Experimental Investigation of the Thermal Performance of Kenya Defence Forces Mobile Diesel Cooker

Ezra O. Were[1], Augustine B. Makokha[2], Charles Nzila[3]

Abstract - Kenya Defence Forces (KDF) invented a diesel mobile field cooker (DEFKITCH) in the year 2010 capable of serving over two hundred soldiers in military camps and in operation areas (patent number KE 0642 dated 28 April 2014). The cooker was designed with three different sizes of cooking pots made of grade 304 stainless steel: (i)-24 gallon light duty with uniform wall thickness of 3 millimetres (ii)-24 gallon heavy duty with wall thickness of 3 millimetres and bottom thickness of 6 millimetres (iii) - 12 gallon pot with wall thickness of 3 millimetres. The cooker was commercialized in 2012 but since then no experimental assessment had been done to ascertain its performance and emission levels. Therefore this research sought to investigate the thermal performance of the cooker by experimental assessment of the combustion and thermal efficiencies as well as the level of emission of CO and CO_2. Thermal efficiency was investigated by conducting Water Boiling Tests (WBT) where parameters like heating time, temperatures and fuel consumption rate were recorded. Average thermal efficiencies computed from the results ranged from 60.37 percent to 65.86 percent using the 24 gallon cooking pots while a lower value of 42.69 percent was obtained using the 12 gallon pot on the same cooker. The average thermal efficiency was found to closely compare with those of other cookers in the open literature – ranging from 58 – 68 percent. Average diesel consumption per burner was found to be 0.8 litres in one hour which was found to be sufficient to prepare a meal for approximately two hundred people. Combustion efficiency of the cooker was determined using TESTO flue gas analyzer and the overall value was determined as 69.0 percent. Emission levels for CO and CO_2 were determined as 172.7 ppm and 4.95 percent. These were found to be within the recommended maximum emission level of 400 ppm according to National Comfort and Institute, Incorporation 2008. The cooker was found to be economical in diesel consumption per unit amount of work and a better substitute to using firewood for cooking food for a large group of people especially in remote locations such as military operation areas.

Keywords **-** Combustion efficiency, Emissions, Kenya Defence Forces, Mobile Field Diesel Cooker, Thermal efficiency.

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I. INTRODUCTION

THE Kenya Ministry of Defence through Kenya Defence Forces (KDF) is committed to responsible energy use and sound environmental management through continuously improving in use of energy in the most efficient, cost effective and in an environmentally sustainable manner in line with the Kenya vision 2030.

The main forms of energy used in the military camps for cooking included Liquefied Petroleum Gas (LPG) and firewood, the latter being the major source of fuel for cooking both in the camps and in operation areas until the year 2010. In one of the energy audits conducted by KDF in the year 2010 in its two barracks, the energy use pattern was found to be as shown in Table 1. From the audit, it was observed that firewood and LPG formed the bulk of energy forms for the Kenyan military.

The use of firewood in large quantities negated the gains achieved by KDF in the Environmental Soldier Program (ESP) because the trees plated in the forests ended up being used as firewood in the camps. It is for this reason that the KDF designed a field cooker branded DEFKITCH that was intended to use diesel. However, no attempt was made to assess the thermal and combustion efficiencies of the cooker as well as the emission levels which formed the basis for the current research.

This study therefore aimed at determining and documenting the thermal and combustion efficiencies of DEFKITCH cooker as is the requirement for all energy utilities [1]. Availability of this performance data would enable manufacturers to modify and adjust design parameters of the cooker during fabrication in order to improve its performance. The data from this study was also aimed at adding to knowledge to earlier studies on various cooker performances. [2]- [4].

Table I
Energy use in KDF (KDF Energy Audit Report 2010)

Energy Source	Unit of Measure	Kahawa	Embakasi	Total	Tons of Oil Equivalent/Yr
Grid Electricity	Kwh/Yr	2,090,618	1,287,655	**3,378,273**	**291**
Diesel	Ltrs/Yr	11,733,532	3,792,347	**15,525,879**	**15,215**
LPG	Tons/Yr	418,789	543,208	**961,998**	**1,110,337**
Firewood	Tons/Yr	6,038,296	2,916,804	**8,955,100**	**2,879,065**
		TOTAL			**4,004,908**

