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Density Equation of Bio-Coal Briquettes and Quantity of Maize Cob in Phitsanulok, Thailand

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Abstract: One of the most important crops in Phitsanulok, a province in Northern Thailand, is maize. Base on the calculation, the quantity of maize cob produced in this region was approximately 220 kton year^{-1}. The net heating value of maize cob was found to be 14.2 MJ kg^{-1}. Therefore, the total energy over 874 TJ year^{-1} can be obtained from this agricultural waste. In the experiments, maize cob was utilized as the major ingredient for producing biomass-coal briquettes. The maize cob was treated with sodium hydroxide solution before mixing with coal fine. The ratios of coal:maize were 1:2 and 1:3, respectively. The range of briquetting pressures was from 4-8 MPa. The result showed that the density was strongly affected by both parameters. Finally, the relationship between biomass ratio, briquetting pressures and briquette density was developed and validated by using regression technique.

Key words: Biomass binder, maize cob binder, coal briquette, biomass-coal briquette

INTRODUCTION

Biomass, particularly agricultural residues, seems to be one of the most promising energy resources for developing countries. The idea of utilizing the residues from agricultural sectors as primary or secondary energy resources is considerably attractive. This kind of waste is available as free, indigenous and environmentally friendly energy sources. Moreover, the decreasing availability of firewood has necessitated that efforts be made towards efficient utilization of agricultural wastes. They have acquired considerable importance as fuels for many purposes viz. domestic cooking, industrial process heating, power generation etc. Some of agricultural residues, such as coconut shell, wood chip and wood waste, are ready to be directly used as fuel. Nevertheless, the majority of these bulky materials are not appropriate to be directly used as fuel without a suitable process. It is because of the fact that they have low density, high moisture content and low energy density. All of these issues may cause problems in transportation, handling, storage, entrained particulate emission control including direct combustion.

Briquetting is a mechanical compaction process for increasing the density of bulky material. This process can be utilized for forming fine or granular materials into a designed shape. With respect to coal fine, this material is not suitable for using in conventional combustion system because of its properties. However, it can be added to the final coal product steam if its handling characteristics are improved. Therefore, it is crucial that this fine material should be economically compacted into the regular shape and size. Several researches about coal-briquette production have been carried out. Some researchers were interested in binderless coal briquette making[1-2] while the other were focused on coal briquettes produced from coal and chemical binding agent. Examples of the binder according to their researches were asphalt[3], potassium[4], magnesia[5], ammonium nitrohumate[6] and commercial pitch[7].

Biomass-coal briquette may be defined as a type of solid fuel prepared from coal and biomass. When the briquetting pressure is applied during the process, the coal particles and biomass material in the biomass-coal briquette adhere and interlace to each other. Thus, these two materials do not separate from each other during the storage, traveling and combustion. During the combustion, the biomass is simultaneously burned with the coal at low ignition temperature. Since the biomass part in the briquette has lower ignition temperature as compared to the other part, it can assure that the quality of combustion of the coal volatile matter at low temperature is improved. Therefore, ignition and fuel properties are also improved because of this reason. Besides, it is widely accepted that biomass-coal briquette technique is one of the most promising technologies for reducing SO_2 emission. With regard to the sulfur content of the coal, a desulfurizing agent can be added for sulfur capturing purpose. The agent effectively reacts with sulfur in the coal to fix the sulfur into the sandy ash. Thus, several coal ranks, including low grade coal containing high sulfur and ash contents, can be used for producing biomass-coal briquette. Many researches about biomass-coal briquettes have been carried out. Olive stone[8-10], sawdust[10] and rice straw[11] are examples of the biomass material in the briquettes.

