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Performance Characterization of a Locally Developed Fish Smoke-Drying Kiln for Charcoal and Briquette

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Abstract

Performance characterization of a locally developed fish smoke-drying kiln (10 kg capacity) was conducted using charcoal and briquette as fuel materials. Samples of fresh African Catfish (*Clarias gariepinus*) weighing1.03±0.24 kg, charcoal of tropical hardwood (*Anthonotha macophylla*) and briquette produced from a combination of saw dust, rice husk, coconut husk and palm kernel shell were procured and used for the study. A completely randomized design (CRD) with three replicates was employed for this study and LSD among treatment means determined at $p \leq 0.05$. Data was collected on moisture content of smoked-dried fish, smoke-drying time, drying rate, energy expended, specific fuel consumption and energy efficiency of kiln. Results showed that the energy efficiency of kiln was 97.02% and 98.45% and specific fuel consumption was 2.57 and 4.20 for charcoal and briquette, respectively. The energy expended by charcoal and briquette fuel materials were 206 MJ and 249.6 MJ, respectively. The energy expended, energy efficiency and specific fuel consumption were higher for briquette than charcoal. The use of charcoal offered higher moisture removal and drying rate for smoke-drying process than briquette but no significant difference was observed. Conversely, using briquette fuel material required almost two extra hours to smoke-dry 1kg of catfish sample compared to using charcoal. Breakeven with charcoal as main fuel material for custom hiring of the smoke-drying kiln occurs at 952 hours vis-à-vis 998 hours when briquette is used. Economically, briquette compares closely with charcoal, and could be considered a good alternative fuel material for smoke-drying of fish. Future research should conduct organoleptic assessment on fish smoked with charcoal and briquette to ascertain consumer acceptability of the final produce.

Keywords: fuel material, charcoal, briquette, energy efficiency, smoke-drying

1. Introduction

Fish is an important source of protein which is critical in the fight against hunger and malnutrition due to its nutritional qualities such as thiamine, riboflavin, vitamin A and D, phosphorus, calcium, iron and high polyunsaturated fatty acids (Areola, 2008). In Ghana, fish accounts for 50% to 80% of the animal protein consumed by the population with annual per capita consumption estimated at 28 kg (Sumberg et al., 2016; FAO, 2018; FAO, 2016). Fish is highly perishable and starts to deteriorate immediately after death (Saliu, 2008) due to factors such as high moisture content, availability of nutrients for microbial growth, ambient temperature and poor handling. Hence, fish processing is done to extend the shelf life and also add value to the fish product (George et al., 2014; Issa et al., 2020). Fish preservation methods such as canning or freezing are used in most developed countries to improve quality and extend the shelf life of fish. Traditional fish smoking is still done in less developed countries, particularly in the tropics. Fish smoking is one of the oldest preservation methods and is still widely used (Theobald et al., 2012; Nerquaye-Tetteh et al., 2002). Fish smoking typically extends the shelf life of a fish by lowering the water activity in the fish, which permits storage in the lean season; enhances flavor and increases utilization of fishes in diets. It enhances the nutritional values and promotes digestibility of protein. Fish smoking is the most popular fish processing method in Ghana and is done at temperatures greater than 65 ^oC to ensure that fish products are well cooked (Sakyi et al., 2019). Odiko and Abolagbo (2015) cited that fish smoking takes about 7-10 hours on average depending on the moisture content, size of the fish, temperature and fuel efficiency. During smoke-drying, the smoke from the burning fuel materials containing a number of compounds inhibits bacterial growth, while the heat from the fire causes drying (Enofe, 1996). However, when the temperature is high enough, the flesh will be cooked, preventing bacteria, fungal growth and enzyme activity (Goulas & Kontominas, 2005).

The most common indigenous technologies being utilized for smoke drying of fish include the traditional mud or drum oven, rectangular oven and *Chorkor*-smoker (Daramola et al., 2020). Most modern smoking kilns already developed in Africa, such as FAO-Thiaroye Technique (FTT) smoker, Cabin smoker, *Ahotor* smoker, *Abuesi* Gas Fish Smoker (AGFS) and the Federal University of Technology Akure (FUTA) (Daramola et al., 2020) model have unique design and functioning having comparative advantage in terms of generating uniformly smoked fish products. The demand for such improved interventions in the aquaculture industry led Ajewole et al. (2021) to develop and test a dual powered fish smoking kiln in Nigeria. A similar improved fish smoking kiln designed and locally fabricated by the Agricultural Engineering and Transport Division at the CSIR-Crops Research Institute, Kumasi was assessed during this study.

