Design of Pyrolyzer for the Production of Fuel Oil Using Palm Kernel Shells

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ABSTRACT
Design of pyrolyzer to process 1000kg/day of palm kernel shells (PKS) to fuel oil, water and char was carried out. The PKS was collected from different geographical locations, identified and authenticated before it was washed, sun dried and crushed to a standard grade of 425 µm. The PKS was later pyrolysed in the reactor from 400 - 450°C. The fuel oil product was passed through a condenser submerged in ice bath for cooling to 10°C. The products were assumed to be a parallel first order irreversible reaction. Rate constants (k_{oil}, k_{water}, and k_{char}) and overall constant k were calculated from the laboratory pyrolysis results and were used to obtain the reactor volume which lead to the determination of the height and diameter of reactor. The thickness of reactor shell was calculated using standard design equations from literature and laboratory data. The heat required for pyrolysis of 1000kg/day of palm kernel shell was obtained from scale up of heat requirement obtained from laboratory results. The lagging thickness was determined through equations of heat transfer resistances across the reactor cross section. The volume of reactor required to pyrolyse 1000kg/day was 107,143m^3, the decomposition reaction constant K_{oil} of the fuel oil was 1.153x10^{-4} min^{-1} whilst the overall constant K was 3.17x10^4 min^{-1}. The energy required to pyrolyse the PKS was 14025kJH^{-1} while the product temperature and the atmospheric temperature were 723K and 378K, respectively. Total heat transfer resistances across the reactor cross section were found to be between 2.798x10^{-6} K/W and 2.51 x 10^{-4} K/W.

KEYWORDS: Pyrolyzer, Design, Palm kernel shells-dura-and-tenera, fuel Oil, Reaction constants.


1. INTRODUCTION
The high energy demand and globalization in the industrialized world intensify the need to adapt to a rapid increase in climate change. This involves strategies that would encourage conservation and alternative energy sources (Cunningham & Cunningham, 2006). One such strategy could be seen in the pyrolysis model for biomass (like the palm kernel shells etc.) pyrolysis in the batch reactor. Pyrolysis is a thermo-chemical decomposition of organic material at elevated temperatures in the absence of oxygen. The word pyrolysis is coined from Greek language with word pyro meaning “fire” and lysis “separating” (Kalyana et al., 2005). There are number of benefits when using biomass residues as fuel instead of using fossil fuels (Song et al., 2004; Tasi et al., 2007; Natthaya, 2013). Biomass fuels do not create any rise in the amount of greenhouse gas in the atmosphere biomass contains almost no Sulphur, thus the combustion of the biomass creates hardly any sulfur acid. The ash is normally alkaline.

Using biomass residues as fuel often solve waste disposal problem and create instead an income for the waste producer or user (Ashok, 2008; Camila et al., 2013; Acikgoz, & Okockar, 2004). There is problem of insufficient energy source and the need for an alternative, less expensive and renewable
energy source. Also, there is need to convert the land pollution caused by Palm Kernel Shells to energy source by using the shells which is a waste after the removal of palm kernel nut. One of the byproducts of pyrolysis of biomass (PKS) which is the char can be converted to activated carbon and used for a lot of industrial and domestic purposes (Ademiluyi & Alex, 2016b; Ademiluyi, & Nze, 2016c). Development of Design data for PKS pyrolysis will encourage local fabrication of this reactor and reduced the cost of importation of the reactors.

The objectives of the research are to obtain kinetic data and use the data to design a batch pyrolyzer for the production of bio-fuel and char from 1000kg of Palm Kernel Shells per day.

2 MATERIALS AND METHODS

A Materials/ Parameters required for the Design of Pyrolyzer

i. Palm Kernel Shells (Dura & Tenera specie PKS)
ii. laboratory scale pyrolyzer
iii. High temperature Thermometer
iv. Burner
v. Bomb calorimeter
vi. Mass Spectrophotometer
vii. Material of construction; stainless steel internal, mild steel external
viii. Lagging material; glass wool

B Input Parameters

i. Density of PKS kg/m³
ii. Mass of PKS
iii. Input temperature T_i
iv. Initial concentration C_A0
v. Conversion X_A0
vi. Heat capacity C_p
vii. Input quantity of heat Q
viii. Conversion Rate r_A
ix. Input time
x. Atmospheric temperature
xi. Thermal conductivity of lagging material
xii. Outside resistance

