CHEMICAL ENGINEERING TRANSACTIONS
VOL. 94, 2022

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Petar S. Varbanov, Yee Van Fan, Jiří J. Klemeš, Sandro Nižetić

ISBN 978-88-95608-93-8; **ISSN** 2283-9216

DOI: 10.3303/CET2294197

Charcoal Briquette Production from Peanut (*Arachis hypogaea L.*) Shells using Cornick Industry Wastewater as Binder through a Torrefaction Process

Roselle Y. Mamuad[a,b], Joyce H. Racuya[a], Angelo Earvin Sy Choi[b,*]

[a]Department of Chemical Engineering, College of Engineering, Mariano Marcos State University, City of Batac, 2906, Ilocos Norte
[b]Department of Chemical Engineering, De La Salle University, 2401 Taft Ave, Manila 0922, Philippines
angelo.choi@dlsu.edu.ph

The torrefaction process was applied to the peanut shells to produce charcoal briquette using Cornick industry wastewater as a binder and a charcoal briquetting press. The results showed that the conversion of peanut shell to biochar was 30.1 wt.%. The density and heating values of the three treatments with charcoal to binder ratio of 80:20 (T1), 75:25 (T2), and 70:30 (T3) were from 0.4623 g/cm^3 to 0.4990 g/cm^3, from 26.6 MJ/kg to 27.3 MJ/kg. The samples of the peanut charcoal briquette were subjected to proximate analysis and ultimate analysis. For the proximate analysis, the moisture content was from 1.88 wt.% to 2.13 wt.%, the volatile matter was from 8.37 wt.% to 8.82 wt.%, ash content was from 6.61 wt.% to 7.34 wt.% and the fixed carbon was from 81.9 wt.% to 83.1 wt.%. Results of the ultimate analysis showed that the content of C, H, O, and S was as follows; 71.6 wt.% to 72.6 wt.%, 2.28 wt.% to 2.40 wt.%, 24.6 wt.% to 25.7 wt.%, and 0.3078 wt.% to 0.4144 wt.%. The characteristics of the charcoal briquettes derived from peanut shells and Cornick wastewater as a binder were compared to the standards for charcoal briquettes used in grilling, cooking, and for electricity generation. The abundance of locally available raw material in the production of charcoal briquette could provide employment to the unemployed individual in the locality. The characteristics of the charcoal briquettes produced demonstrated that it can be used for grilling, cooking, and electricity generation.

Introduction

Technologies that depend on energy from fossil fuels are controlling the world's economy from the sources of power, transitional materials, chemicals, and fuels (Choi et al., 2021). The utilization of traditional energy such as electricity, coal, and oil has increased remarkably in ASEAN economies in the last 25 y. The Philippines is heavily reliant on foreign oil, which routes to profitability and social unpredictability.
Biomass is a source of local energy that is plenty and obtains favorable opportunities as a source of sustained energy. According to Silva et al. (2022), biomass contributes to about 12 % of the primary energy source worldwide after coal and oils. In rural areas of agricultural countries like the Philippines, biomass can still attribute a larger portion of its energy requirement. About 1.25 x 10^9 t oil equivalent of essential energy annually that is utilized worldwide were generated from biomass in all forms (Werther et al., 2000). In the last three decades, multiple global initiatives in the technological development and research in transforming agricultural residues into enhanced quality fuel were conducted through biological and thermochemical conversion (Sugumaran and Seshadri, 2010).
Developing countries dominate the efforts of the potential application of agricultural wastes due to the decreasing availability of wood fuel (Tripathi et al., 1998). Biomass particularly from the agricultural residues as feedstocks has numerous drawbacks that include low calorific values, adversity in managing the burning rate, a complication in mechanization for continuous feeding, large storage area requirement, and difficulties in the shipment and delivery (Balatinecz, 1983). These drawbacks are allotted to the agricultural residues that have a low bulk density that can be transformed into fuel with high density through briquetting. The improved performance of charcoal briquettes through the production technology revived the interest in utilizing it as an