Fuelwood remains an important source of energy for cooking and economic activities in large part of the world with global consumption of about 1.86 billion m^3 in 2016 (FAO, 2018). Over dependent on trees as source of fuel has led to serious deforestation which continues to destroy the ecosystem. The use of charcoal as a source of thermal energy requires the felling of trees for the purpose of fuelwood, which is not environmentally beneficial. Briquette fuel is an important way to handle the weed, wood chips, paper, and sawdust material in an efficient way. Briquette is a compressed block of coal dust made from wood chips, sawdust, peat, paper and contributes to environmental management by saving trees that can reduce so soil and forest degradation (Musa, 2006). According to a study by Agyemang and Opoku (2018), desertification can be reduced by offering an alternative to burning wood for residential and industrial heating and cooking, as well as producing jobs and money for those who are most affected by it. Briquette combustion is an environmentally favorable option. This study seeks to examine the feasibility and operation of charcoal and briquette as fuel materials to improve the factors that determine the performance of a locally constructed smoke-drying kiln.

Specifically, the study sought to:

- Determine the energy efficiency, specific fuel consumption and energy expended using charcoal and briquette;
- Calculate the smoking time and rate of drying fish using charcoal and briquette;
- Assess the economic feasibility of the smoked-drying kiln for charcoal and briquette fuel materials.

2. Materials and Methods

2.1 Experimental Site

The study was conducted at the Cottage on the premises of CSIR-Crops Research Institute, Fumesua near Kumasi, Ghana in May 2022. The detail of kiln, fish and various experimental parameters and analysis methodology is given below.

2.2 Description of Kiln and Smoke-Drying Process

The smoke-drying kiln (Figure 1) has double walls lagged to reduce heat loss by conduction. It has a sloping overhead cover with a chimney for escape of vapour and smoke. Wire mesh was used in the construction of the fish trays to keep the raw fish products from falling through. The fish trays could easily be slid in and out to allow the fish to be moved without tipping. The kiln has a single door to allow for easy opening and closure. This sieve prevents oil and water droplets from directly falling on the fire; a situation that could lower the combustion temperature and lead to the production of Polycyclic Aromatic Hydrocarbons on the fish product. Technical specification of the smoke-drying kiln is provided in Table 1.

Table 1. Technical specifications of the smoke-drying kiln

Parameter	Specification
Dimension of smoking kiln (L × B × H)	615 mm × 305 mm × 465 mm
Weight of kiln (under no-load)	25 kg
Estimated capacity of kiln	15 kg of fish per batch
Dimension of smoking chamber (L × B)	400 mm × 240 mm
Dimension of combustion chamber (L × B × H)	410 mm × 290 mm × 100 mm
Number of smoking chambers	1
Number of fish trays	4
Material used for construction	Galvanized steel sheet and mild steel angle iron
Insulation material used	Rice husk and saw dust
Oil collector sieve present	Yes

Figure 1. The fish smoke-drying kiln prototype

Three smoking kilns per fuel material (charcoal and briquette) were used for the study. Fire was set to the fuel material of predetermined weight in the combustion chamber. Prepared fish on trays were arranged in the smoking kiln to begin the smoke-drying process. Temperature readings for each smoking kiln were taken hourly at the combustion chamber, smoking chamber and chimney areas using an infrared thermometer gun (Raytek Raynger MX4+). Ambient temperature was also recorded each time. Fish trays were rotated in two-hour interval and individual fish turned upside down (where required) to ensure even distribution of heat to the fish. Fuel material was weighed and recorded each time before placing them in the combustion chamber. The duration for the smoke-drying operation was determined using a stopwatch. The opening and closure of the vents on the combustion chamber was used to control temperature during the smoke-drying process.

