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Gas Flow Rate Identification in Biomass Power Plants by Response Surface Method

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***Abstract*—** The utilize of renewable energy sources becomes more crucial and fascinatingly, wider application of renewable energy devices at domestic, commercial and industrial levels is not only affect to stronger awareness but also significantly installed capacities. Moreover, biomass principally is in form of woods and converts to be energy for using by humans for a long time. Gasification is a process of conversion of solid carbonaceous fuel into combustible gas by partial combustion. Many gasified models have various operating conditions because the parameters kept in each model are differentiated. This study applied the experimental data including three inputs variables including biomass consumption; temperature at combustion zone and ash discharge rate and gas flow rate as only one output variable. In this paper, response surface methods were applied for identification of the gasified system equation suitable for experimental data. The result showed that linear model gave superlative results.

***Keywords*—** Gasified System, Identification, Response Surface Method

I. Introduction

THE use of renewable and sustainable energy resources will play a major role in many aspects of electricity generation. In particular, due to environment issues and ever increasing energy demands, the world is forced to look for alternative energy sources. Also, it is anticipated that shortage of hydrocarbon fuel will be inevitable. In terms of population growth, it has been estimated that by the year 2060, the world population will be in excess of 12 billions. Currently, over 80% of the crude oil reserves are under the control of only eight countries. Therefore, a number of strategies, such as special tariff and subsidy agreements, have been established in many countries in order to stimulate the research and utilization of alternative energy sources [5].

Biomass is organic material, which has stored solar energy from sunlight in the form of chemical in the plants through the process called photosynthesis. Biomass fuels include agricultural wastes, crop residues, wood, and woody wastes etc. Unless like fossil fuels biomass does not add carbon dioxide to the atmosphere as it absorbs the same amount of carbon while growing. It is the cheapest, eco-friendly, renewable source of energy [4].

Power generation from biomass has emerged as a very interesting complement to conventional sources of energy because of its contribution to the reduction of the green house effect [1]. Biomass is recognized to be one of the major potential sources for energy production. There has been an increasing interest for thermo chemical conversion of biomass and urban wastes for upgrading the energy in terms of more easily handled fuels, namely gases, liquids, and charcoal in the past of decade. It is a renewable source of energy and has many advantages from an ecological point of view [2]. Biomass fuels are characterized by high and variable moisture content, low ash content, low density, and fibrous structure [3].

Biomass gasification is a technology that transforms solid biomass into syngas. It is important and efficient energy conversion technology along with interventions to enhance the sustainable supply of biomass fuels can transform the energy supply situation in rural areas [2].

Gasified system is an important part to produce fuel gas. This paper studied the experimental data which have three inputs that are biomass consumption; temperature at combustion zone and ash discharge rate and one output is gas flow rate. This is the energy conversion technologies which is suitable for small-scale.

The response surface method has been widely used in practical engineering design optimization problems [6]. This method originates from science disciplines in which physical experiments are performed to explore the unknown relations between a set of variables and the system output, and these unknown relations are modeled as polynomials using the least square method. These straightforward polynomial models allow the objective and constraints of the optimization to be evaluated quickly to obtain better search points for more accurate surrogate models and eventually converge to the global optimum [7].

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This paper is divided into five sections. Section 2 presents gasification system. Section 3 presents response surface method. Section 4 shows results. Finally, conclusions are presented in section 5.

II. Biomass Gasification

Biomass gasification is a Technology that transforms solid biomass into syngas (hydrogen and carbon monoxide mixtures produced from carbonaceous fuel). Biomass fuels are characterized by high and variable moisture content, low ash content, low density and fibrous structure. In comparison with other fuels, they are regarded as of low quality despite low ash content and very low sulfur content [1]. Biomass gasification system consists of 2 main parts. They are gasified and gas cleaning system. For the first part, this paper used downdraft gasifier which are simple and robust. The gas exiting the reactor flowed through a cyclone and scrubbers just to remove a dust and the tars. Next, the clean gas passed through several heat exchangers to condense water vapor. After that, the gas was conditioned to be used in the internal combustion engine [1]. Figure 1 show the biomass gasification system which consists of gasified, gas cleaning system and engine-generator.