II. DEFKITCH COOKER

The construction of the DEFKITCH cooker is as shown in Figure 1. The main components of the cooker (DEFKITCH) are the fire chambers, burners, fuel pressure cylinder (tank) and fuel pipes. The fuel tank is a seventeen litre pressure cylinder fitted with a pressure relief valve, pressure gauge and a fuel outlet fitting. During operation, fuel is pressurized in the tank to a pressure of between one and maximum of three bars. After the burner has received pressurized diesel from the pressure cylinder, the fuel is then passed through preheating coils before atomization through a nozzle where it is combusted with the aid of natural flow of air from the burner base plate at the bottom of the fire chamber. When gas was used, preheating coils were bypassed and the gas flowed directly to the nozzle for direct ignition. The heat produced from the burner was retained within an insulated fire chamber lagged to reduce heat losses. The cooking pot capacities used were twelve and twenty four gallons depending on the amount of food to be prepared.

Figure 1: DEFKITCH (a) Two burner cooker

(b) Three burner cooker

III. EXPERIMENTAL WORK

A. Equipment

The research was conducted at Kenya Ordnance Factories Corporation (KOFC) in Eldoret where the cookers were being manufactured and the guiding principle for the assessment was the performance of DEFKITCH cooker using Water Boiling Test (WBT) with diesel and flue gas analysis.

The following equipment, tools and materials were used in the study.

(a) DEFKITCH cooker and cooking pots

DEFKITCH cooker complete with stainless steel cooking pots (12 gallon, 24 gallon heavy duty and 12 gallon light duty) was acquired from Production department at KOFC. The DEFKITCH used was a two burner cooker designed to use diesel or LPG and it had fuel cylinder fitted with pressure gauge and a level sight glass. The three different sizes of cooking pots were availed for the tests.

Fig 2: (a) 12 gallon Pot

(b) 24 gallon pots

(b) Atomic absorption spectrophotometer

The spectrophotometer used was model AA-6300 manufactured by SHIMADZU. The equipment was borrowed from physiochemical laboratory in the Quality Assurance Department at KOFC. The spectrophotometer was used in the study to test the composition of water used in the boiling tests.

Figure 3: Atomic absorption spectrometer at KOFC physiochemical laboratory

(c) Thermometer and pH meter

A combined thermometer and pH meter model HI-9025 microcomputer manufactured by HANNA INSTRUMENTS capable of measuring pH and temperature was also obtained from KOFC. It was used to check the pH level of the water and also to measure temperature rise with time during the boiling tests. The boiling time was measured using a stop watch.

(d) Flue gas analyzer

A flue gas analyzer model number 320 manufactured by TESTO was used to analyze flue gas composition, flue gas temperatures and combustion efficiency of the cooker.

Figure 4: TESTO flue gas analyzer

(e) Weighing machine

A weighing machine METTLER TOLEDO brand was acquired from production department in KOFC for initial weighing of cooking pots, water and diesel.

B. Materials

(a) Water

The water used in the boiling test was collected from KOFC treated water supply system meant for drinking and use in production processes. The water used in the experiments was found to be fit for drinking [5] and had chemical composition as indicated in the table below.

Table II
Characteristics of water used in the boiling test

S/No	Parameter	Recommended limits	Results
1	pH	6.5 -9.2	7.8
2	Turbidity	≤ 25 FAU	1 FAU
3	Temperature	≤ 25 ˚C	21.7 ˚C
4	Zinc	3 mg/l	0.4 mg/l
5	Iron	3 mg/l	0.05 mg/l
6	Lead	0.05 mg/l	0.001 mg/l
7	Hardness - (Ca, Mg)	25 mg/l	4 mg/l
8	Chlorine	0.2 - 0.6 mg/l	0.4 mg/l
9	Micro-organisms	Nil	Nil

10	Conductivity	≤ 5 mV	-0.03 mV

(b) Diesel

The cooker was tested on the automotive diesel. One litre of diesel fuel used in the experiment was weighed and its density determined as 800 kg/m^3.

C. Experimental Methods

Water Boiling Test was used to find thermal efficiency and rate of diesel consumption [6]; water was heated to boiling point at standard conditions in 24 gallon light duty, 24 gallon heavy duty and 12 gallon cooking pots using the diesel as fuel. Measurements of burner flame and flue gas temperatures together with composition of flue gases was done for each fuel used in the cooker to determine combustion efficiency. WBT were done in Eldoret where atmospheric pressure is 0.8 bars and room temperature of between 22.1˚C to 22.3˚C. The combusting diesel was pressurized at 2.5 bars.

