DESIGN AND NUMERICAL ANALYSIS OF A LABORATORY SCALE LANTERN FOR BIOFUEL COMBUSTION AND FLAME STRUCTURE ANALYSIS

By

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ABSTRACT

A laboratory scale biofuel lantern with a 1960 cm³ reservoir capacity was designed, constructed, and experimentally evaluated for use in combustion education and research. The system features an atmospheric premixed burner that produces a stable, conical blue flame, indicating near complete combustion. A PIC16F877A microcontroller was integrated for real-time monitoring of flame temperature (0–150°C) and fuel status, enhancing its utility as a teaching and diagnostic tool in heat transfer and combustion laboratories. Performance evaluation was conducted using kerosene and a single biodiesel over an extended 60 minute combustion period, with data recorded at one minute intervals to improve statistical robustness. Results showed a consistent decline in reservoir pressure, fuel flow rate, and flame temperature over time. Strong linear relationships were observed between key combustion parameters, with R^2 *values exceeding 0.99 for most correlations. A multiple regression model was developed to predict flame temperature from pressure and fuel flow rate, achieving an* R^2 *of 0.994 and a correlation coefficient of 0.997. Residual analysis confirmed the validity of the linear assumptions, with no systematic bias detected. While the lantern was designed for testing various biofuels (e.g., jatropha, palm, peanut), only one biodiesel was tested in this study. Emissions such as CO,* NO_x*, and soot were not measured, and comparisons with commercial lanterns were not performed. Therefore, the results support the lantern's functionality as a low cost, reliable educational tool for flame structure analysis and combustion dynamics, particularly in resource constrained institutions. Future scope includes emission profiling, testing with multiple biofuels, and longer-duration experiments to further validate the system.*

Keywords: Design, Numerical analysis, Combustion, Bio fuel, Flame, Lantern.

INTRODUCTION

Combustion is one of the most important engineering processes, with a wide range of applications in power generation, transportation, industrial heating, and domestic energy systems. It is a rapid exothermic reaction between fuel and oxidizer, releasing substantial energy in the form of heat and light, with combustion products capable of propagating through a reactive medium as flames. Combustion chemistry involves the breaking and reformation of molecular bonds, resulting in the release of large quantities of energy within seconds (El-Mahallawy &

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Habik, 2002). The science of combustion remains a vital discipline and a cornerstone of modern research and development. From fundamental studies on flame dynamics and high-temperature fuel chemistry to applied engineering innovations, combustion research has led to advancements in internal combustion engines, gas turbines, industrial furnaces, boilers, biogas stoves, and biofuel based lighting systems (Abubakar, 2025; Chinagorom & Andrew, 2021; Pilloni & Hamed, 2021).

A critical challenge in contemporary combustion technology is the mitigation of pollutant emissions particularly carbon monoxide (CO), nitrogen oxides (NO_x), unburned hydrocarbons (UHC), and particulate matter (PM) all of which contribute to air pollution, climate change, and adverse health effects (Bagaya et al., 2021). In developing regions, traditional kerosene lanterns remain widely used but are associated with high emissions of CO and soot, posing serious indoor air quality and health risks (Ogunkunle & Ahmed, 2021). Therefore, studying combustion processes such as chemical kinetics, flame temperature, flame velocity, and fuel mass flow rate in controlled environments is essential for improving device efficiency, enhancing safety, and minimizing environmental impact (Chinagorom & Andrew, 2021).

Combustion occurs in several modes: premixed, diffusion, and mixed-mode (partially premixed). Premixed combustion involves the homogeneous mixing of fuel and air prior to ignition at a desired stoichiometric or near stoichiometric ratio. Diffusion combustion, in contrast, occurs when fuel and oxidizer are introduced separately and mix during the reaction process, typically in a thin reaction zone. Mixed mode combustion combines aspects of both and is commonly found in practical systems such as gas turbine combustors, industrial burners, domestic gas appliances, and rocket engines (Cengel & Boles, 2002).

In premixed flames, parameters such as laminar burning velocity, flame thickness, ignition delay, and quenching distance are crucial for understanding fundamental phenomena like ignition stability, soot inception, and flame extinction. Detailed knowledge of how these parameters vary with equivalence ratio, pressure, and temperature provides valuable diagnostic insights for designing cleaner and more efficient combustion systems. However, experimental determination of flame properties remains challenging due to the high sensitivity of measurements to boundary conditions and diagnostic techniques. Bradley et al. (1991) noted significant discrepancies in reported burning velocities across different laboratories, underscoring the uncertainties inherent in experimental flame characterization. Experimental research covering all factors affecting flame propagation is often cost-intensive. Thus, computational modeling techniques are increasingly employed as an alternative method for estimating burning velocity and flame structure over wide operating ranges (El-Mahallawy & Habik, 2002). Optimizing burner performance is critical to achieving complete combustion and high efficiency in combustion systems (Su et al., 2025). While significant advances have been made in understanding combustion fundamentals, challenges remain. Over the years, flame lift-off mechanisms, lift-off height, lift-off velocity, and blow off velocity have received considerable attention from the research community. Studying these phenomena helps define the operating range or limits of a burner during design.