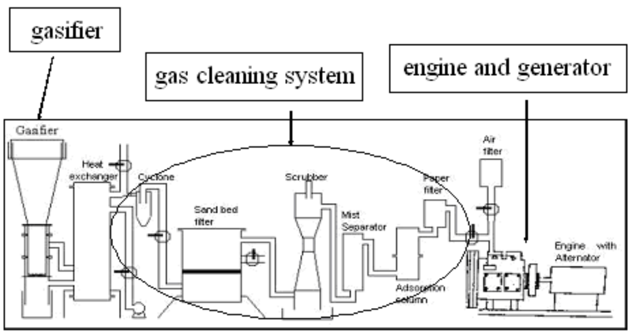

Fig. 1 Shows biomass gasification system.

A. Gasified

Biomass gasification converts solid biomass into more convenient gaseous form. This process is made possible in a device called gasified. The gasified was a cylindrical reactor which had the moving bed of biomass rested on a perforated eccentric rotating grate which was at the bottom of the gasified. The ash fell through the perforated grate to be collected in a lower chamber. The biomass feeding at the top of gasified after that biomass was burnt in process zones. Finally, the gasified received producer gas [4].This is the energy conversion technologies which is suitable for small-scale. Figure 2 shows process zone for downdraft gasifier.

B. Process zone

Four distinct processes take place in a gasified as the fuel makes its way to gasification. They are:

a) Drying zone
b) Pyrolysis zone
c) Combustion zone
d) Reduction zone

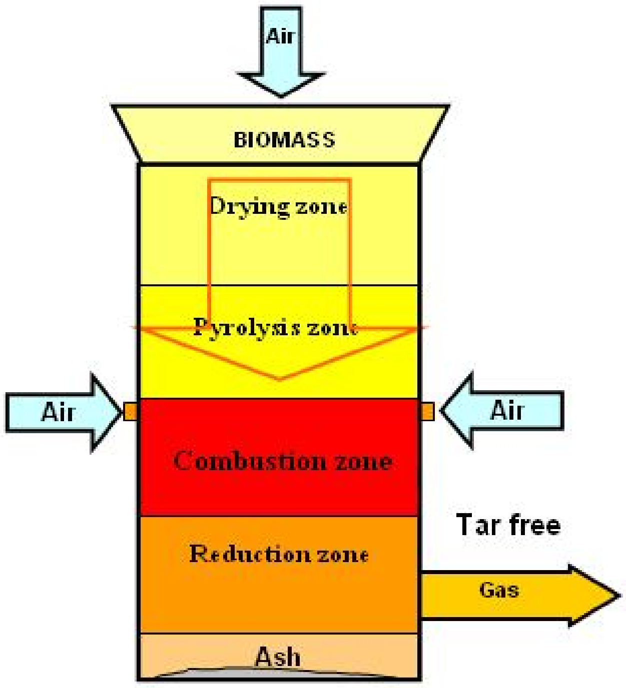

Fig.2 Shows process zone for downdraft gasifieds.

III. Response Surface Method

Response surface method is a statistical and mathematical method that gives an effective practical means for design optimization. When response , which should be taken into consideration for design, is determined as a function of multiple design variables , the behavior in response surface method is expressed by the approximation as a polynomial on the basis of conservation data [8],[10],[13-15]. The response surface method postulates a model of term:

$$y = f\left(x_1, x_2, ..., x_k\right) + \varepsilon \qquad (1)$$

where the form of the true response function y is unknown or very complicated, $f\left(x_1, x_2, ..., x_k\right)$ is a known polynomial function of $\left(x_1, x_2, ..., x_k\right)$, and ε is a term that represents random error. It is assumed to be normally distributed with mean zero and variance.

