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Research Article

Optimisation of Energy Content of Palm Kernel Shell (PKS) using Modelling Approach

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Abstract

Twenty samples of Palm Kernel Shells (PKS) (ranging from 0.1g to 2g in step of 0.1g) were prepared. The samples were subjected to ultimate and proximate analyses to determine the energy content using methods of Association of Official Analytical Chemist (A.O.A.C.). The PKS samples were heated in a locally made tubular furnace (oven) and the oven temperatures were consecutively maintained between 200^{0}C and 350^{0}C in step 30^{0}C. The twenty (20) experimental runs (based on number of samples) were carried out at every oven temperature step. The outcomes of the experiment showed that the Optimum Higher heating Value (HHV) of the PKS (6618.50) is predictable at 260^{0}C (furnace temperature) over contents' composition using Response Surface Analysis (RSA). The results indicated that the PKS can be optimally converted to heat energy under the stated experimental conditions.

Keywords: *PKS, A.O.A.C., HHV, energy content, regression model, optimisation, tubular furnace.*

1. Introduction

Energy exists in different forms. All forms of energy can be measured based on the ability of an object or system to do work on another object or system. Energy is critical to the survival of mankind. It is used in different areas of human endeavours; including domestic and industrial lighting, powering of appliances, vehicles, trains, planes, rockets, machinery and tractors. The different forms of energy (electrical and fossil fuels) are coal, oil and natural gases; hydro, nuclear and wind energy (Energy-quest, 2011).

Analyses were carried out on the rate of depletion done to the ozone layer as a result of wide use of fossil fuels. From the study it was discovered that the rate of depletion has been greatly high. The high rate of depletion was attributed to the daily harmful elements released to the atmosphere after burning of petroleum fuels (Mark *et al.,* 2005). Daily human health deterioration resulted from ozone layer depletion is a challenge that can be addressed by looking into alternative (or renewable) source of energy. Biomass is a renewable energy source which can be generated from living or dead organisms including plants, domestic and industrial wastes (Renewable Energy, 2011). Substantial heat energy generated from PKS biomass can be adequately converted to electric power generation if combustion temperature is properly managed. In this study process parameters at which optimum heat energy can be generated from PKS will be determined using experimental and modelling approaches.

The African oil palm is native to tropical Africa, from Sierra Leone in the west through the Democratic Republic of Congo in the east. It was domesticated in its range, probably in Nigeria, and moved throughout tropical Africa by human beings who practiced shifting agriculture at least 500 years ago. European explorers discovered the palm in the late 1400s, and distributed it throughout the world during the slave trade ended but British began trading with West Africans in ivory, lumber, and palm oil (Mark, 2006)

Oil palm can grow up to 60 – 80ft (18000 – 24000m) in height, in nature but rarely more than 20 or 30ft (6000 or 9000m) in cultivation. Optimal plant density is 58 trees/acre with triangular patterns about 30ft (9000m) apart (Mark, 2006). The palm tree produces palm fruits from which oil is extracted. Oil extraction is complex process, carried out by large mills that may process up to 60 tons of fruit per hour, or by small scale mills in rural villages that produce only about 1ton 1000kg) of oil in an 8hr shift (Kwasi and Poku, 2002). Oil extraction process from fruit is as follows in the sequence. Bunch reception is the receiving of fresh palm fruits from the field as bunches or loose fruit. Sterilization is the use of high–temperature wet – heat treatment of loose fruit. Cooking normally uses hot water, while sterilization uses pressurized steam (Kwasi and Poku, 2002). Bunch