2.3 Sample Collection and Fish Preparation

Freshly harvested African Catfish (*Clarias gariepinus*) samples in their 6th month of production at 1.03±0.24 kg weight obtained from a recirculating aquaculture system (RAS) was used for the study. Whole fish was weighed with an electronic weight scale (FB 300 kg digital electronic scale) and then washed thoroughly with salt and water solution to remove slime from the body. Fish samples were marked with toothpick; the toothpick was punctured into the flesh of the catfish for easy identification. The fish were folded (coiled) and arranged on trays ready for the smoke-drying process as shown in Figure 2.

Figure 2. Coiled fish on trays ready for the smoke-drying process

2.4 Fuel Material

Charcoal of tropical hardwood (*Anthonotha macophylla*) (Figure 3a) and briquette produced from a combination of saw dust, rice husk, coconut husk and palm kernel shell (Figure 3b) were procured and used for the smoke-drying experiment.

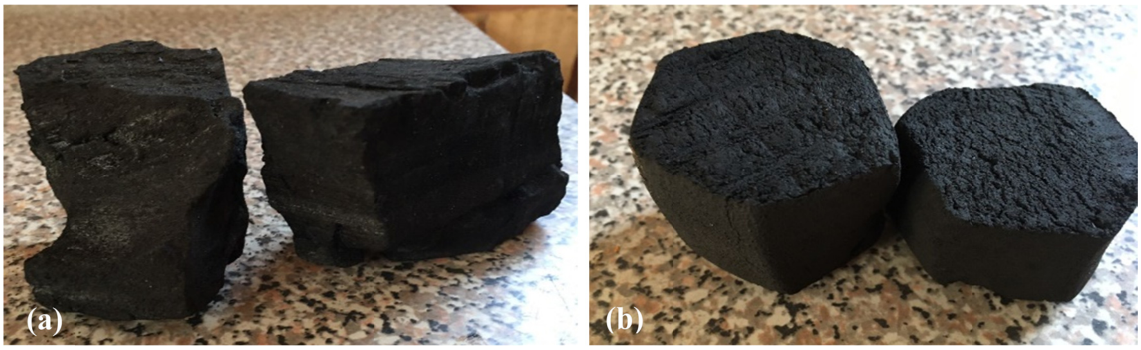

Figure 3. Charcoal (a) and briquette (b) fuel material

2.5 Performance Parameters

The performance of the two fuel materials (charcoal and briquette) were assessed based on relevant performance parameters. Data was collected on moisture content of smoked-dried fish, duration of smoke-drying operation, smoke-drying rate, energy expended, specific fuel consumption and energy efficiency of smoke-drying kiln.

2.5.1 Moisture Content

The percentage moisture removed from smoked Catfish was determined using the expression by Issa et al. (2020) in Equation 1.

$$\text{Moisture removed (\%wb)} = \frac{\text{Weight of Fresh Catfish (g)}}{\text{Weight of Smoke-Dried Catfish}} \times 100 \quad (1)$$

Based on the assumption that fish contains 80% water (Ikrang & Umani, 2019) content of the smoked fish is calculated using Equation 2.

$$\text{Moisture remained (\%)} = 80 - \text{Moisture removed} \quad (2)$$

2.5.2 Specific Fuel Consumption

The specific fuel consumption (SFC) was determined using Equation 3 as adopted by Davies et al. (2012):

$$SFC = \frac{\text{Total mass of fuel consumed (kg)}}{\text{Total mass of smoked fish (kg)}} \quad (3)$$

2.5.3 Energy Efficiency

The energy efficiency of fuel material was calculated using the expression in Equation 4 by Mujumdar (1995):

$$\text{Energy efficiency} = \frac{T_{cc} - T_{out}}{T_{cc} - T_{amb}} \times 100 \quad (4)$$

Where, T_{amb}: Mean ambient temperature (outside); T_{cc}: Mean inlet air temperature (combustion chamber); T_{out}: Mean outlet air temperature (chimney).

2.5.4 Energy Consumed

The energy expended in smoke-drying with charcoal and briquette in the smoke-drying kiln was calculated using expression in Equation 5 by Ajewole et al. (2021):

$$E_d = E_f \times M_f \quad (5)$$

Where, E_d: Energy expended in drying (MJ); E_f: Energy in fuel material (MJ/kg); M_f: Total weight of fuel material used (kg); E_f for charcoal and briquettes were 31.8 MJ/kg (Felix & Gheewala, 2011) and 24.7 MJ/kg (Onukak et al., 2017), respectively.