C Output parameters for design of pyrolyzer

i. Height
ii. Diameter
iii. Volume
iv. Heat Required
v. Internal Temperature (T_i)
vi. Outside Temperature T_out
vii. Stainless steel thickness for (ℓ mm) internal
viii. Mild Steel Thickness (ℓ mm) for external
ix. Rate constant K_O for Oil
x. Rate constant K_W for water
xi. Rate constant K_C for Char
xii. Overall Rate constant K
xiii. Internal Resistance R_1 for Hot Air
xiv. Resistance R_2 for internal Stainless Steel Material
xv. Resistance R_3 for the Insulating Material thickness
xvi. Resistance R_4 for Mild Steel
xvii. Resistance R_5 for the Air Surrounding the Reactor

2.1 Design Equations for Batch Pyrolyzer of Palm Kernel Shell

2.1.1. Kinetic Model for Pyrolysis of Palm Kernel Shell

Let: Palm kernel shells be denoted as A
Fuel Oil denoted as O
Water denoted as W
Bio char denoted as C

The design was based on the use of 1000kg/day of palm kernel shells to produce oil, water and char. The products were assumed to be a parallel first order
irreversible reaction. Rate constants (K_o, K_w, and K_c) for oil, water and char and overall constants K were calculated from the laboratory pyrolysis results and were used to obtain the reactor volume which lead to the determination of the height and diameter of reactor. The thicknesses of reactor shells were calculated using standard design equations from literature and laboratory data. The heat required for pyrolysis of 1000kg/day of palm kernel shell was obtained from scale up of heat requirement obtained from laboratory results. The lagging thickness was determined through equations of heat transfer resistances across the reactor cross section (R1 for the resistance of the internal hot air within the reactor, R2 is for the internal stainless steel reactor thickness, R3 resistance of the insulating material (glass wool) thickness, R4 resistance of mild steel lagging cover and R5 for the resistance of surrounding air).

**Rate Equation**

The rate of pyrolysis of PKS can be related to a batch reactor as (Octave, 2007):

\[ r_A = \frac{dC_A}{dt} = (k_o - k_w - k_c) C_A \]  
(1)

\[ -r_A = (k_o + k_w + k_c) C_A \]  
(2)

\[ -r_o = \frac{dC_o}{dt} = (k_o) C_A \]  
(3)

\[ -r_w = \frac{dC_w}{dt} = (k_w) C_A \]  
(4)

\[ -r_c = \frac{dC_c}{dt} = (k_c) C_A \]  
(5)

The overall constant k

\[ k = (k_o + k_w + k_c) C_A \]  
(6)

For overall constant k,

\[ \frac{dC_A}{dt} = k C_A \]  
(7)

\[ -r_A = \ln C_A C_{A0} = k t \]  
(8)

Rearrange and integrate using boundary conditions gives

\[ -r_A = \ln C_A C_{A0} = k t \]  
(9)

\[ -r_A = \ln(C_A/C_{A0}) = kt \]  
(10)

\[ r_A = \frac{C_{A0}(1 - X_A)}{C_{A0}} = kt \]  
(11)

**Assume the Decomposition Reaction to be Parallel 1st Order and is Irreversible**

When \( r_A = \frac{dC_A}{dt} = (-k_o - k_w - k_c) C_A \)

To calculate K_o, rate of pyrolysis shell \( r_A \) is given as

Also in term of PKS Converted

\[ r_A = \frac{dC_A}{dt} = (+k_o + k_w + k_c) C_A \]  
(12)

\[ r_A = -\ln(1 - X_A) = kt \]  
(13)

Conversion of PKS to obtain fractional conversion \( X_{Ao} \) of oil.

\[ -\ln(1 - X_{Ao}) = k_o t \]  
(14)

**2.1.2 Determination of Reaction Constants k_o, k_w, k_c and Overall Reaction Constant, k**

When time of conversion is t in seconds

\[ k_o = -\ln(1 - X_{Ao}) \frac{1}{t} \]  
(15)

b) Conversion of PKS to obtain fractional conversion \( X_{Aw} \) of water

\[ -\ln(1 - X_{Aw}) = k_w t \]  
(16)
\[ k_w = -\ln(1 - x_{Ac}) \frac{1}{t} \]

Where \( K_w = \text{rate constant } k \text{ for water} \)

\[-\ln(1 - x_{Ac}) = k_w t \]  
(17)

c) Conversion of PKS to obtain fractional conversion \( X_{Ac} \) of Char

\[-\ln(1 - x_{Ac}) = k_e t \]  
(18)

