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Analysis and Control of Temperature Process Dynamics during Biomass Gasification Process in Downdraft Gasifier

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Abstract

Improved energy care and weakening climate change are the primary reasons for converting the energy system to renewable sources from standard sources. In this shift to a low fossil fuel economy, biomass has to play a important role. It is essential to analyse and comprehend the gasifier temperature dynamic behaviour to guarantee maximum producer gas effectiveness during the gasification phase. This article introduces the creation with airflow of a dynamic model for the downdraft method of biomass gasification. In order to find the dynamic model, experiments are carried out by providing various step changes in the different regions during the biomass gasification process. Increasing the airflow velocity to 50 Lpm, 100 Lpm and 150 Lpm the step changes were applied on the gasification process. Based on the experimental results three different transfer function models has been developed. The developed models were validated by comparing with the actual system response. The PID controller was intended for the dynamic model and the outcomes are contrasted with the downdraft biomass gasifier manual control.

Keywords: *biomass gasification, airflow effect, dynamic modelling, gasification temperature control, temperature dynamic behaviour, PID controller*

1. Introduction

Biomass is one of the most promising sources of renewable energy from living or dead organisms. When used straight through the combustion cycle to generate heat, biomass can be used as a fuel. The biomass has also been transformed into different biofuel forms [14]. Wood and coconut shells are today's biggest source of biomass energy. Forest residues such as dead trees, branches, and tree stumps, yard clippings, wood chips, and even municipal solid waste are regarded to be the various biomass feed materials. The waste stream of wood and wood can be used directly as a fuel or processed into pellet fuel [1]. Gasification is the transformation process of biomass into a gaseous mixture of CO, CO2, CH4, H2, and H2O. This conversion was achieved by reacting with a controlled amount of oxygen to the biomass at high temperatures around 800 ° C. The final combination of gas is referred to as syngas or gas producer. Gasification power is used as a source of renewable energy [7].

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Producer gas can be used as a standby for fossil fuels, the gas can be liquefied and used as a substitute to petrol, and diesel etc. properly cleaned producer gas is a good renewable source of fuel which can be used to power engines and other mechanical processes [3]. In biomass gasification moisture, airflow, ash, pressure, and temperature are influencing the efficiency of the producer gas [13, 15]. Among all the parameters the temperature control is playing a major role during the gasification process [2]. Modern development of numerical simulation methods is becoming an efficient means of developing more advanced and sophisticated models. Research offers more precise qualitative and quantitative data on biomass gasification and extensive gasifier modelling studies [4, 17]. The conditions of the gasifier during the gasification phase should be regarded as having a clear knowledge of the purpose of the control in the model [16, 24]. As the impact of airflow on temperature control during gasification remains restricted. It is compulsory to keep the temperature in the combustion area in order to obtain the elevated heating value of the gas produced by the producer. Many researchers have tried to maintain the temperature [20] by varying the moisture content, airflow rate, different feed materials and design of gasifier to improve the efficiency of the producer gas. In this study, the airflow rate is controlled to maintain the gasification temperature. The aim of this job is to develop a dynamic model and controller for the biomass gasification method by changing the air flow rate. The objective of this document is therefore to create a dynamic model and a PID controller for the gasification method. The response of the PID controller was likened to the Manuel control.

2. Biomass Gasifier Setup and Measurement Techniques

For the experimental study, the 6 kg downdraft biomass gasifier is used. Because of its simple accessibility as agricultural waste, the coconut shell is used as feed for the biomass plant. Fig.1 showed the experimental configuration of the system of the downdraft biomass gasifier. The biomass gasifier includes an air blower system used to supply the plant with enough oxygen. The rate of air entering the plant is tracked by a rotameter positioned at the gasifier's input level. The main supply of air enters the gasifier through an injection nozzle installed around the plant's neck periphery and the secondary supply of air is preheated and passes through the top of the plant. The plant's body is produced from mild steel. The shell space offers a passage to flow the secondary air supply. This secondary air is preheated between the shells by this passage. The primary air flows into the inner shell and two parts of the inner shell. The upper portion is in form cylindrical and the reduced part is in form conical. The warm gas generated by the plant is cooled by a cooling tower and is fed into two cyclone separators that are used to decrease the concentration of dust in the gas. It also uses three bag filters to remove any tar and other particles of fine dust current in the gas. An educator is used to torch the feed material and to stabilize the combustion inside the reactor in the beginning.