In the boiling phase, water was heated from an initial average temperature (T_1) of 21.7 °C to boiling point of 90.1 °C. During this phase, water in the cooking pot gained energy from fuel with the help of the burner and that value of energy is equivalent to energy required to raise the temperature of that mass of water from T_1°C to boiling point. Heating time and temperatures were recorded at intervals of five minutes for the first twenty minutes followed by intervals of three minutes up to boiling point.

In the simmering phase, predetermined weight of water at boiling point was then subjected to boil for 30 minutes and energy gained by this water was calculated by multiplying latent heat of vaporization of water and mass of vaporized water. Fuel consumed during each process was recorded as input energy for these phases. The cooker's thermal efficiency was determined by calculating the heat gained by the water and amount of fuel consumed during this process. Overall thermal efficiency was calculated by dividing output energy by input energy [6]. Three replications of different amounts of water was employed throughout the experiments for different cooking pot sizes and averages of thermal efficiency obtained.

The combustion efficiency test was conducted in Nairobi near Jomo Kenyatta International Airport where atmospheric pressure and ambient temperature were 1.024 bars and 32°C respectively.

IV. RESULTS AND DISCUSSION

A. *Water boiling tests*

From the results of water boiling tests, it was observed that the temperature of water rose uniformly from an average of 21.7 ˚C to an average boiling point of 90.1 ˚C. After boiling, the temperature remained almost constant at 91 ˚C which is attributed to change of phase of water from liquid to vapour, a process that takes place without increase in temperature [7]. The average flame temperature of the burner while using diesel was 1500˚C.

Results of heating time against water temperature were plotted for the 24 gallon heavy duty, 24 gallon light duty and the 12 gallon cooking pots as shown in Figure 5.

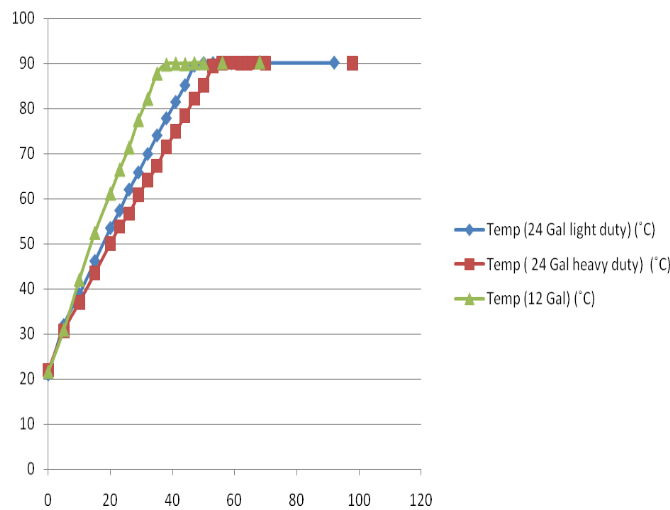


Figure 5: Heating curves for the 24 gallon light pot, 24 gallon heavy pot and 12 gallon *pots*

The gradients of the boiling curves varied with the 12 gallon pot being steeper due to the low mass of water of 30 kg and that of the pot of 21.7 kg compared to the 24 gallon pots. This implied less time and energy was needed to raise the temperature of a lesser mass of water to boiling point.

The mass of the 24 gallon heavy duty pot which was the heaviest at 41.8 kg compared to the 24 gallon light duty of 35.1 kg contributed to slower heating rate of water in the heavy duty pot as depicted by the lower gradient of its heating curve.

For comparison, water boiling curve for the ARPA kerosene cooker that was in use in KDF before the development of DEFKITCH cooker is also presented as shown in Figure 6.