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threshing is the removal of the fruit from bunches. Digestion is the process of releasing the palm oil in the fruit through the rupture or breaking down of the oil – bearing cells. Pulp pressing is the extraction of oil from the digested palm fruit. Oil clarification is the separation of oil from its impurities. Oil drying and packaging are referred to as oil storage processes and are done to prevent solidification and fraction. The residue from the press consists of a mixture of fiber and palm nuts (Kwasi and Poku, 2002). Kernel recovery is the separation of the palm kernel nuts from the fiber by hand in the small scale operations. The sorted fiber is covered and allowed to heat, using its own internal exothermic reactions, for about two or three days. The fiber is then pressed in spindle press to recover second grade (technical) oil usable in soap making (Kwasi and Poku, 2002). Nut drying is the removal of moisture from the kernel nuts, palm kernel nut cracking is the breaking of the palm kernel nuts to release the kernels through which the shell is gotten. The sequence of extraction is detailed in the study of Kwasi and Poku (2002). The palm oil was introduced to the Americans hundreds of years ago, but did not become an industry of its own until the1960s.The first plantations were established on Sumatra in 1911, and in 1917 in Malaysia (Mark, 2006).

There are three common methods of biomass conversion (Biomass, 2011); they are Biochemical, mechanical and thermo-chemical methods. Biochemical method involves the application of chemicals and biological organisms such bacteria, fungi, enzymes to act on the material so as to produce some toxic materials to enhance its decomposition and decay, such methods of conversion includes: anaerobic fermentation of biomass and methane production. Some of the materials are used in briquetting and pelletisation, which defines the mechanical usage of the biomass where density and compaction played an active role. Nature has created a large diversity of biomass with varying specifications. In order to create highly efficient biomass-to-energy chains, torrefaction of biomass in combination with densification (pelletisation/briquetting), is a promising step to overcome logistic economics in large scale green energy solutions (Roland, 2011). Thermo-chemical processes do not necessarily produce useful energy directly, but under controlled temperature and oxygen conditions, convert the original biomass feedstock into more convenient forms of energy carriers, such as producer gas, oils or methanol. These carriers are either more energy dense or have more predictable and convenient combustion characteristics useful in internal combustion engines and gas turbines.

Related past studies include the following. Usman *et al.,* (2012) examined the use of locally available building materials such as sawdust and palm kernel shell as possible substitutes for fine and coarse aggregate in concrete. Edmund *et al.,* (2012) studied the effect of pyrolysis conversion of palm kernel shell to bioenergy on the energy potential of the parent feedstock by pyrolyzing one kilogram of the biomass in a bench-scale screw-conveyor pyrolysis reactor at 450^0C. Olisa and Kotingo (2014) examined the utilization of empty fruit bunch as an alternative fuel for firing a steam turbine plant for the production of electricity. Ibhadode and Dagwa (2008) developed a non-asbestos friction material using an agro-waste material base palm kernel shell along with other constituents. Reza *et al.,* (2012) investigated on gasification of palm kernel shell, residues from palm oil industry as potential hydrogen feedstock. Amin and Murni (2011) investigated on the potential of torrefaction to improve the properties of Malaysian palm kernel shell as a solid fuel.

Olutoge (2010) investigated the use of saw dust and palm kernel shells as replacement for fine and coarse aggregates in reinforced concrete slabs. Okoroigwe and Saffron (2012) determined the physiochemical properties of palm kernel shell as an application in renewable energy options such as bioenergy and biomass utilization. Their results showed that palm kernel shell possess valuable potential to supplement the energy supply of developing countries through sustainable renewable energy technologies. The stated studies had not considered possibility of optimizing the heat energy form PKS using relevant process parameters (combustion temperature and contents) on the bases at which this study stand to address.

2. Materials and methods

Materials used in the experiment comprise Palm Kernel Shell (PKS), Hydrogen peroxide, Copper oxide, Magnesium percolate, Sodium Hydroxide, Weighing balance, Crucibles, Filter paper, Test tube, Gallenkamp oven and Pyrolysis reactor, which consist of the following components:

Tubular Furnace (Oven): materials used for the oven were 1.5kw hot plate, fibreglass (insulator), 1200°C temperature controller and TJ-type thermocouple. The casing was made of 1mm metal sheet formed into a cylindrical shape of capacity 50 litres**.**