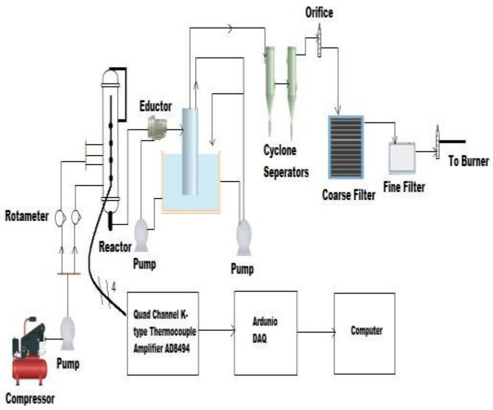

Figure 1: Experimental configuration of the gasifier

The primary gasification procedures are categorized as drying, pyrolysis, combustion, and reduction. The temperature of each area must be evaluated individually in order to use a K-type four channel thermocouple. To preserve the separation between thermocouples, the 1250 mm SS 304 rod is used for thermocouple placement and high-temperature cement is filled inside the rod. The four thermocouples are placed respectively at a distance of 13 cm. The thermocouple generates a very tiny range output, henceforth a quad channel thermocouple amplifier AD8494 is used to get an output in the required value. In LAB view software, the process of temperature gasification is continually tracked and registered.

3. System Identification

In this research, the model of downdraft biomass gasification was created by offering step modifications in the gasification process in the four primary procedures in distinct areas. Airflow and type of biomass are the most significant variables affecting a biomass gasifier's temperature. Assuming that a first-order plus time delay system can estimate the gasification method and the unit-step reaction looks like an S-shaped curve without overshooting[8,6,11]. The S-shaped curve of response shown in Fig. 2 Can be characterized by two constants, delay time L, time constant T and system gain K, determined by drawing a tangent line at the curve inflection point and finding the intersections between the tangent line and the time axis and the steady-state level[18,21,6].

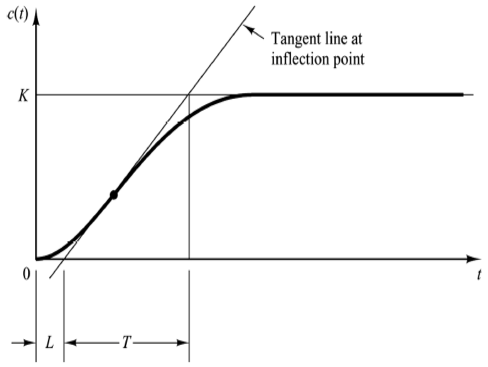

Figure 2: Reaction curve

The general transfer function of the first order system is shown in Eq. (1) [10]

