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Determining the Thermal Efficiency of Firing of a Cross Draft Kiln using Methane and Liquefied Petroleum Gas

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Abstract: Thermal efficiency in the ceramic firing process is crucial to reducing energy consumption, emissions of gaseous pollutants, and the cost of production. This study, reports on the determination of thermal efficiencies of a traditional 3m x 28m x 2.7m cross draft kiln using the heat balance approach. Results of the study showed that the thermal efficiencies of 46.4% and 1.9% for methane and liquefied petroleum gas kiln with a firing temperature of 1, 200^{O}C and inlet temperature of 26^{O}C. Findings from the study also showed that only 2.1%, and 32.3% of the thermal energy inputs from methane, and liquefied petroleum gas (LPG) were effectively utilized for the physio-chemical transformation of ceramic ware. Findings also revealed that thermal energy wastes, in the form of heat losses through radiation, and convection accounted for up to 280,1522.7 kcal/kg, and 102,338.592 kcal/kg for both methanes, and LPG fired kilns respectively. Other sources of heat wastage included heat lost in the form of waste heat and combusted exhaust gas. This study addressed the gross thermal inefficiency of the traditional cross draft kiln.

Keywords: Ceramic, Firing, Greenhouse gas, Methane, Thermal efficiency.

1. Introduction

The high rate of energy consumption in the ceramic firing process is contributing significantly to greenhouse gas emissions and the exploitation of energy resources. About 90% of CO_2 emissions [1] and 55% of all thermal energy used in the ceramic production process is attributed to ceramic firing [2]. However, the high rate of energy consumption is not only responsible for the over-use of resources, and the emissions of pollutants, but also impacts the cost of ceramic production. Up to 60% of the cost of ceramic production, is due to thermal energy losses occurring in the form of waste heat [3].

These losses which have been linked to inefficient firing fuel [4], poorly designed kilns [5], and inefficient burner systems [6] have impacted negatively the green credentials of the ceramic production process by limiting the ability of the ceramic industry, particularly in developing economies to attain low carbon objectives of the sustainable development goals.

Although, improvements have been made in reducing the carbon footprints and increasing the efficiency of the ceramic firing process in advanced economies through the use of novel and highly technical mathematical models [7]-[10] for energy-saving and conservations [11]-[13].

However, the application of these novel technologies appears not feasible in developing economies where production is done on a cottage and medium scale, using traditional cross draft kilns with table and decorative wares accounting for 90% of the production base.

Therefore, considering the investment limitations of traditional ceramic industries in developing economies, in terms of the technical and material requirements [14] as well as the observable deficits in modern equipment and financial requirements for adopting novel and innovative approaches. It became pertinent to look inward, to adopt an energy efficiency improvement strategy

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that is appropriate, suitable, and fits into the prevailing economic, and technical realities of the ceramic production process in low-income countries.

The objectives of this study are to evaluate the firing efficiency of a traditional cross draft kiln using methane, and LPG (propane), identify areas of heat losses, and the adoption of a suitable firing fuel, all of these are aimed at improving the thermal performance of the ceramic firing process.

In this study upgraded biogas was used to fire a ceramic kiln to 1200^{O}C. Although various methodologies for upgrading biogas to methane such as the removal of CO_2 [15]-[16], the utilization of CO_2 for the production of chemicals [17], and innovative process of converting CO_2 into methane [18] are all in existence. However, in this study, simple water scrubbing technology which is based on the solubility of CO_2, and H_2S in water was adopted for the removal of the contaminants and upscaling of biogas to methane.

The selection was based on ease of operation, cost-effectiveness, and environmental friendliness of the process and the procedure for upscaling the methane involved bubbling the gas through a column of water and stripping up the contaminants from the gas stream as the gas passed through the water.

2. Materials and Methods

The methodology involved the anaerobic digestion of a mixture of cow dung and chicken waste to generate biogas, the up-scaling of generated biogas to methane, the deployment of methane, and liquefied petroleum gas to fire a cross draft kiln (Fig 1) using a single firing technique to a maximum firing temperature of 1,200^{O}C, as well as the determination of the firing efficiency of methane, and liquefied petroleum gas (LPG) (propane) using the heat balance approach.

