Asian Journal of Scientific Research

ISSN 1992-1454

Asian Journal of Scientific Research 6 (3): 498-507, 2013
ISSN 1992-1454 / DOI: 10.3923/ajsr.2013.498.507

Fuel Characterization and Energy Prediction of Malaysian Poultry Processing

A.H. Abbas, A.B.A. Ibrahim, M.F.H.A. Muttalib and M.S. Aris
Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

Corresponding Author: M.S. Aris, Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

ABSTRACT

Poultry Processing Waste Sludge (PPWS) is one of the largest contributors of waste material in Malaysia. The use of this waste material can be an effective alternative fuel solution, as it can not only contributes as an energy source but also solves environmental issues related to PPWS disposal. This study examines the utilization of PPWS as fuel by investigating its fuel characteristics and developing a new empirical model using multiple regression analysis to predict higher heating value from its ultimate analysis results. An extensive number of PPWS samples were collected from three poultry processing wastewater treatment plants in Malaysia. The samples were analyzed for their heating values and key elemental compositions. The measured energy content in PPWS (27-34 MJ kg^{-1}) is comparable to coal and can therefore be proposed to be used as an alternative fuel in power plants. By applying multiple regression analysis on the experimental results, the relevant coefficients of the model equation was determined. A validation of the newly developed correlation, HHV = 230 C%+761 H%+1247 N%+14259 indicates a very good fit between the measured and predicted values whereby the correlation coefficient was found to be 0.91. This model can be considered as an excellent tool to predict the higher heating value of PPWS from an ultimate analysis and is potentially helpful for engineers and researchers.

Key words: Biomass, poultry sludge, higher heating value, ultimate analysis, regression analysis

INTRODUCTION

The dewatered poultry sludge is one of the waste products generated daily from the poultry industry. Today in Malaysia, this poultry industry is growing not only to support the local consumption but is also part of the Malaysian government's plans to become a major supplier of chicken meat for the Asian market (Kluyver, 2010). The slaughtering of chicken and the subsequent processes in the poultry plant generate the substantial amount of wastes such as feather, bone meal, blood and offal (Marculescua and Stan, 2011) and cannot be used for human consumption. These waste materials contribute toward environmental problems such as organic pollution and issues related to disposal such as land scarcity and increasing costs must be urgently addressed to adhere to legislative constraints which are meant to protect the environment (Hj *et al*., 1996). A schematic of the common process involved in handling poultry waste from the various collection points in the plant until its release into the waterways is shown in Fig. 1. The components of the process involve storage, transport, treatment and dewatering procedures before an acceptable waste water quality is achieved and can be released into the water-ways. The solid by-product is

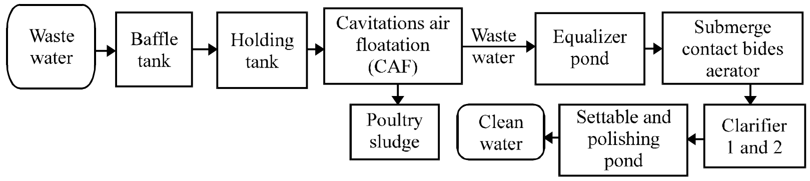

Fig. 1: Wastewater treatment in poultry processing industry

known as dewatered sludge and is commonly disposed at specialized landfills at a cost to the poultry industries. At the baffle tank, a rot strainer is used to segregate water and feathers. Feathers and processed chickens will be accumulated in baskets and sent-out separately for disposal. The water flows to a holding tank where it is stored for subsequent treatment in the Cavitations Air Floatation (CAF) equipment, the sludge leaving the CAF consists of chicken manure and residue which have been removed from the wastewater. The wastewater continues to be processed through an equalization pond before entering the Submerge Contact Bodies Aerator (SCBA), clarifier, stable pond, polishing pond and finally discharged as clean water.

The most common use of PPWS and sewage sludge is in the agricultural sector is as a fertilizer supplement (Al-Sohaibani, 2011). However, this application increases the risk of transferring pollutants to the human food chain. An unexplored application for PPWS is its conversion into an alternative fuel which not only contributes as a renewable energy source but also helps resolve environmental issues related to the current PPWS disposal route.