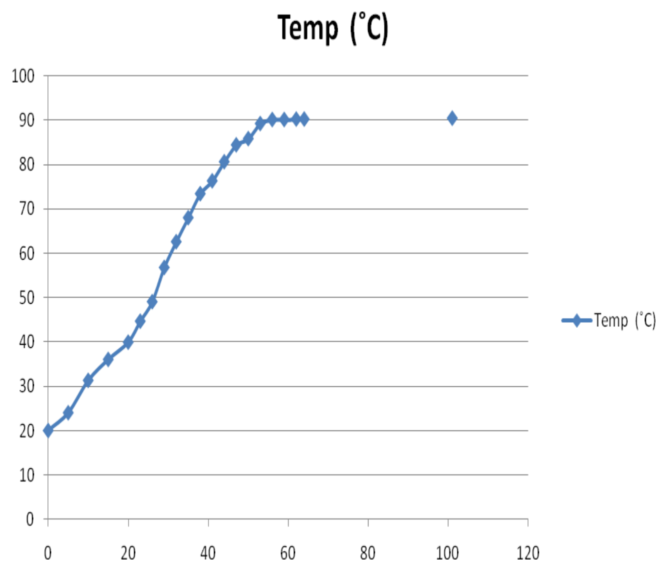


Figure 6: Heating curve for ARPA cooker

B. Fuel consumption rate

The average diesel consumption was found to be 0.8 litres in one hour when operating at tank pressure of 2.5 bars for the three types of cooking pots namely 24 gallon light duty, 24 gallon heavy duty and 12 gallon. The consumption of the fuel was found to be lower than in the earlier models like ARPA cooker due to the small size of the nozzles, that is approximately 0.6mm, therefore leading to build up of pressure that result into atomization of the fuel. Thus when the fuel is atomized under pressure its rate of consumption tends to be low since it is released in small quantities of vapour for the burning process and fuel air mixing is sufficient [8].

C. *Thermal efficiency*

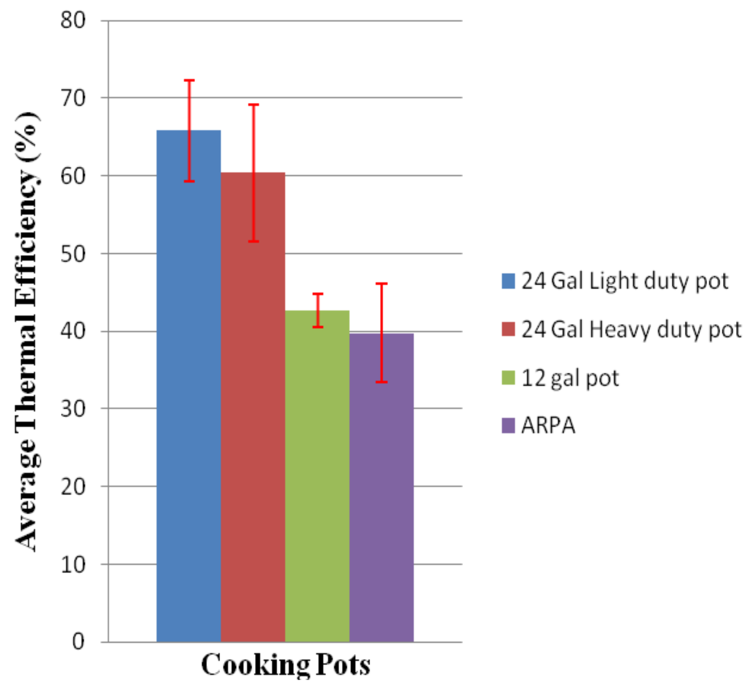


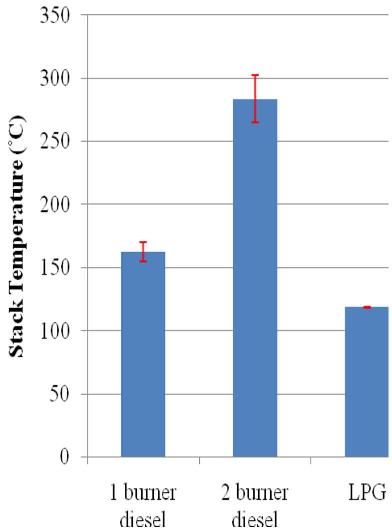
Figure 7: Comparison of efficiencies on different pots

Figure 7 above shows the average thermal efficiency of each of the pots and the error bars obtained with four different tests. The thermal efficiency of the cooker using 24 gallon light duty cooking pot was found to be 65.86 percent on average which implies that 34.14 percent of heat energy was being lost through conduction in fire chamber walls and top plate and also through convection to heat the surrounding air. This value dropped to 60.37 percent while using 24 gallon heavy duty cooking pot which was attributed to heat energy lost through conduction by the thick walled bottom of the pot. Thermal efficiency obtained using 12 gallon cooking pot was 42.69 percent. This massive decrease in thermal efficiency was attributed to energy loss through conduction from the cooking pot to the 9.4 kg stainless steel pot adapter used in supporting the pot in the fire chamber. Since the pot diameter is smaller than the fire chamber diameter, the adapter is used to hold the small pot onto the cooker. This therefore makes the 12 gallon pot not energy efficient on the cooker.