Paper Received: 30 March 2022; Revised: 29 April 2022; Accepted: 08 May 2022
Please cite this article as: Mamuad R.Y., Racuya J.H., Choi A.E.S., 2022, Charcoal Briquette Production from Peanut (Arachis hypogaea L.) Shells using Cornick Industry Wastewater as Binder through a Torrefaction Process, Chemical Engineering Transactions, 94, 1183-1188 DOI:10.3303/CET2294197

energy source that can be easily stored and transported in recent times (Sugumaran and Seshadri, 2009). One of the technologies being utilized for charcoal briquettes is torrefaction. Torrefaction is a moderate temperature (200 - 300 °C) thermochemical pyrolysis process carried out under the anoxic condition procedures at atmospheric pressure with a low particle heating rate. The process causes the fibrous structure and tenacity of biomass to partially decompose, producing a torrefied biomass feedstock or char, also known as bio-coal (van der Stelt et al., 2011).

In the Philippines, charcoal is a fuel used nationwide. When compressed, charcoal particles are composed mainly of carbon, without any binding mechanism. The greatest challenge in the production of the briquettes is the exploration for a binder that upgrades the features of the produced charcoal briquette. The most frequently used binders in the energy densification process are the corn starch (Zhang et al., 2022). Cornick industry, one of the leading industries in northern part of the Philippines discharged a starchy wastewater from the boiling of corn. There is a lack of studies that has conducted on the briquetting of agricultural waste particularly on peanut shells in the Philippines setting. There are limited studies conducted on the potential charcoal briquette production from agricultural waste for electricity generation in the Philippines. The novelty of this study is the utilization of peanut shell and Cornick wastewater as binder that could be a value-added product for both farmers and Cornick industry owners. The abundance of agricultural waste resources and naturally occurring binder materials locally available makes the production of charcoal briquette profitable and could also provide employment to the unemployed individual in the locality. This study also addresses one of the advocacies in science and technology which is the waste to energy conversion. In this research, the use of peanut shell taken from Ilocos Sur, Philippines and the binder specifically the wastewater from the first boiling of corn from the Cornick industry was investigated to make charcoal briquettes. The study worked on one of the readily available agricultural wastes which is the peanut shell. This aims to produce and characterize charcoal briquette, and to draw comparisons with the selected biofuels. The succeeding section explains the specific steps of the proposed method and its underlying results. This is presented as follows. Section 2 explains the materials and methods of briquette production and testing, followed by the discussion of data gathered based on the different parameters considered in Section 3. Section 4 gives the conclusions and recommendations for future work.

2. Materials and Methods

2.1 Materials

Peanut shells used were taken from Ilocos Sur, Philippines and the shells were dried and charred at a specified temperature for the torrefaction process which is 240 – 270 °C.

2.2. Torrefaction of the Peanut Shell

Approximately 850 g of peanut shells were charred for 90 min in a furnace at a temperature required for the torrefaction process which is 240 – 270 °C, the time and temperature of torrefaction that obtained the highest wt.% yield when preliminary experiment was conducted.

2.3. Determination of the Peanut Shell to Bio-char Conversion

In determining the conversion of peanut shell to char, the torrefied peanut shell was weighed in an analytical balance. The conversion was determined using Eq(1):

$$\text{wt.\% Conversion of torrefied peanut shell} = \frac{\text{mass of torrefied peanut shell}}{\text{mass of peanut shell feedstock}} \times 100\% \quad (1)$$

2.4. Charcoal Briquettes Production

The torrefied peanut shells were crushed into fine particles then screened and the char having less than 6 mm diameter size was collected for charcoal briquette production. The wastewater used as a binder from the first boiling of corn derived from the Cornick industry was heated at a temperature of 85-100 °C until reached a viscosity similar to a 5 wt.% starch solution (Oyelaran, 2014). The charcoal briquettes were produced using three different biochar to binder ratios, 80:20 (T1), 75:25 (T2), and 70:30 (T3). The mixture was compacted using a charcoal briquetting press and was oven-dried at 105 °C until the briquette moisture was less than 10 wt.%.