For \( k_e = \text{rate constant } k \text{ for char} \)

\[-\ln(1 - x_A) = k_e t \]  
(19)

\[ k = (k_0 + k_w + k_e) \]  
(20)

\[ K_0 = \text{Reaction constant for oil (s}^{-1}) \]

\[ K_w = \text{Reaction constant for water (s}^{-1}) \]

\[ K_e = \text{Reaction constant for char (s}^{-1}) \]

\[ K = \text{Overall constant for the decomposition reaction (s}^{-1}) \]

\[ V = \pi r^2 h \Rightarrow h = \frac{V}{\pi r^2} \]  
(21)

\[ V = \pi r^2 h \Rightarrow h = \frac{V}{\pi r^2} \]  
(21a)

\[ h = \frac{N_{A0}}{\pi r^2 t} \int_0^{\chi_A} \frac{\partial \chi_A}{-r_A} \]  
(21b)

Volume of the reactor rearranging equation 21a and 21b give

\[ V = \frac{N_{A0}}{\pi} \int_0^{\chi_A} \frac{d\chi_A}{(1-r_A)} \]  
(22)

\[ V = \frac{N_{A0}}{\pi} \int_0^{\chi_A} \frac{d\chi_A}{K_{CA}} \]  
(23)

Relationship between diameter \( D \) to height \( H \) of reactor as specified from Chemical Engineers handbook are into ratio 1 to 2 (Perry, 2008).

so that

\[ h = 2D \]

\[ D = 0.5h \]  
(24)

\[ \frac{\pi D^2}{4} h = V \]  
(25)

\[ h = \frac{V X 4}{\pi D^2} = \frac{V X 4}{(0.5h)^2 X \pi} \]  
(26)

\[ h = \frac{4V}{\pi D^2} \]  
(27)

### 2.1.3 Determination of Pyrolyzer Reactor Thickness

Pyrolyzer reactor thickness was computed using equation 29.

\[ \ell = \frac{P_i D_i}{2Jf - P_i} \]  
(28)

(Coulson & Richardson, 2013)

Design Temp was 450°C (Obtain from pyrolysis experiment). Typical design stress for stainless steel at 450°C was obtained from Sinnott and Galvin (2013). Also design pressure, was taken as 10% above operating of pressure. A corrosion allowance of 2mm should be used.

### 2.1.4 Determination of Thickness of the Reactor Insulator Cover Cylinder

Diameter of the insulator reactor cover Cylinder \( (D_s) = \text{ Diameter of the internal stainless steel } (D_i) + 2(\text{thickness of the steel plate } (t_s) + \text{2(thickness of the insulated } (t_{insl}) + 2 \text{ (thickness of the external mild steel cover } (t_{ms}) \text{). i.e.}) \)

\[ D_s = D_i + 2t_s + 2t_{insl} + 2t_{ms} \]  
(29)

### 2.1.5 Thickness of the reactor insulator covers Cylinder

\[ \lambda = \frac{P_i D_s \times 1000}{2Jf - P_i} + \text{corrosion allowance (Coulson & Richardson, 2013)} \]  
(30)

where \( P_i = \text{design pressure} \)

Design temperature 450°C,

Design stress \( (f) = 100N/mm^2 \) (Sinnott, & Galvin, 2013).

Corrosion allowance of 2mm was used.
2.1.6 Determination of the Lagging Thickness of the Reactor

To calculate the thickness of the insulating material, Heat lost by reactor to surrounding is

\[ Q = (T_{\text{ai}} - T_{\text{atm}})/R_T \]  \hspace{1cm} (31)

The total resistance \( R_T \) = Resistance of products in reactor + Resistance of stainless-steel reactor + Resistance of insulation (glass wool) + Resistance of stainless-steel cylinder covering insulator + Resistance of air at surrounding of reactor as developed by Ademiluyi (2016a) for design of lagging for rotary dryers.

\[ R_T = R_1 + R_2 + R_3 + R_4 + R_5 \text{ (K/W)} \]  \hspace{1cm} (32)

\[ R_T = \frac{1}{(h_{\text{va}} \times 2 \times 3.142 \times (D/2) \times L)} \quad \text{In} \,(r_2/r_1) + \quad \text{In} \,(r_3/r_2) + \quad \text{In} \,(r_4/r_3) + \quad \text{In} \,(r_5/r_4) + \quad \frac{1}{(h_{\text{out}} \times 2 \times 3.142 \times (t_{\text{isl}} + D/2 + t_d + t_{\text{ic}}) \times L)} \]  \hspace{1cm} (33)

\[ Q = \frac{T_{\text{ai}} - T_{\text{atm}}}{R_T} = Q = \frac{T_{\text{os}} - T_{\text{atm}}}{R_5} \quad \text{(34)} \]

Where \( h_{\text{out}} \) is heat transfer coefficient for air outside dryer was taken as 15W/m\(^2\)K.