Retort: The retort was made of stainless steel pipe of 2.5mm thickness, 200mm internal diameter and height of 260mm. The two ends were sealed with a 2.5mm thick stainless steel plate. A hole of 90mm was bored on the edge of the top flange on which was welded a stainless pipe of 2.5mm thick. Offloading of the samples into the retort was done through the pipe. The air tightness of the retort was achieved by welding a 5mm square metal plate of side 150mm on both the top loading pipe and the delivery copper pipe. Four 10mm holes were drilled at each of the four corners. Cog insulating materials was place in between the two plates after furnace gum had been robbed on them. 13mm diameter bolt and nut, together with washer were used to tighten the two plates together. At the

centre of the lower plate a 90 mm hole was bore, while a 10mm hole was drilled on the top plate and the coupling. The copper pipe was connected to the first condenser with a high -pressure cable tubing and jubilee clip.

Condenser: The condenser was designed based on the estimate of the expected condensate. Provisions were also made to allow the gaseous effluents from the retort to make contact with the condensers wall in order to aid condensation of the 115mm internal diameter and 320mm long. The two condensers were made of the same dimensions. The inlet and outlet pipes were situated at the extreme ends of the pipe, to allow the gaseous effluence from the retort to come in direct contact with the condensers wall in order to aid condensation of the liquid products. The condensers were connected with pressure tubing secured with jubilee clips. The two condensers were placed in a 20liter plastic bath, filled with cold water.

Gas Collecting Unit: This was adapted from two 25liter cans, two holes were bored on the cover of each can through which two rubber hoses were passed. The hose from the condenser ends at a position very down inside the can filled with water. As the experiment commenced, non-condensable gasses from the condenser displaced the water in the first 25liter can to the second empty can.

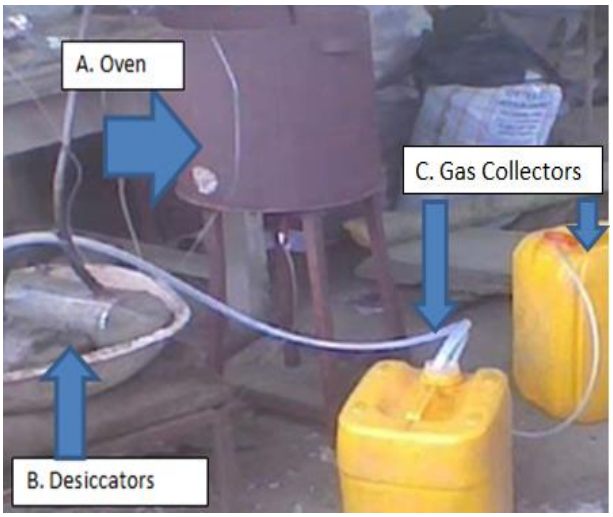

Fig.1. Experimental set-up for the determination PKS compositions (%FC, %Ash, %VC, VN, VC, VH, %S, and $\%O_2$) (A) Tubular Furnace (Oven). (B) Set of locally fabricated Desiccators (condensers). (C) Gas Collectors

Methods applied include sample acquisition and preparation, ultimate and proximate analysis of the prepared samples of Palm Kernel Shell (PKS) using official methods of analysis by the association of official analytical chemist (A.O.A.C), evaluation of the experimental outcomes using statistical techniques, which are Response Surface Analysis (RSA) and Analysis of Variance (ANOVA).

Palm Kernel Shell (PKS) were collected from cultivated cultiva, *tenera* at Owo Local Government, Ondo State. Batches of eight harvests were collected, before selecting about 4kg each to ensure uniform representation. Samples were pre-treated by removing foreign materials like sand, stone, and other plant residues from them. The samples were sundried to reduce the moisture content. Samples were analyzed chemically according to the official methods of analysis by the Association of Official Analytical Chemist (A.O.A.C.). The analysis was carried out in duplicate and average of measurements was recorded for the twenty (20) samples.