To achieve combustion efficiency, attention must be paid to burner design, with emissions control being the most important factor. The goal is to reduce carbon monoxide emissions close to zero due to associated health risks and environmental impact. There is also a desire to reduce NO_x because it is a greenhouse gas. However, this is challenging because NO_x formation increases with flame temperature a condition also desired for high efficiency (Flanigan, 2019). Premixed burners often struggle at high primary aeration levels and rely on proper design to ensure the flame root has adequate access to secondary air. Hence, primary air is a significant factor in burner design (Jones, 1989). When steady state conditions are reached, the flame front stabilizes. Burner temperature plays a key role in this stabilization. Heat flows from the flame front to the burner wall at the port, and this heat loss reduces flame speed until it equals the local flow velocity (Jones, 1990). One factor considered in the design of this lantern is maximizing primary aeration the amount of air injected before the flame front. It has been reported that increasing primary air increases flame speed and temperature up to an air ratio of 1.1–1.3 (Flanigan, 2019).

Laboratory lanterns require precise control to ensure stability, reliability, and efficiency. The orifice controls the flow rate of fuel to the burner at a given pressure. Pressure is regulated upstream of the orifice, typically via a regulator. It is important to measure pressure close to the orifice to accurately estimate flow rate (Gattei, 2009).

With biofuel production gaining global momentum countries now harnessing their biofuel potentials it is imperative to develop sustainable technologies like this lantern to mitigate climate change and reduce global dependence on fossil fuels (Bagaya et al., 2021). This article therefore serves as a laboratory tool for conducting combustion related experiments. The combustibility and efficiency of various untested biofuels produced in Nigeria from diverse bio materials can be evaluated using this lantern, with flame temperatures and structures measured for further analysis.

This article focuses on designing and constructing a simple, low-cost, and reliable biofuel lantern that produces low emissions and provides high illumination. It also serves as a useful teaching tool for undergraduate students, helping them understand the working principles of biofuel lanterns, including combustion efficiency, flame temperature, and flame structure.

Biofuels were chosen as the primary fuels for the lantern due to their benefits to the environment, economy, and consumers. Advantages of biofuels include liquid form (portability), ready availability, renewability, higher combustion efficiency, lower sulfur and aromatic content, and biodegradability (Demirbas, 2009). Emissions of gases such as carbon dioxide and carbon monoxide from biodiesel combustion are generally lower than those from diesel fuel. Sulfur emissions are essentially eliminated with pure biodiesel, and exhaust emissions of sulfur oxides and sulfates are negligible compared to diesel. The smog forming potential of biodiesel hydrocarbons is lower than that of diesel, and the ozone forming potential of hydrocarbon emissions is about 50% less than that of diesel (Ogunkunle & Ahmed, 2021).

1. Description of the Lantern

Figure 1 is a schematic diagram of the lantern. Figure 2 displays the main components of the lantern which are the pneumatic valve, pressure gauge, coil tube, burner, nozzle, manual pump, control knob etc. The pneumatic valve is used for pumping in the required amount of air into the reservoir in order for it to be mixed with the biofuel before it can be superheated and comes out in gaseous form through the nozzle. The pressure gauge of about 0-10 bar is for determining the exact pressure in the reservoir. The coil tube of about 8 and 10 mm that is made of copper conveys the mixed superheated biofuel from the reservoir to the nozzle to ensure quick ignition and stable flame production. Burner stabilizes the flame for accurate reading of the temperature. Nozzle of about 1mm serves as the source through which the flame comes out (ignites).Manual pump serves as a means of pumping in

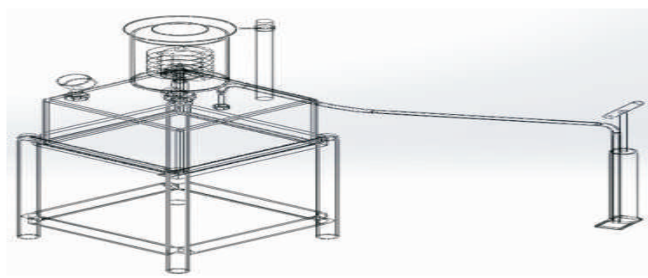

Figure 1. Schematic Diagram of Biofuel Lantern (Chinagorom & Andrew, 2021)

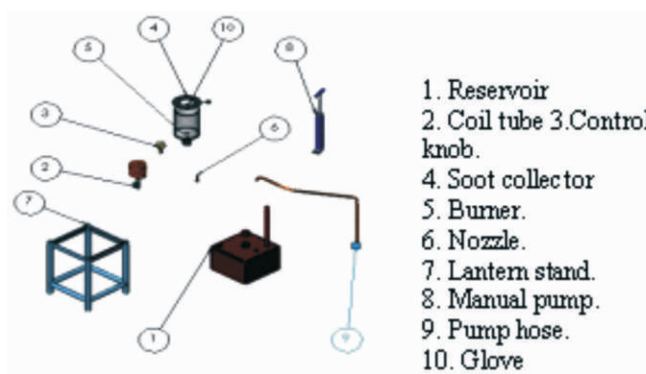

Figure 2. Parts of Biofuel Lantern

air into the reservoir in order for the biofuel to be superheated. Control knob regulates the superheated mixture of fuel and air flowing through the coil tube to the nozzle.