\( T_{\text{ai}} \) = inlet air temperature of dryer

\( T_{\text{atm}} \) = atmospheric temperature

\( T_{\text{os}} \) = temperature of the outside surface

\( \pi = 3.142 \)

Hence

\[ R_T = R_5 \frac{T_{\text{ai}} - T_{\text{atm}}}{T_{\text{os}} - T_{\text{atm}}} \]  \hspace{1cm} (35)

The thickness of insulation \( t_{\text{isl}} \), was then obtained by combining equation 33 and 34 choosing values of from \( t_{\text{isl}} \) from (0.03-0.3m) until equation 33 balance 34.

2.1.6 Determination of the Energy Required to Pyrolyse Palm Kernel Shells

The energy required to pyrolyse Palm Kernel Shells was calculated from equation (36).

\[ Q = MC \Delta T \]  \hspace{1cm} (36)

where \( Q \) = Quantity of Heat

\( M = \text{Mass of the Shell} = 1000 \text{kg} \)

\( C = \text{Specific Capacity of Palm Kernel Shell (kJ/kgK)} = 1.98 \text{kJ/kgK} \) (Fono et al, 2013)

\( \Delta T = \text{Temperature Change (K)} \)

2.1.7 Lagging/Insulating material of Pyrolyzer

Glass wool was recommended as lagging for pyrolyser.

2.1.8 Materials of Construction for Batch Reactor Type Pyrolyzer

Stainless steel material was recommended for construction of reactor to avoid contamination of fuel oil and mild steel as lagging cover to reduce cost of fabrication of material.

2.1.9 Pyrolysis of Palm Kernel Shells

In order to obtain data and other parameters for the design of pyrolyzer to process 1000 kg/day of PKS, fuel oil was produced in laboratory scale using palm kernel shells of different species in order to identify palm kernel shells with the highest fuel oil yield. Five hundred grams 500g, 1000g and 1500g of fresh samples of Tenera and Dura species of palm kernel shells obtained from Osun, Imo and Rivers States, were washed and dried. It was transferred to cellophane bags.
and sealed. The samples were crushed using crusher to a particle size of 425µm dried and later poured serially and separately into the reactor through the hopper. The hopper was properly sealed to avoid leakages before switching on the heater. The shells were pyrolysed until the product temperature rise to 400°C, the reaction time and temperature were taken as the reaction progresses further to 450°C. The fuel oil produced was cooled using condensers.

3. RESULTS AND DISCUSSION

3.1.1 Product Temperature of Palm Kernel Shells Specie Collected from Different locations with Respect to Pyrolysis Time

Figure 2 shows a comparable pyrolysis temperature of Tenera PKS collected from Osun and Omagwa from 0 to 55mins while Dura PKS showed a distinct and lowest pyrolysis temperature up to 55 minutes. At 58mins, the temperature of Dura was comparable to that of Tenera PKS collected from Omagwa while the Tenera from Omagwa revealed a comparable pyrolyzed temperature of 350 °C at 66 minutes to Osun type and remained constant at the climax temperature of 350 °C. The close pyrolysis temperature of Osun and Omagwa Tenera shell implied that they can be a substitute to each other. These results also show that location of planting same kernel type did not affect the pyrolysis temperature. The pyrolysis of Dura Palm Kernel differs slightly from Tenera palm shell.