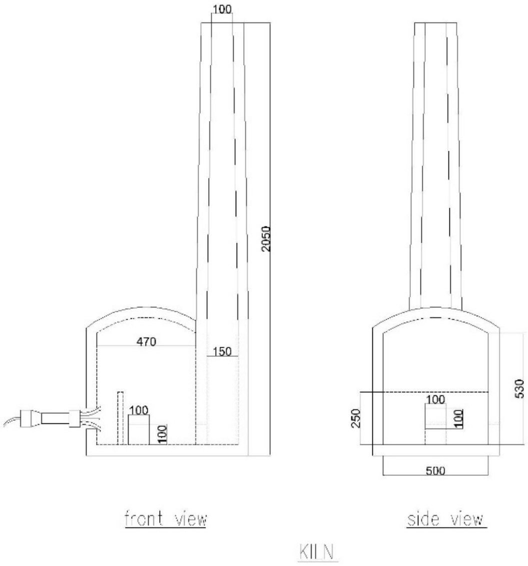

Figure 1. Schematic diagram of the cross-draft Kiln

Propane used in the firing process was acquired from gas vendors around the vicinity of Abubakar Tafawa Balewa University, Bauchi. All calculations were based on the ceramic industry manual [19].

2.1 Biogas production

Anaerobic digestion technology was employed in the generation of biogas. The procedure involved mixing proportions of cow dung, and chicken waste with water in the ratio of 1:4 (combined substrate: water). The mixture was done after the substrates have been screened for stones, and other impuritiesand then charged into a digester as prescribed by Nwofe and Agbo [20]. Firstly, a feeding started in batch and then in a continuous mode, at an interval of two days for 26 days. A total of 373 liters of biogas was produced within a digestion period.

2.2 Upscaling of biogas and bottling of methane

The up-scaled biogas was collected over water into a vehicle tire, dried using a silica mental bed, compressed into an LPG cylinder at 330 bars (4714 Pressure Per Square Inch [PSI]), and ambient temperature of 37^{O}C (Fig. 2).

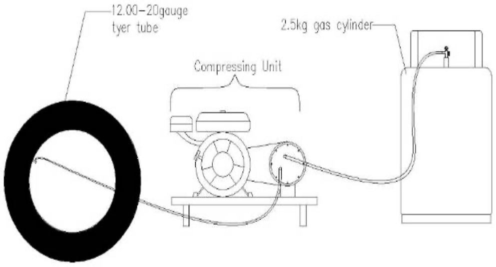

Figure 2. Compressing Methane into LPG Cylinder

2.3 *Firing*

A cross draft kiln of internal dimensions 3m x 2.8m x 2.7m, made of dense refractory brick was fired to 1200^{O}C at an ambient temperature of 26^{O}C, maximum firing temperature of 145^{O}C, and 180^{O}C, the firing rate of 120 ^{O}C/hr, and 150 ^{O}C/hr, for methane, and LPG respectively.

2.3.1 *Heat balance of the firing system*

The heat balance of the firing system was calculated by determining the combustion heat of the firing system based on the heat input, and heat output approach as shown in equation (1) below:

$$Q_c = C_v \times Fc \quad (1)$$

Where: Q_c = Combustion heat
C_v = Calorific value of fuel
F_c = Fuel consumption

300L scrubbed gas which translated to 214.8 kg and methane calorific value of 13284 kcal/kg were used in equation (1) to calculate the heat retained by the fuel in the form of combustion heat. The volume of methane (300L) was converted to weight in kg by multiplying the volume by the density (0.716kg/m^3).

The volumes of kiln prop, kiln shelve, and ceramic ware inputted into equation (2) was 3516.8 m^3, 62.35 m^3, and 61,472 m^3 to calculate the heat carried in by heated objects as shown below:

$$Q_{in} = V_{hb} \times C_P \times \Delta t \quad (2)$$

Where:
Q_{in} = Heat carried in by the heated object
V_{hb} = volume of heated object
C_{P} = its specific heat
Δt = temperature difference

A temperature change of 1 ^{O}C was used in the calculations to allow for variation between hot, and cold air [19] while the specific heat of 100 was used in calculating the heat carried in, and out by the object, because 90% of the material used in formulating the kiln furniture and the ceramic ware were made from kaolinite, whose hydrated specific heat is 100 j/kg.

