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# Performance analysis of a kerosene-powered dryer

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**Abstract**

In Nigeria the pressing need to harness the increasing output of agricultural products and to help small, medium and large scale farmers' process and preserve food products such as vegetables, cereals, tubers etc from wastage is paramount. Consequently, the performance analysis of a kero-dryer was carried out. The dryer was evaluated in terms of drying efficiency, drying rate and the time taken to dry the samples. The samples of 3kg each of Okra, Irish Potato, Pepper, Plantain and Yam locally sourced for were used in the experiment and data collected. Results showed that the initial moisture contents of Okra, Potato, Pepper, Plantain and Yam which were 92.35% (wb), 81.70%(wb), 91.40%(wb), 65.10%(wb) and 62.80%(wb) were reduced to 11.08% (wb), 17.43 %(wb), 17.96%(wb), 11.94%(wb) and 14.65%(wb) respectively at a temperature of 90$^{o}$C and total time of 10hrs. The average drying rates were 0.26kg/hr (Okra), 0.21kg/hr (potato), 0.23kg/hr (pepper), 0.25kg/hr (plantain) and 0.23kg/hr (yam) Compared with other types of dryers (solar, platform, flat-bed, continuous etc) the kero-dryer is preferred because of its multi-products drying ability and can be used even in rainy season and does not require electricity. It can be used directly in the farm during harvesting period in order to reduce the weights of agro produce for easy transportation and bagging purposes. Also, its smokeless nature gives a superior mark compared to the fuel-wood batch dryer. The average efficiency of the dryer is 76.46%. These results show that the kero-dryer can perform drying of these agricultural products satisfactorily.

**Key words:** kero-dryer, moisture content, drying rate, drying efficiency, resident time

## 1. Introduction

Drying is the removal of moisture from a product, usually to some predetermined moisture content while dehydration is the rapid removal of moisture, usually to a very low level (Asabe, 2008). Usually, it is a process of simultaneous heat and moisture transfer, the heat being required to remove (by evaporation) the moisture from the product being dried. The heat is removed from the drying product surface by external drying medium, usually air. Agricultural produce such as Okra, Potato, Pepper, Plantain and Yam has considerably high moisture content which makes it liable to rapid deterioration resulting in heavy losses during handling, transportation and storage after harvesting; therefore, drying of these products becomes very essential.

The agricultural products are selected from the fruits and vegetables family and the roots and tubers family. The vegetables are **Okra** (*Abelmoschus esculentus*) and **Pepper** (*Capsicum spp)* while those of the roots and tubers are **Irish potato** (*Ipomea batatas* Poir.), **Plantain** (genus *Musa*) and **yams** *(Dioscorea* spp).

These vegetables (Okra and Pepper) are known for their higher fibre and folate content, vitamin C, high in antioxidants, calcium and potassium contents. Pepper is used in modern medicine as stimulants, analegesic, as non lethal means of incapacitating person, high in unsaturated fats, vegetable oils and even insecticides (Duvauchelle, 2011).

The roots and tubers (plantain, Potato and Yam) have high carbohydrate content (low in fat and protein) and provide a good source of energy. They are consumed boiled (as cooked vegetable) or fufu or fried in oil and then consumed (Duke, 1983). It is often pounded into a thick paste after boiling and is consumed with soup. It is also processed into flour for use in the preparation of the paste. Their medicinal uses as a heart stimulant are attributed to its chemical composition and are appreciated in pharmaceutical industries (Chittaranjan, 2007). Its use as an industrial starch has also been established as the quality of some of the species is able to provide as much starch as in cereals. (DELSU, 2006)