2.5.5 Smoking Time

The time spent in smoking fish was calculated using Equation 6 adopted by Davies et al. (2012):

$$\text{Time spent (hkg}^{-1}\text{)} = \frac{\text{Total time spent in smoking (h)}}{\text{Total weight of smoked fish (kg)}} \quad (6)$$

2.5.6 Drying Rate

The rate at which fish dries was calculated using Equation 7 as adopted by Ajewole et al. (2021):

$$\text{Drying rate (kgh}^{-1}\text{)} = \frac{\text{Initial mass of fish (kg)-final mass of fish (kg)}}{\text{Time spent in smoke drying (h)}} \quad (7)$$

2.6 Economic Assessment

The cost of smoke-drying with the smoke-drying kiln for each fuel material was computed by considering the total fixed (ownership) and total variable (operating) costs. Depreciation on the smoke-drying kiln was calculated using the straight-line method according to Hunt (1983) as in Equation 8 whereas interest on equipment ownership was determined using Equation 9.

$$\text{Depreciation} = \frac{\text{Purchase price - Salvage price}}{\text{Economic life}} \quad (8)$$

$$\text{Interest} = \frac{\text{Purchase price + Salvage price}}{2} \quad (9)$$

Table 2 provides the mathematical assumptions for the relevant cost items used in estimation of ownership and operating cost for the smoke-drying kiln.

Table 2. Assumptions for relevant cost items

Cost item	Assumption	Reference
Salvage	10% of purchase price	Hanna (2001)
Interest rate	5% on principal	Hunt (1983)
Tax	0% of purchase price	Hunt (1983)
Insurance	0.5% of purchase price	Hunt (1983)
Shelter	0.5% of purchase price	Hunt (1983)
Repairs & maintenance	5% of purchase price	Hanna (2001)

Fuel cost was estimated as a product of fuel material consumed (kg), cost of fuel (GH₵/kg) and fuel efficiency (%). Based on calculated total cost and assumed hiring cost, the expected revenue and break-even period were determined using the approach by Fairhurst (2012).

2.7 Experimental Design and Statistical Analysis

A completely randomized design (CRD) with three replicates was employed for this study with fuel material (charcoal and briquette) as the only factor. Analysis of variance (ANOVA) on data set collected was conducted using GenStat statistical package version 11(VSN International, 2011). Least Significance Difference (LSD) among treatment means was determined for p-value of 0.05.

3. Results and Discussion

Results on energy efficiency of the smoking kiln for charcoal and briquette fuel materials is shown in Figure 4.

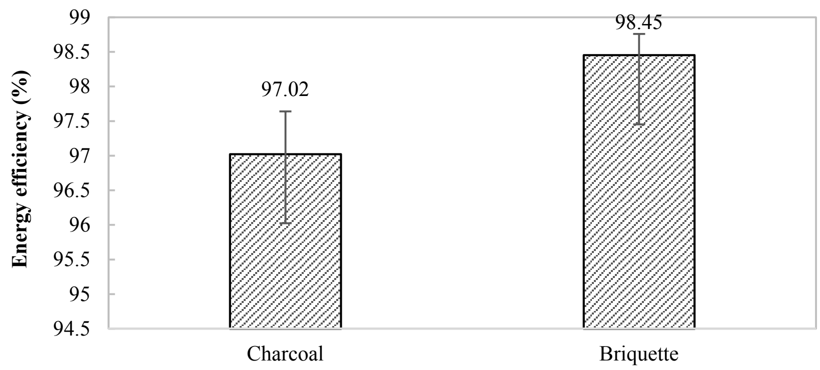

Figure 4. Energy efficiency of the kiln for charcoal and briquette

The energy efficiency of the kiln was 97.02% and 98.45% for charcoal and briquette fuel materials, respectively. Although, the energy efficiencies from both fuel materials were closely related, briquette offered a significantly higher energy efficiency than charcoal. It was observed that briquette kept most of its heat energy within the smoking chamber due to the relatively lower burning temperatures (Table 4) as compared to charcoal. Fasakin et al. (2009) recorded an energy efficiency of 69.4% for a rotatory fish smoking kiln (300 kg) which uses fuel from agro-waste sources.

Figure 5 illustrates the results of specific fuel consumption for charcoal and briquette during the smoke-drying process.