The output heat of the firing process was determined by calculating heat carried away by the heated object, heat carried away by waste heat, heat carried away by combusted exhaust gas, and heat carried away by radiation, and conduction using equation (3), (4), (5), and (6) respectively as indicated below:

$$Q_{aw} = V_{hb} \times C_P \times \Delta t \quad (3)$$

Where:
Q_{aw} = Heat carried in by the heated object
V_{hb} = Volume of heated object
C_P = its specific heat
Δt = temperature difference

$$Q_{wh} = V_{wh} \times C_P \times \Delta t \quad (4)$$

Where:
Q_{wh} = Heat carried away by waste heat
V_{wh} = Volume of waste heat
C_P = its specific heat
Δt = temperature difference

$$Q_g = V_g \times C_P \times \Delta t \quad (5)$$

Where:
Q_g = Heat carried away by combusted exhaust gas
V_g = Volume of exhaust gas
C_{P} = its specific heat
Δt = temperature difference

$$Q_{rc} = Q_{in} - Q_{out} \quad (6)$$

Where:
Q_{rc} = Heat loss by radiation and conduction
Q_{in} = Total heat input
Q_{out} = Total heat output

The thermal efficiency of the firing system was determined using equation (7) blow:

$$\eta_{th} = \frac{V_g}{Q_{in}} \qquad (7)$$

Where:
η_{th} = Thermal efficiency
V_g = Volume of gas required to hear ceramic ware
Q_{in} = Total heat input.

A dew point of 100^{O}C was used in calculating the heat loss by combusted exhaust gas since the concentration of H_2S is less than 1% in the firing fuels [19]. It gave a difference of 63^{O}C between exhaust, and the ambient temperature. The specific heat of 1.68 j/kg for methane and 2.25 KJ/kg for propane was used to determine the energy inputs of methane, and propane. And based on Olsen's principle of kiln design [21], the volume of the chimney exit (151.2 m^3) was used as the volume of exhaust gas.

3 Results and Discussion

3.1 Harnessed Gas

Gas generation started on day 7 with 10 liters of gas produced at 337.7^{O}C. The volume of the generated gas increased, as the digestion period progressed. The peak value of gas production (40L) was recorded at a digestion temperature of 38 ^{O}C on day 20 (Fig. 3), at an average digester operating temperature of 37.7^{O}C, and pH of 8.5. A sharp decline in gas production was recorded after the peak period-an indication that the substrates have been exhausted. Thereafter gas production continued to decline, until day 26 when the digestion was stopped

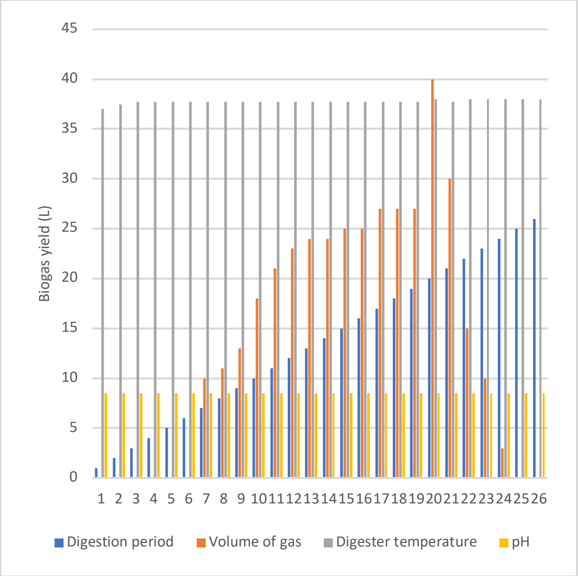

Figure 3. Relationship Between Digestion Period, the Volume of Gas, Temperature and pH

3.2 Upscaled and Compressed Gas

The value of methane increased from 55% in the un-scrubbed gas (Fig. 4) to 90% in the scrubbed gas while the value of CO_2 decreased from 40% in the un-scrubbed gas to 1% in the scrubbed gas (Fig. 5).

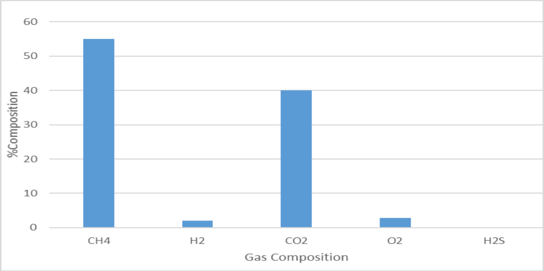

Figure 4. Composition of Un-scrubbed Gas

These values were consistent with Ray, Mohanty, and Mohanty [22]. Although, the presence of H_2S was not detected in the scrubbed gas stream which is an indication of the viability of the water scrubbing system; nonetheless there was an increase in the value of hydrogen from 2% in un-scrubbed gas to 4% in the up-scaled gas.

