

# Formulation, Classification and Combustion Models of Ethanol Fuel Gel with an Open Chamber Stove.

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**Abstract:** *The continuous increases in global oil prices, forest depletion, and mounting electricity bills have induced a growing interest in the use of accessible alternative energy for cooking in recent years. This has sparked interest in the development of the Ethanol Fuel Gel as a replacement for fossil and wood fuels for cooking. A fuel gel composed of ethanol, neem oil, ethyl hydroxyl-ethyl cellulose, sodium chloride, and water were formulated by a standard method with selected preliminary analysis that declared the nature of its pH, viscosity, turbidity, ignition temperature, and calorific value. The fuel gel practically exhibits a decreased evaporation rate of the active ethanol by slow, even, and consistent burning. The FT-IR, the combustion performance, flame stability and linear mathematical models of the fuel gel were established through an improvised open dimension aluminum appliance. Conclusively, chemically modified ethanol fuel stands to be one of the most cost-effective and safe fuel alternatives for domestic usage.*

**Keywords**— Ethanol, fuel gel, neem oil, hydroxyl-ethyl cellulose, combustion, viscosity

## 1.0 INTRODUCTION

Energy is an essential component of human endeavors, especially in the areas of health, industrial and agricultural processes. On average, man utilizes almost 2,500 kcal of energy daily with a strong correlation between individual energy consumption and prosperity among different societies [1]. "Bio-energy," a usable energy packet from organic biomass, is currently the most frequently used of all renewable energy technologies domestically, accounting for almost two-thirds of all renewable energy used globally [2,3,4]. Consequently, there are important benefits to be gained from growing attention to contemporary bio-energy facilities, as the availability of adequate clean energy is imperative in basically reducing the effects of pollution and its harmful effects through the recycling of biomass products. International communities have increasingly recognized alcohol fuel as a clean liquid fuel solution for the future [5]. In basic applications where clean-burning, environmental security, and ease are essential, ethanol-based gel fuel is relatively famous and suitable [5].

Ethanol is an innately cheap fuel that can be produced at a scale that meets societal demand because it can be generated from several low-cost, sugar feedstocks. For example, ethanol is sourced from the government-owned Sugar Corporation in Ethiopia to cover the cooking needs of thousands of homes and the stoves have proven to be effective, especially in humanitarian situations where the energy required for heating is in high demand with limited resources [6].

Ethanol is a chemical compound, also known as ethyl alcohol, constituted of carbon, hydrogen, and oxygen; like any other organic compound, it reacts with molecular oxygen, producing carbon dioxide and water.

This oxidation process is a combination of several chemical reactions with exothermic effects, which qualifies it as a fuel in many applications. It is a clear, combustible liquid with a smokeless blue flame that is not always noticeable in daylight [7].

Ethanol gel fuel is ethanol in the form of a gel that has been reinforced with a thickening agent to make it gelatinous and safer to manage. One of the key advantages is the flexible distribution in a compartment without leakage. However, this

property makes it impossible to precisely manage the energy output of the stove appliance. Advantageously, small amounts of coloring and denaturing agents are added to improve the visibility of the flame and to prevent excessive consumption of the fuel [7,8]. As a result, making fuel from locally available raw materials is the most cost-effective and safe fuel available to occupants of informal housing and the poor.

As the world's oil and gas output are approaching their maximum levels, the global quest and hunt for possible fossil-fuel replacements has become critical [9]. In other words, renewable, feasible, effective, and lucrative energy resources with zero emissions would be perfectly represented in this regard.

Jyoti *et al.*, 2017 compiled and analyzed imageries from a photron high-speed camera to investigate the hypergolicity of gelled ethanol biofuel blends with nanocatalysts particle substitutions, with ignition delays of 1 to 30 milliseconds. The bond energy of the ethanol gel, with the nature of liquid hypergolic bipropellant systems in relationship with an active and dynamic combination system with a shear rate characteristic, was estimated to be between 7 to 13 kJ per mole. In the experiment, factors such as the fuel's observed viscosity, drop altitude, and quantity dictate the hypergolicity of the entire system. The construction of a cage containing the high-temperature gases in a network created by the gelling agent was also mentioned as having the potential to lengthen the ignition delay [10].