$$\frac{C(s)}{U(s)} = \frac{Ke^{-Ls}}{Ts+1} \quad (1)$$

C(s) = combustion zone temperature

U(s) = airflow rate

(K) = (Final Temperature- Initial Temperature) / Change in Airflow

Time constant (T) = time for the response to reach temperature T1

T1 = 63.2 % of (change in steady state) + offset

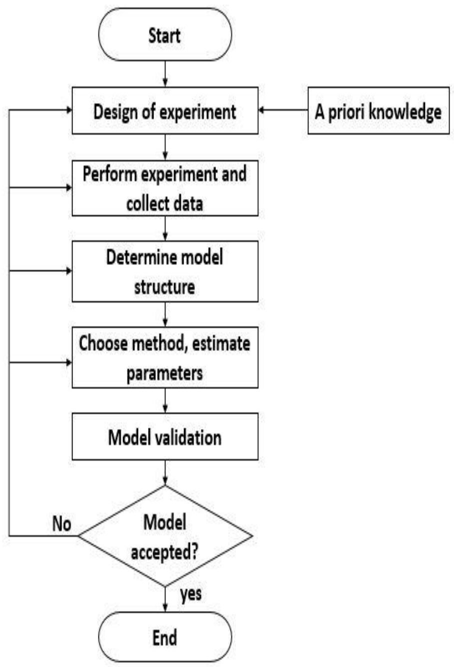

Figure 3: Flowchart of System Identification

The flowchart of system identification procedure is shown in Fig. 3. The system identification experiment can be initiated by exciting the system with the step change. The input and output response observed with respect to time. Then, a finite dimensional model compared to the input and output sequences. After determining a linear differential equation of a certain order. The model's unknown parameters are predicted by the technique based on statistics. Iteratively, the estimation of structure and parameters is often performed. The model acquired is then validated to verify that it is a suitable system representation. If the model created is not satisfied, consideration may be given to the more complicated model structure for system identification.

Hence in this study, the input as airflow rate and the output as gasification temperature were considered for the system identification. In the combustion zone has been identified as operating range region such as 400°C to 500°C, 600-800°C and above 900°C by applying three different step change 0-50 Lpm, 50-100 Lpm and 100-150 Lpm respectively. Then from the graph, the parameters are estimated to develop the dynamic model.

4. Results and Discussion

Empirical Modelling of the gasification Process

Model-I

Experiments were carried out to determine process parameters such as time constant and time delay. Figure 4 demonstrates the reaction when the airflow rate from 0 Lpm to 50 Lpm is increased. From the graph shown in figure 4, the original and final steady state temperature can be noted.

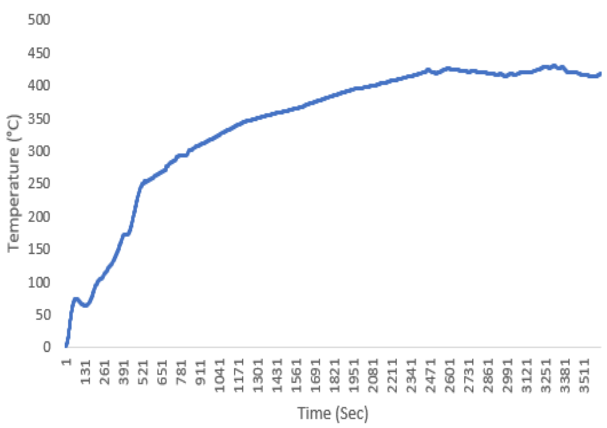

Figure 4: Transient response in the first region (Model-I)

The calculations are as follows from the response:

i. (*K*) = (Final Temperature- Initial Temperature) / Change in Airflow
= (421-50) / (50-0)
= 371/ 50
= 7.42
ii. Time constant (*T*) = time for the response to reach temperature *T*1
*T*1 = 63.2 % of (change in steady state) + offset
= 63.2 % of (421-50) + 50
= 265.23°C
Time constant = 545 seconds

$$\frac{C(s)}{U(s)} = \frac{7.42e^{-5}}{545s+1} \qquad (2)$$

The transfer function model-II is shown in Eq. (2).

Model-II

The response of increase in airflow velocity 50 Lpm to 100 Lpm is shown in Fig. 5. From experimentation the data is acquired which is used for System Identification to obtain transfer function model.

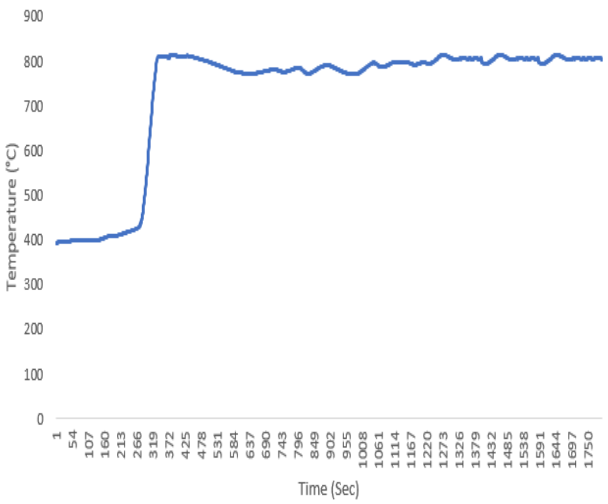

Figure 5: Transient response in the second region (Model-II)