Thailand is located in the center of mainland South East Asia. It has an area of 513,115 square kilometers. The country may be divided into four topographical regions viz. the northern area, the central plains, the northeast plateau and the peninsula south. The north of Thailand is a mountainous region comprising natural forest, ridges, lower foothill and alluvial valleys. This northern area can be sub-divided into two distinct groups viz. the lower north from Nakhon Sawan province to Sukhothai province and the mountainous upper north leading to borders of Myanmar and Laos. Phitsanulok, a province in lower northern part of Thailand, is located between the latitude 16°21' N to 17°44' N and longitude 99°52' E to 101°4' E. It has an area of approximately 10,816 km^2 which is divided into nine districts, namely Muang Phitsanulok district, Nakhon Thai district, Chat Trakan district, Bang Rakam district, Bang Krathum district, Phrom Phiram district, Wat Bot district, Wang Thong district and Noen Maprang district. One of the major agricultural products of the province is maize. Therefore, a considerable amount of maize waste, such as maize cob, is available in this area.

The objective of this research was to investigate the effects of chemical-treated maize-cob ratio and briquetting pressures on the density of biomass-coal briquette. With regard to maize productivity and residue-to-product ratio, the quantity of maize cob available in Phitsanulok was also computed. Finally, by using regression technique, the relationship between the biomass ratio, briquetting pressure and briquette density was developed and validated.

MATERIALS AND METHODS

The agricultural products are one of the most important parts of Phitsanulok's economic. A large amount of maize has been produced every year. According to this, a considerable quantity of maize cob was generated in this area. For maize cob calculation purpose, the residue-to-product ratio (RPR) of maize cob and maize productivity of this province were used. The RPR value of 0.273[12-13] and the productivity of maize in 2006 were utilized in this calculation. The potential energy content in maize cob was also investigated. The heating value of this agricultural waste was examined. The Parr isoperibol bomb calorimeter with an accuracy of 0.0001°C was used for that purpose. The moisture content of maize cob was studied according to ASAE S269.4 method. The raw material utilized in the experiments was obtained from two villages in Phitsanulok during summer of 2007.

Maize cob was air dried and crushed into small pieces. By using a sieve with an accuracy of ±0.025 mm, the particles larger than 2 mm were removed before use. Then, maize cob was treated with 3% wt/wt sodium hydroxide solution at 90°C for 1 h. With regard to the coal, it was collected from a local factory. Only coal fine, smaller than 2 mm, was used in the experiment. Biomass-coal briquettes were produced in the laboratory of Biomass Energy Research Unit, Engineering Faculty, Naresuan University. The coal was mixed with sodium hydroxide treated maize cob at two different ratios. As maize cob is abundant in this area, the percentage of it in this research was set to be over 50% in order to maximize the amount of maize cob utilization. Therefore, the biomass:coal ratios were 2:1 and 3:1 (wt/wt), respectively. A digital balance with an accuracy of ±0.001 g was used for mixture preparation. For each sample, 20 g of the mixture was compacted at ambient temperature by using a calibrated laboratory-scale hydraulic press. A pressure switch with an accuracy of 1% was used to control the pressure of hydraulic machine. A harden steel with an inner diameter of 25 mm and a height of 200 mm was utilized as a die for producing biomass-coal briquettes. The briquetting pressure range in the experiments was from 4-8 MPa. Three briquettes were prepared for each set of the experimental conditions.

Least-squares technique was used for developing an empirical model of biomass-coal briquette density over the studied range. Normal probability plot of the residuals was used for checking the normal distribution of the residuals. Then, the multiple correlation coefficient; R^2, the adjusted coefficient of determination; $R^2_{adjusted}$ and the coefficient of multiple determination for prediction; $R^2_{prediction}$ were used as criteria for model adequacy checking.

RESULTS AND DISCUSSION

Residue-to-product ratio of maize cob and maize productivity of Phitsanulok were used for computing the amount of maize cob available in the province. In crop year 2006, it was found that the production of maize was approximately 220 kton. Figure 1 shows the calculated amount of maize cob in nine districts of Phitsanulok viz. Muang Phitsanulok, Nakhon Thai, Chat Trakan, Bang Rakam, Bang Krathum, Phrom