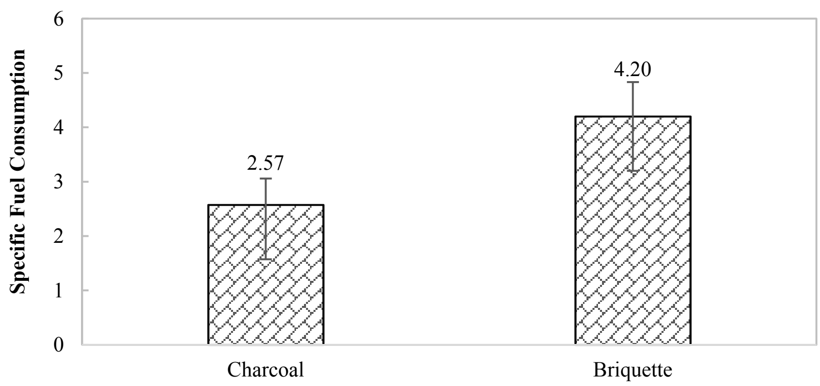

Figure 5. Specific fuel consumption for charcoal and briquette

The smoke-drying kiln recorded a specific fuel consumption of 2.57 and 4.20 for charcoal and briquette, respectively. The amount of charcoal required to obtain 1 kg of smoked fish was significantly lower than the amount of briquette required to obtain 1 kg of smoked fish. Conventional charcoal has higher calorific value and could burn better and longer than briquette, hence the results obtained.

The energy expended by charcoal and briquette fuel materials during the smoke-drying process is shown in Figure 6. The energy expended by charcoal and briquette fuel materials were 206 MJ and 249.6 MJ respectively. The energy expended during the smoke-drying process by briquette was significantly higher than charcoal. This could essentially be attributed to the differences in the calorific values of both fuel materials. A study by Ajewole et al. (2021) revealed that 185 MJ energy was expended during smoke-drying of Catfish with a dual-powered fish smoking kiln when charcoal was used.

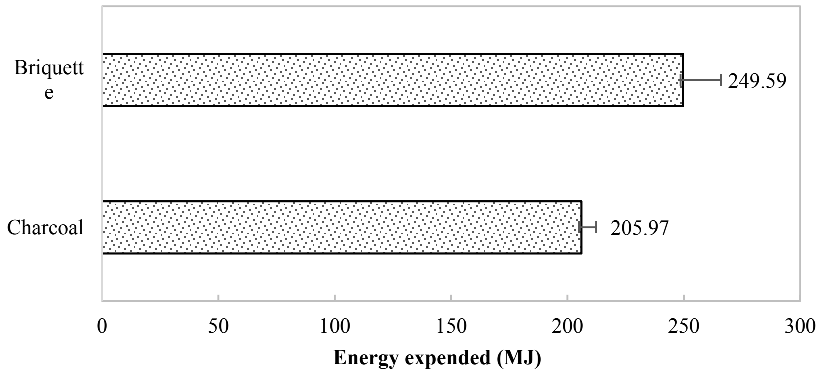

Figure 6. Energy expended by charcoal and briquette fuel materials

Table 3 presents the comparative summary of the statistical analysis on performance parameters for charcoal and briquette fuel materials. The use of charcoal offered higher moisture removal and drying rate during the smoke-drying process than briquette but the difference was not statically significant. Conversely, using briquette fuel material required extra 1.59 hours to smoke-dry 1 kg of catfish sample than when charcoal was used, though no significant difference exists. This could be attributed to the fact that charcoal burns faster and at higher temperatures than briquette leading to the relatively higher moisture removed, higher drying rate hence, less time spent in the drying process.

Table 3. Statistical analysis summary on performance parameters for charcoal and briquette

Fuel type	Parameter					
	Fuel efficiency (%)	Moisture removed (% w.b.)	SFC	Drying rate (kg/h)	Time spent (h/kg)	Energy expended (MJ/kg)
Charcoal	97.02	71.1	2.57	0.536	10.71	206
Briquette	98.45	69.5	4.20	0.469	12.30	249.6
LSD	1.10	ns	1.28	ns	ns	28.23

Characterization of the smoke-drying kiln for charcoal and briquette fuel materials based on relevant performance parameters is presented in Table 4.