To identifying the feasibility to convert PPWS into alternative fuel, the characterization of its energy content and chemical composition is an important step in determining the feasibility for power generation applications. In general, the main challenge in processing PPWS fuels is related to managing the high moisture content and the unstable organic substances that decompose to create bad odor. For designed and operating the mass burn incineration; the energy content of PPWS is a very important control parameter which define the energy content and determine the efficient use of these fuels. The energy content of PPWS can be determined by using a laboratory bomb colorimeter or modeling calculation based on its chemical composition. Calculation of energy content from the enthalpy of formation of CO_2 and H_2O and other product is very difficult because solid-fuel materials are complex mixtures of compounds and the relevant bond energies cannot be considered properly (Changa *et al*., 2007). And determination of HHV by calorimetric methods requires time and manual laboratory work, while ultimate analyses can be automated. Therefore, numerous empirical models have been developed to predict the higher heating value of many types of materials such as coal, sewage sludge, municipal solid waste and different type of biomass fuel (Changa *et al*., 2007; Akkaya and Demir, 2009; Thipkhunthod *et al*., 2005; Demirbas, 1997; Parikh *et al*., 2005; Friedl *et al*., 2005). Moreover, there is no model considers PPWS. In this study, a new empirical model was established to predict the energy content of PPWS from elemental composition (carbon, hydrogen and nitrogen).

MATERIALS AND METHODS

Waste sample collection: The research started by selecting a few closer chicken broiler factories that have their own water-treatment system. According to the feedback from early our survey, there are three factories agreed to give a co-operation for waste sample collecting purpose.

Respective factories are using the similar chemical coagulation and sedimentation processes in their water treatment plant. This condition is good to ensure the sample of PPWS is in standard conditions and behavior.

Characterization of Poultry processing waste sludge: The characterization of potential solid fuels for their energy content and chemical composition is an important step in determining the feasibility for power generation applications. The biomass waste materials explored in this work were obtained from major poultry processing plants from around Malaysia; poultry processing is dominated by a few major companies operating in the northern, central and southern regions of the country. For the experiments reported in the paper, 30 samples each was collected from the poultry processing plants and the results will be labeled as Plants 1 for the northern region, while Plants 2 and 3 represent the central and southern regions, respectively.

To acquire an understanding of the fuel characteristics, the samples from three different plants were collected and tested for moisture, HHV and chemical composition. To obtain the moisture content the samples from each plant were first dried according to ASAE standard S358.2 and then experimental procedures were carried out to measure the calorific values and chemical compositions through bomb calorimeter and ultimate analysis respectively. The high heating value procedure was carried out in accordance to ASTM D2015. CHNS analyzer (Leco CHNS-932, VTF-900) was used to find the carbon (C), hydrogen (H), nitrogen (N) and sulfur (S) contents in the samples. To account for repeatability and the uncertainty in measurements, the characterization tests were repeated 30 times and the uncertainty was calculated.

Heating value estimation process: Multiple regression analysis was used to develop an empirical equation for the HHV of PPWS in Malaysia. The dependent variable was the higher heating value. The independent variables were the elemental composition of fuels (carbon, hydrogen, nitrogen and sulfur). Figure 2 shows the regression analysis process used to build a model (Zhu, 2005).

The significant of variables: From the collected data, the relationship between the dependent variable (HHV) and independent variables (elemental composition) was developed using a correlation coefficient which can be used to determine whether a clear trend can only be consequential or pure chance. If we have two variables x and y and attempt to produce a set of n pairs of data, we can determine the correlation coefficient as follows (Wheeler and Ganji, 2004):

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\left[\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2\right]^{1/2}} \tag{1}$$

where:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{2}$$

$$\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n} \tag{3}$$

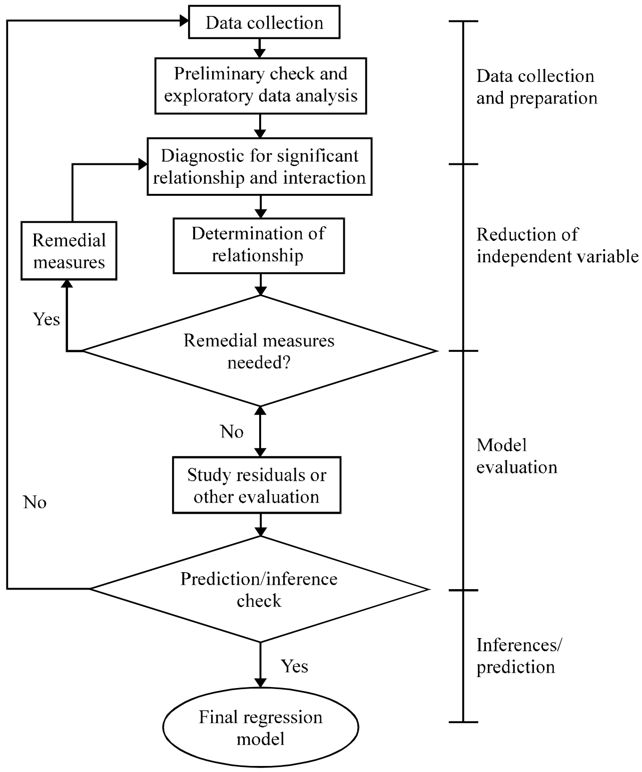

Fig. 2: Regression analysis procedure

The calculated correlation coefficient value r_{xy} is significant if it is equal to, or greater than a critical value which can be obtained from tables (Wheeler and Ganji, 2004) based on the number of samples and the confidence level. Then the insignificant variables eliminated and the significant variables were used to develop the model (Changa *et al.*, 2007).

Heating value regression model: In the development of multiple regression models the actual higher heating values are used to target as output dependent variable while the fuel composition, carbon, hydrogen, sulfur and nitrogen are taken as model input independent variables. The oxygen content has been calculated as the difference between 100 and the sum of the other composition, it is not an independent variable and will not be used in the regression model (Friedl *et al.*, 2005). The multiple regression method helps us to model the relationship between two or more input variables and target variable by fitting an equation for the observed data (Changa *et al.*, 2007; Akkaya and Demir, 2009). The governing equation can be described as follows:

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_k x_{ik} = \beta_i + \sum_{i=1}^{k} x_{ij} \qquad i = 1, 2, \ldots, n \tag{4}$$

where, β_o, β_1, β_2 and β_k are the regression coefficient and x_{ij} represents the selected independent variables, carbon (C), hydrogen (H) and nitrogen (N) in this model. Then the Least Square Estimation (LSE) method is used to find the regression coefficient to minimize the SSE defined as (Friedl *et al.*, 2005; Zhu, 2005):

$$SSE = \sum(y_i - \bar{y}_i)^2 \quad (5)$$

where, $\bar{y}_i$ is an estimated value.

Regression model evaluation: When the regression model used for a given data set, it is uncertain whether the regression model appropriate for the applicant. To confirm the validity of the model it is necessary to have a mathematical expression to evaluate the model. In this study, the considered criteria to estimate the relative error between the predicted HHV and the measured HHV is a coefficient of multiple determination (R^2) and residual analysis which can be expressed in Eq. 6 (Akkaya and Demir, 2009; Wheeler and Ganji, 2004) and Eq. 7 (Zhu, 2005):

$$r^2 = 1 - \frac{\sum(\hat{y} - y_i)^2}{\sum(y_i - \bar{y})^2} \quad (6)$$

$$\varepsilon_i = y_i - \bar{y} \quad (7)$$

The residual is more useful criteria for evaluating the performance of the model than direct diagnosis of response variables. The reason is that the residuals can be assumed to be identical independent variables with normal random distribution with mean zero and constant variance (Zhu, 2005). The examination can be realized by the plot of predicted HHV against the residuals (Zhu, 2005). Finally, the validation of the model developed in this work has been carried out by comparison of estimated and actual values of HHV.

RESULTS AND DISCUSSION

The results from the current work presents the main fuel characteristics of Malaysian poultry processing sludge such as moisture content, higher heating value and identifies the key elemental composition. From the measured values, a new model has been developed using multiple nonlinear regression analyses to predict the higher heating value of poultry sludge.

Initial moisture content: The initial moisture content in wet basis of PPWS is referring to the quantity of water in the sample divided by the total mass of the sample, expressed as a percentage of the material's weight. The mass of water is found through the drying process, where the reduction of final mass weight showed the mass of water. Through oven drying, the moisture content in the 30 samples from plants 1, 2 and 3 were reduced and the initial percentage of moisture content representing as-received conditions together with the respective uncertainty in the measurements, are shown in Fig. 3.

