ISSN NO 2320-5407 International Journal of Advanced Research (2013), Volume 1, Issue 4, 196-201

ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Development and Performance Evaluation of an Extractor for Removing Oil from Soaked Kenaf Bast and Core

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Manuscript Info

Manuscript History:

Received: 01 April 2013
Final Accepted: 10 May 2013
Published Online: June 2013

Key words:
kenaf bast and core,
oil spill, worm shaft,
oil extractors, briquettes

Abstract

Crude oil is a major natural resource and the mainstay of any country that have it in abundance; its sole disadvantage is its tendency of spilling to the environment. Kenaf has been found to be a good absorbent for physical clean-up and treatment of oil spillage both on land and water surfaces. Kenaf absorbs the oil thus making it soaked and the absorbed oil can however be recovered using appropriate technology. The aim of the research work is to design and construct an oil extractor to remove and recover the absorbed oil from kenaf bast and core. The functional parts of the machine are: barrel (80 mm diameter and 1000 mm length), worm shaft (minimum diameter 50 mm and maximum diameter 65 mm), gear reduction box (20:1), prime mover (7 hp, 1420 rpm), oil and cake outlet, hopper, conical restrictor, pulley and transmission belts. The worm shaft was tapered to build up pressure as it travels across the length of the barrel and it conveys, grinds, presses and squeezes oil out of kenaf into the oil outlet via the oil collection tray. The residual cake from where the oil was extracted is extruded out of the cake outlet in form of briquettes. The oil extractor machine was evaluated in compliance with Philippines Agricultural Engineering Standard PAES 230 and 231: 2005 and the results showed a percent kenaf recovery of 60 %, extraction efficiency of 62.2 %, throughput capacity of 36.5 kg/hr and an extraction loss of 37.8 %. The extraction efficiency varies with the moisture content of the soaked kenaf bast and core. The operation of the machine does not require any technical-know-how and the machine can be easily maintained as it has the tendency of self-lubricating the extraction chamber due to presence of oil in the input materials.

1. Introduction

Oil spillage has diverse effects on the environment; it causes shifts in population structure, species abundance, diversity and distribution. Various existing technologies for cleaning-up and treating oil spills have shown diverse disadvantages including the possibility of introducing toxic compounds to the natural environment when chemical treatment method is used (Zhu *et al*., 2001), partial (incomplete) removal of oil, time wastage, expensive equipment, non-recovery of the spilled oil, adequate monitoring system requirements (Wolicka and Suscek, 2008), high reagent or energy requirement and generation of toxic sludge or other waste products that requires disposal. Kenaf plant (*Hibiscus cannabinus*) has been found to be very efficient in absorbing oil when spilled on water, concrete, asphalt pavement and other hard surfaces such as a factory floor, shop or work area. This is achieved by bringing milled bast and core of kenaf in physical contact with the spilled oil. The latest technology ensures complete clean-up, cost effectiveness, less time consumption, non-generation of wastes and requires less monitoring system and above all the possibility of recovering the spilled oil from the soaked kenaf;

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this factors gives kenaf a better advantage over the existing clean-up technologies. However, the adoption of kenaf as a clean-up technology involves various post-harvest handling and unit operations which include removal of leaves, seeds and flower from the kenaf stalk (decortication), separation of the bast and core of kenaf from the fibres, milling of the bast and core to powder to increase the surface-to-volume ratio of kenaf and for easy handling and scooping when in contact with oil. Most oils are extracted from oil bearing crops by grinding, cooking, expelling or pressing by chemical method or solvent extraction of the raw materials (Ajao *et al.*, 2009) though, the most common method of extracting oil from oilseeds is the mechanical pressing method (Mrema and McNulty, 1985; Bamgboye and Adejumo, 2007) which may be hydraulic press or screw press principle. Ojomo *et al.* (2012) reported that the screw press principle is more reliable, has a higher efficiency and are usually more adaptable for small and medium scale producers (Abubakar and Yiljep, 1996; Adigzi *et al.*, 2006; Olayanju *et al.*, 2004; NCRI, 1995) than the hydraulic press which is otherwise more expensive, need more maintenance, requires more labour and involves risking the contamination of the oil with poisonous hydraulic fluid. Thus, the screw press principle was adopted in designing and constructing an oil extractor for removing and recovering oil from soaked kenaf powder when used for oil spill clean-up.