Table 4. Performance characterization of the kiln for charcoal and briquette fuel material

Fuel material	Parameter				
	Qty of fuel used (kg)	Duration (h)	Max. Temp. (°C)	Fuel efficiency (%)	MC of dried fish (%)
Charcoal	6.80±1.96	10.71±1.34	203±40.67	97.02±0.62	8.86±1.35
Briquette	10.39±2.62	12.30±1.69	117±11.24	98.45±0.31	10.47±1.28

Using the smoke-drying kiln requires 6.80±1.96 kg of charcoal or 10.39±2.62 kg of briquette fuel material to smoke-dry Catfish at full loading capacity of 10 kg. The results revealed that fish can be dried at a maximum temperature of 203±40.67 °C to a final moisture content of 8.86±1.35% and at 117±11.24 °C to 10.47±1.28% for charcoal and briquette, respectively. Average temperature of 152.50 °C was reported by Ajewole et al. (2021) when charcoal fuel material was used to smoke-dry Catfish with a dual-powered fish smoking kiln. Ashaolu

(2014) cited 60-119 °C temperature range for fish smoking lasting for 4-12 hours. Result of moisture content of smoked-dried Catfish compares favourably with study by Faturoti (1985) which revealed that most smoked fish samples of African catfish had moisture content as 6.27% to 10.92%. According to Kumar (2013), moisture content less than 20% enhances the dried fish quality with an estimated shelf life of 9-10 months.

Breakeven analysis was conducted for the fish smoke-drying kiln based on the assumptions in Table 5 and cost summary outlined in Table 6.

Table 5. Assumptions for breakeven analysis

Parameter	Charcoal	Briquette
Total fixed cost (GH₵*)	315	315
Total variable cost (GH₵/h)	0.17	0.18
Working hours (minimum)	50	50
Hiring cost (GH₵/h)	0.5	0.5

Note. *GH₵ 9.22 = US$1.00 as of May 2022.

Generally, the cost implications associated with charcoal or briquette use in the smoke-drying operation within for smoking kiln was closely related. However, under the prevailing assumptions, charcoal seems to be an economically viable fuel material compared to briquette. Figure 7 attests that breakeven with charcoal as the main fuel material for custom hiring services of the smoke-drying kiln is at 952 hours vis-à-vis 998 hours when briquette is used. Surprisingly, a kg of briquette fuel material is sold at half the price of 1kg of charcoal. This perhaps confirms why charcoal use is widespread against the general notion that fuelwood burning to make charcoal is a major cause of deforestation. The suggestion is that since briquette thermal characteristics compared favourably with charcoal, it could be an alternative fuel material for smoke-drying of fish.

Table 6. Cost analysis summary for smoking kiln using charcoal or briquette

Cost item	Charcoal	Briquette
Purchase price (GH₵*)	1200	1200
Salvage value (GH₵)	120	120
Economic life (y)	4	4
Fixed cost (GH₵/y)		
Depreciation	270	270
Interest	33	33
Insurance	6	6
Tax	0	0
Shelter	6	6
Total fixed cost	315	315
Fuel cost (GH₵/kg)	6	3
Fuel Consumption (kg)	6.8	10.4
Fuel efficiency (%)	0.97	0.99
Drying rate (kg/h)	0.54	0.47
Working hours/y	1500	1500
Smoking kiln capacity (kg)	10	10
Time spent (h/kg)	10.71	12.30
Worker's wage (GH₵/h)	2	2
Number of Workers	1	1
Variable cost (GH₵/h)		
Fuel	39.58	30.72
Repairs & Maintenance	0.04	0.04
Labour	214.20	246.00
Total Variable Cost (GH₵/h)	0.17	0.18

Note. *GH₵ 9.22 = US$1.00 as of May 2022.

Figure 7 illustrates the breakeven chart for the smoke-drying kiln using charcoal or briquette fuel material.