Heating value: The heating value of samples (HHV) is an indication of the amount of energy chemically bound in the fuel (MJ kg^{-1}), is one of the most important characteristics because it indicates the total amount of energy that available in the PPWS samples. Figure 4 shows HHV and uncertainty for 30 PPWS samples from Plants 1, 2 and 3. The mean HHV of the PS was found to be 27.83 MJ kg^{-1} with a standard deviation of 5.13. It is also observed that HHV of the PS obtained from the current experiment is higher than the HHV of low-grade coal (23.3 MJ kg^{-1}) (Lu *et al*., 2000).

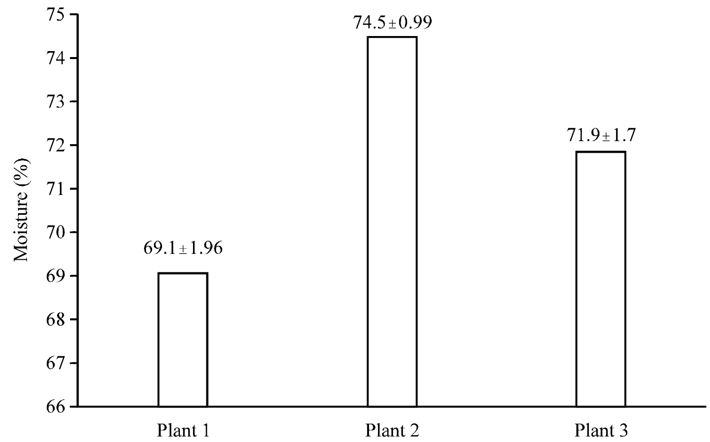

Fig. 3: Moisture content in the As-received poultry sludge samples

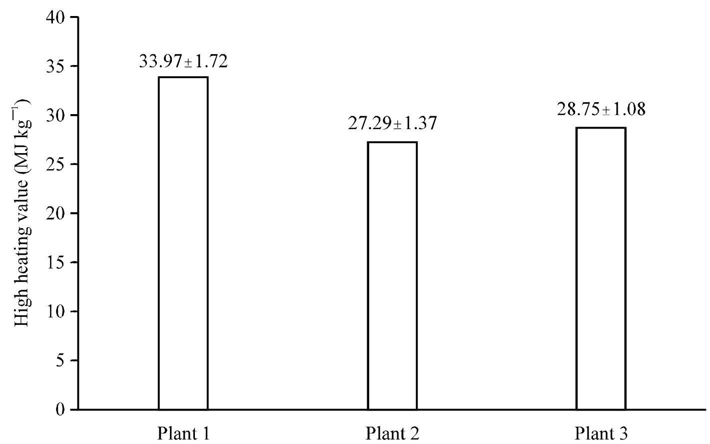

Fig. 4: Measured high heating value and uncertainty calculation of the poultry sludge samples

Table 1: Ultimate analysis of poultry sludge plant samples

Plant	Carbon (%)	Hydrogen (%)	Sulfur (%)	Nitrogen (%)
1	68.96±1.31	9.78±0.25	0.27±0.10	3.14±0.17
2	53.89±0.76	7.35±0.12	0.43±0.05	4.24±0.13
3	56.35±0.74	8.25±0.27	0.59±0.13	3.82±0.12

Ultimate analysis: The ultimate analysis for plants 1, 2 and 3 samples with their respective uncertainties are shown in Table 1. On average, the carbon and hydrogen elements contents in the samples were found to be 56 and 8%, respectively. These values are higher than values of common low grade coal reported by Lu *et al.* (1998). In general, the increase in carbon and hydrogen content leads to an increase in the HHV (Yin, 2011; Sheng and Azevedo, 2005). The mean percentage of nitrogen available in the PS samples was approximately 5%. The nitrogen content in PS was found to be higher than coal as reported by Lu *et al.* (1998) and this increase will unfortunately require additional controls on temperature, pressure and air concentration during

Table 2: The computed and critical correlation coefficient of elemental composition for poultry sludge samples

Factors	Computed correlation coefficient (r_{xy})	Critical correlation coefficient (r_t)*
Carbon	0.91	0.21
Hydrogen	0.88	0.21
Nitrogen	-0.79	0.21
Sulfur	-0.19	0.21