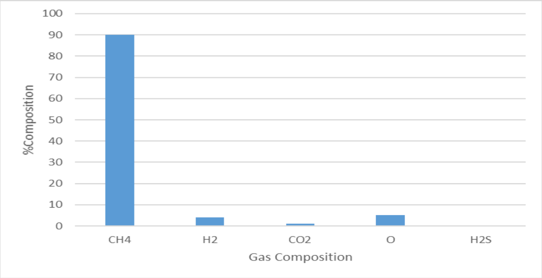

Figure 5. Composition of Scrubbed Gas

3.2.1 *First phase of firing*

300L upgraded and compressed biogas was used to fire a cross draft ceramic kiln to 1200^{O}C using compressed methane in a 10-h firing cycle (Fig. 6). The kiln was operated at an ambient temperature of 26^{O}C, a firing rate of 120^{O}C/hr, and an average firing temperature of 673.3 ^{O}C. The firing curve is observed to progress steadily with a rise in temperature from the beginning of the firing, up to the fourth hour which correspond to 450^{O}C, which 1% to 2% of moisture content of the clay evaporated [19].

A constant firing curve that was attributed to heat absorbed by the ceramic ware is observed from 450^{O}C up to 650^{O}C. The pressure of the compressed methane decreased as the firing process progresses. The decrease in pressure was ascribed to the large orifice size of the burner system (0.082 inches

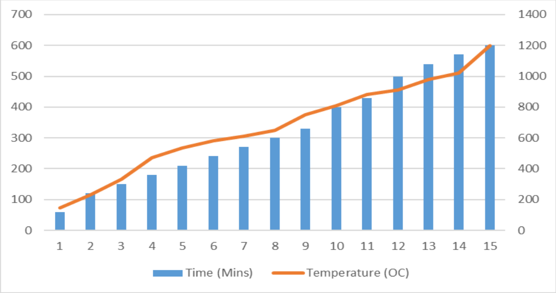

Figure 6. Relationship Between Firing Time and Temperature

3.2.2 *Second phase of firing*

Firing with LPG required 8h, consuming 10 kg of gas (Fig. 7). A steep firing curve was recorded from the begging of the firing up to833^{O}C. This contrasts with the constant firing curve recording for methane gas. The steep firing curve of the LPG was attributed to the high firing rate of the gas. However, as the firing process progresses, a flat firing curve was observed from 833^{O}C up to 843^{O}C. The trend continued until it got to 1000^{O}C, and there was a spike in the firing curve from 1000^{O}C to 1200^{O}C.

Fluctuations observed in the firing curve were attributed to the ambient temperature of 26^{O}C which appeared to have altered the temperature, and pressure of the gas; resulting in alternation in the firing curve. However, ambient temperature influenced the temperature and pressure of LPG, while methane appeared not affected by the external temperature.

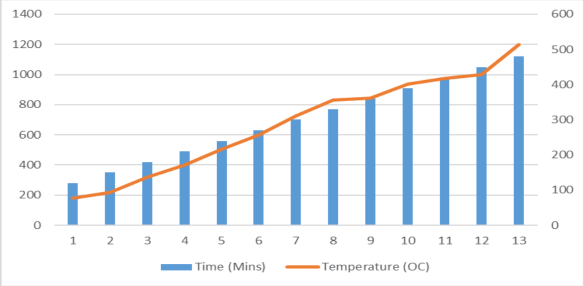

Figure 7. Relationship Between Firing Time and Temperature

3.3 *Heat balance of the fired kiln*

Table 2 indicated that a total of 2,924,627 kcal of methane was expended to fire a 22.68 m^{3} ceramic kiln to1200^{O}C in 10h at a firing rate of 120^{O}C/hr. However, 61472 kcal which translated to 2.1 % of the total expended energy was used to expel the water of crystallization, and to convert the ceramic from the bisque to gloss ware at 1200^{O}C. Heat balance (equilibrium) between heat input and heat output of the kiln was also recorded for the methane-fired kiln. This observation is consistent with the ceramic industry manual [19].