Because the form of y is unknown, it must be approximated by a known polynomials function $f\left(x_1, x_2, ..., x_k\right)$. The more suitable approximation for y, the accuracy is higher. In general, the first-order polynomials is [9],[11]

$$y = b_0 + \sum_{i=1}^{k} b_i x_i + \varepsilon \quad (2)$$

The first-order model is likely to be appropriate when the experimenter is interested in approximating the true response surface over a relatively small region of the input variable space in a location where there is little curvature in f.

For a quadratic response function with k variables by a regression model, it is expressed by (3)

$$y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{i=1}^{k} \sum_{j=i+1}^{k} b_{ij} x_i x_j + \varepsilon \quad (3)$$

For this paper, the response function with k =3 variables, the first-order polynomials is

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + \varepsilon \quad (4)$$

the quadratic response function is

$$\begin{aligned} y &= b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 \\ &+ b_{23} x_2 x_3 + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2 + \varepsilon \end{aligned} \quad (5)$$

where
x_1 is biomass consumption (kg/h)
x_2 is ash discharge rate (kg/h)
x_3 is temperature at combustion zone (°C)
y is gas flow rate (m^3/h)

Then, n sets of observation data in correspondence with design variables can be expressed by matrix representation in (6) and (7)

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} = \begin{bmatrix} 1 & x_{11} & x_{12} & \vdots & x_{1k} \\ 1 & x_{21} & x_{22} & \vdots & x_{2k} \\ 1 & \vdots & \vdots & \ddots & \vdots \\ 1 & x_{n1} & x_{n2} & \vdots & x_{nk} \end{bmatrix} \begin{bmatrix} b_0 \\ b_1 \\ \vdots \\ b_n \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{bmatrix} \quad (6)$$

$$y = Xb + \varepsilon \quad (7)$$

Coefficient vector b is obtained by the following equation using the condition where the square of error is minimized:

$$b = \left(X^T X\right)^{-1} X^T Y \quad (8)$$

where X the design matrix of sample data points is, X^T is its transpose, Y is a column vector containing the values of the response at each sample point.

By obtaining coefficient vector b from (8), the response surface is prepared [8].

IV. Results and Discussion

The method described in the previous section was applied to estimate the coefficient of model. Fig.3-6 show values comparison of response surface method with observed data set 1. Fig. 3 presents comparison of RSM order 1 with training data. Fig.4 presents comparison of RSM order 1 with testing data. Fig. 5 presents gas flow rate error with RSM order 1 with training data set 1. Fig. 6 presents gas flow rate error with RSM order 1 with testing data set 1.