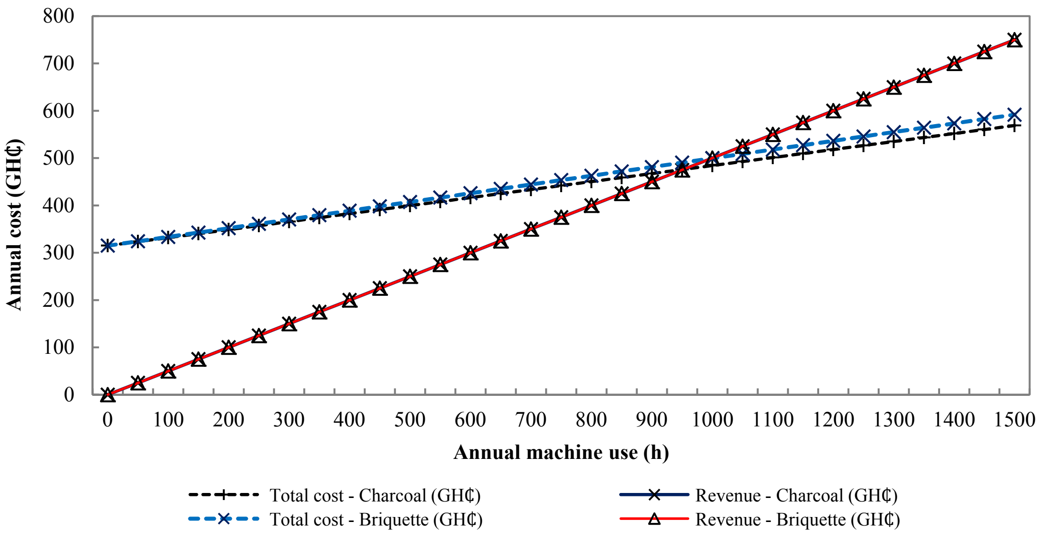

Figure 7. Breakeven chart for the smoke-drying kiln

4. Discussion

It was observed that briquette kept most of its heat energy within the smoking chamber due to the relatively lower burning temperatures (Table 3) as compared to charcoal. Fasakin et al. (2009) recorded an energy efficiency of 69.4% for a rotatory fish smoking kiln (300 kg) which uses fuel from agro-waste sources. The quantity of charcoal required to obtain 1kg of smoked fish was significantly lower than the amount of briquette required to obtain 1 kg of smoked fish. Conventional charcoal has higher calorific value and could burn better and longer than briquette, hence the results obtained. The energy expended during the smoke-drying process by briquette was significantly higher than charcoal. This could essentially be attributed to the differences in the calorific values of both fuel materials. A study by Ajewole et al. (2021) revealed that 185 MJ energy was expended during smoke-drying of Catfish with a dual-powered fish smoking kiln when charcoal was used. Average temperature of 152.50 °C was reported by Ajewole et al. (2021) when charcoal fuel material was used to smoke-dry Catfish with a dual-powered fish smoking kiln. Ashaolu (2014) cited 60-119 °C temperature range for fish smoking lasting for 4-12 hours. Result of moisture content of smoked-dried Catfish compares favorably with study by Faturoti (1985) which revealed that most smoked fish samples of African catfish had moisture content as 6.27% to 10.92%. According to Kumar (2013), moisture content less than 20% enhances the dried fish quality with an estimated shelf life of 9-10 months.

5. Conclusion and Recommendation

Energy efficiency and specific fuel consumption for the smoke-drying kiln were 97.02% and 2.57, 98.45% and 4.20 for charcoal and briquette fuel materials, respectively. The energy expended by charcoal and briquette fuel materials were 206 MJ and 249.6 MJ, respectively. Briquette use offered the smoking kiln a significantly higher energy efficiency, specific fuel consumption and energy expended than charcoal.

The use of charcoal offered higher moisture removal and drying rate for smoke-drying process than briquette with no significant difference observed. Conversely, using briquette fuel material required extra 1.59 hours to smoke-dry 1 kg of catfish sample than when charcoal was used, though no significant difference exists.

Breakeven with charcoal as main fuel material for custom hiring of the smoke-drying kiln occurs at 952 hours vis-à-vis 998 hours when briquette is used. Economically, briquette compares closely with charcoal, and could be considered a good alternative fuel material for smoke-drying of fish.

Future research should conduct organoleptic assessment on fish smoked with charcoal and briquette to ascertain consumer acceptability of the final produce. Performance of a bigger capacity (≥ 100 kg fish per batch) of the smoke-drying fish kiln for other common fish species like Nile Tilapia (*Oreochromis niloticus*) and Heterobranchus should be assessed.

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