*Parikh *et al*. (2005)

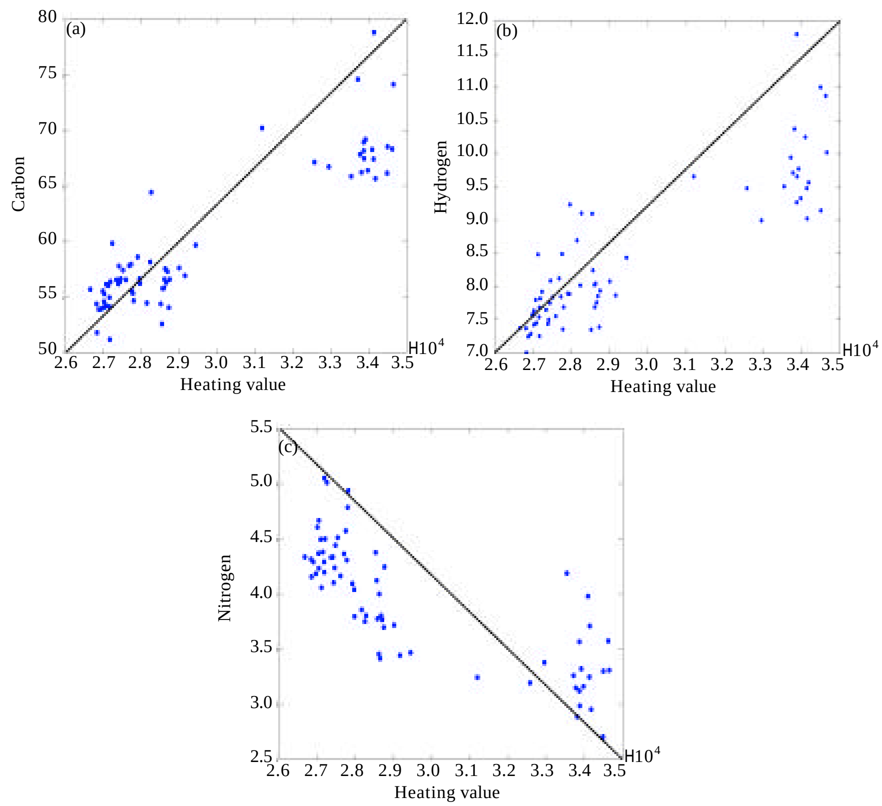

Fig. 5(a-c): Shows the correlation between heating value and fuel composition (a) Carbon (b) Hydrogen and (c) Nitrogen

the thermal conversion process to reduce the NO_X emissions. The mean percentage of sulfur in the PS samples was almost zero and this will results in low SO_2 emissions from incineration (Lu *et al*., 1998).

In general, the fuel characterization results suggested that fuel from PS can be used in power generation or process heating supply due to its high calorific value and acceptable chemical composition for emission controls.

Heating value model: The correlation coefficient for carbon, hydrogen, nitrogen and sulfur with the heating value for PPWS was calculated by using Eq. 1. For 95% confidence level, α = 1-0.95 = 0.05 and for 100 pairs of data, we obtained the critical value of r (r_t) (Wheeler and Ganji, 2004). Table 2 contains the computed and critical correlation coefficients.

Figure 5 gives an impression about the correlations between features. From Table 2 and Fig. 5 there is strong relationship between carbon, hydrogen and nitrogen with