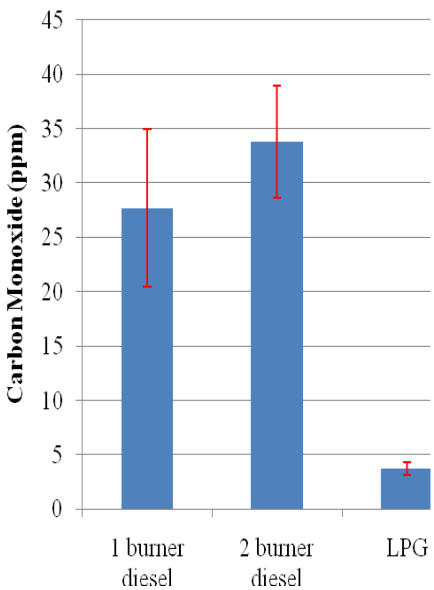
The boiling time in the 24 gallon light duty pot was observed to be lower at an average of 46 minutes in the first two experiments as compared with an average of 53 minutes in the 24 gallon heavy duty cooking pot. Despite using the same amount of water in the two cooking pots, the boiling time was longer on the heavy duty pot due to the initial heat energy used to raise the temperature of the double walled bottom of the pot.

D. Flue gas test

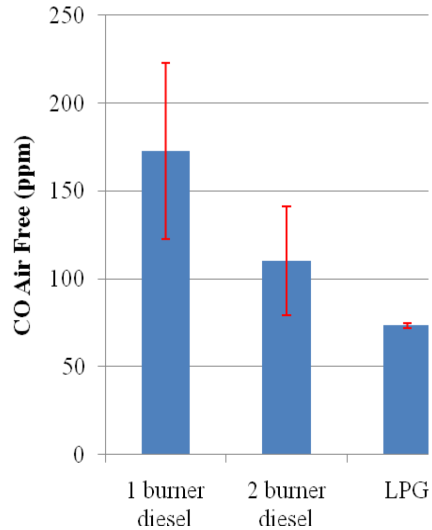
From the flue gas analysis conducted on the two burner DEFKITCH cooker with one burner on followed by two burners simultaneously at an ambient temperature of 33.5 degrees Celsius, the composition of the flue gas found was summarised as shown in the error bar graphs in Figure 8a – 8g below.