2.5. Characterization of Charcoal Briquette Produced

2.5.1. Heating value determination

Using the values of fixed carbon (FC), volatile matter (VM), wt.% C and wt.% S obtained in the proximate analysis and ultimate analysis, the heating value or calorific value (CV) was obtained by Eq(2) (Laurito, 1994):

$$\text{wt.\% C} = 5.88 + 2.206\,(CV - 0.094S) + 0.0053\left(80 - \frac{\%\,VM}{\%\,FC}\right)^{1.55} \quad (2)$$

2.5.2. Density determination

As per the procedure of Rabier et al. (2006), the density of the charcoal briquette from peanut shells was determined by dividing the mass of the briquette was found by over its volume computed from the identified briquette diameter and height using a vernier caliper. The density was calculated using Eq(3):

$$\text{Density} = \frac{\text{Mass of charcoal briquette, (g)}}{\text{Volume of the briquette, (cm}^3\text{)}} \quad (3)$$

2.5.3. Proximate analysis determination

The methods of the ASTM standard D5373-02 (2003) were used to obtain the proximate analysis of the briquette.
The percentage moisture content (PMC) was determined by pulverizing 2 g of briquette sample and oven drying it at 105 ^{o}C until constant weight is achieved. The weight difference was then used in Eq(4) to determine the sample moisture:

$$PMC = \frac{D}{E} \times 100\ \% \quad (4)$$

The percentage volatile matter (PVM) was determined by pulverizing 2 g of the briquette sample in a crucible and drying it in an oven until the weight is constant then subjected it in the furnace at a temperature of 550 ^{o}C for 10 min and weighed after cooling in a desiccator. The PVM was then determined using Eq(5):

$$PVM = \frac{A-B}{A} \times 100\ \% \quad (5)$$

The percentage ash content (PAC) was also determined by heating 2 g of the pulverized briquette sample at a temperature of 550 °C in the furnace for 4 h to determine the ash weight. The PAC was determined using Eq(6):

$$PAC = \frac{C}{A} \times 100\ \% \quad (6)$$

The percentage fixed carbon (% FC) was determined by getting the difference of the sum of PMC, PVM, and PAC from 100 as presented in Eq(7):

$$\%\ FC = 100 - (PMC + PAC + PVM) \quad (7)$$

The ultimate analysis of the briquette produced was done at the Center for Innovative Materials and Emerging Applications. The sample was analyzed using Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS).

2.6. Comparison of the Different Charcoal to Binder Ratio

In identifying the best charcoal to binder ratio, different ratios (80:20, 75:25, and 70:30) were used in the production of charcoal briquette. The best ratio was determined by ranking their characteristics.

2.7. Comparison of the Peanut Shell Charcoal Briquette Characteristics to the Standards

The characteristics of the produced peanut shell briquette were compared to the standards for charcoal briquette used in grilling, cooking, and barbecuing and standards for charcoal briquette used in electricity generation.

3. Results and Discussion

3.1. Determination of the Peanut Shell to Bio-char Conversion

The wt.% yield represents the conversion efficiency of the peanut shells to charcoal and the effect of the torrefaction process on the raw materials is represented by the conversion efficiency. For an initial weight of 3,150 g, the torrefied mass produced was 948.4 g which results to a conversion efficiency of 30.1 wt.%. The volatile matter which largely affected the yield in charcoal production is one of the most common parameters in coal, it is essentially a measure of the nonwatery gases liberated at high temperatures without air.

3.2. Characterization of the Charcoal Briquette Produce from Peanut Shell

The best quality of briquette should produce an ample amount of heat, ignite without smoke to improve indoor air quality, and must be advantageous to the user. The quality of a briquette can be characterized by its calorific value, density, ash content, and volatile matter content (Sastry et al., 2013).

3.2.1. Density Determination

The density of the briquetted torrefied peanut shell at varying charcoal to binder ratios was studied. The highest density of 499 kg/m^3 was calculated for T3 which has biochar to binder ratio of 70:30 and the lowest density was calculated for T1 with an 80:20 ratio has a density of 462.3 kg/m^3 while 484.1 kg/m^3 for T2 with 75:25 ratio. These results indicate that as the binder ratio increased, the density of the briquette increased which indicates that the starch binder ratio is directly proportional to briquette density. A higher density is preferred because at high density, the heating value is improved.

3.2.2. Heating Value Determination

Heating or calorific value dictates the energy content of fuel. Calorific value is the characteristic of fuel that depends on its chemical composition and moisture (Chuah et al., 2021). Among the three biochar to binder ratios considered, T3 obtained the greatest heating value with an amount of 27.33 MJ/kg and the lowest heating value was obtained from T1 at 26.6 MJ/kg while in the middle is T2 at 26.8 MJ/kg. All the briquettes produced exceed the standard minimum heating value of briquettes derived from other biomass (Onukak et al., 2017).