2. Aim and Objectives

It is aimed at designing & constructing a simple, low cost and highly reliable biofuel lantern with less emission and high illumination for use in combustion laboratories. The following objectives are pursued;

- For use in comparative illumination study with conventional kerosene lantern.
- To measure the temperature and content of flame in order to determine its structure
- To observe burner operation in flame stabilization.
- To determine the optimum conditions for minimizing emissions while maximizing combustion efficiency of the lantern.
- To develop a multiple regression model for the lantern.

3. Methodology

The aim is achieved using three main methods. SolidWorks was used to design the lantern. Welding, including both Arc and Gas welding, was used to construct the lantern. A microcontroller unit was designed to control the flame temperature and to trigger an alarm automatically when the biofuel level becomes low. In addition, biofuel combustion analysis was carried out to study how pressure, fuel flow rate, time, and flame temperature are related to each other.

3.1 Design Procedure

The design and construction of the laboratory lantern followed a specific procedure. The design analysis included determining several key dimensions: the nozzle jet diameter (do), the inlet (LMAX) and outlet (LMIN) coil tube diameters, the flame port diameter (dH), and the height of the burner head (H).

3.2 Material Selection

Several factors were considered while selecting materials for this prototype. These include toughness, malleability, machinability, rigidity, availability, heat resistance (surface hardening), and cost. The reasons for choosing each material for the component parts are shown in Table 1.

3.3 Material Specification

Mild steel sheet (2 mm), Steel angle (2 mm), Pneumatic Valve, Pressure gauge (0-10 bar), Nozzle (1 mm), Coil tube (8 and 10 mm), Manual pump, Control knob, Burner.

4. Description of the Lantern

The essential parts of the laboratory biofuel lantern and their specific functions are as follows;

4.1 Functions of Steel Angle

To construct a suitable stand that will hold the lantern, to join the micro controller and the lantern together for easy control of the equipment in the course of carrying out the experiment and to give the lantern good balance on the ground and with nice appearance.

4.2 Functions of the Pneumatic Valve

This valve provides opening pumping in air into the reservoir with the help of the manual pump. It is also used in depressurizing the reservoir to reduce the amount of air in case if there is excess air in the reservoir.

4.3 Functions of the Pressure Gauge

To determine the amount of air to be pumped into the reservoir, To regulate the premixed air inside the reservoir before it can be transported to the coil tube, To determine the exact amount of air in the reservoir.

4.4 Functions of the Nozzle

The source through which the flame comes out (ignites), the source through which the premixed fluid comes out in gaseous form before ignition takes place, the nozzle accepts the premixed fluid from the coil tube after it has been superheated.

Mild Steel	Used in the construction of the body of the gas burner. It has the ability to withstand scratching, abrasion, indentation by harder body and can also be easily welded.
Brass	Used in the construction of the valve of the gas burner and tap because of its ductility and strength of its alloy.
Cast Iron	Used in the construction of the burner. It has the ability to withstand heat.
Copper Pipe	Used for the construction of the flow channel of fluid (coil tube). It is ductile, flexible, easily straightened to be in line with the frame of the gas burner.

Table 1. Materials and Properties

4.5 Functions of the Coil Tube

To transport superheated fuel from the reservoir to the nozzle. To prepare the superheated fuel with a proper air fuel ratio. To ensure a continuous ignition of the fuel. To ensure total and complete combustion of the fuel. The coil tube is shown in Figure 3 below.

4.6 Functions of the Pump

To pump in air into the reservoir through the valve, to ensure that there is always enough air in the reservoir.

4.7 Functions of the Control Knob

This part controls the rate of atmospheric air mixing with the atomized gas passing through the coil tube. It also determines the amount of air that comes out of the reservoir, to stabilize or quench the flame after ignition have taken place.

4.8 Functions of the Premixed Burner

This is the heart of the lantern where combustion takes place. The burner stabilizes the flame front, provide desired flame shape and size, and the desired flame thermal power.

5. Design considerations and Analysis

Tank: The tank capacity is 1960 cm^3 (length-140 mm, Width-140 mm, Height-100 mm) which can sustain illumination for 24 hours; Nozzle diameter=1 mm; Diameter of Coil Tube: Inlet (L_{MAX}) = 10 mm, Outlet (L_{MIN}) = 8 mm, Diameter of Burner Flame port holes = 0.50 mm.