Drying is an excellent way to preserve food and solar food dryers are appropriate food preservation technology for sustainable development (Scalin D. 1997). Drying was probably the first ever food preserving method used by man, even before cooking. It involves the removal of moisture from agricultural produce so as to provide a product that can be safely stored for longer period of time. Drying is a mass transfer process consisting of the removal of water or another solvent (Greensmith M, 1998) by evaporation from a solid, semi-solid or liquid. This process is often used as a final production step before selling or packaging products. To be considered "dried", the final product must be solid, in the form of a continuous sheet (e.g., paper), long pieces (e.g., wood), particles (e.g., cereal grains or corn flakes) or powder (e.g., sand, salt, washing powder, milk powder). A source of heat and an agent to remove the vapour produced by the process are often involved. In bio products like food, grains, and pharmaceuticals like vaccines, the solvent to be removed is almost invariably water. These drying processes are sometimes classified based on their heat source. These include sun drying, solar drying, oven drying, heated air drying and freeze drying. Also the heated air fuel source could be biogas, wood or kerosene.

In this work the tray dryer cabinet type is designed and kerosene fuel (kero-dryer) is used in drying the 3kg each the selected samples at a constant temperature of 90$^o$C. The following parameters; moisture content, drying rate, drying time and drying efficiency were used to analyse the effectiveness of the kero-dryer.

## 2. Materials and methods

### 2.1 Basic principle

The design and construction of kero-dryer (kerosene fuel) , for agricultural produce such as vegetables, cereals, tubers etc in their sliced/ chipped form is based on the understanding of the principles that governs heat and mass transfer in food processing. Heat transfer is a dynamic process in which heat is transferred spontaneously from hot body to cooler body. The rate of heat transfer depends upon the difference in temperature between the bod*ies*. In air drying, the rate of removal of water depends on the conditions of the air (hot air), the properties of the food and the design of the dryer. Also, it is expected that the water that is loosely held will be removed most easily. Thus it would be expected that drying rates would decrease as moisture content decreases, with the remaining water being bound more and more strongly as its quantity decreases.

### 2.2 Description of the equipment

The photograph of the kero-dryer is shown in Fig 1. However, the dryer consist of (1) Structural Frame work. (2) Drying chamber (3) Mesh trays, (4) Hot air pipes, (5) Temperature indicating Unit, (6) Chimney, (7) Fibre glass layer (8) kerosene fuel housing, (9) metal hinges, (10) Rivets and (11) wicks and heating units.

The structural frame is the part of the equipment on which other components are coupled to. It is welded in a skeleton fashion to provide the required support to the loads acting on the equipment from within and outside. The hot air pipes are systematically arrayed vertically and horizontally with proper connection to each other for free flow of hot air arising from the combusting Kerosene. These pipes connection arrayed within the drying chamber are all joined together to the top for proper circulation of the hot air. The various sliced/chip samples are exposed to heat in the Drying chamber and Meshed trays; and the dryer is composed of triple walls; an outside layer made of mild steel, a middle layer properly insulated with fibre glass as lagging material and inner layer of stainless metal sheet. The inside of the chamber allows a tray to be arranged at a time. The chamber has two doors to allow the tray to be placed inside and removed from either side. The kerosene fuel housing is attached below with proper clearance, with the wicks (flammable fabric) casing directed with a cone shape design sheet to direct the hot air through the pipe. The hot air can be regulated with the control knob of the wick systems attached to each unit.

**Fig 1: Photograph of Kero dryer**

### 2.3 Working principle

Once the samples are spread on the trays and fixed in the drying chambers, the doors are firmly locked (air tight).The wicks of the heating units of the kero- dryer at the base is lighted when the kerosene fuel have been supply to its housing.

The wick flame generates heat which is directed by the cone shape sheet metal into the pipes. The products of combustion pass through the inside of the array pipes which converge at the chimney and from there to the atmosphere. Heat is conducted through the walls of the pipes into the drying chamber of the dryer. In this manner the samples being dried cannot be contaminated.

The evaporated moisture from the drying materials escape to the atmosphere through provided channels. The hot air rises in the air pipe by principle of heat transfer and circulates in the air pipes arrayed systematically in the drying chamber. As the hot air rises it dries or removes the water content of the samples; whose vapour exit through the chimney.