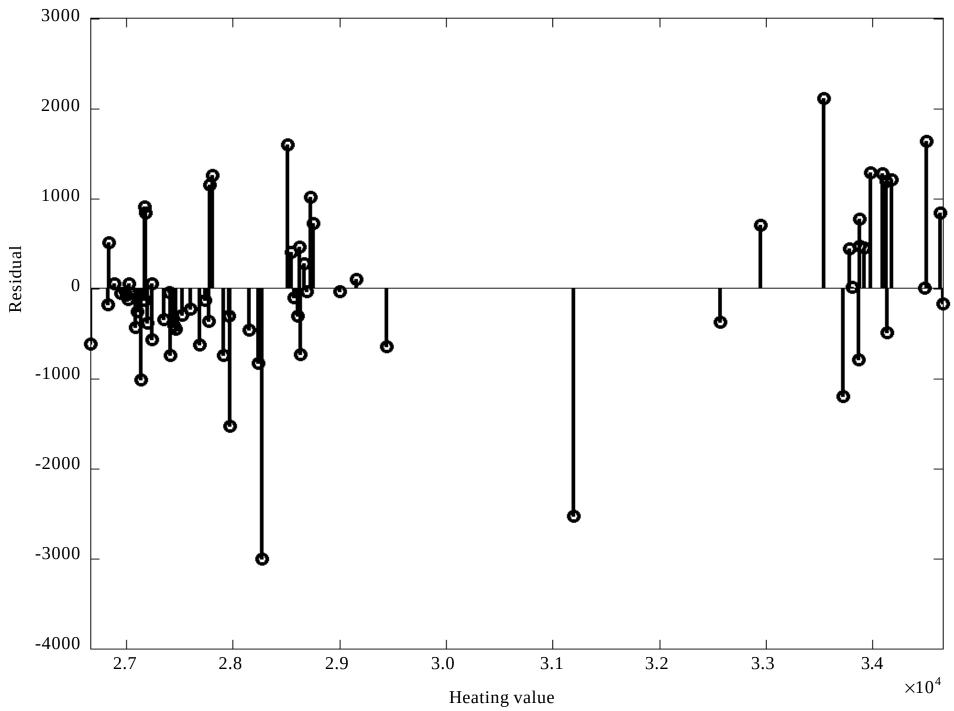

Fig. 6: Residual errors between actual and estimated high heating value

heating value, the heating value increase with increasing amount of carbon and hydrogen respectively, this agreed with Parikh *et al.* (2005), on the other hand; the amount will decrease with decreasing amount of nitrogen and this in agreement with Demirbas (1997), for sulfur a value of r_{xy} less than r_t. We conclude that the apparent trend in the data is probably caused by pure chance. Therefore, the selected independent variables are Carbon (C), Hydrogen (H) and Nitrogen (N).

The values of the multiple regression coefficients are carried out. According to these regression coefficient values, the prediction heating value can be form as follows:

$$\text{HHV (kJ kg}^{-1}\text{)} = 230\ \text{C\%} + 761\ \text{H\%} + 1247\ \text{N\%} + 14259 \quad (8)$$

The considered model equation gives the coefficient of multiple determinations (R^2) as 0.91. These results show that the regression between the model outputs and actual higher heating values has been shown to be acceptable with a high correlation which indicates only 9% error on fitting the collected data, the closer value to unity, the better is the correlation between the observed and predicted values. This value should be quite high between 0.8-0.9 and higher (Wheeler and Ganji, 2004).

Figure 6 shows the residual plot against the predicted heating value (HHV). From the figure, clearly the residuals are randomly distributed along with the predicted value. There is no trend which means the error terms of residuals has constant variance with mean zero. And we can conclude that the regression model well fit the data observed (Zhu, 2005). The results from the

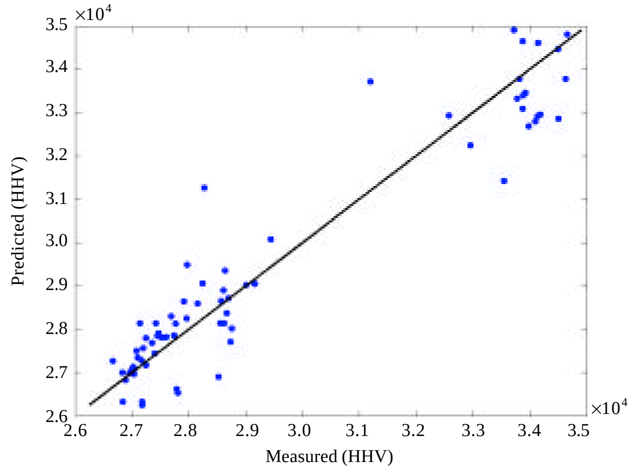

Fig. 7: Comparison between measured and predicted high heating value

calorimeter measurements and proposed regression models are presented in Fig. 7, the estimated values are quite consistent with the experimental measurements.