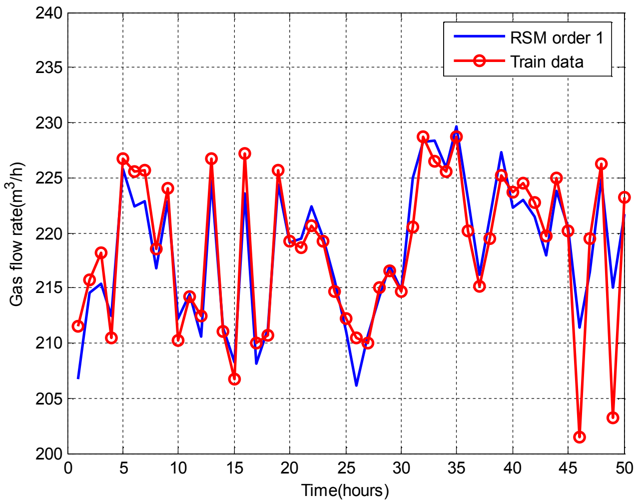

Fig. 3 Comparison of RSM order 1 with training data set 1

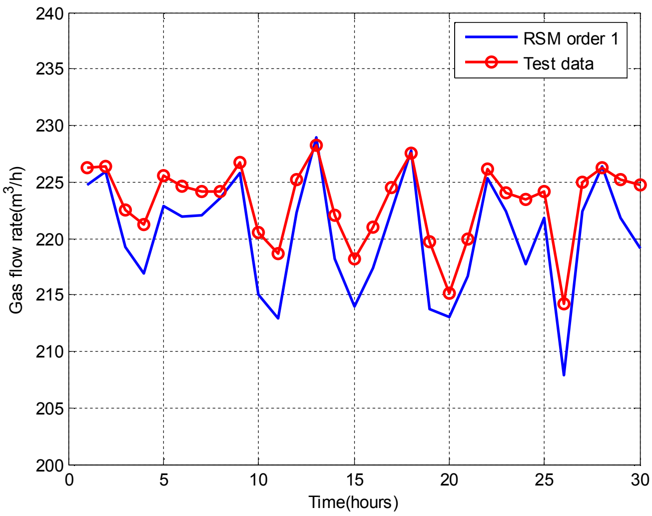

Fig. 4 Comparison of RSM order 1 with testing data set 1

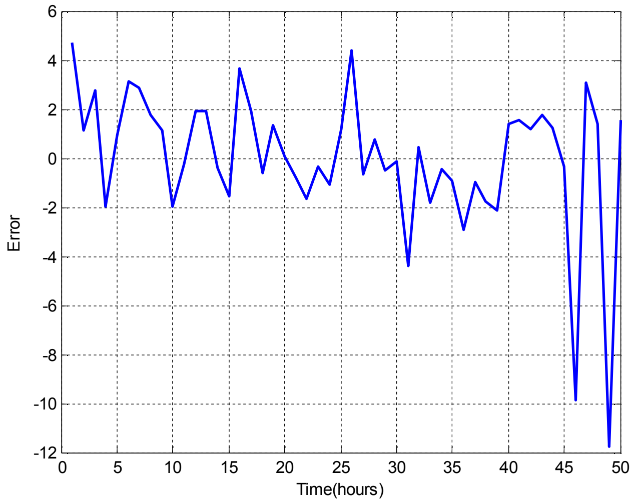

Fig. 5 Gas flow rate error with RSM order 1 with training data set 1

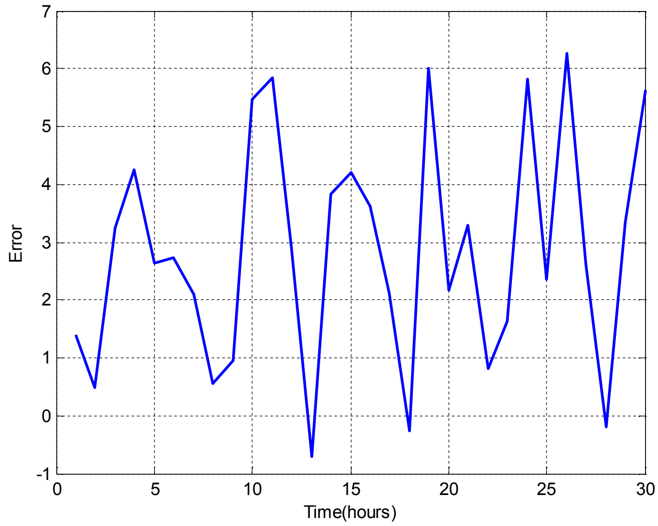

Fig. 6 Gas flow rate error with RSM order 1 with testing data set 1

V. CONCLUSION

Gasified system is an important part to produce fuel gas. It is the good way to know the function which can use to predict the results. This study applied the experimental data which have three inputs that entry the system are biomass consumption, ash discharge rate and temperature at combustion zone and the output of system is gas flow rate which means fuel gas that used in the internal combustion engine. In the results, first order equation is appropriate for gasified system when compared with experimental data.

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