### 2.4 Sample preparation and Experimentation

Fresh sample of Okra, Potato, Pepper, Plantain and Yam were purchased from Ogbete main market Enugu state. They were washed, peeled and sliced in bits or chips as the case maybe. Then, equal weight of 3kg of each sample were collected and their moisture content determined; 92.35% (wb), 81.70% (wb), 91.4% (wb), 65.10% (wb) and 62.80% (wb) for okra, Irish potato, pepper, plantain and yam respectively. The samples were observed at a temperature of 90°C every hour after which they were re-weighed and data recorded.

## 3. Results and Discussions

The results obtained from the experiment are shown in the Table 1. The initial moisture contents of the samples were obtained using the equation below

- % moisture content = $\frac{(W_1 - W_2)}{W_1} \times 100\%$ (1)

Where,

$W_1$ = Initial weight (kg), $W_2$ = Final weight (kg)

The drying rates were obtained by calculating the change in weight of samples and dividing by the time period within which that change occurred. It is expressed by the equation below

- Drying rate = $\frac{\partial w}{\partial t}$ (kg/hr) (2)

Where, $\partial w$= change in mass $\partial t$ = change in time

The plots of moisture content versus drying time are shown in Figs 2 – 6. It would be seen that the moisture content decreases with drying time for all the products. This can be attributed to the fact that as drying progresses, moisture is being removed from the products leading to decrease in moisture content. For the first three hours, the moisture content of pepper was found to be the greatest among the five crops. This was because pepper was not sliced and due to its nature the rate of moisture removal was lowest. All the other crops were sliced, thus having more surface area which made it easier for heat transfer and moisture removal.