Okusanya *et al.*, 2019 declared a growing interest in the use of more accessible alternative energy for cooking. It consists of a stainless-steel combustion chamber, a seat for the pot, and an air inlet portion controlled by a choke adjustment. When compared to existing records on cook stoves using fossil goods and fuel woods, the results of its evaluation reveal greater performance. Cooking tests with the gel stove and kerosene stove revealed a 1 minute and 20 g/l difference in cooking time and specific fuel usage, respectively. As a result, the Ethanol gel cook-stove, a sustainable energy product, will be important as long as the world seeks to address fossil reserve exhaustion and shows concern for greenhouse gases [11].

Similarly, according to Az-Zahra *et al.*, 2019, bioethanol gel can be generated by hydrolyzing sugar cane waste and fermenting it with *Saccharomyces cerevisiae* for four days, yielding a 95 percent grade bioethanol gel. Carbopol was added to bioethanol made from sugar cane waste as a thickening agent, resulting in bioethanol gel.

The best result was found with a carbopol 1,8 g and NaOH 1 mL variation, which resulted in a flowing gel. Flare time of 237 seconds, the residual component of 0.03 g, 25 kJ/kg calorific factor, and 5 g of ethanol were properties of the fuel gel [12].

The fuel gel's stability and flame color were tested using 5 grams of sample gel in a porcelain dish and subsequently

Feng *et al.* 2018 published a paper in 2004 about the possibilities of ethanol gel fuel as a clean, renewable, and low-cost domestic cooking fuel in African countries with the discussion on the "Millennium Gel Fuel Initiative (MGI)," a collaboration between the public and commercial sectors in Africa coordinated by the World Bank's RPTES Program. The options of encouraging rural, agricultural, and agro-industrial advancement as well as poverty alleviation in the African continent by instigating ethanol production programs are discussed, along with a conceptual development model. Following that, the study discusses three important implementation concerns: the context-specific character of bio-energy production systems, the "fuel vs. food issue," and the scale-up challenge.

The study finishes with a summary of a proposed implementation structure, which includes the private sector's, governments', and other stakeholders' roles [13].

Lee *et al.* (2018) used 10 wt.% methylcellulose as a gellant in liquid ethanol to examine the autoignition point of an ethanol gel droplet. The evaporation, ignition and combustion characteristics of a gel droplet hinged on a K thermocouple were assessed and compared to pure ethanol at ambient temperatures of 600, 700, and 800 °C under atmospheric pressure circumstances. A linear decrease in droplet diameter was seen multiple times before igniting, followed by a fast increase due to evaporation and swelling processes, respectively. The combustion duration accounts for 31 percent at 800°C, 88 percent at 700 °C, and 93 percent of the gel droplet activity at 600°C [14].

In this context., standard formulated ethanol fuel gel was evaluated for its properties, combustion characteristics, and the models of interaction with the identified combustion parameters.

## 2.0 MATERIALS AND METHODS

860ml of ethanol and 90ml of neem oil were mixed in one-liter glass beaker with agitation using a mechanical stirrer and a simultaneous addition of the required aqueous sodium chloride. Under standard atmospheric conditions, 30g of ethyl hydroxyl ethyl cellulose was added portion-wise under continuous agitation, until the formation of a stable homogenous gel under standard atmospheric conditions. The gel was kept in an airtight glass container for subsequent physicochemical characterization [15] of the fuel gel with respect to pH [16], turbidity [17], viscosity [18], auto-ignition temperature [19], calorific value [20] and FTIR [21].

The rates of combustion were evaluated with the direct ignition of 5, 10, 15, 20, 25, and 30g of the formulated fuel gel within the exposed stove for the corresponding period of seconds.

burned as the nature of the color and flame were observed and recorded [12].

## 3.0 RESULTS AND DISCUSSION

Table 1. Formulation of the cooking fuel gel

Ethanol	Water	Neem Oil	EHEC (Ethyl Hydroxyl-Ethyl Cellulose)	NaCl (g/20ml)	Reference
200 L	40L	20L	7kg	10.00 g	[15]
860ml	170ml	90ml	30g	0.04 g	This study
<b>Open stove aluminum sheet chamber</b>					
Diameter (cm)	Radius (cm)	Height (cm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )	
d	r	h	$\Pi r(2r + h)$	$\Pi r^2(h)$	
6.50	3.25	4	107.25	132.79	

Table 2. Physicochemical properties of the fuel gel

Property	Value
Viscosity (cP)	3,680
Turbidity (NTU)	350
pH	4.8
Ignition temperature (°C)	26
Calorific value (KJ/Kg)	33,064.25

Generally, the active flammable components of a fuel gel are alcohols stabilized with a gelling agent. The gels are clean burning with relatively little soot, a low toxicity level, and combustion by-products [22]. In the course of this formulation, as stated in Table 1, the proportions of constituents were manipulated to achieve a composition with the desired consistency and viscosity.