Table 2 indicated the heat balance of 2.44 % of the total energy was absorbed by the ceramic ware, and the kiln furniture. It is also clear from the table that, 95.8% of the total energy used in the firing was lost to radiation and conduction.

Table 1. Heat Input Balance of Methane Fired Kiln

Input category	Calorific value (kcal/kg)	%
Kiln prop		0.1
Kiln shelve		0.2
Ceramic ware		2.1
Fuel		97.6
Total		100

Table 2. Heat output Balance of Methane Fired Kiln

Input category	Calorific value(kcal/kg)	%
Heat carried away by kiln furniture and ceramic ware	71223.8	2.44
Heat carried away by waste heat	30447.9	1.04
Heat carried away by combusted exhaust gas	21432.6	0.73
Heat loss by radiation and conduction	2801522.7	95.7
Total	2924627	100

Firing the same kiln to 1200$^{\mathrm{O}}$C using LPG, consumed 190623.8 kcal of energy as shown in Table 3, and lasted 8h, at a firing rate of 150$^{\mathrm{O}}$C/hr. Less than 8.6% of the volume of methane used in the first phase of the firing was translated to 54% of the total energy. The differences in the firing time, and the volume of gas consumed between methane, and LPG fired kiln were attributed to the fast, and high firing rate of LPG, as well as the reduced volume of heat loses due to radiation, and conduction. It was also observed that the high firing rate of LPG has enhanced the heat absorption of ceramic in the LPG-fired kiln compared with the methane-fired kiln.

The heat absorption rate of LPG-fired ceramic has also aided the reduction of heat losses due to radiation, and convection. Although no significant difference was observed in heat carried away by kiln furniture, there is a 7.3% difference in the heat carried away by combusted exhaust gas of LPG and methane fired kiln.

Table 3. Heat Input Balance of LPG Fired Kiln

Output category	Calorific Value (kcal/kg)	%
Kiln prop	3516.8	1.8
Kiln shelve	6235	3.3
Ceramicware	61472	32.3
Fuel	119400	62.6
Total	190623.8	100

Table 4. Heat Output Balance of LPG Fired Kiln

Output category	Calorific value (kcal/kg)	%
Heat carried away by kiln furniture and ceramic ware	71223.8	37
Heat carried away by waste heat	1058.4	1.0
heat carried away by combusted exhaust gas	16003.008	8.0
Heat loss by radiation and conduction	102338.592	54
Total	190623.8	100

3.4. Thermal efficiency

Thermal efficiencies of 46.4% and 1.9%, were recorded for methane, and LPG-fired kilns. These values are consistent with Imran et al. [23] who reported that, due to the high rate of radiation, and convection in kilns, thermal efficiency is usually not more than 30%. The study also showed that 53.6% of methane gas and 98.1% of LPG used in the firing were wasted. It meant that only a small portion (less than half) of the energy content of the fuels was utilized. Although, a previous report by Gomez et al. [24] has shown that, regardless of the volume of fuel used, the thermal efficiency of the kiln remained the same. It was observed in this study that even though methane-fired kiln has high thermal energy losses compared with LPG-fired kiln, it still had higher thermal efficiency. The study attributed this finding to the high volume of gas consumed (Table 2), and the calorific value of the gas (methane).

Similarly, the recorded 44.5 % thermal efficiency difference between methane, and LPG-fired kiln was attributed to high thermal energy losses due to radiation, convection, the heat lost by combusted exhaust gas, and waste heat in the LPG-fired kiln.

A total of 30447.9 kcal/kg of thermal energy was lost in the methane-fired kiln as waste heat, compared with 1058.4 kcal/kg (Table 4) in LPG-fired kiln. Heat lost through combusted exhaust gas in the methane-fired kiln stands at 21432.6 kcal/kg. This value is 5429.592 kcal/kg greater than the value of 16003.008 kcal/kg recorded in LPG fired kiln. However, a significant heat loss of 2801522.7 kcal/kg which translated to 95.8% was recorded for methane-fired kiln compared with 102338.592 kcal/kg which translated to 54% in LPG fired kiln.

Consequently, despite the high thermal losses, longer firing time, and high energy consumption recorded for the methane-fired kiln, it was thermally more efficient compared with the LPG-fired kiln which consumed less amount of energy and firing time. The differences in fuel consumption rate, and firing time, accounted for the less thermal losses in the LPG kiln, which led to more energy intake by the ceramic ware.