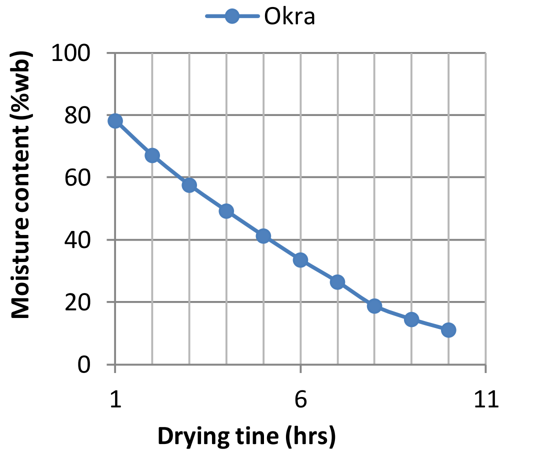


**Fig 2: Drying curve of okra sample**

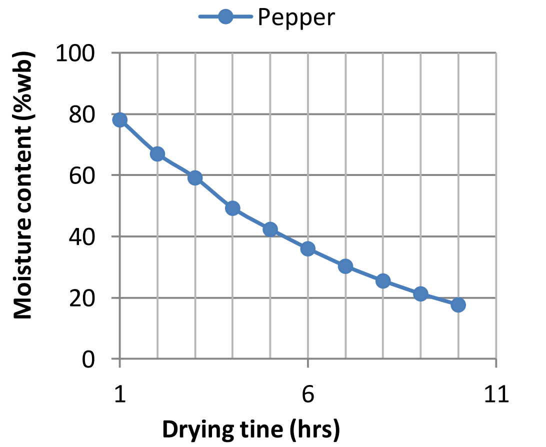


**Fig 3: Drying curve of Pepper sample**

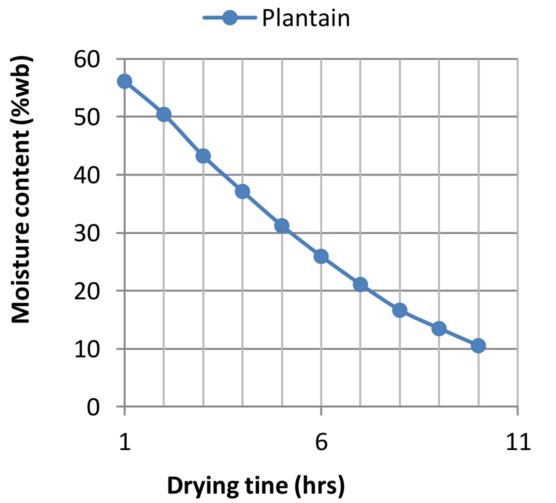


**Fig 4: Drying curve of Plantain sample**

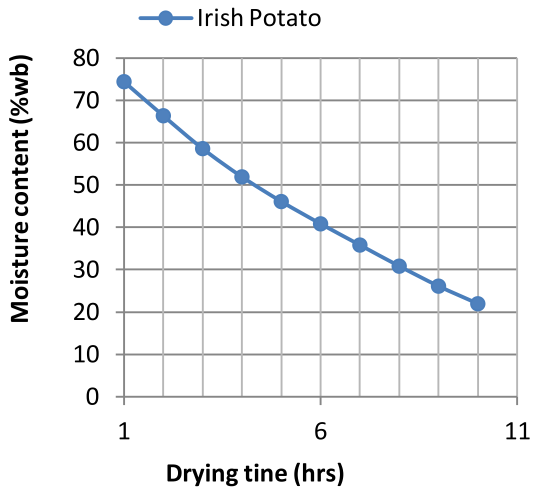


**Fig 5: Drying curve of Irish Potato sample**

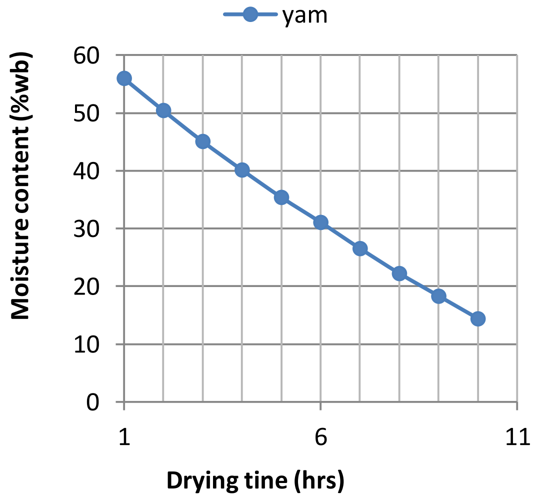


**Fig 6: Drying curve of Yam sample**

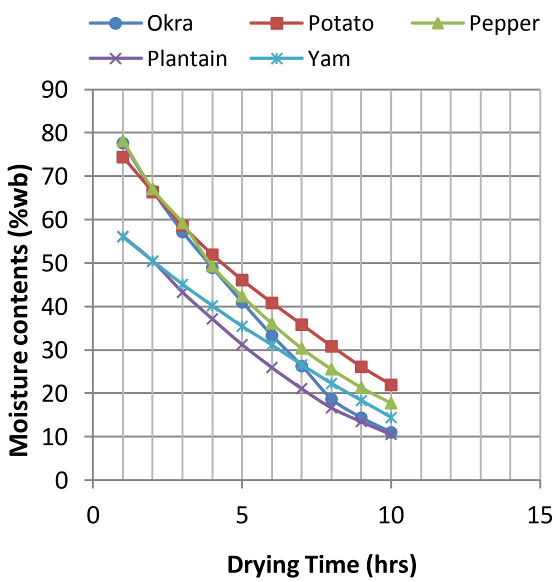


**Fig 7: Drying curves of the samples**

From the above plot, it can be observed that Okro, Pepper and Irish potato had similar trends at the early stages of drying which was different from Plantain and yam. All crops showed variation in the latter stages of drying and had moisture contents (11.08%, 17.96%, 17.43%, 11.94% and 14.65% respectively) after 10hrs of drying which would allow shelf storage of products with little or no deterioration.