3.1.2 Volume of Liquid Produced

Fig 3 shows the volume of liquid produced during pyrolysis by different Palm Kernel Shells with respect to time. Tenera (Osun) kernel shell showed sharp increase in production of liquid at 10 minutes before it reduced at increasing rate after 20 mins (Fig. 3). Dura and Tenera PKS from Umuagwo showed a close comparable volume of liquid at 28 mins and Dura PKS maintained this volume up to 40 mins before reaching climax of about 500 ml while the volume of liquid obtained Tenera (Umuagwo) was increased at lower rate before reaching the climax at 80 mins as shown in Figure 3. The volume of liquid produced was in this order; Dura (Ubima) > Tenera (Umagwa) > Tenera (Osun) at 80 mins. Since Dura gave the highest volume of oil within 60 mins out of the three palm kernel shells investigated, it was therefore considered as the best and this fuel oil subjected for further analysis.
3.1.3 Variation of Product Temperature and Pyrolysis Time on the Quantity of Palm Kernel Shells (Dura)

The product temperature increases with increase in pyrolysis time as shown in Fig 4. Pyrolysis temperature of Dura at 500g showed an increase temperature that rose to 400°C which was attained in less than 60mins and was distinct from that of Dura PKS 1000 and 1500g with pyrolysis temperature of 275 and 220°C respectively. Pyrolysis temperature of Dura at 500 g showed an increase temperature that rose to 400 °C which was attained in less than 60 mins and was distinct from that of 1000g and 1500g with pyrolysis temperature of 275 and 220 ºC, respectively (Fig.4). This result shows that the pyrolysis time and product temperature is characterized by the quantity of PKS pyrolysed.

3.1.4 Variation of Volume of Liquid Produced with Respect to Pyrolysis Time and the Quantity of Palm Kernel Shells (Dura)

Fig. 5 shows the variation of liquid fuel produced with respect to pyrolysis time using different quantity of Dura palm kernel shell. The volume of liquid fuel produced increased with increase in pyrolysis time. As expected, the volume of liquid produce increase with increase in mass of Palm Kernel Shell and pyrolysis time/
3.1.5 Percentage Product Yield of Products from Palm Kernel Shells.

Table 1 shows the yield of char, oil and water during the pyrolysis of different mass of Dura PKS. Pyrolysis products showed increased char, oil and water with respect to increased masses of (500, 1000 and 1500g) Palm Kernel Shells while the percentage fuel oil yield was reduced with increase in the mass of PKS. In respect to mass of fuel oil, water and charcoal produced, it was worthwhile using 1000 g in this experiment since the percentage product was at highest value in this gram. Moreover, Table 1 showed that increase in mass did not affect the fuel yield and % water content obtained after separating the fuel oil from the liquid obtained during pyrolysis. The % non-condensable gases were small in comparison with other by products.

Table 1: Percentage yield of products from pyrolysis of palm kernel shells

<table>
<thead>
<tr>
<th>Mass of PKS (g)</th>
<th>Fuel yield (%)</th>
<th>Water content (%)</th>
<th>Char yield (%)</th>
<th>Non condensable gas (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>28.90</td>
<td>43.20</td>
<td>27.00</td>
<td>0.90</td>
</tr>
<tr>
<td>1000</td>
<td>36.65</td>
<td>41.02</td>
<td>22.21</td>
<td>0.08</td>
</tr>
<tr>
<td>1500</td>
<td>36.65</td>
<td>40.09</td>
<td>23.10</td>
<td>0.26</td>
</tr>
<tr>
<td>1000000</td>
<td>36.75</td>
<td>40.08</td>
<td>22.99</td>
<td>0.10</td>
</tr>
</tbody>
</table>

3.1.6. Specification of Design of pyrolyser

The reactor was designed to process 1000kg/day. The reaction stoichiometry, material and energy balances were prepared to specify the input quantity and to know the expected output products. The data obtained from Table 1 were used to obtained the conversion of char, oil and water and from the kinetics/mathematical model developed in section 3 the rate constants were obtained further from pyrolysis of 1000kg/day of palm kernel shells. A computer program was written for this design and scale up using some dimensionless factors and constants obtained from literature to design batch reactor-pyrolyzer of 1000kg/day to process Palm Kernel Shells. Data obtained at laboratory scale, and data obtained from literature and other parameters mentioned in section 3, were also used to obtain the height, diameter and volume of the reactor. Table 3 shows the final specifications of pyrolyzer for 1000kg/day of Palm Kernel Shells.