3.2.3. Proximate Analysis Determination

The proximate analysis of coal consists of the moisture content, volatile matter, ash, and fixed carbon determination. It is the simplest and most common form of evaluation for coal performance. Table 1 represents the summary of the proximate analysis of the briquettes obtained using the three treatments.

Table 1: Proximate analysis of charcoal briquette at different treatments.

Treatment No.	Proximate Analysis			
	Moisture content (wt.%)	Volatile matter (wt.%)	Ash content (wt.%)	Fixed carbon (wt.%)
T1	1.96	8.82	7.34	81.9
T2	2.13	8.26	6.87	82.7
T3	1.88	8.37	6.61	83.1

It shows the amount of moisture, volatile matter and ash content of the briquettes created. The amount of moisture of the created briquettes is 1.96 wt.%, 2.13 wt.%, and 1.88 wt.% for T1, T2, and T3 which is less than the maximum standard moisture content for commercial briquette for barbecuing and electricity generation.

The volatile matter of the briquettes produced was 8.82 wt.%, 8.25 wt.%, and 8.37 wt.% for T1, T2, and T3, lower than the standard maximum value of volatile matter of commercial briquettes for electricity generation and barbecue use.

The ash content of the briquettes produced was 7.34 wt.%, 6.87 wt.%, and 6.61 wt.% for T1, T2, and T3 which falls within the standard for ash content of commercial briquettes for barbecue use and electricity generation.

The briquettes fixed carbon from the three treatments used in the study is 81.9 wt.%, 82.7 wt.%, and 83.1 wt.% which increases as the binder increases. Based on the study of Anshariah et al. (2020), at a high carbon level, calorific value will be higher, and since corn starch has a carbon content of 81.9 wt.% (a total of carbohydrate, protein, and fat), it causes an increase in fixed carbon content as well as its calorific value.

3.2.4. Ultimate Analysis Determination

The ultimate analysis provides a convenient method for reporting the elemental constituents such as carbon, hydrogen, oxygen, and sulphur. The ultimate analysis is essential in determining the amount of air needed for burning so with the volume and composition of the combustion gases. The elemental constituent of the briquettes produced is shown in Table 2.

Table 2: Elemental composition of the briquette at different binder ratios.

Treatment No	Ultimate Analysis				
	C (wt. %)	H (wt. %)	O (wt. %)	S (wt. %)	H/C
T1	71.6	2.28	25.7	0.4144	0.0329
T2	71.7	2.31	25.6	0.3436	0.0332
T3	72.6	2.40	24.6	0.3078	0.0339

The amount of carbon and hydrogen in the sample indicates ease of ignitability of the briquette as suggested by Saeed et al. (2021). The briquettes produced have carbon contents of 71.6 wt.%, 71.7 wt.%, and 72.6 wt.% for T1, T2, and T3. The H/C is an expression often utilized to find out the age and degree of aromaticity of the biochar, which is linked to their long-term constancy in the environment (Schmidt and Noack, 2000). The oxygen content of the briquettes made is 25.7 wt.%, 25.6 wt.%, and 24.6 wt.% for T1, T2, and T3 are within the standard percent oxygen of coal for lignite that is from 20 wt.% to 30 wt.% (Ozbayoglu, 2018). The sulphur content of the briquettes made is 0.4144 wt.%, 0.3436 wt.%, and 0.3078 wt.% for T1, T2, and T3.are also within the standard. Low sulphur content indicates a minimum discharge of sulphur oxides into the air, hence restricting the contaminating effect of the briquettes (Guo et al., 2020).

3.3. Comparison of the Different Charcoal to Binder Ratio

Table 3: Comparison of the characteristics of the briquettes produced for the three treatments.