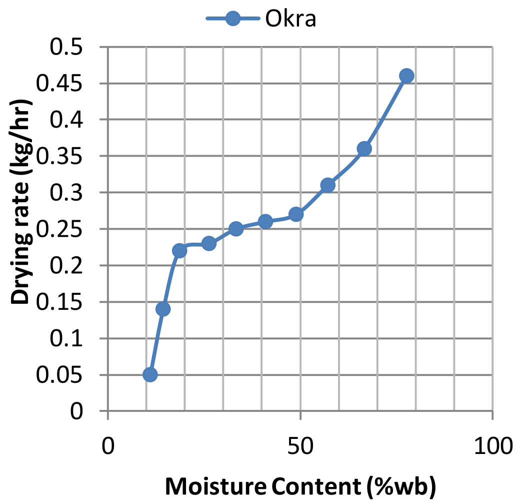


**Fig 8: Drying Rate curve of the Okro sample**

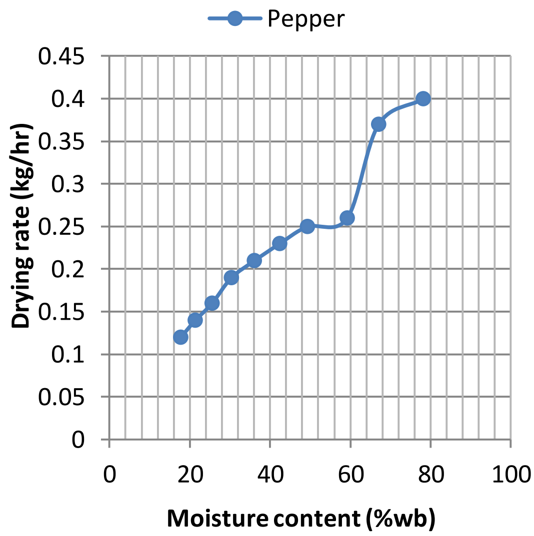


**Fig 9: Drying Rate curve of the Pepper sample**

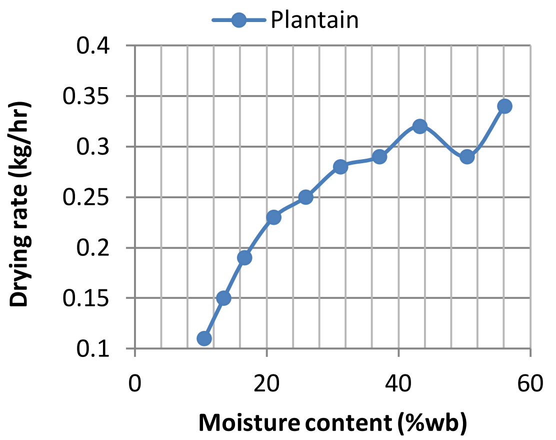


**Fig 10: Drying Rate curve of the Plantain sample**

Figs 8 – 12 show the drying rate curves of the observed samples. The plots showed that drying occurred in all samples within the falling rate period (no constant rate period). This can be attributed to fact that samples were sliced to selected thicknesses, thereby increase surface area of contact between food sample and hot air. It can also imply that in the drying process of the samples, internal diffusion of moisture is likely to be the dominant mechanism of moisture movement from the very start of drying. This conforms to results reported in lierature by Doymaz (2007), Sobukola (2009), Tunde-Akintunde and Ajala (2010) and Deepak and Suresh (2010).