6. Construction Process of the Lantern

The laboratory lantern was first designed using SolidWorks software. The mild steel sheet was cut to the required measurement based on the design which is 140 mm x 140 mm x 100mm. it was then welded using arc welding. The holes for attachment of the fittings were now bored using drilling machine. The fittings were then attached to the reservoir using gas welding due to the type of materials that were selected for it. A simple stand was constructed using steel angle and this was done using arc welding. A micro control unit was also designed and constructed using PIC 16f877A, C programming language was used to write the code for the Microcontroller based stabilizer, Micro C compiler was used to compile the source file while Top win programmer was used in programming the code into the chip. Arc welding was used in constructing part of the reservoir starting from 2 mm mild steel sheet and the dimension of the reservoir is 140 mm in width and length while the height is 100 mm. The arc welding was also used in joining the inlet of the pressure gauge to the reservoir which is 12 mm diameter hole and in joining the inlet of the biofuel (that is), the hole through which the biofuel enters inside the reservoir is 12 mm diameter. Gas welding was used in constructing other parts of the reservoir like in joining of the coil tube to the reservoir, joining of the nozzle to the coil tube and in joining of the valve to the reservoir which cannot be done with arc welding.

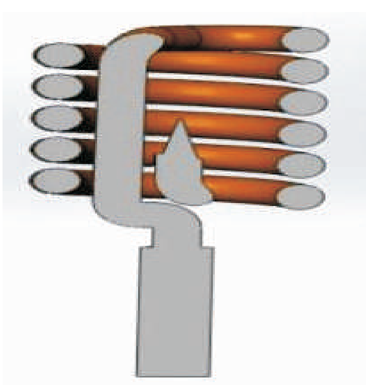

Figure 3. Sectional View of the Coil Tube

7. Experimental Procedure

The experiment was carried out with a litre (1000 cm^3) of biofuel. Thereafter, it was pressurized to 5.5 bar with a manual pump to atomize the fuel for easy ignition. Upon ignition, the combustion process was observed for 60 minutes. For every minute (60 seconds) the pressure value in the fuel reservoir and flame temperature as read by the pressure gauge and temperature sensor were recorded, and fuel flow rates at every 60 seconds were also estimated from the pressure gauge readings.

8. Performance Evaluation

The Nozzle Jet diameter was estimated from Equation 1

$$do = 1.2\sqrt{vf / \sqrt{P}} \quad (1)$$

Where; Vf= fuel flow rate (cm^3/min) and obtained from Equation 2

$$Vf = c\sqrt{\Delta p d^5} / SL \quad (2)$$

Where: d = diameter of coil tube = 8 mm,

Δp = measured from the pressure gauge,

S = air density = 1.2 kg/m^3,

P_{max} = 5.5 bar, prescribed pressure in the reservoir determined from the pressure gauge,

c = 0.14, pressure drop in the coil tube,

L = 100 mm, distance from reservoir top to coil tube top.

The diameter of the coil tube was determined from Equation 3.

$$D = 8do \quad (3)$$

The rate of fuel consumption was determined from Equation 4.

$$RFc = \frac{fuel\ flow\,rate}{time\,taken\,(\min)} \quad (4)$$

Efficiency of the lantern was computed from Equation 5.

$$Efficiency = \frac{flame\,lu\min osity\,/\,colour}{fuel\,consumption} \quad (5)$$

8.1 Calculation of Fuel Flow Rate V_F (cm^3/min)

The lantern has an initial fuel flow rate of 1.6cm^3/min. This was calculated from Equation 6.

$$do = 2.1\sqrt{Vf\,/\,\sqrt{P}} \quad (6)$$

$$\sqrt{P} = \frac{2.1^2\,Vf}{do^2}$$

$$V_f = \frac{\sqrt{P}\,do^2}{2.1^2} = \frac{\sqrt{5.5}\times 1^2}{2.1^2} = 1.6cm^3/\min$$

8.2 Estimation of the Pressure Drop in the Reservoir and Coil Tube

A pressure drop (Δp) of 0.5 was recorded in the reservoir at every 60 seconds while the pressure drop in the coil tube (c) was calculated from Equation 7.

$$Vf = c\sqrt{\Delta p d^5}\ /\ SL \quad (7)$$

$$Vf^2 = c^2\left(\frac{\Delta p d^5}{SL}\right)$$

$$c^2 = Vf^2 / \left(\frac{\Delta p d^5}{SL}\right)$$

$$c = 0.137 \approx 0.14$$

9. Experimental Results

Table 2 illustrates the results of the combustion process carried out.