	T1	T2	T3	Standard Deviation
Density (kg/m^3)	462.3	484.1	499.0	0.0185
Heating Value (MJ/kg)	26.6	26.8	27.33	0.3606
Moisture Content (wt.%)	1.96	2.13	1.88	0.1277
Volatile Matter (wt.%)	8.82	8.26	8.37	0.2967
Ash Content (wt.%)	7.34	6.87	6.61	0.3700
Fixed Carbon (wt.%)	81.9	82.7	83.1	0.4990

In Table 3, the three treatments with different charcoal to binder ratio of T1 (80:20), T2 (75:25), and T3 (70:30) were analyzed to identify the best combination in terms of density, heating value, moisture content, volatile matter, ash content and fixed carbon. Based on statistical analysis through standard deviation, the values within the three treatments were very closed from each other and can be regarded as no significant differences. The best charcoal to binder ratio considered is T3 since it possesses most of the best characteristics of briquette base from standards.

3.4. Comparison of the Peanut Shell Charcoal Briquette from the Standards

Table 4: Comparison of the briquetted peanut shell to charcoal standards for grilling, barbecuing, and for electricity generation

	T1	T2	T3	Standards for grilling, barbequing (Yuhazri, et al., 2012)	Standards for electricity generation (Onchieku et al., 2012)
Density (kg/m^3)	462.3	484.1	499.0	> 130 kg/m^3	-
Moisture Content (wt.%)	1.96	2.13	1.88	> 8 %	< 10 %
Volatile Matter (wt.%)	8.82	8.25	8.37	< 30 %	< 27 %
Ash Content (wt.%)	7.34	6.87	6.61	maximum of 8 %	< 14.4 %
Fixed Carbon (wt.%)	81.9	82.7	83.12	> 75 %	> 62.5 %
Heating Value (MJ/kg)	26.6	26.8	27.33	17.5 MJ/kg	3.53 kcal/kg

Table 4 shows comparison of the briquetted peanut shell to charcoal standards for grilling, barbecuing, and for electricity generation. The amount of moisture, volatile matter, fixed carbon, and ash are within the standards for grilling and barbecuing and for electricity generation. The key difference in the mechanism is the material utilized for briquetting. Peanut shell is much denser than other biomass-derived briquette like the corncobs and sugarcane bagasse. The denser the material the better the quality of briquette produced. According to Zubairu et al. (2014), starch binder was regarded as the most effective binder for briquette production since it produces the least amount of ash among the other types of binder utilized.

4. Conclusions

Torrefaction of peanut shells enhanced the different characteristics of biomass. Torrefaction of peanut shells yields 30.1 % biochar. The briquettes peanut shells were characterized and the treatment containing 70 % biochar and 30 % binder exhibits the best characteristics in terms of density (0.4990 g/cm^3), moisture content (1.88 wt.%), heating value (27.3 MJ/kg), ash content (6.61 wt.%) and fixed carbon (83.13 wt.%). The briquettes produced from peanut shell and Cornick wastewater as binder were compared to standards and all the produced briquettes can be used for commercialization and industrial process such as grilling, barbecuing, and electricity generation. Based on the results and conclusions, the following recommendations are made. The conversion of waste peanut shells using Cornick wastewater is an effective mean of waste to energy conversion. The abundance of locally available raw material in the production of charcoal briquette can give essential employment opportunities for the needs of the locality. Other starchy wastewater could also be explored as binders for briquetting to improve its economics. Other crop residues or its corresponding mixtures to produce briquette could also be investigated.

References

Anshariah, Imran, A.M., Widodo, S., Irvan, U.R., 2020, Correlation of fixed carbon content and calorific value of South Sulawesi Coal, Indonesia IOP Earth and Environmental Science, 473, 012106.

Balatinecz, J.J., 1983, The Potential Role of Densification in Biomass Utilization, In: W.A. C. (ed) Biomass Utilization, NATO Advance Science Conference Series, Springer, Boston, MA, 181-190.

Choi, A.E.S., Roces, S.A., Dugos, N.P., Wan, M.-W.W., 2021, Parametric Screening Analysis for the Oxidative Desulfurization of Diesel Oil, Chemical Engineering Transactions, 88, 91–96.

Chuah, L.F., Klemeš, J.J., Bokhari, A., Asif, S., 2021, A Review of Biodiesel Production from Renewable Resources: Chemical Reactions, Chemical Engineering Transactions, 88, 943–948.