Table 2: Final design specifications of pyrolyzer for 1000kg/day capacity size of palm kernel shells

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The specifications of the reactor are as follows:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Dimension</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>8.15402</td>
<td>m</td>
</tr>
<tr>
<td>Diameter</td>
<td>4.07701</td>
<td>m</td>
</tr>
<tr>
<td>Volume</td>
<td>107.1429</td>
<td>m³</td>
</tr>
<tr>
<td>Heat Required for pyrolysis</td>
<td>14,025</td>
<td>kJ/hr</td>
</tr>
<tr>
<td>Internal Temperature (T_{ai})</td>
<td>723</td>
<td>K</td>
</tr>
<tr>
<td>Outside Temperature T_{out}</td>
<td>378</td>
<td>K</td>
</tr>
<tr>
<td>Stainless steel thickness</td>
<td>5</td>
<td>mm</td>
</tr>
<tr>
<td>Mild Steel Thickness for external</td>
<td>5</td>
<td>mm</td>
</tr>
<tr>
<td>Constant K_0 for Oil</td>
<td>1.53 x 10^{-4}</td>
<td>s^{-1}</td>
</tr>
<tr>
<td>Overall Constant K</td>
<td>3.17 x 10^{-4}</td>
<td>s^{-1}</td>
</tr>
<tr>
<td>Lagging Insulating Thickness thickness</td>
<td>0.10</td>
<td>m</td>
</tr>
<tr>
<td>Thickness of cover Plate</td>
<td>5</td>
<td>mm</td>
</tr>
<tr>
<td>Lagging Material</td>
<td>glass wool</td>
<td></td>
</tr>
<tr>
<td>internal Resistance R_1 for Hot Air</td>
<td>2.51 x 10^{-4}</td>
<td>K/W</td>
</tr>
<tr>
<td>Resistance R_2 for internal</td>
<td>2.798 x 10^{-6}</td>
<td>K/W</td>
</tr>
<tr>
<td>Stainless Steel Material</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance R_3 for the Insulating Material thickness</td>
<td>2.3194 x 10^{-3}</td>
<td>K/W</td>
</tr>
<tr>
<td>Resistance R_4 for Mild Steel Thickness</td>
<td>1.904 x 10^{-4}</td>
<td>K/W</td>
</tr>
<tr>
<td>Resistance R_5 for the Air</td>
<td>6.0265 x 10^{-4}</td>
<td>K/W</td>
</tr>
<tr>
<td>Surrounding the Reactor Total resistance R_T across the reactor thickness</td>
<td>3.578 x 10^{-3}</td>
<td>K/W</td>
</tr>
</tbody>
</table>

The volume of the reactor was found to be 107.1429 m³, the height of the reactor was obtained to be 8.15402 m, the diameter was calculated to be 4.07713 m while the lagging thickness for conserving the heat was found to be 0.10 m. The cross-sectional view, the first angle autographic view, the exploded view and the 3d model of the complete pyrolyzer batch reactor design are shown in Figures 6.

The materials of construction for this design were obtained from literature to be stainless with internal of 0.005 m thickness, glass wool for insulating/lagging material, and mild steel of 0.005 m thickness for covering of lagging externally.
4. CONCLUSION

The Design of pyrolyser for pyrolysis of palm kernel shells was investigated. The quantity of PKS pyrolysed affects the pyrolysis temperature and time. The volume of reactor required to pyrolyse 1000kg/day of palm kernel shells was found to be 107.143m$^3$. The thickness of reactor was 5mm and material of construction of stainless steel and the lagging thickness of 0.1m. The height of the reactor was found to be 8.15403m with the diameter of 4.0771m. The decomposition reaction constant $k_{oil}$ of the fuel oil obtained was determined to be $1.153 \times 10^{-4}$s$^{-1}$ and the overall constant $k$ was calculated to be $3.17 \times 10^{-4}$s$^{-1}$. Energy requires to pyrolyse the PKS was 841500kJ. The reactor temperature was 723K while the outside temperature was 378K. Total heat transfer resistances $R_1$, $R_2$, $R_3$, $R_4$, and $R_5$ across the reactor cross section were found to be; $2.51 \times 10^{-4}$ K/W, $2.798 \times 10^{-6}$ K/W, $2.3194 \times 10^{-3}$ K/W, $1.904 \times 10^{-4}$ K/W and $6.026 \times 10^{-3}$ K/W respectively. The results obtained from this work can be used to scale up design of pyrolyser for production of fuel oil from palm kernel shells.

5. ACKNOWLEDGEMENT

The authors would want to thank Prof. (Mrs.) G. O. Akinola, and Dr. (Mrs.) Aransiola of Obafemi Awolowo University for their support. More so, we appreciate the staff of the Department of Chemical/Petrochemical Engineering of Rivers State University, for their technical support.

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