CONCLUSION

Basic characterization of Poultry Processing Waste Sludge (PPWS) was successfully carried out to evaluate its potential source of energy. Samples from three local wastewater treatment plants of the factory chicken broilers were found to have potential as a fuel for combustion in energy recovery plant. The preliminary findings reported in this paper, for Malaysian poultry processing waste sludge, found the following properties through the respective experiments, (a) the ultimate analysis (Carbon; 55.68-67.38%, Hydrogen; 7.61-9.81%, Nitrogen; 3.28-4.41% and Sulfur; 0.42-0.49%), (b) bomb calorimeter (heating value; 27-34 MJ kg^{-1}) and (c) moisture content; 69-74%. The usage of PPWS as an alternative fuel is cost effective and reasonable with the amount of its HHV nearly to coal that are using in the energy power plant recently. A new empirical model has been developed to predict HHV of (PPWS) from their ultimate analysis data based on a large number of samples having widely varying fuel composition. The results of this study show that the developed model shows high estimation performance and good agreement with experimental results. It can be concluded from the results that the developed model is an excellent tool to predict HHV of (PPWS), from its ultimate analysis and will provide new references for other studies related to determination of higher heating value of PPWS and be helpful for engineers and researchers.

ACKNOWLEDGMENTS

The authors wish to thank Universiti Teknologi PETRONAS (UTP) and STIRF grant 80/09.10 for providing support for this study.

REFERENCES

Akkaya, E. and A. Demir, 2009. Energy content estimation of municipal solid waste by multiple regression analysis. Proceedings of the 5th International Advance Technologies Symposium, May 13-15, 2009, Karabuk, Turkey.

Al-Sohaibani, S.A., 2011. Heavy metal tolerant filamentous fungi from municipal sewage for bioleaching. Asian J. Biotechnol., 3: 226-236.

Changa, Y.F., C.J. Linb, J.M. Chyanb, I.M. Chena and J.E. Changc, 2007. Multiple regression models for the lower heating value of municipal solid waste in Taiwan. J. Environment. Manag., 85: 891-899.

Demirbas, A., 1997. Calculation of higher heating value of biomass fuel. Fuel, 76: 431-434.

Friedl, A., E. Padouvas, H. Rotter and K. Varmuza, 2005. Prediction of heating values of biomass fuel from elemental composition. Anal. Chim. Acta, 544: 191-198.

Hj, M.Y., O. Mohd, B. Yatim and M.M. Salleh, 1996. Chicken dung biogas power generating system in Malaysia. Renewable Energy, 9: 930-933.

Kluyver, C.D., 2010. Fundamental on Global Strategy. 1st Edn., Business Export Press, LLC, Baton Rouge, LA., Pages: 175.

Lu, G., H. Kim, J. Yuan, I. Naruse, and K. Ohtake, 1998. Experimental study on self-desulfurization characteristics of biobriquettes in combustion. Energy Fuels, 12: 689-696.

Lu, G., Q. Wang, S. Kazuhiko, K. Heejoon and N. Ichiro *et al.*, 2000. Experimental study on combustion and pollutant control of briquettes. Energy Fuels, 14: 1133-1138.

Marculescua, C. and C. Stan, 2011. Poultry processing industry waste to energy conversion. Energy procedia, 6: 550-557.

Parikh, J., S.A. Channiwalab and G.K. Ghosal, 2005. A correlation for calculating HHV from proximate analysis of solid fuels. Fuel, 84: 487-494.

Sheng, C. and J.L.T. Azevedo, 2005. Estimating the higher heating value of biomass fuels from basic analysis data. Biomass Bioenergy, 28: 499-507.

Thipkhunthod, P., V. Meeyoo, P. Rangsunvigit, B. Kitiyanan, K. Siemanond and T. Rirksomboon, 2005. Predicting the heating value of sewage sludges in Thailand from proximate and ultimate analyses. Fuel, 84: 849-857.

Wheeler, A.J. and A.R. Ganji, 2004. Introduction to Engineering Experimentatio. 2nd Edn., Pearson Education Inc., Upper Saddle River, New Jersey, pp: 150-165.

Yin, C.Y., 2011. Prediction of higher heating values of biomass from proximate and ultimate analyses. Fuel, 90: 1128-1132.

Zhu, S., 2005. The constrained optimization of biomass wastes co-combustion process in the advanced fluidized bed combustorusing applied statistical methods. Ph.D. Thesis, Morgan State University, USA.