The apparatus used in the determination of the moisture content are oven, crucibles, desiccators and weighing balance. The moisture content of both biomass feedstock and the torrefied char were determined in accordance with the certified method. A known weight of the samples, W_0, was oven dried at a temperature of 103±2°C until a constant weight, W_f was reached. The loss in the weight of each sample expressed as a percentage of W_f gave the moisture content on dry basis, MC_{db}, as:

$$MC_{db} = \frac{W_0 - W_f}{W_f} \times 100\%$$

For ash content determination, about 2g of finely ground oven dried sample was placed in a porcelain crucible and weighed, W_1, before it was transferred into a preheated muffle furnace set at temperature of 900°C. The furnace was left on for about an hour after which the crucible with the content was transferred to the desiccators and allowed to cool. The crucible with its content was re-weighed, W_f, and the weight of the empty crucible was W_c. The content (% dry basis) was determined by:

$$Ash = \frac{W_f - W_c}{W_1 - W_c} \times 100\%$$

The fixed carbon content was determined by computing the difference between 100 and the sum of the moisture (MC), volatile matter (VC) and Ash contents (AC) of the samples and it is given as:

$$C = 100 - (MC + VC + AC)$$

In the case of Volatile Content (VC), about 2g of the air-dried samples of the biomass feedstock W_1, was heated at about 900°C for seven minutes in a partially enclosed porcelain crucible, placed in a furnace, in accordance with BSI standard. The crucible was retrieved and left to cool in the desiccators. The weight of the refuse left, Volatile Content (VC) was determined from the equation.

$$VC = \frac{W_1 - W_P}{W_f} \times 100\%$$

Where W_f is the oven- dried weight of samples

Carbon and hydrogen contents biomass feedstock were determined simultaneously by Leibig-Pregle method.

1g of sample flour was placed in a quartz test tube and burned off through the absorbents magnesium percolate to absorb water and sodium hydroxide to absorb carbon dioxide. The amounts of water and carbon dioxide were determined from the difference between the two weightings, one before the other after the absorption of water and carbon dioxide. The percentage of Carbon (%C) and hydrogen (%H) were evaluated thus.

$$\%C = a(0.2727)/g \times 100\%$$
$$\%H = b(0.2727)/g \times 100\%$$

Where: g= weight of the sample
a =quantity of CO_2
b = quantity of H_2O

Nitrogen content of biomass feedstock was determined by Dumas-pregle method. A 0.2g of the sample flour was mixed with powder of copper oxide in the ignition tube. Air was displaced from the tube by passing through a stream of CO_2 until minute bubble appeared in the Nitrogen flow meter filled with about 50% solution of potassium hydrogen. The weighed sample was burned off at between 700°C and 750°C in a gas burner and later burned in an atmosphere of CO_2 with the gas cylinder shut off. After ignition, the combustion product was displaced with carbon dioxide into the nitrogen flow meter. The percentage of Nitrogen (%N) content was determined by the equation:

$$\%N = V(1.097)/g \times 100\%$$

Where: V = volume of Nitrogen in the Nitrogen flow meter
1.097 = mass of 1ml of Nitrogen at the test tube
g = weight of sample

For sulphur content determination, a 1g of biomass feedstock sample flour was wrapped in a filter paper free from ash and it was secured in the platinum wire seal into a glass rod held fast to the stopper of a flask filled with Oxygen. The weighed sample was ignited in filter and inserted in the flask immediately, and the flask was plugged with the stopper. The product was absorbed with a mixture of water and Hydrogen peroxide to oxidize the combustion product immediately. The combustion product was titrated with a solution of Barium percolate in the presence of the indicator Toron with a PH value of 4.5. The percentage of sulphur was found by the equation:

$$\%S = (T \times V)/g \times 100\%$$

Where: T= Titre of $Ba(CO_4)_2$ solution
V = volume of $Ba(CO_4)_2$ solution
g = weight of the sample