2. Material and Methods

2.1 Design Considerations

Critical considerations in the design of the machine included: high extraction efficiency, low extraction loss, costs and availability of construction materials, more efficient use of power by reducing the time and drudgery as well as elimination of the risk of injury and the simplicity of operation and maintenance. Also considered is the design of the worm shaft to ensure maximum conveyance, mixing and pressing of the soaked kenaf powder and pellets, consideration was also given to the frame to ensure maximum support and avoid structural failure.

2.2 Design Conception

The machine consists of four segments; the feeding segment, extraction segment, power segment and the frame. The feeding segment consists of the hopper which was made of mild steel due to its availablilty and the inedibility of the soaked kenaf bast and core; the extraction chamber consists of the worm shaft, the perforated barrel and the conical restrictor; the power segment consists of the prime mover, reduction gear and the pulley while the frame serves as a support or stand for the machine on which all other segements were mounted. The worm shaft rotates in the barrel and conveys the soaked kenaf powder from the feeding section towards the discharge section where there is a conical restrictor to force the caked kenaf out of the machine. The maximum compression ratio achieved by the machine is the ratio of intake to the rate of discharge at the conical restrictor (this is 80 mm: 20 mm). The oil extracted is collected at the oil collection tray and the cake (briquette) was discharged from the tip of the conical restrictor. Pressure is achieved in the machine by the operation of the worm shaft which was designed to have an increasing diameter thus reducing the area available for the soaked kenaf in the barrel. The isometric view of the oil extractor for kenaf bast and core is presented in figure 1.

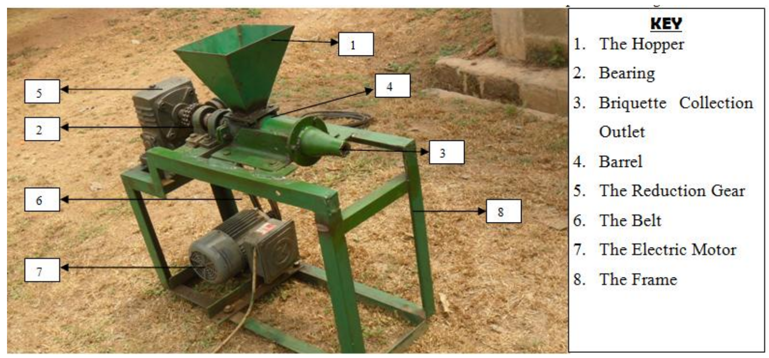


Figure 1: Isometric View of the Kenaf Oil Extractor

2.3 Selection of Parameters

The design parameters were designed for or selected based on standard and instruction manual presented by FMC (2009) for an irregular, stringy, fibrous and powdery material. The following parameters were used for the design of the oil extractor: type of conveyor: Ribbon Flight, horizontal screw conveyor; maximum recommended Speed: 60 rpm, material of Construction: mild Steel, diameter and length of barrel : 80 mm and 1000 mm respectively.

Density of Mild Steel: 7850 m^3

2.4 Design calculations

2.4.1 Bulk Density of the Soaked kenaf

The average bulk density of soaked kenaf was obtained using standard test weight procedure by immersing a known mass of soaked kenaf in a known volume of water and measuring the rise in volume of water (Oyelande *et al*., 2005; Sharma *et al*., 2011). The bulk density was however calculated as the ratio the mass of soaked kenaf immersed in water to the the difference between the new level of water in the measuring cylinder and the initial level of water is the bulk volume of the seed. Mathematically, it is expressed as:

$$\rho = \frac{mass\ of\ soaked\ kenaf\ immersed\ in\ water\ (kg)}{volume\ of\ water\ displaced\ by\ the\ immersed\ soaked\ kenaf\ (m^3)} \quad (1)$$

Where: ρ is the bulk density of the soaked kenaf bast and core (kg/m^3)