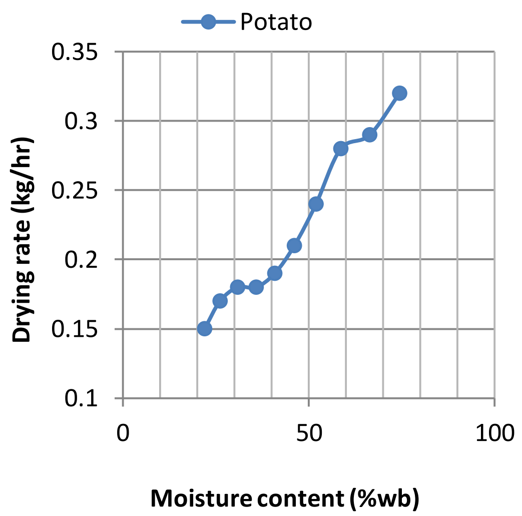


**Fig 11: Drying Rate curve of the Potato sample**

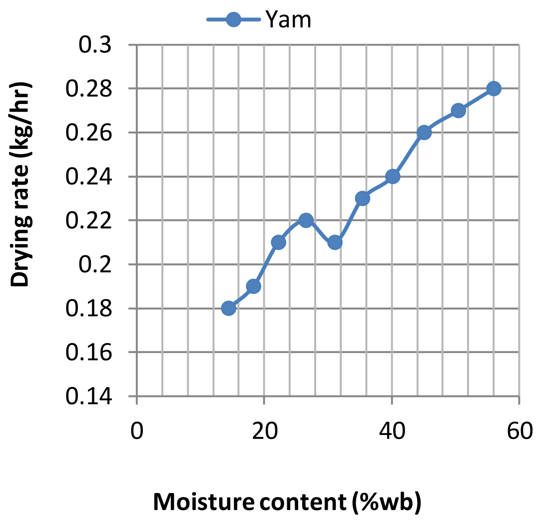


**Fig 12: Drying Rate curve of the Yam sample**

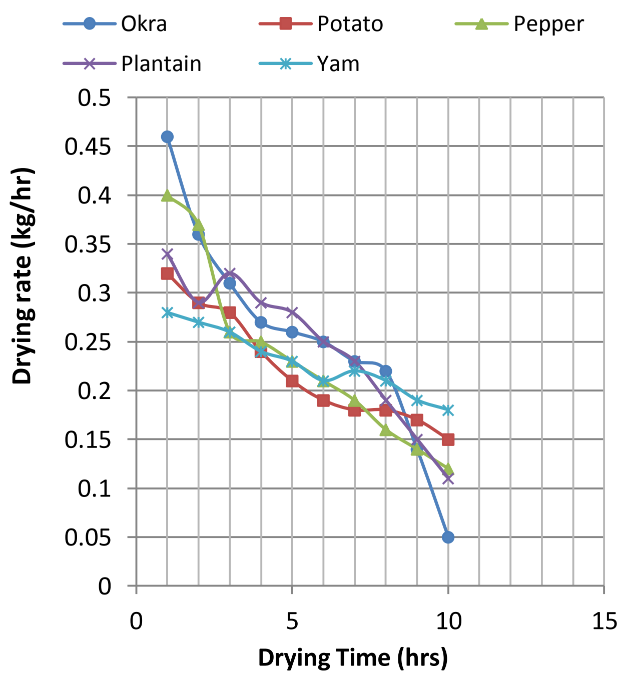


**Fig 13: Drying Rate curves of all observed samples**

The plot above shows that the drying rate decreased as drying progressed for all the samples. The largest decrease occurred with the Okro samples while yam showed the least decrease in drying rate. This decrease in drying rate with time could be attributed low internal resistance of moisture at the beginning of drying, in which when energy was impacted, moisture easily moved to the surface where it was evaporated. As the drying progressed, more energy was required to break the molecular bond of the moisture and since constant energy (heat) was supplied, it took longer time to break the bond, therefore drying rate decreased. This agreed with the findings of Ndukwu (2009) who observed that the drying rate was highest at the first hour of continuous drying of cocoa bean.