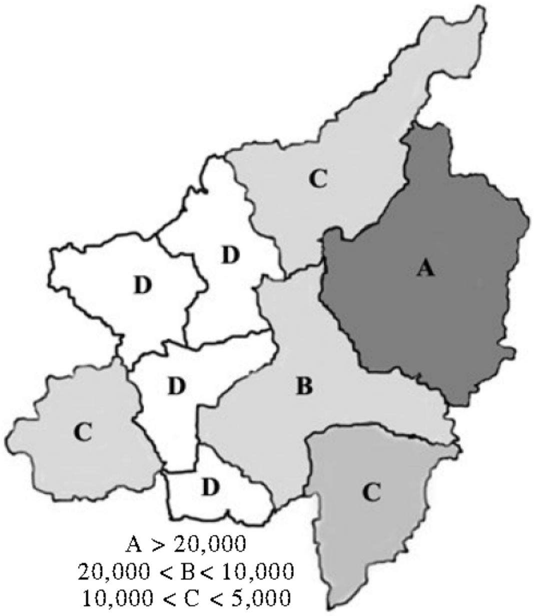

Fig. 1: Calculated amount of maize cob available in Phitsanulok, Thailand

Phiram, Wat Bot, Wang Thong and Noen Maprang. As can be seen from the figure, the quantity of maize cob over 10 kton $year^{-1}$ exists in two districts viz. Nakhon Thai and Noen Maprang districts. The maximum amount of the agricultural waste was accounted for Nakhon Thai district with a value over 20 kton. The first two districts together accounted for over 60% of the maize cob generated in Phitsanulok. In addition, the summation of maize cob available in the D-group was less than 1% of the total quantity.

According to the heating value study, it was found that the net heating value of maize cob was about 14.2 MJ kg^{-1}. The moisture content of this raw material was found to be 20%. From the calculation, the estimated energy values of maize cob available in Nakhon Thai and Noen Maprang districts were nearly 334 and 207 TJ $year^{-1}$, respectively. The sum of the values for the case of Phitsanulok was approximately 874 TJ $year^{-1}$.

The density of produced biomass-coal briquettes was ranging from 0.98 to 1.12 g cm^{-3}. It was found that the values were increased with an increasing in briquetting pressure. Moreover, at the same pressure, the 2:1-ratio briquette density is found to be slightly lower than the value of 3:1-ratio briquette. By using regression technique, the relationship between density, briquetting pressure and maize percentage over the studied range was developed. The empirical variable, response, was the density while the independent variables were briquetting pressure (4-8 MPa) and maize percentage (0.67 and 0.75), respectively.

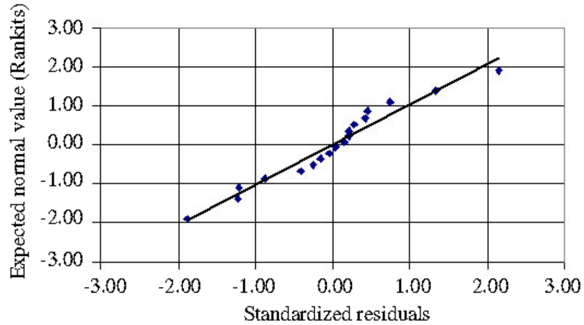

Fig. 2: Model adequacy checking (expected normal value vs. standardized residuals)

$$D = 0.833 + 0.279M^2 + 0.00168P^2$$

Where:

D: Density (g cm^{-3})

P: Briquetting pressure (MPa)

M: Maize percentage (%)

For model adequacy checking purpose, the coefficient of multiple determination, R^2 and the adjusted coefficient of determination, $R^2_{adjusted}$, were used to investigate the quality of fit. In addition, by using the prediction error sum of squares, the coefficient of multiple determination for prediction, $R^2_{prediction}$, was also studied. According to the calculations, the values of R^2, $R^2_{adjusted}$ and $R^2_{prediction}$ are 89.8, 88.4 and 86.1% respectively. The R^2 and $R^2_{adjusted}$ values show that the proposed relationship was not over-fitted while the $R^2_{prediction}$ value is the indication of the predictive capability of the model. Finally, a graph between expected normal value and standardized residuals was also plotted as shown in Fig. 2.