Typically, a suitable gelling agent such as Ethyl Hydroxyl-Ethyl Cellulose (EHEC) is expected to induce an in-situ gel structure in a mixture with alcohol towards the desired properties. Technically, over 5% of the entire formulation is needed to prepare a significantly viscous and stable gel with the effects of a reduced rate of evaporation [23]. As well, the presence of natural glycerides and triglycerides, which is neem oil in this case, will practically raise the flash point of the entire fuel gel in contrast to the formulation without. It was established that the presence of this oil reduces the evaporation rate and flammable volatile fractions of the gel [24]. Also, the film surface tension of the gel, irrespective of any theory, will be enhanced by the indirect formation of a layer that could slow down the evaporation rate of the flammable components in the presence of natural triglycerides [25].

Additionally, a congealing agent may also be required to enable the gel to develop a robust structure. Most often, the agent, which is water with 0.5% to 30% by weight of the gel, is infused in the formulation. However, it is an advantage of the fuel gel to retain a low proportion of the congealing agent with the fact that; they are not flammable, therefore requiring more energy to burn and vaporize [26].

Acidic or alkaline gels have the disadvantage of increasing rates of corrosion of gel storage containers and toxic environmental discharges. Therefore, a pH modifying agent

such as sodium chloride of 0.5 to 1.5% by weight is necessary [27]. The formulated gel generated some specific properties in Table 2, which are the direct factors of performance in terms of the combustion rate with the experimental conditions. The viscosity was conducted with the DV3TRVTJO Brookfield Rheometer at a speed of 50rpm, 26.2°C, and torque of 18.4% with the RV-06 (6) spindle for 47 seconds. Understanding the dependence of gel rheology on temperature is critical when determining its operating temperature and limitations. A value as high as 3,680cP justifies the level of stability during the combustion process.

The nature of the turbidity reflects the homogeneity of the gel with respect to its components. The acidic pH of the gel is a favorable condition that enhances its formation and stability under the specified conditions. The ignition temperature was determined at atmospheric pressure and the ambient temperature was around 27°C. Calorific value is the amount of heat energy stored in fuel produced through combustion reactions. The higher the calorie value possessed, the better the quality of fuel and the higher the combustion efficiency.

In this test, the formulation was measured across the length of ignition. The value obtained with the Bomb Calorimeter is closely related to the composition of carbon bound to the fuel. The higher carbon bound gives a higher calorific value [28,29]. The ethanol gel was charred in a calorimeter where the combustion product is then cooled again to reach room temperature, while the energy used to cool combustion products is equivalent to the energy available in fuel. From the results above, the fuel gel heating value was significantly higher than liquid ethanol, which could be due to the chemical activities of the gel components in the fuel system increasing the calorific value [30].

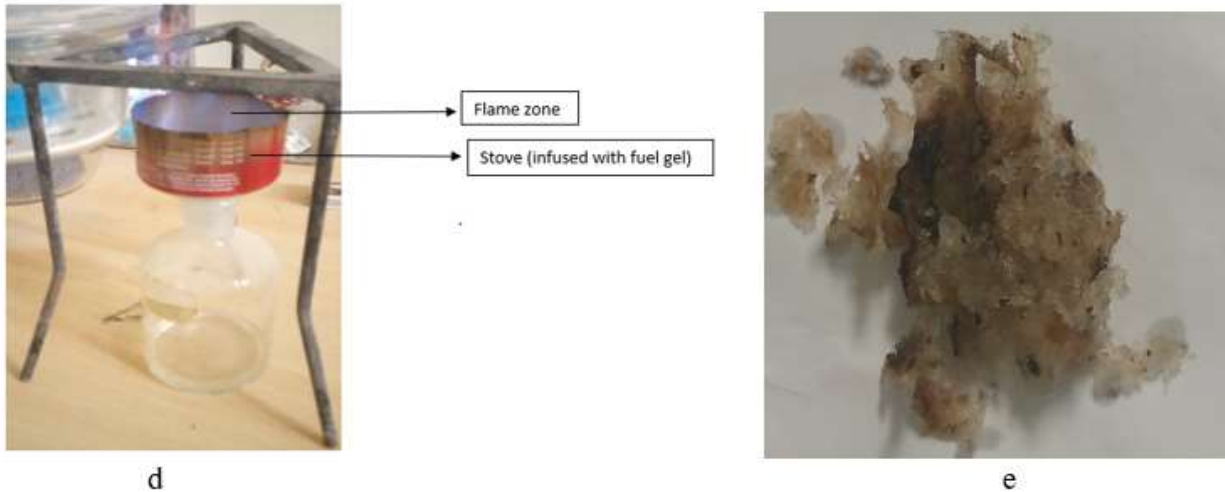


Figure 1. a. Formulated cooking fuel gel  
 b. Section of the stove's diameter  
 c. Section of the stove's height  
 d. Flame performance of the fuel gel  
 e. The fuel gel residue