**Efficiency of machine:**

The efficiency of the Kero dryer is expressed in terms of total energy generated by combustion of kerosene in a given time and the amount of the same energy utilised

$$\boldsymbol{efficiency} = \frac{\boldsymbol{energy\ utilized}}{\boldsymbol{total\ energy\ generated}} \times \mathbf{100}\%$$

$$E = \frac{E_u}{E_T} \times 100\%$$

The total energy generated by combustion of kerosene is given as

Mass of kerosene combusted in a given time **($M_k$)** × calorific value of kerosene **($C_k$)**

**$E_T = M_k$** x **$C_k$** (3)

30kg of kerosene was used in the experiment in 10 hours time interval. Calorific value of kerosene is taken as 35.24 MJ/kg

$E_T$ = 30 x 35.24 x 10 = 10,572 MJ

Energy per hour = 10,572 /10 = 1,057.2 MJ

The temperature inside the drying chamber was maintained at 90°C ± 2 °C while the outside wall of the dryer was 38°C. The conductivity of fiber glass used as insulating material is given as

K = 0.04w/m$^{2o}$C (ETB, 2015)

Energy Utilized = Total energy generated – energy lost

Energy lost = Heat lost by conduction, convection and radiation + Heat carried away by products of combustion

Applying Fouriers law of heat conduction through a slab, the heat lost by conduction can be quantified as

$$Q_c = KA\frac{dT}{dx} \quad (4)$$

$$Q_c dx = KAdT$$

$$Q_c \int_1^2 dx = KA \int_2^1 dT$$

$$Q_c[x_2 - x_1] = KA[T_1 - T_2]$$

$$Q_c = KA\frac{[T_1 - T_2]}{[x_2 - x_1]}$$

**Where;** K = conductivity of fibre glass

$T_1$ –$T_2$ = temperature difference btw the inside and outside walls of drying chamber = 52 °C

$X_2$ – $X_1$ = thickness of insulation = 100mm

A = area of insulation = 1m$^2$

$$Q_c = \frac{0.00000004 \times 1 \times 52}{0.1}$$

$$Q_c = 2.08 \times 10^{-5}\ MW$$

Converting this to Joules

$= 2.08 \times 10^{-5} \times 3600 = 0.07488MJ$

Heat loss by Convection is given by

$$Q_{cv} = hAdT = hA\,[T_1 - T_2] \quad (5)$$

**Where** h = convective heat transfer coefficient which from literature has a range of [25 - 50] W/m$^2$ °C (EE, 2015). The value of 40 W/m$^2$ °C was selected for this study. Hence,

$$Q_{cv} = 40 \times 1\ (90 - 38) = 2{,}080\ W.$$

Converting to Joules

2,080 x 3600 = 7,488, 000J = 7.488 MJ

Heat loss by Radiation is given by

$$Q_{rad} = \sigma A\,[T_{in} - T_{os}]$$

**Where** $\sigma$ = Stefan boltzman constant of radiation

= 56.7 x 10$^{-12}$ W/ m$^2$K

$T_{in} - T_{os}$ = absolute temperature difference from inside and outside walls of the dryer

$$Q_{rad} = 56.7 \text{ x } 10^{-12} \times 1\ [363 - 311]$$

$$Q_{rad} = 56.7 \text{ x } 10^{-12} \times 52$$

$$Q_{rad} = 2.9484 \text{ x } 10^{-9}\text{W}$$

Converting to Joules

$$2.9484 \text{ x } 10^{-9} \times 3600 = 1.061424 \times 10^{-5}\text{J}$$
$$= 1.061424 \times 10^{-11}\text{MJ}$$

Heat lost by products of combustion is given by multiplying the mass of gas by the specific heat capacity and temperature difference. It was assumed that complete combustion took place in the dryer. Temperature reached at combustion of kerosene was taken as 300°C. The masses of the products of combustion were determined from stoichiometric analysis, thus

$C_{12}H_{16}$ + 18.5 $O_2$ → $12CO_2$ + $13H_2O$ (source: Inspectapedia.com)