The calculations are as follows from the response:
i. (*K*) = (Final Temperature- Initial Temperature) / Change in Airflow
= (804-421) / (100-50)
= 383/ 50
= 7.66
ii. Time constant (*T*) = time for the response to reach temperature T1
*T*1 = 63.2 % of (change in steady state) + offset
= 63.2 % of (804-421) + 421
= 663°C
Time constant = 115 seconds

$$\frac{C(s)}{U(s)} = \frac{8e^{-10s}}{115s+1} \qquad (3)$$

The transfer function model-III is shown in Eq. (3).

Model-III

The fig.6 represents the response graph of gasifier temperature process when the step is input is increased to 150 Lpm from 100 Lpm. The process parameters are calculated and the model-III is shown in Eq. (4).

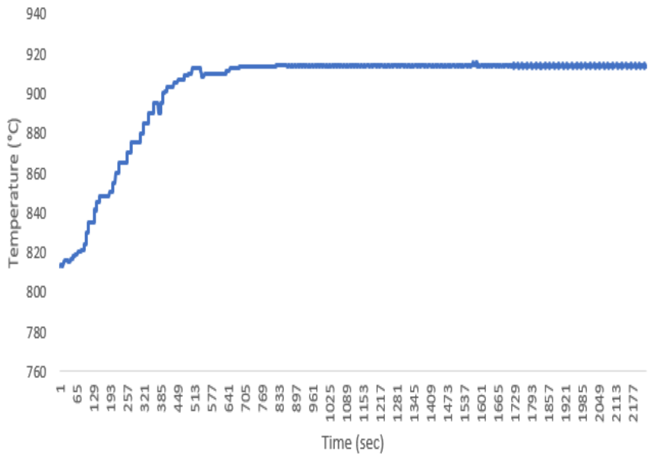

Figure 6: Transient response in the third region (Model-III)

The calculations are as follows from the response:
i. (*K*) = (Final Temperature- Initial Temperature) / Change in Airflow
= (911-804) / (150-100)
= 107/ 50
= 2.14
ii. Time constant (*T*) = time for the response to reach temperature *T*1
*T*1 = 63.2 % of (change in steady state) + offset
= 63.2 % of (911-804) + 804
= 871°C
Time constant = 285 seconds

$$\frac{C(s)}{U(s)} = \frac{2.14e^{-2}}{285s+1} \qquad (4)$$

The transfer function model-III is developed using experimental data and shown in Eq. (4).

Model validation

Models I, II and III were developed based on the responses from the experimental study. The optimum temperature of the gasification is around 700°C [7], so the model-II has been considered for the further model validation and to design the PID controller.