Figure 2 and Table 2 are the results of FT-IR spectroscopic tests which showed a spectrum with vibration peaks in area, wavelength, class, structure, and assignment of the clearly defined peaks.

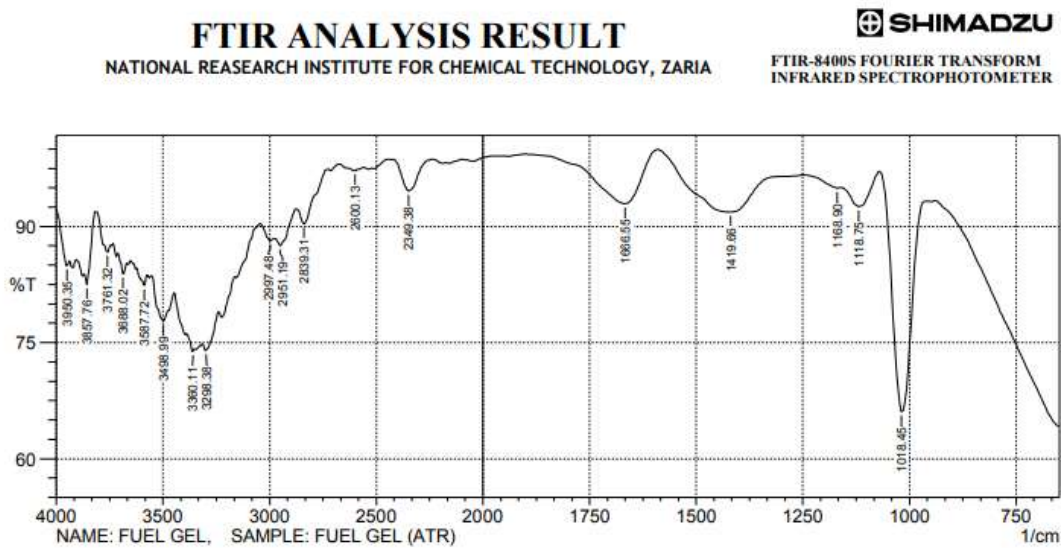


Figure 2. The FT-IR profile of the formulated fuel gel

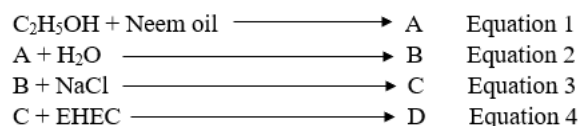
Table 3. FT-IR interpretation

Wavelength (cm <sup>-1</sup> )	Class	Structure	Assignment
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1018.45	Alkyl halides	R-X	C-X stretch
	Carboxylic acids	RCO-OH	C-O stretch
	Esters	RCOOR <sup>1</sup>	C-O stretch
1118.75	Alkyl halides	R-X	C-X stretch
	Ethers	R-O-R	C-O stretch
	Amines	RNH <sub>2</sub>	C-N stretch
	Amines	R <sub>2</sub> NH	C-N stretch
	Carboxylic acids	RCO-OH	C-O stretch
	Esters	RCOOR <sup>1</sup>	C-O stretch
1168.9	Alkyl halides	R-X	C-X stretch
	Amines	RNH <sub>2</sub>	C-N stretch
	Amines	R <sub>2</sub> NH	C-N stretch
	Carboxylic acids	RCO-OH	C-O stretch
	Esters	RCOOR <sup>1</sup>	C-O stretch
	Alkyl halides	CH <sub>2</sub> X	C-H wag (-CH <sub>2</sub> X)
1419.66	Aromatics	C-C in ring	ArC-C stretch
1666.55	Alkenes	R <sub>2</sub> C=CHR	C=C stretch
	Alkenes	R <sub>2</sub> C=CR <sub>2</sub>	C=C stretch
2349.38	Miscellaneous	P-H phosphine	P-H phosphane sharp
2600.13	Miscellaneous	S-H thiols	S-H sharp
2839.31	Carboxylic acids	RCO-OH	dimer OH
	Carboxylic acids	C=C-CO-OH	dimer OH
2951.19	Alkanes	RCH <sub>2</sub> CH <sub>3</sub>	CH-stretch
	Carboxylic acids	RCO-OH	dimer OH
	Carboxylic acids	C=C-CO-OH	dimer OH
2997.48	Alkanes	RCH <sub>2</sub> CH <sub>3</sub>	CH stretch
	Carboxylic acid	RCO-OH	dimer OH
	Carboxylic acid	C=C-CO-OH	dimer OH
3360.11	Alkynes	RC#C-H	#C-H stretch
	Carboxylic acids	RCO-OH	dimer OH
	Carboxylic acids	C=C-CO-OH	dimer OH
	Phenols	ArO-H	ArO-H H-bonded
3498.99	Alcohols	RCH <sub>2</sub> OH	OH stretch
	Alcohols	R <sub>2</sub> CHOH	OH stretch
	Alcohols	R <sub>3</sub> COH	OH stretch
	Amides	RCONH <sub>2</sub>	NH- stretch
	Amines	RNH <sub>2</sub>	NH- stretch
	Phenols	ArO-H	ArO-H bonded
3587.72	Alcohols	RCH <sub>2</sub> OH	O-H stretch
	Alcohols	R <sub>2</sub> CHOH	O-H stretch
	Alcohols	R <sub>3</sub> COH	O-H stretch