Dulong-petit formula was used in calculating the approximate higher heating values of the biomass feedstock samples:

$$HHV = 337C + 1428(H - O/8) + 95S(KJ/Kg)$$

Where: C =% Carbon, H = % Hydrogen, O = % Oxygen, S = % Sulphur

Modeling and analysis of experimental outcomes was carried out using Response Surface Methodology (RSM). Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques useful for the modelling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response (Montgometry, 2005). Higher Heating Value (HHV) of palm kernel shell under varying combustion temperature is related to weight of sample (X_1), percentage of fixed carbon (X_2), ash (X_3), volatile matter (X_4), nitrogen (X_5), carbon (X_6), hydrogen (X_7), sulphur (X_8) and oxygen (X_9) which are obtainable from experimental analysis. On this bases, the HHV (Y) is the response variable that dependent on weight of sample, percentage of fixed carbon, ash, volatile matter, nitrogen, carbon, hydrogen, sulphur and oxygen (which are independent variables), and expressed as

$$Y = f(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9) + e$$

Where, e is experimental error. The first-order model of this kind can be expressed as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + e \quad (1)$$

The influence of the various investigated factors on Higher Heating Values (HHV) of the palm kernel shell was also analyzed using Analysis of Variance (ANOVA) under the consideration of PKS combustion temperatures.

3. Results and Discussion

Experimental results, on average basis, recorded at combustion temperature of 200^0C are given in Table 1. From the results it can be seen, at different weights (0.1 to 2.0 g) of sample under proximate and ultimate analyses, that the percentage of ash content varies between 4.0% and 8.2%; the percentage of the volatile matter in the palm kernel shell varies between 9.9% and 13.0%; the percentage composition of the carbon ranges between 12.2% and 13.9%; percentage of oxygen content ranges from 9.3% and 11.9% and that of the higher heating value ranges from 6078.2KJ/Kg to 7002.2KJ/Kg. The summarised results (on average bases) for furnace combustion temperatures (200^0C, 230^0C, 260^0C, 290^0C, 320^0C and 350^0C) considered are presented in Table 2.

It can be clearly observed from Table 2 that the weight of the PKS has little or no effect on some parameters including percentage compositions of Nitrogen, Sulphur, Hydrogen, ash, and Oxygen. It was evident that the highest HHV is obtainable at 260^0C combustion temperature. Optimum higher heating

value of 6618.5 kJ/kg obtained at that temperature (as clearly shown in Fig. 2) may be attributed to the Carbon content generation which was at the highest level as at that temperature (Fig. 3).

The results of the Analysis of Variance performed on overall combustion temperature are presented in Table 3.

The HHV predictions from multiple linear regression equation were in good agreement with the experimental data recorded. The analysis shows that only percentage compositions of FC, C, H, S and O_2 have significant effects on the generated higher heating value of the palm kernel shell at 5% significance level of the overall combustion temperature.

The coefficient of determination (R^2) of 98.13% obtained for the model shows a good fit of the experimental data.

Response surface (multiple linear regression) analysis has yielded optimum prediction models that related the independent variables or predictors (WS, %FC, %ASH, %VC, %N, %C, %H, %S and $\%O_2$) to the dependent variable or the Higher Heating Value (HHV) at all combustion temperatures (200^{0}C, 230^{0}C, 260^{0}C, 290^{0}C, 320^{0}C, and 350^{0}C) is given as:

$$HHV_{\text{overall }(200-350)} = -167.90 - 8.43WS + 12.03FC + 0.05ASH - 6.74VC - 153.94N + 345.56C + 1503.00H + 98.04S - 180.54O_2 \quad (2)$$

The outcome is supported by the high coefficient of determination (R-squared ≈ 1) realized from the analysis. It implies that the optimum Higher Heating Value (HHV) can accurately be predicted by the process factors under consideration.