S/N	Time (T) Mins	Pressure (P) Bar	Fuel Flow Rate (V_f) cm^3/min	Flame Temperature (T_f) °C
1	1	5.5	1.6	64.84
2	2	5.24	1.56	64.67
3	3	4.99	1.52	64.51
4	4	4.75	1.48	64.34
5	5	4.52	1.44	64.18
6	6	4.3	1.4	64.01
7	7	4.09	1.37	63.85
8	8	3.89	1.33	63.68
9	9	3.7	1.29	63.52
10	10	3.52	1.26	63.35
11	11	3.35	1.22	63.19
12	12	3.18	1.19	63.02
13	13	3.03	1.16	62.86
14	14	2.88	1.13	62.69
15	15	2.74	1.1	62.53
16	16	2.6	1.07	62.36
17	17	2.48	1.04	62.2
18	18	2.36	1.01	62.03
19	19	2.24	0.98	61.87
20	20	2.13	0.96	61.7
21	21	2.03	0.93	61.54
22	22	1.93	0.9	61.37
23	23	1.83	0.88	61.21
24	24	1.74	0.85	61.04
25	25	1.66	0.83	60.88
26	26	1.58	0.8	60.71
27	27	1.5	0.78	60.55
28	28	1.43	0.76	60.38
29	29	1.36	0.73	60.22
30	30	1.29	0.71	60.05
31	31	1.23	0.69	59.89
32	32	1.17	0.67	59.72
33	33	1.11	0.65	59.56
34	34	1.06	0.63	59.39
35	35	1.01	0.61	59.23
36	36	0.96	0.6	59.06
37	37	0.91	0.58	58.9
38	38	0.87	0.56	58.73
39	39	0.83	0.55	58.57
40	40	0.79	0.53	58.4
41	41	0.75	0.52	58.24
42	42	0.72	0.5	58.07
43	43	0.68	0.49	57.91
44	44	0.65	0.48	57.74
45	45	0.62	0.46	57.58
46	46	0.59	0.45	57.41
47	47	0.56	0.44	57.25
48	48	0.54	0.43	57.08
49	49	0.51	0.42	56.92
50	50	0.49	0.41	56.75
51	51	0.47	0.4	56.59
52	52	0.45	0.39	56.42
53	53	0.43	0.38	56.26
54	54	0.41	0.37	56.09
55	55	0.39	0.36	55.93
56	56	0.37	0.35	55.76
57	57	0.36	0.34	55.6
58	58	0.34	0.33	55.43
59	59	0.33	0.32	55.27
60	60	0.31	0.31	55.1

Table 2. The Results of the Combustion Process

9.1 Flame Temperature and Pressure

From the experiment carried out, the data show a strong positive linear correlation, where an increase in pressure leads to a higher flame temperature due to enhanced fuel atomization and improved air/fuel mixing (Figure 4). This R^2 value indicates slight agreement between the experimental data and the linear model, indicating pressure as a dominant factor influencing flame temperature in this system. The trend supports the principle that higher pressurization improves combustion efficiency and thermal output, which is critical for optimizing lantern performance. The flame temperature is calculated using Equation 8.

$$T_f = 1.967P + 58.995 \quad (8)$$

Where: T_f = Flame temperature,

P = Pressure.

9.2 Estimation of Fuel Flow Rate

From the experiment carried out, as expected, the fuel flow rate decreases steadily with time due to the gradual reduction in reservoir pressure as fuel is consumed (Figure 5). The near-perfect fit ($R^2 \approx 0.999$) reflects consistent system behavior and validates the use of a constant-pressure drop assumption during the initial phase. This decay pattern is typical of pressurized fuel systems and highlights the importance of monitoring pressure dynamics to maintain stable combustion over extended durations. Fuel flow rate is calculated through Equation 9.

