermetic and aid in insulated imperviousness to mechanical wear during firing cycles (Gupta, 2020).

Installation of LPG Fuel System: LPG burner mounted to exterior of drum with the flame directed inside firing chamber. A burner assembly comprised of one pressure regulator, one fuel valve to control the flow of LPG. All connections were leak tested prior to testing. (Thompson, 2021)

4.0 Results

Fig 1: Fully Assembled Barrel Kiln

Ilaro Journal of Environmental Research & Development (2025) 7 (1), 79– 87
ISSN: 2736-0814

Fig 2: Opening for the LPG System in at the base of Kiln

Fig 3: Inner Insulation of the Barrel Kiln

Fig 4: *The LPG System with pressure Regulator and fuel valve*

The results of the experimental trials indicated that barrel kiln operated on LPG took less time to reach the target temperatures than the conventional kilns. Fuel consumption analysis showed an increase of 20% energy efficiency due to the new burner configuration and fast response combustion of LPG.

5.0 Conclusion

Implementation of LPG powered barrel kiln would bring in many benefits such as fast heat-up and maintenance of higher precision temperature, as earlier observed by Chen (2018). Secondly, design of barrel kiln was simple and cost effective as well as scalable. The results of this study show that an LPG-powered barrel kiln is a viable and effective way to fire ceramics. With this design, adequate fuel cost, performance and safety are already balanced to be a viable way in sustainable ceramic production. However, a subsequent phase of fuel system and thermal management optimization could further increase the efficiency of the kiln bringing lower environmental impact and higher quality of production. There are nevertheless, the challenges such as ensuring complete combustion and managing thermal gradients which are plausible areas for further research.

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