1kg $C_{12}H_{16}$ requires 3.482 kg of $O_2$ to give 3.11kg $CO_2$ and 1.38kg $H_2O$

Heat capacity of $CO_2$ at 300°C =127.54 KJ/kg K = 0.12754 MJ

Heat capacity of $H_2O$ at 300°C = 378.26 KJ/kg K = 0.37826 MJ

$Q_{c02}$= 3.11x 0.12754 x 262 = 103.92 MJ

$Q_{h2o}$ = 1.38 x 0.37826 x 262 = 136.74 MJ
Total heat loss by products = $Q_p$ = $Q_{co2}$ + $Q_{h2o}$

$Q_p$ = 103.9 + 136.74 = 240.66MJ =

Total energy loss = 7.488 + 0.7488 + 240.66 + 1.0614 x $10^{-11}$ = 248.897 MJ

$$Efficiency = \frac{1057.2 - 248.897}{1057.2} \times 100\% = 76.46\%$$

**4. Conclusion**

From the results, 23% of total heat generated by combustion of kerosene was carried away by products of combustion. The remaining heat was utilised in the drying of the agricultural produce. Generally heat loss in the Kero dryer is low and this could be attributed to the good lagging in the dryer. The machine efficiency of 76.46% would ensure that the dryer performs satisfactorily.

**Advantages of the machine**

1. The equipment is simple to operate; it does not require special skill.
2. Materials of construction are locally sourced
3. Less time of drying, faster than sun drying and solar drying
4. It is smokeless compare to the fuel wood type
5. It can be used in any season, even in the farm
6. It does not require electric power supply
7. It is multi-usage i.e. different food crops can be dried simultaneously

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## APPENDIX 1


Okra


Pepper


Plantain


Potato


Yam

**Samples before drying**

## APPENDIX 2

Okra

Pepper

Plantain

Potato

Yam

**Samples after drying**

**Table 1: Data obtained from the designed machine test.**

| Time (hrs) | Okro | | Pepper | | Plantain | | Irish Potatoes | | Yam | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Wgt | DR | Wgt | DR | Wgt | DR | Wgt | DR | Wgt | DR |
| 1 | 2.54 | 0.46 | 2.60 | 0.40 | 2.66 | 0.34 | 2.64 | 0.36 | 2.72 | 0.28 |
| 2 | 2.18 | 0.36 | 2.23 | 0.37 | 2.37 | 0.29 | 2.32 | 0.32 | 2.45 | 0.27 |
| 3 | 1.87 | 0.31 | 1.97 | 0.26 | 2.05 | 0.32 | 2.01 | 0.30 | 2.19 | 0.26 |
| 4 | 1.60 | 0.27 | 1.64 | 0.25 | 1.76 | 0.29 | 1.75 | 0.26 | 1.95 | 0.24 |
| 5 | 1.34 | 0.26 | 1.41 | 0.23 | 1.48 | 0.28 | 1.52 | 0.23 | 1.72 | 0.23 |
| 6 | 1.09 | 0.25 | 1.20 | 0.21 | 1.23 | 0.25 | 1.32 | 0.20 | 1.51 | 0.21 |
| 7 | 0.86 | 0.23 | 1.01 | 0.19 | 1.00 | 0.23 | 1.14 | 0.18 | 1.29 | 0.22 |
| 8 | 0.61 | 0.22 | 0.85 | 0.16 | 0.81 | 0.19 | 0.96 | 0.18 | 1.08 | 0.21 |
| 9 | 0.47 | 0.14 | 0.71 | 0.14 | 0.66 | 0.15 | 0.79 | 0.17 | 0.89 | 0.19 |
| 10 | 0.36 | 0.11 | 0.59 | 0.12 | 0.55 | 0.11 | 0.64 | 0.15 | 0.70 | 0.19 |
| | | | | | | | | | | |

**(Source; Oriaku et al 2014).**