Figure 2 and Table 3 are the results of the FT-IR spectroscopic test with vibration peaks in the area, wavelength, class, structure, and assignment of the clearly defined peaks. The FT-IR of the five-component gel blend technically should be the function of the chemical product formation amongst these components [31].

The individual reaction to product mechanisms is predicted as follows;



The possible products are denoted as equations 1, 2, 3, and 4, respectively. Product D, equation 4, represents the chemical identity of the formulated gel. From the table above, eighteen prominent peaks were identified and thirteen were interpreted with respect to the formulated fuel gel product.

Table 4. The open space stove combustion rate

Fuel Gel mass (g)	Combustion Period (seconds)	Residue (g)
5	134	0.74
10	257	1.42
15	357	1.97
20	452	2.50
25	631	3.49
30	739	3.72

The combustion rate is calculated until the fire is entirely extinguished to determine the ability of the ethanol gel to burn until the only part that cannot be burned again remains. Table 4 showed the highest ethanol gel burning time at 739 seconds (12 minutes and 19 seconds) with a quantity of 30 grams of the fuel gel. The increased activity of the gel components practically extends the length of the flame as the vapor of the ethanol is trapped in the gelling agent with slow-release, making it run out longer.

However, it will be apparent that as the gel increased the burning rate for a few seconds, the ethanol evaporation is inhibited by the ethyl hydroxy ethyl cellulose [32].

Similarly, it was examined that bioethanol gel displayed the same results as the ignition period was increased by the addition of the carbopol gelling agent. After combustion, changes, or incomplete reactions, the residue is a part of the fuel that is not completely burned and is left behind. As

presented in Table 4, the remaining residue is the amount of ethyl hydroxy ethyl cellulose contained in the ethanol gel, which is ensnared in the form of a gel, resulting in a dried brownish mass. The level of residue produced in the burning process also reflects the activity of the gelling agent within the formulation. Az-zahra (2019), stated that the more carbopol added to 70% ethanol caused the residue to increase [33]. According to Bartlett (2019), fire is a continuous heat spread that is carried out by itself in a combustion zone that is localized at very high speeds [34].

One characteristic of hydrocarbon combustion is the appearance of blue flashes in the zone of rapid combustion in excess air conditions. In the burning process, a good fire gives blue color as red color is produced due to an incomplete combustion process. The bioethanol gel flame (Figure 1d) was blueish, with an uneven yellow-red touch and a long-flaring flame.