Guo, Z., Wu, J., Zhang, Y., Wang, F., Guo, Y., Chen, K., Liu, H., 2020, Characteristics of biomass charcoal briquettes and pollutant emission reduction for sulfur and nitrogen during combustion, Fuel, 272, 117632.

Laurito, E., 1994, Stoichiometry of Fuel Combustion and Related Process Industries, 2nd ed. Maxie Lithorgraphic Arts & Printing Press, Quezon City, Philippines.

Onchieku, J.M., Chikamai, B.N., Rao, M.S., 2012, Optimum Parameters for the Formulation of Charcoal Briquettes Using Bagasse and Clay as Binder, Europian Journal of Sustainable Development, 1, 477.

Onukak, I.E., Mohammed-Dabo, I.A., Ameh, A.O., Okoduwa, S.I.R., Fasanya, O.O., 2017, Production and Characterization of Biomass Briquettes from Tannery Solid Waste, Recycling, 2, 17.

Oyelaran, O.A., 2014, Effects of Binding Ratios on Some Densification Characteristics of Groundnut Shell Briquettes, Iranica Journal of Energy Environment, 5, 167–172.

Ozbayoglu, G., 2018, Energy Production From Coal, Comprehensive Energy Systems 3, 788–821.

Rabier, F., Temmerman, M., Böhm, T., Hartmann, H., Daugbjerg Jensen, P., Rathbauer, J., Carrasco, J., Fernández, M., 2006, Particle density determination of pellets and briquettes, Biomass and Bioenergy, 30, 954–963.

Saeed, A.A.H., Harun, N.Y., Bilad, M.R., Afzal, M.T., Parvez, A.M., Roslan, F.A.S., Rahim, S.A., Vinayagam, V.D., Afolabi, H.K., 2021, Moisture content impact on properties of briquette produced from rice husk waste, Sustainability, 13, 3069.

Sastry, M.K.S., Bridge, J., Brown, A., Williams, R., 2013, Biomass Briquettes : A Sustainable and Environment Friendly Energy Option for the Caribbean, Fifth International Symposium on Energy, Puerto Rico Energy Center, 1–8.

Schmidt, M.W.I., Noack, A.G., 2000, Black carbon in soils and sediments: Analysis, distribution, implications, and current challenges, Global Biogeochemical Cycles 14, 777–793.

Silva, D.A.L., Filleti, R.A.P., Musule, R., Matheus, T.T., Freire, F., 2022, A systematic review and life cycle assessment of biomass pellets and briquettes production in Latin America, Renewable and Sustainable Energy Reviews, 157, 112042.

Sugumaran, P., Seshadri, S., 2010, Biomass charcoal briquetting, technology for alternative energy based income generation in rural areas, Booklet on Biomass Charcoal Briquetting, 1–20.

Sugumaran, P., Seshadri, S., 2009, Evaluation of selected biomass for charcoal production, Journal of Scientific and Industrial Research, 68, 719–723.

Tripathi, A.K., Iyer, P.V.R., Kandpal, T.C., 1998, A techno-economic evaluation of biomass briquetting in India, Biomass and Bioenergy, 14, 479–488.

van der Stelt, M.J.C., Gerhauser, H., Kiel, J.H.A., Ptasinski, K.J., 2011, Biomass upgrading by torrefaction for the production of biofuels: A review, Biomass and Bioenergy, 35, 3748–3762.

Werther, J., Saenger, M., Hartge, E.U., Ogada, T., Siagi, Z., 2000, Combustion of agricultural residues, Progress in Energy and Combustion Science, 26, 1–27.

Yuhazri, M., Haeryip S., Yahaya, S. Said, M., Umar, N., Saijod, L. and Phongsakorn, P., 2012, Solid Fuel From Empty Fruit Bunch Fiber and Waste Papers Part 5 : Crack Test for Transportation and Storage Purpose. Global Engineers and Technologists Review, 2, 20–24.

Zhang, Z., Fang, Y., Yang, J., Li, X., 2022, A comprehensive review of bio-oil, bio-binder and bio-asphalt materials: Their source, composition, preparation and performance, Journal of Traffic Transportation Engineering, 9, 1-28.

Zubairu A., Gana S., 2014, Production and characterization of briquette charcoal by carbonization of agro-waste, Energy and Power, 4, 41-47.