Nonetheless, both the methane and LPG-fired kiln produced heat lost through radiation, and convection accounted for the highest energy loss. This is consistent with Gomez et al. [24], who reported that 50% and 27% of thermal energy lost in kiln firing are through radiation and convection which mostly occur through the sidewalls, base, and ceiling of the kiln.

4. Conclusion

The heat balance and thermal efficiency of a traditional cross draft kiln were determined using the heat balance approach and the main findings of the study are summarized: (1)

The traditional cross-draft kiln currently employed in firing ceramic wares is grossly thermally inefficient and its design needs to be improved to minimize heat losses; (2)

Heat losses through radiation, convection, and heat carried away by wasted heat and combusted exhaust gas were identified as sources of heat wastage in the traditional cross draft kiln; (3)

Thermal heat losses through radiation and convections are highest in both methane and LPG-fired kiln. More than half of the energy (53.6%) was lost in methane-fired kiln, while in the LPG fired kiln only 1.9 % of the energy was utilized; (4)

Firing time and fuel consumption rate were higher in the methane-fired kilns. Both methane and LPG are suitable and sustainable alternatives to traditional ceramic fuels.

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References

[1] K. A. Le. “Optimization of energy usage in a ceramic kiln using pinch technique,” *Chem. Eng. Trans.*, vol. 63, pp. 313-318, May, 2018, doi: https://doi.org/10.3303/CET1863053

[2] E. Monfort, A. Mezquita, R. Granel, E. Vanquer, A. Escrig, A. Miralles, and V. Zaera. “Analysis of energy consumptions and carbon dioxide emissions in ceramic tile manufacture”, *Bol. de la Socie. Esp. de Cera. y Vid.*, vol. 49, no.4, pp. 303-310, Jul. 2010, Accessed: October 10, 2021 [Online]. Available: (https://www.scirp.org/)

[3] S. A. Hussain, M. Farooq, M. Amjad, F. Riaz, Z. U. R. Tahir, M. Sultan,I. Hussain, M. A. Shakir, M. A. Qyyum, and N. Han “Thermal analysis and energy efficiency improvements in tunnel kiln for a sustainable environment”, *Proce.,vol.* 9, no. 9. pp. 1692, Aug. 2021, doi: https://doi.org/10.3390/pr9091629

[4] M. C. Oliveira, M. Iten, L. P. Cruz, and H. Monteiro. “Review on energy efficiency progresses, technologies, and strategies in the ceramic sector focusing on waste heat recovery”, *Ener.*, vol.13, no. 22, pp.1-24, Nov. 2020, doi: 10.3390/en13226096

[5] P. Kumari, R. Krishan, and L. K. Sharma. “Energy-efficient tunnel kilns with superlative firing atmosphere for ceramic industries”, *Inter.*

Jour. of Innov. Scie. Eng. and Tech., vol. 2, no.7, pp. 588-590, Jul. 2015.

[6] G. Cantore, M. Milan, L. Montorsi, and F. Paltrinieri. “Energy efficiency analysis of an entire ceramic kiln: A numerical approach”, *Mod, Measure. and Cont. B.,* vol. 87, no. 3 pp. 159-166, May, 2018, doi: https://doi.org/10.18280/mmc_b.870307

[7] V. Plesu, J. S. Puicasas, G. B. Surroca, J. Bonet, A. E. B. A. Ruiz, and J. L. Tuluc. “Process intensification in biodiesel production with energy reduction by pinch analysis”, *Ener.*, vol. 79, pp. 273-287,Jan.2015, doi: 10.`1016/j.energy.2014.11.013

[8] S. Bandyopadhyay and N. B. Desai. “Cost optimal energy sector planning: A pinch analysis approach”, *Jour. of Clea. Prod.*, vol. 136, pp. 246-253, Nov. 2016, doi: https://doi.org/10.1016/j.jclepro.2016.03.077

[9] K. O’Reilly and J. Jeswiet. “Improving industrial energy efficiency through the implementation of waste heat recovery systems”, *Trans.-Can. Socie. for Mech. Eng.*, vol. 39, no. 1, pp. 125-136, Sep. 2014, doi:10.1139/tcsme-2015-0010