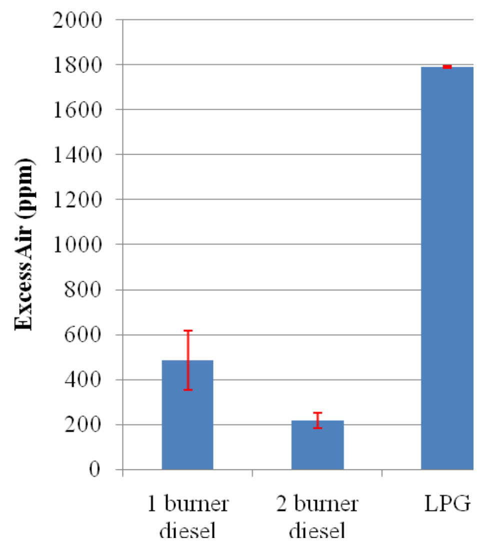
(a) Stack temperatures



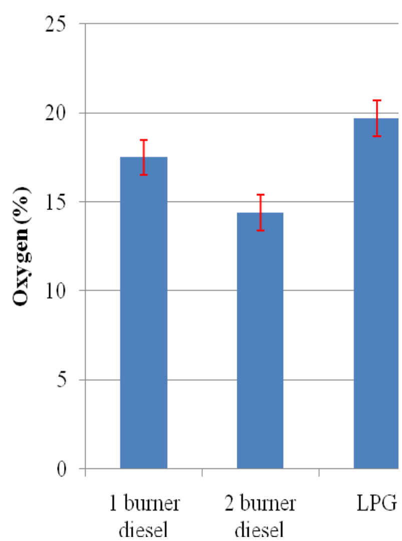
(b) CO emission



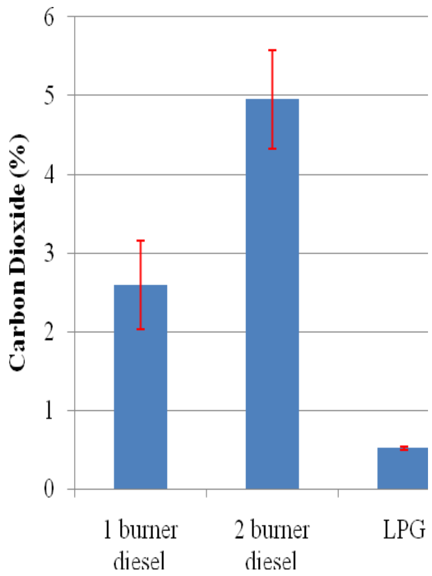
(c) CO air free in flue gas



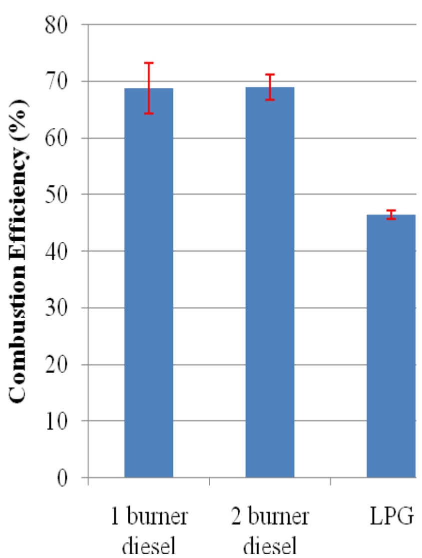
(d) Excess air in flue gas



(e) Oxygen in flue gas



(f) Carbon dioxide in flue gas



(g) Combustion efficiencies

Figure 8: Error bars from flue gas tests

The average combustion efficiency of the two burner DEFKITCH cooker was found to be 69 percent while using diesel either on a single burner or on two burners (Fig 8g).

(a) Carbon monoxide

Diluted carbon monoxide level in the flue gas was found to be 27.7 ppm on diesel while the value of CO air free was found to be 172.7 ppm average both for single burner (Fig 8b). The average values of CO air-free for two burners was 110.3 ppm. The CO emission was noted to increase when using two burners due to more fuel injected while maintaining the same amount of the available air for combustion. This trend of CO emitted was observed to be within the recommended maximum limits of 400 ppm air free basis [9].

(b) Carbon dioxide

CO_2 increased on using two burners which implied that better combustion of the cooker was achieved using two burners running concurrently as opposed to using a single burner. Complete combustion of any fuel takes place in excess air with production of CO_2 and no CO [8].

(c) Oxygen and excess air

The presence of O_2 in the flue gas meant that more air (20.9 percent of which is O_2) was supplied than was needed for complete combustion to occur therefore some O_2 is left over. The value of excess air in the flue gas was observed to reduce from 486.3 ppm using single burner to 217.6 ppm while using two burners (Fig 8d). This was attributed to increased fuel supply due to the introduction of the second burner hence more air was consumed in the combustion process.

(d) Stack temperature

The flue gas temperature of the cooker increased from 162.4 ˚C when using a single burner to 283.4 ˚C when using two burners on diesel (Fig 8a). This increase was attributed to the introduction of the second burner which meant more heat directed to the chimney stack. These temperatures were high enough to prevent water formation in the chimney; however the rise in temperatures obtained on two burners indicated that more heat energy was being lost through exhaust gases and this could be tapped to recover waste heat for higher efficiencies.

(e) Other observations

It was observed that the field kitchen burner produced a lot of noise during operation. This noise may negatively affect cooks and the people nearby the kitchen. This could be minimized by use of noise absorbing materials in the body of the field cooker.

IV. CONCLUSION

This work is a contribution to the understanding and improvement of thermal and combustion efficiency of the DEFKITCH cooker. The data obtained contributes to the existing database of information on performance of various types of cook stoves and other energy utilities. The equipment was found to be economical in diesel consumption per unit amount of work and a better substitute to using firewood for cooking food for a large group of people especially in remote locations like in military operation areas.

Emission levels for CO and CO_2 were obtained, however NO_x and SO_x were not obtained due to the limitation of the flue gas analyser used in the study.

The objectives of this research work of determining DEFKITCH cooker's thermal performance in water boiling test, analyzing emissions in flue gas test and computing thermal and combustion efficiencies were successfully achieved and suggestion on the future improvements recommended.

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