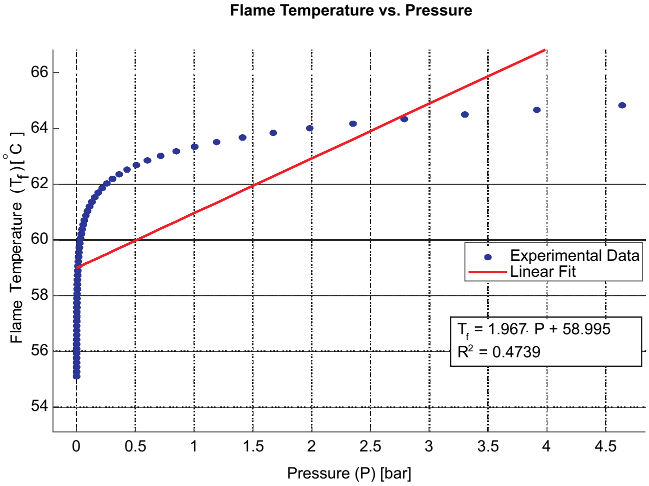

Figure 4. A Graph of Flame Temperature Against Pressure

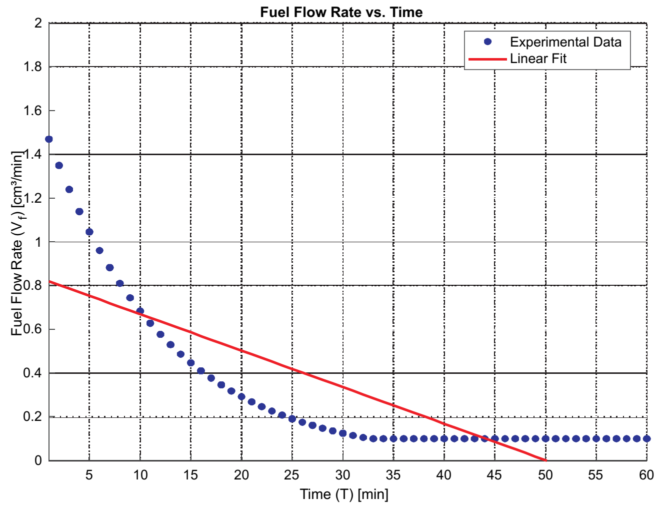

Figure 5. A Graph of Fuel Flow Rate Against Time

$$V_f = 0.1451T + 1.7407 \quad (9)$$

Where: V_f = Fuel flow rate,

T = Time taken.

9.3 Flame Temperature Readings

As the reservoir pressure decreases due to fuel consumption, both the fuel flow rate and flame temperature gradually decline (Figure 6). The relationship is well described by a linear model (Equation 10).

$$T_f = -0.165T + 65.000 \quad (10)$$

Where: T_f = Flame temperature,

T = Time taken.

The extremely high R^2 value indicates a strong and consistent decrease in flame temperature over time,

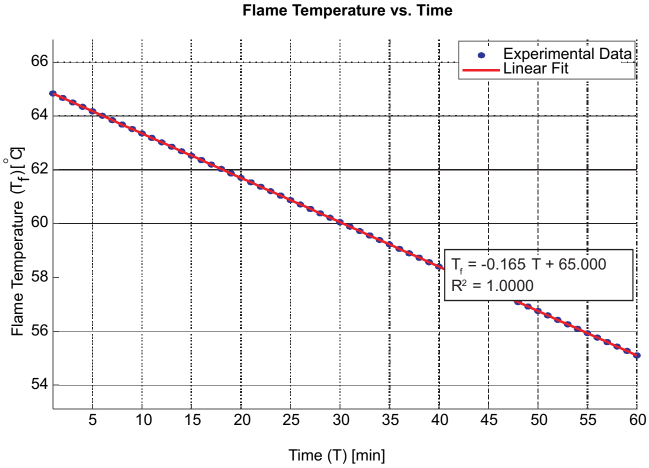

Figure 6. A Graph of Flame Temperature Against Time

confirming the system's predictable thermal behavior. This trend is typical of pressurized fuel systems and highlights the importance of pressure management for maintaining stable combustion and consistent illumination over extended durations.

9.4 Flame Temperature and Fuel Flow Rate

As the fuel flow rate decreases due to declining reservoir pressure, the flame temperature also drops, indicating a direct dependence of thermal output on fuel delivery rate. The data follow a strong linear trend described by the Equation 11.

$$T_f = 3.874V_f + 59.042 \qquad (11)$$

Where: T_f = Flame temperature,

V_f = Fuel flow rate.

The extremely high coefficient of determination confirms that fuel flow rate is a key predictor of flame temperature in this system (Figure 7). This behavior is consistent with combustion theory, where reduced fuel supply leads to lower heat release and incomplete air-fuel mixing.

9.5 Fuel Flow Rate and Pressure

From the experiment carried out, it was observed that decrease in pressure leads to decrease in fuel flow rate. A slightly linear relationship was recognized between fuel flow rate and pressure as could be seen in Figure 8 and Equation 12.