[10] M. Fiehl, J. Leicher, A. Giese, A. Gomer, K. Fleischmann, and B. S. Spielmann, “Biogas as a co-firing fuel in thermal processing industries: Implementation in glass melting furnace”, *Ener. Prece.,* vol. 120, pp. 302-308, Aug. 2017, doi: 10.1016/j.egypro.2017.07.221

[11] C. W. Sinton. “Is there a place for renewable energy in ceramics? glass manufacturing,? *Amer. Cera. Socie. Bull.*, vol.84, no. 10, pp.18-22, Oct. 2015

[12] A. Mezquita, J. Boix, B. E. Monfort and G. Mallol. “Energy-saving in ceramic tile kilns: Cooling gas heat recovery, *Appl. Therm. Eng.l*”, vol. 65, no. 1-2. pp. 102-110, Apr. 2014, doi: https://doi.org.10.1016/j.applthermaleng.2014.01.002

[13] D. E. Winterborne *Advanced thermodynamics for Engineers* Cambridge, UK: Butterworth-Heinemann, 1997.

[14] O.S. Adelabu, T.P. Ologunwa and T.L. Akinbogun. “Challenges of glazed-ceramic production in Nigeria from materials to methods”. *Asha. Jour. of Ceram.,* vol. 10, pp. 24-36. Jun. 2013. https://www.researchgate.net.3033

[15] N. I. H. A. Aziz, M. M. Hanafiah and S. H. Cheewala. “A review of life cycle analysis of biogas production: challenges and future perspectives in Malaysia”, *Biom. and Bioen.,* vol. 122, pp.361-374, Mar. 2019, doi: https://10.1016/j.biobioe.2019.01.047

[16] P. Garcia-Gutierrez, J. Jacquemin, C. MacCrellis, I. Dimitriou, S. F. R. Taylor, C. Hardacre, and R. W. K. Allen. “Techno-economic feasibility of selected CO_2 capture process from biogas stream using ionic liquids as physical absorbents”, *Ener. and Fuels*, vol. 30, no. 6 pp. 5052-5064, May, 2016, doi: https://doi.org/10/1021/acs.energyfuels.6b00364

[17] Y. Gao, J. Jiang, Y. Meng, F. Yan, F. Yan, and A. Aihemaiti. “A review of recent developments in hydrogen production via biogas dry reforming”, *Ener. Conver. and Manag.,* vol. 171, pp. 133-155, Sep. 2018, doi: 10.1016/j.enconman.2018.05.083

[18] E. Alper and O. Yuksel. “CO2 Utilization: Developments in conversion processes”, *Petro.,*vol. 3, no. 1, pp. 109-126, Mar. 2016, https://doi.org/10.1016/j.petlm.2016.11.003

[19] United Nations Industrial Development Organization. *Handy Manual on Energy Conservation in Ceramic Industry.* Accessed: October 10, 2021 [Online]. Available: http://portalcdi.mecon.gov.ar)

[20] P. A. Nwofe and P.E. Agbo. “Enhancement of biogas yield from cowdung and rice husk using guano as nitrogen source”, *Inter. Jour. Of Sustain. and Gre. Ener.,* vol. 4, pp. 66–72, Jan. 2015, doi: 10.11648/j.ijrse.20150403.11

[21] F.L. Olsen. *Kiln Book: Materials, Specifications, and Construction*. Iola, USA: Krause Publication, 2001.

[22] N. H. S. Ray, M. K. Mohanty and R. C. Mohanty. “Water scrubbing of biogas produced from kitchen wastes for the enrichment and bottling in LPG cylinder for cooking applications”, *Inter. Jour. of Innov. Scie., Eng. and Tech.,*vol. 2, no.5 pp. 45-53, May, 2021

[23] M. Imran, H. A. Muhammad, F. Sher, M. Farooq, Y-J. Balik and Z. Rehman. “Exergoeconomic optimization of a binary geothermal power plant”, in thermodynamic analysis and optimization of geothermal plant *Else. Pp.* 315-326, Jan. 2021.

[24] R. S. Gomez, T. R. N. Porto, H. L. F. Magalhaes, G. Moreira, A. M. M. C. N. Andre, R. B. F. Melo and A. G. B. Lima. “Natural gas intermittent kiln for the ceramic industry: A Transient thermal analysis”, *Ener.,* vol.12, no. 8, pp.1568, 2019, doi:10.3390/en12081568.