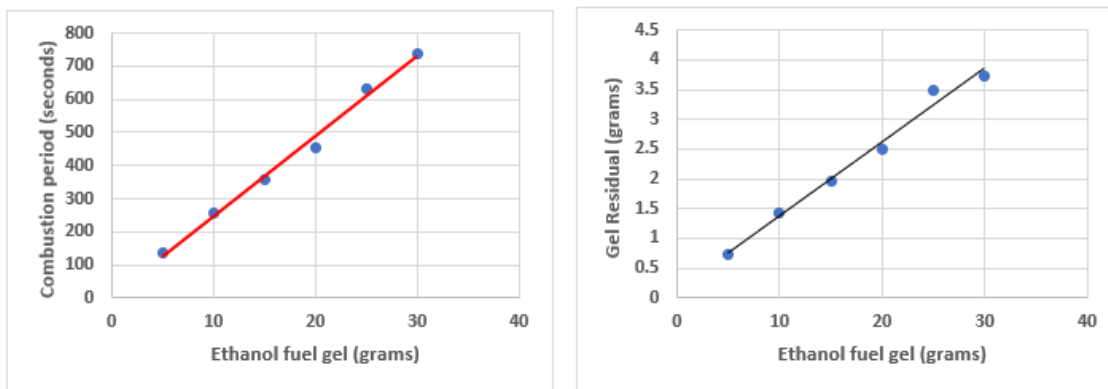


Figure 3. Linear plots of the combustion period against the fuel gel (f) and the gel residue against the fuel gel (g).

Table 5. The models

Parametric relationship	Model	R <sup>2</sup>
Combustion period(secs.) vs Fuel gel (g)	$y = 24.24x + 4.1333$	0.9917
Fuel gel residue (g) vs Fuel gel (g)	$y = 0.1237x + 0.1427$	0.9854

The effective ignition process with any appliance is a function of direct oxidation of the fuel with air, producing a flame [36]. This flame may be confined in a closed or open combustion chamber, provided with a burner or without it. The main role of the burner, when present, is to supply the correct volume of fuel- air and mix them to maintain the optimal combustion conditions. Under these conditions, the

maximum efficiency of combustion and the minimum production by-products due to incomplete combustion are achieved. Where a burner is not present, the fuel burns freely until all the fuel load is consumed. In these cases, the flame is largely uncontrolled, since the air supply can only handle the combustion rate as this parameter is generally fixed. The optimal combustion action yields not only carbon dioxide and

water as by-products, theoretically, but also discharges other chemical pollutants that have polluting impacts on humans. Carbon monoxide (CO), polycyclic aromatic hydrocarbons, nitrogen and sulfur oxides (NO<sub>x</sub>, SO<sub>x</sub>), volatile organic compounds, polychlorodibenzodioxines-furanes, heavy metals, and colloidal solids are the most frequently occurring consequences<sup>36</sup>. The nature and quantity of the pollutants produced depend on many factors related to the composition of the fuel, the characteristics of the appliance, and the service behavior and maintenance. The composition of the fuel determines the possibility of the formation of some species. For instance, a fuel not containing sulfur cannot produce SO<sub>x</sub>, while if it does not contain chlorine PCDD-PCDFs are not formed and fuel without metal compounds cannot generate metals in the fuel gases. Hence, a smokeless flame and soot that characterized the presence of the aforementioned pollutants was very obvious during the combustion process [37].

Besides the chemical composition, the physical state of the fuel also influences its combustion behavior and, eventually, its reaction products. For example, gaseous fuels are easily mixed with air and burn directly through gas-phase reactions, while liquid and solid fuels have to be vaporized before combustion takes place.

The configuration of the appliance is equally important in determining the number of pollutants produced through combustion. The appliance design controls the conditions of combustion in terms of fuel/air ratio, temperature, the residence time of the fumes in the combustion zone, mixing, and turbulence; all these aspects have a strong effect on the combustion process and the mechanisms of formation. For example, a reduced oxygen concentration and/or a low temperature produce high amounts of carbon monoxide, while high temperatures enhance the synthesis of nitrogen oxides. The components of the linear models (Figure 3, Table 5) are comprised of descriptive variables that have additive effects with the independent operation and a response with a dependent effect. Two responses to two independent variables were modeled linearly.

#### 4.0 CONCLUSION

The emergence of ethanol fuel gel as a cooking alternative significantly rely on the availability of raw constituents, low production costs, and reduced health and environmental risks. The development of this innovative product is most relevant to reducing the environmental and health risks of people, mostly in developing areas, while supporting a growing economy, thus improving the lives of man. The development of ethanol fuel gel through locally accessible feedstocks have proved to be very cheap, environmentally friendly, and consequently an improved substitute for cooking. The production does not necessitate a toxic chemical process and fewer mechanical processes, thus reducing environmental risk. It has the high promise of providing a satisfactory solution to the problem of cooking safety, largely because it burns with a blue flame with little emission impact. The need for conversion of waste to wealth was demonstrated in this

investigation by providing a clean environment and healthy living.

#### CONFLICT OF INTEREST

The authors declared that they have no conflict of interest

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