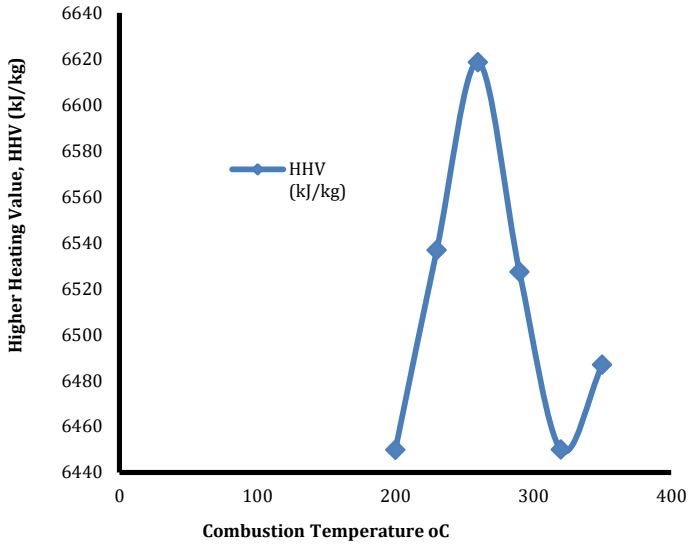

Fig. 2. PKS Higher Heating Value at heating conditions

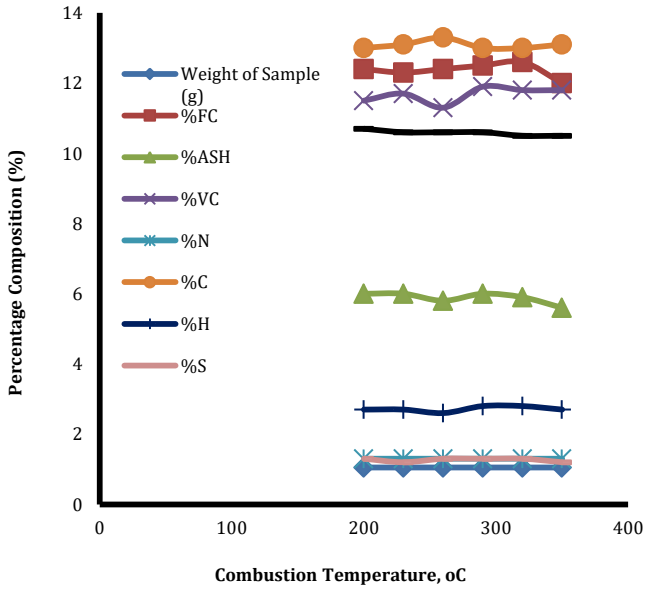

Fig. 3. PKS Composition at the Heating conditions

Table 1 Mean of Proximate, Ultimate and Higher Heating Values at 200^{0}C

Temp (^{0}C)	Sample Weight (g)	HHV (KJ/Kg)	%FC	%ASH	%VC	%N	%C	%H	%S	%O_2
200	0.1	6272	11.2	4.0	10.1	1.3	13.4	2.5	1.2	10.8
200	0.2	6488.4	12.0	5.3	12.5	1.3	12.4	2.7	1.2	9.3
200	0.3	6698.4	11.6	7.0	9.9	1.3	13.5	2.7	1.2	10.2
200	0.4	6564.8	11.4	4.0	13.0	1.3	13.1	2.6	1.4	9.5
200	0.5	7002.2	12.2	8.2	11.9	1.2	13.9	2.8	1.1	10.0
200	0.6	6453.8	13.5	6.3	12.9	1.3	12.4	2.8	1.4	10.4
200	0.7	6933.6	12.9	6.1	11.8	1.3	13.4	2.8	1.4	9.6
200	0.8	6254.7	13.5	5.3	11.6	1.3	12.9	2.6	1.1	10.7
200	0.9	6268.2	13.4	4.3	9.9	1.3	12.7	2.8	1.2	11.9
200	1.0	6094.0	11.1	6.7	11.0	1.2	12.9	2.6	1.1	11.6
200	1.1	6449.8	11.6	7.0	10.4	1.3	12.6	2.8	1.4	10.8
200	1.2	6381.5	11.5	5.8	11.4	1.3	13.7	2.5	1.1	10.7
200	1.3	6329.2	13.3	6.9	10.2	1.3	12.8	2.6	1.3	10.2
200	1.4	6338.7	11.6	7.7	10.0	1.3	12.8	2.5	1.4	9.4
200	1.5	6778.2	13.0	4.0	10.4	1.2	13.5	2.9	1.1	11.3
200	1.6	6078.2	12.3	6.0	12.5	1.3	12.8	2.6	1.1	11.5
200	1.7	6099.7	13.6	6.4	12.3	1.3	12.2	2.8	1.2	11.9
200	1.8	6442.7	12.0	7.6	13.0	1.3	12.9	2.8	1.2	11.3
200	1.9	6581.5	12.6	6.1	12.8	1.3	13.1	2.8	1.2	10.9
200	2.0	6486.7	13.4	6.0	11.8	1.2	12.9	2.9	1.1	11.8
Mean	1.05	6449.8	12.4	6.0	11.5	1.3	13.0	2.7	1.3	10.7