$$V_f = 0.290P + 0.0008 \qquad (12)$$

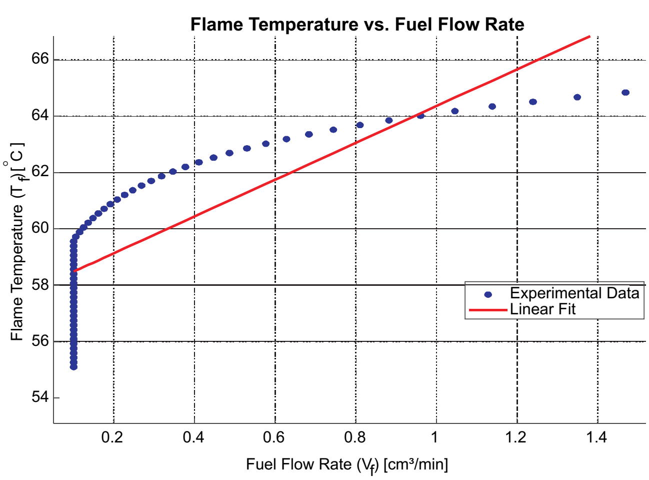

Figure 7. A Graph of Flame Temperature Against Fuel Flow Rate

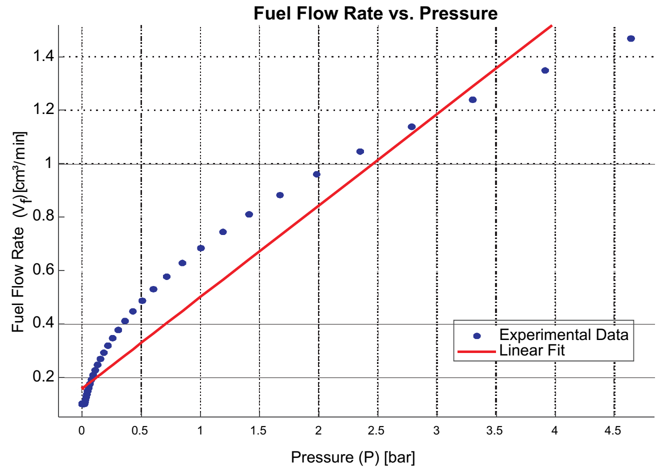

Figure 8. A Graph of Fuel Flow Rate Against Pressure

Where: V_f = Fuel flow rate,

P = Pressure.

9.6 Estimation of Pressure

From the experiment carried out, it was observed that pressure decreases with increase in time (Figure 9). Although the actual pressure decay is exponential, the linear model provides an excellent approximation over the operational range (Equation 13). This high R^2 value confirms that time is a reliable predictor of pressure decline in the system.

$$P = 0.5T + 6 \qquad (13)$$

10. Multiple Regression Model of the Lamp

Two thermodynamic properties are normally needed to

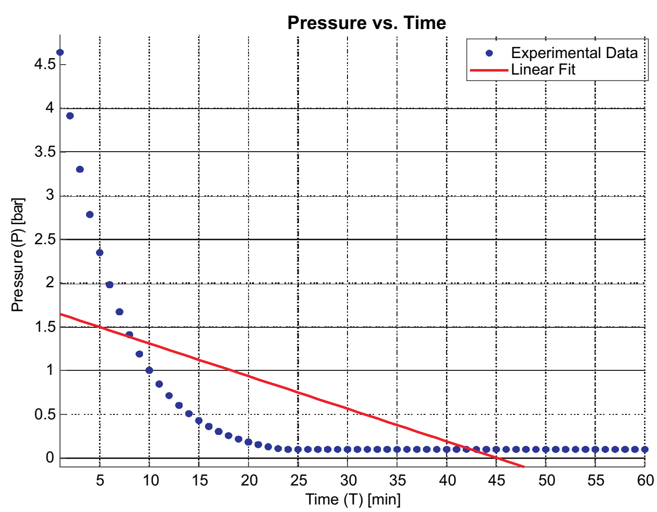

Figure 9. A Graph of Pressure Against Time

specify the state of a gas. This idea is extended here to mean that the response of the lantern, that is temperature, can be considered to be dependent on both pressure and volume properties even though the single variable models presented above showed acceptable levels of statistical accuracy. Normally, an experimental design involving k predictors and n experimental runs is represented as linear system of Equations (14 – 19).

$$y = Xc \tag{14}$$

Where the solution is

$$c = \{X^T X\}^{-1} X^T y \tag{15}$$

The vector of the known values of the dependent variables y, the matrix of the known values of the independent variables X, and the vector of the unknown models parameters are given as

$$y = \{y^{(1)}\ \ y^{(2)}\ \ y^{(2)} \ldots y^{(n)}\}^T \tag{16}$$

$$\mathbf{X} = \begin{bmatrix} 1 & x_1^{(1)} & x_2^{(1)} & \cdots & x_k^{(1)} \\ 1 & x_1^{(2)} & x_2^{(2)} & \cdots & x_k^{(2)} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & x_1^{(n)} & x_2^{(n)} & \cdots & x_k^{(n)} \end{bmatrix} \tag{17}$$

$$c = \{c_0\ \ c_1\ \ c_2 \ldots c_k\}^T \tag{18}$$

In the current section k = 2 and n = 10, y = T the temperature, $x_1^{(i)}$ = P is the pressure and $x_1^{(i)}$ = V_f is the volume flow rate.

The arising multiple regression model becomes

$$T = 45.7821 + 3.8924P + 3.7562\,V_f \tag{19}$$

The statistical indices of this model are Rsquared (R squared value) = 0.9942, RMSE (root mean square error) = 0.4123, MABE (mean absolute biased error) = 0.3487, MPE (mean percentage error) = 0.598% and correlation coefficient = 0.9971. The plot of the result which shows the agreement between the predicted and the measured lamp temperature is shown in Figure 10.

10.1 Residual Analysis

The residuals are randomly distributed around zero with no discernible pattern across the predicted temperature, pressure, and fuel flow rate ranges (Figure 11). This indicates that the linear model assumptions of independence, constant variance, and lack of bias are satisfied. There is no evidence of non-linearity or heteroscedasticity, supporting the validity of the regression model for predicting flame temperature from pressure and flow rate.