2.4.2 Design of the Worm Shaft and the Power required by the Machine

The worm shaft is the main component of the kenaf oil extractor, it is acted upon by the weight of raw materials being processed, pulley and the screw thread hence it was designed to guard against bending and torsional stresses, the diameter of the worm shaft was obtained with the relation given by Shigley and Mischke (2001); Khurmi and Gurpta (2008); Olaniyan *et al.* (2011)

$$d_s = \frac{16\ T}{0.27\ \pi \delta_o} \quad (2)$$

Where: d_s is the Diameter of the Screw Shaft (mm), T is the Torque transmitted by the shaft (820 N/mm and δ_o is the yield stress of mild steel (248 N/mm^2) hence, $d_s = 62.4\ mm$. Therefore, a mild steel rod of 65 mm diameter was used for the worm shaft. Similarly, the torque transmitted by the shaft is given by:

$$T = \frac{BD_m}{2} \left(\frac{\tan\theta + \mu}{1 - \mu \tan\theta}\right) \quad (3)$$

Where: T is the torque transmitted by the screw, B is the force that pulls the load (N), *Dm* is the mean diameter of the screw, μ is the coefficient of friction and θ is the lead angle of the screw. Given that B is 15.4 N, *Dm* is 0.058 m, μ is 0.5 and tan θ is 0.22 then, the torque transmitted by the shaft is 0.82 Nm.
Therefore, power required for extraction of oil is obtained thus:

$$power = \text{torque x speed} \left(\frac{\text{rad}}{\text{sec}}\right) \quad (4)$$

Given that speed is 6.3 rad/s then, power require by the machine is 5.2 kW (7 horse power)

2.4.3 Design of the Screw Thread

The worm shaft is essentially a tapered screw conveyor with the volumetric displacement being decreased from the feeding segment to the discharge end of the barrel. The soaked kenaf are thereby subjected to pressure which forces oil from them as they are propelled forward by the worm shaft (Sivakumaran *et al*., 1985). The screw threading system was designed as a step up shaft diameter and decreasing screw depth using the expression in Eqn. 3 below as:

$$U = a + (n - 1)d \quad (5)$$

Where: Un is the screw depth at the discharge end, a is the screw depth at the feed end, n is the number of screw turns, and d is the common difference between next successive screw depths.

2.4.4 The Discharge Chute and the Frame

The discharge chute was designed to be tapered to enable compression and increase the pressure in the extraction segment. All the segments of the machine were mounted on the frame with dimensions 1200 mm x 450 mm x 900 mm for length x width x height respectively. An additional hopper height brings the overall height of the machine to 1600 mm, suitable for an average person to stand on the ground and operate the machine.

1. Input Materials and Method of Testing

Kenaf stalks were obtained from Teaching and Research Farm, Faculty of Agriculture, University of Ibadan and the Institute of Agricultural research and Training, Moor Plantation, Apata, Ibadan. The stalks were decorticated to separate and remove the basts and core from the outer fibres, the basts and core was later milled to powder improve the absorbing properties. The powdery form of kenaf was placed in physical contact with simulated crude oil (mixture of a litre each of kerosene, petrol gas, diesel and engine oil) already spilled on water and workshop floor and allowed to stay till the entirety of the oil was visibly wiped off and cleaned thus making the powdered kenaf soaked. The soaked kenaf was scooped and discharged into the hopper of the oil extractor as the input materials. The performance test of the oil extractor was carried out in accordance with Philippine Agricultural Engineering Standard PAES 230 and 231:2005 to obtain actual data on overall machine performance. After test running the oil extractor, the oil extraction area was cleaned and prepared for the test trial; this procedure was repeated for succeeding test trials and a minimum of three test trials were carried out as stipulated by PAES 231:2005, the duration of each test trial started with the extraction of oil from the soaked pellets of kenaf in the extraction chamber and end after the last discharge from the briquette output chute comes out, the time expended was recorded as operating time. The following relations in accordance with PAES 231: 2005 were used in determining the performance of the oil extractor:

i. **Input Capacity, *Ci***

$$Ci = \frac{Wi}{Ti} \quad (6)$$

Where: *Ci* is the Input Capacity (*kg/h*), *Wi* is the Weight of Input Material (*kg*), and *Ti* is the Time Required to empty the hopper (*hr*)

ii. **Crude oil recovery, Ro (%)**

$$Ro = \frac{Wo}{Wi}\ x\ 100 \quad (7)$$

Where: *Ro* is the Crude Oil Recovery (%), *Wo* is the Weight of Crude Oil extracted (*kg*) and *Ws* is the Weight of oil spilled or used for the clean-up process (*kg*)

iii. **Kenaf Pellets Recovery, *Mr* (%)**

$$Mr = \frac{Wm}{Wi} x\ 100 \quad (8)$$

Where: *Wm* is the Weight of Cake/Briquette Collected (*kg*) and *Wk* is the Weight of input materials used for the oil clean-up process (kg)

iv. **Crude Oil Production rate, *Pr***

$$Pr = \frac{Wo}{Tt} \quad (9)$$

Where: *Pr* is the Crude Oil Production Rate (*kg/hr*), *Wo* is the Weight of Crude Oil collected (*kg*) and *Tt* is the Total Time Used (*hr*)

v. **Extraction Efficiency, ∫**

$$\int\ = \frac{\textbf{\textit{weight of oil collected,kg}}}{\textbf{\textit{weight of oil content of test material,kg}}}\ \boldsymbol{x\ 100} \quad (10)$$

Where: ∫ is the Extraction Efficiency of the Oil Extractor (%)

vi. **Extraction losses, EL**

$$\text{EL} = 100 - \int \quad (11)$$

4. Results and Discussions

The bulk weight of the soaked kenaf bast and core used for the evaluation of the machine ranges from 480 grams to 2370 grams, the mass of simulated crude oil used for absorption ranges from 430 grams to 1750 grams. The mass of briquettes obtained ranges from 600 grams to 2300 grams and the mass of simulated crude oil extracted by the machine ranges from 250 grams to 1200 grams respectively. The time taken by the machine to empty the hopper ranges from 57 seconds to 477 seconds while the total operating time for extracting oil from the soaked kenaf ranges from 75 seconds to 542 seconds. An increase in temperature was observed from the feeding section (the hopper) to the discharge section (briquette collection section), temperature at the feeding section varies from 34 to 37 ^{0}C and is equivalent to the ambient temperature while the temperature at the discharge section increases from 69 ^{0}C to 92 ^{0}C. The mass of oil, kenaf and the soaked kenaf, time taken for emptying the machine hopper, total time used for oil extraction, weight of briquette obtained and the weight of oil extracted are presented in Table 1.

However, the average values of the parameters presented in Table 1 are used for calculating the machine throughput, percent crude oil recovery, extraction efficiency and losses based on the PAES 230 and 231 Standard for evaluating oil expellers. The machine input capacity was obtained to be 36.5 kg/hr, the percent kenaf recovery rate was obtained to be 60 %; the extraction efficiency was obtained to be 62.2 % while the extraction loss was 37.8 %.

4.1 Effect of Moisture Content on the Extraction Efficiency and Losses

The extraction efficiency of the machine varies with the moisture content of the input materials. The surface response predictions to obtain the optimized conditions using a full quadratic multiple regression analysis is presented in Figure 2.

Table 1: Evaluation of the Oil Extractor

TRIALS	1	2	3	AVE	S. D.
Mass of kenaf used before oil absorption (kg)	0.99	0.48	2.4	1.29	0.99
Mass of oil used for absorption (kg)	0.86	0.43	1.75	1.013	0.67
Volume of Oil used for absorption (cm^3)	1000	500	1300	933	404
Mass of input material (soaked kenaf) (kg)	1.84	0.92	4.15	2.3	1.67
Mass of cake (briquette) collected (kg)	1.25	0.6	2.3	1.38	0.86
Mass of oil extracted (kg)	0.45	0.25	1.2	0.63	0.5
Volume of Oil Extracted (cm^3)	525	290	890	570	302
Mass of materials retained in the machine (kg)	0.14	0.07	0.65	0.29	0.32
Time taken to empty the hopper (hr)	0.04	0.02	0.13	0.063	0.06
Total time consumed by the machine (hr)	0.05	0.021	0.15	0.074	0.07
Moisture Content Input materials (% dry basis)	85.9	91.7	72.9	83.5	9.6
Bulk Volume (m^3)	1.25	0.66	3.2	1.703	1.33
Bulk Density (kg/m^3)	0.798	0.727	0.75	0.758	0.04