Table 2 Proximate, Ultimate and Experimental Higher Heating Values on Average Bases

Temp (^{0}C)	Weight of Sample (g)	HHV (kJ/kg)	%FC	%ASH	%VC	%N	%C	%H	%S	%O_2
200	1.05	6449.8	12.4	6.0	11.5	1.3	13.0	2.7	1.3	10.7
230	1.05	6536.7	12.3	6.0	11.7	1.3	13.1	2.7	1.2	10.6
260	1.05	6618.5	12.4	5.8	11.3	1.3	13.3	2.6	1.3	10.6
290	1.05	6527.2	12.5	6.0	11.9	1.3	13.0	2.8	1.3	10.6
320	1.05	6449.9	12.6	5.9	11.8	1.3	13.0	2.8	1.3	10.5
350	1.05	6486.8	12.0	5.6	11.8	1.3	13.1	2.7	1.2	10.5

Table 3 ANOVA based on Overall Temperature on Higher Heating Value (kJ/kg)

Factor	DOF	Sum of Square (SS)	Mean of Sum of Square (MSS)	F-Statistic	Predicted Value (P-value)
Wt (g)	1	531154	2526	1.44	0.232
%FC	1	67727	9128	5.22	0.024
%ASH	1	121	1	0.00	0.986
%VC	1	23756	4442	2.54	0.114
%N	1	82034	4808	2.75	0.100
%C	1	4058692	3687724	2107.61	0.000
%H	1	3043199	3395190	1940.42	0.000
%S	1	76469	9461	5.41	0.022
%O2	1	2225154	2225154	1271.72	0.000
Error	110	192469	1750		
Total	119	10300776			
R^2 = 98.13%; Adj. R^2 = 97.98%. *P-value < 0.05 is Significant					

Conclusions

In this study, HHV of PKS was determined experimentally at varying process parameters at which change in combustion temperature played a significant role. The process parameters considered are weight of sample, percentage of fixed carbon, ash, volatile matter, nitrogen, carbon, hydrogen, sulphur, oxygen and oven temperature on the basis of which Higher Heating Value (HHV) of PKS was optimized using response surface methodology. The results obtained indicated that the effect of fixed carbon, carbon, hydrogen and oxygen on the higher heating value of PKS had been significant. The optimum factors' combination effects on the higher heating value also showed good agreement with the prediction models' outcomes. From the results, the following conclusions can be drawn:

1) The average higher heating value of PKS is obtainable at a combustion temperature of 260^{0}C. That is PKS can be optimally converted to heat energy at a combustion temperature of 260^{0}C.
2) Analysis of Variance (ANOVA) outcomes indicated that the effects of carbon, hydrogen and oxygen were more on the higher heating value at all combustion temperatures.

3) The confirmation experiment has shown that response surface methodology can efficiently optimize HHV of PKS over other process parameters considered.
4) The prediction model was characterized with excellent coefficients of determination (close to unity), which indicated a good agreement with the experimental results.

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