CONCLUSION

Maize is one of the most important agricultural products of Phitsanulok, Thailand. With regard to the productivity of maize exceed 220 kton $year^{-1}$, approximately 61 kton of maize cob has been generated. The calculated amount of potential energy from this agricultural waste was over 874 TJ $year^{-1}$. Therefore, maize cob is one of the most promising agricultural residues which can be used as fuel. With respect to maize cob fuel production, bio-coal briquettes produced from sodium hydroxide treated maize cob and coal were studied. The relationship between the density and briquetting pressure as well as maize ratio was investigated. Then, the density model was developed and validated. The model adequacy checking showed that the proposed equation gave a good result in density prediction.

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REFERENCES

1. Mangena, S.J. and V.M. Cann, 2007. Binderless briquetting of some selected South African prime coking, blend coking and weathered bituminous coals and the effect of coal properties on binderless briquetting. Int. J. Coal Geol., 71: 303-312. Doi: 10.1016/j.coal.2006.11.001.
2. Mangena, S.J., G.J. Korte, R.I. McCrindle and D.L. Morgan, 2004. The amenability of some Witbank bituminous ultrafine coals to binderless briquetting. Fuel Process. Technol., 85: 1647-1662. Doi: 10.1016/j.fuproc.2003.12.011.
3. Steven, A.P., A.S. Hull, H. Plancher and P.K. Agarwal, 2002. Use of asphalts for formcoke briquettes. Fuel Process. Technol., 76: 211-230. Doi: 10.1016/S0378-3820(02)00027-9.
4. Garcia-Garcia, A., M.J. Illan-Gomez, A. Linares-Solano and C.S.M. Lecea, 1997. Potassium-containing briquetted coal for the reduction of NO. Fuel, 76: 499-505. Doi: 10.1016/S0016-2361(97)00009-4.
5. Tosun, Y.I., 2007. Clean fuel-magnesia bonded coal briquetting. Fuel Process. Technol., 88: 977-981. Doi: 10.1016/j.fuproc.2007.05.008.
6. Yildirim, M. and G. Ozbayoglu, 1997. Production of ammonium nitrodumate from Elbistan lignite and its use as a coal binder. Fuel, 76: 385-389. Doi: 10.1016/S0016-2361(97)85514-7.
7. Rubio, B., M.T. Izquirerdo and E. Segura, 1999. Effect of binder addition on the mechanical and physicochemical properties of low rank coal char briquettes. Carbon, 37: 1833-1841. Doi: 10.1016/S0008-6223(99)00057-3.
8. Mayoral, M.C., M.T. Izquierdo, M.J. Blesa, J.M. Andres, B. Rubio and J.L. Miranda, 2001. DSC study of curing in smokeless briquetting. Thermochim. Acta, 371: 41-44. Doi: 10.1016/S0040-6031(00)00788-7.
9. Blesa, M.J., J.L. Miranda, M.T. Izquierdo and R. Moliner, 2003. Curing temperature effect on mechanical strength of smokeless fuel briquettes prepared with molasses. Fuel, 82: 943-947. Doi: 10.1016/S0016-2361(02)00416-7.
10. Blesa, M.J., J.L. Miranda, R. Moliner, M.T. Izquierdo and J.M. Palacios, 2003. Low-temperature co-pyrolysis of low-rank coal and biomass to prepare smokeless fuel briquettes. J. Anal. Applied Pyrolysis, 70: 665-677. Doi: 10.1016/S0165-2370(03)00047-0.
11. Zhang, X., D. Xu, Z. Xu and Q. Cheng, 2001. The effect of different treatment conditions on biomass binder preparation for lignite briquette. Fuel Process. Technol., 73: 185-196. DOI: 10.1016/S0378-3820(01)00179-5.
12. Yokoyama, S., T. Ogi and A. Nalampoon, 2000. Biomass energy potential in Thailand. Biomass Bioenergy, 18: 405-410. Doi: 10.1016/S0961-9534(00)00004-0.
13. Wilaipon, P., 2007. Physical characteristics of maize cob briquette under moderate die pressure. Am. J. Applied Sci., 4: 995-998. URL: http://www.scipub.org/fulltext/ajas/ajas412995-998.pdf.