S.D means STANDARD DEVIATIONS and AVE means AVERAGE VALUES

Figure 2: Surface Response of the Extraction Efficiency

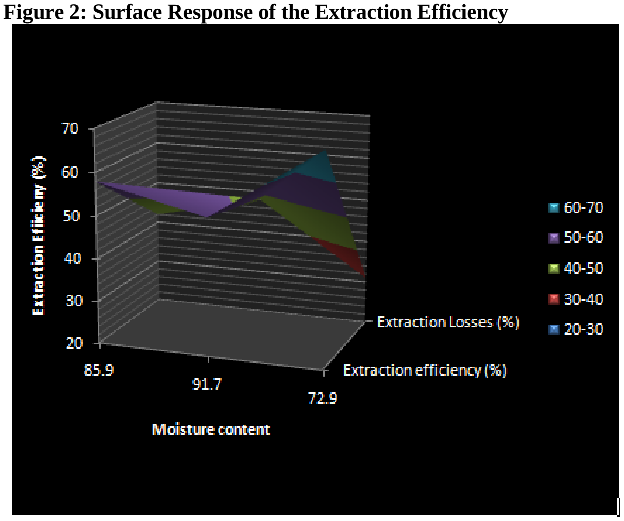
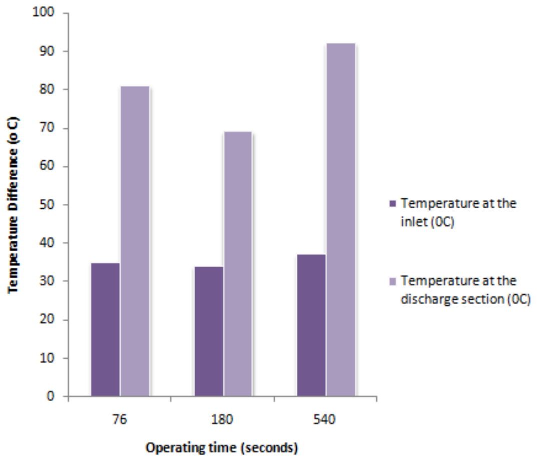


Figure 3: Temperature Difference between the Feeding and Discharge



4.2 Temperature Rise from the Feeding to the Discharge section

Variations were observed in the temperature at the inlet and discharge section of the oil extractor as measured with a dry-bulb thermometer, the temperature at the inlet (feeding) section of the machine is equivalent to the ambient temperature, a temperature rise was observed between the inlet and outlet (discharge section) of the machine for each test trial, the temperature difference between the inlet section and outlet section of the machine is presented in Figure 3.

A similar temperature rise was reported by Zafari (2012) for cattle manure pellets in an open-end die pelletizing machine where a temperature rise of 40 ^{O}C to 80 ^{O}C was reported, Hassan (2011) reported a similar trend for coconut oil extractor machine which has a temperature rise of 25 ^{O}C to 75 ^{O}C, however, the temperature rise may be attributed to the pressure and compression developed in the extraction chamber of the machine.

5. Conclusions

An oil extractor machine was designed, constructed and tested to remove and recover oil from kenaf when used for the absorption and clean-up of crude oil spillage. The machine has a throughput capacity of 36.5 kg/hr and oil Extraction Efficiency (percent oil yield) of 62.2 % and the oil yield was dependent on the moisture content of the soaked kenaf bast and core used for the absorption (clean-up) process. The operation of the machine does not require any technical-know-how and the machine can be easily maintained as it has the tendency of self-lubricating the extraction chamber due to presence of oil in the input materials.

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