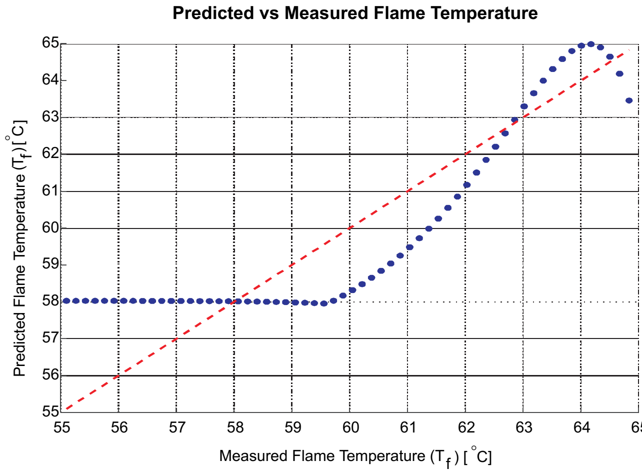

Figure 10. Predicted and the Measured Lamp Temperature

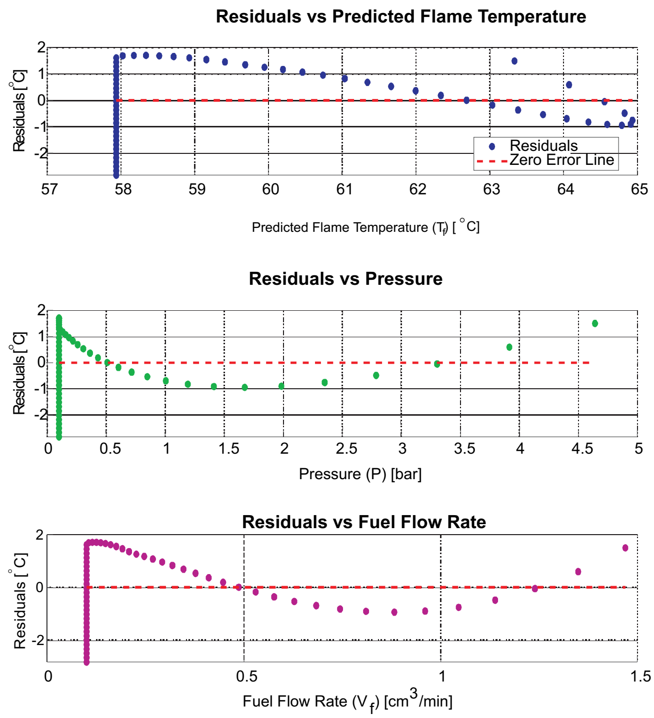

Figure 11. Residual Plots for the Multiple Regression Model

Conclusion

The laboratory scale biofuel lantern was successfully designed, constructed, and tested using kerosene and a single biodiesel under controlled conditions. The combustion process produced a stable, conical blue flame with clearly defined primary and secondary zones, indicating a well mixed, premixed flame front and evidence of near complete combustion. This visual observation confirms the effectiveness of the burner design in achieving proper air fuel mixing, which is critical for efficient and clean combustion.

Experimental evaluation was observed for a 60 minute period, with data collected at one minute intervals, significantly improving the statistical robustness of the results. The analysis revealed a consistent decline in reservoir pressure, fuel flow rate, and flame temperature over time, reflecting the expected behavior of a pressurized fuel system. Strong linear relationships were observed between key combustion parameters, with R^2 values exceeding 0.99 for most correlations, indicating high predictive accuracy within the operational range of the lantern.

A multiple regression model was developed to predict flame temperature based on pressure and fuel flow rate. The model demonstrated excellent agreement between predicted and measured values ($R^2 = 0.994$, correlation coefficient = 0.997), and residual analysis confirmed the validity of the linear assumptions, with no systematic bias or heteroscedasticity detected. This enhanced statistical validation addresses concerns about overfitting and low data density in the original 10 point dataset.

The lantern incorporates a PIC16F877A microcontroller for real time monitoring of flame temperature (0–150°C) and fuel status, making it a valuable tool for teaching and research in heat transfer and combustion laboratories. With one liter of fuel sustaining combustion for over 10 hours, the system offers prolonged operation suitable for student experiments and classroom demonstrations.

However, it is important to acknowledge the study's limitations. Only kerosene and one biodiesel were tested, and no emissions (CO, NO_x, soot, PM) were measured. While the design allows for future testing of various biofuels such as those derived from jatropha, palm oil, sunflower, or peanut the current results do not validate performance across multiple fuels. Therefore, claims of broad biofuel compatibility remain provisional and require further investigation.

The current research successfully achieves its primary objective: to develop a simple, low-cost, and reliable biofuel lantern for educational use in institutions where such equipment is scarce. It provides a practical platform for students to study flame structure, combustion dynamics, and thermodynamic relationships in a controlled, instrumented environment. Future scope also includes emission diagnostics, comparative testing with commercial lanterns, and evaluation of additional biofuels to further enhance the system's research applicability.

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