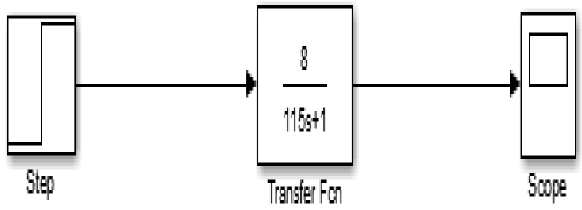

Figure 7: Step input to the model

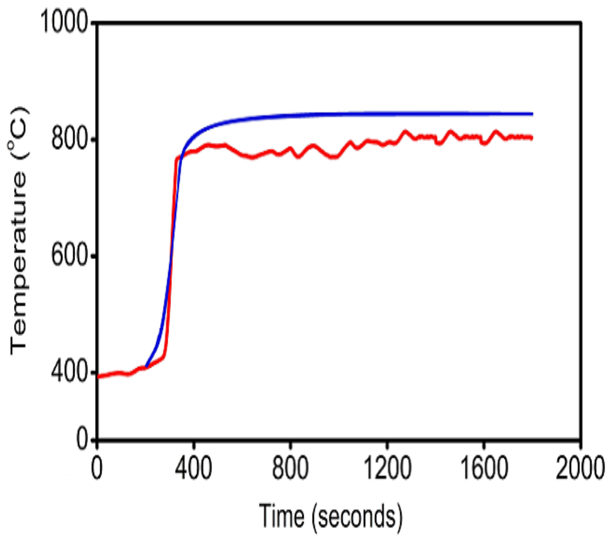

Figure 8: Comparison of experimental data and model output

The graph shown in fig.8 is by applying steady airflow velocity to compare experimental information with the model. From the graph it showed similarity between the experimental reaction and the model reaction.

5. Design of PID Controller

Most manufacturers use the proportional integral and derivative controller (PID) to regulate the plant and retain the required set point. It is easy to execute and adaptable to alter the Proportional Integral Derivative Control Technique. The following constants such as proportional (K_p), derivative (K_d) and integral (K_i) have to be tuned for the performance of PID controller. PID controller manual tuning can be acquired using the method Ziegler and Nichols. The computed PID controller constants are shown in Table 1.

Table 1: Computed PID controller constants

Constants	Computed values
K_p	1.9632
K_d	0.00291
K_i	92.97

The proportional value affects the current error response, the integral value affects the response based on the amount of past, and the derivative value affects the response depending on the pace at which the error changed. To minimize the mistake over time, the PID controller adjusts the final control component. It is possible to express the PID controller mathematically as [25, 23, 12].

$$G(s) = k_p\left(e(t) + \frac{1}{T_i} e(t)dt + T_d \frac{de(t)}{dt}\right) \qquad (5)$$

The PID controller has been designed for the transfer function model $\frac{C(s)}{U(s)} = \frac{8e^{-8}}{115s+1}$. And the PID controller was tested with different set point temperatures like 500°C, 600°C, 700°C, 800°C and 900°C, respectively.

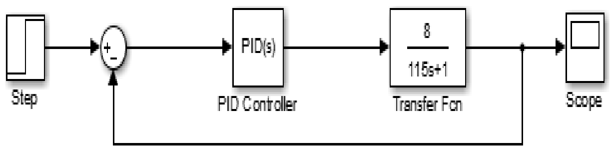

Figure 9: PID controller

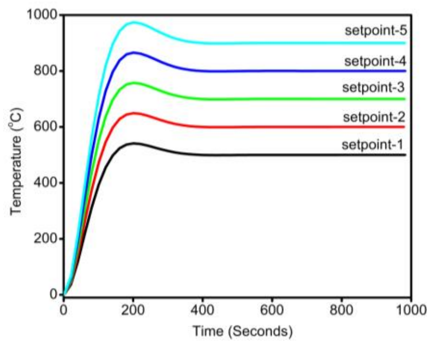

Figure 10: Simulation of the transfer function with PID controller for different set points

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Table 2: Comparison of system Response between Manuel Control and PID Controller

Characteristics	**Set point-1 500°C**		**Setpoint-2 600°C**		**Setpoint-3 700°C**		**Setpoint-4 800°C**		**Setpoint-5 900°C**	
	Manuel	**PID**	**Manuel**	**PID**	**Manuel**	**PID**	**Manuel**	**PID**	**Manuel**	**PID**
Peak over Shoot (%)	26	14.6	29	11	18	9.7	20	9.75	21	9.75
Rise time (sec)	300	121	310	123	320	124	332	124.8	350	124.8
Settling time (sec)	650	473.6	675	375	690	385	700	400	750	400

As seen from the Table 2 the results shows that the comparison of steady state responses of different set point. Since the model is from 700-800 °C the peak overshoot (%), Settling time and rise time are minimum for the range of set points within 700-800 °C.

6. Conclusions

In this research, using experimental information from the gasification method, the downdraft biomass gasification process model was researched and established. By applying 50 Lpm, 100 Lpm, and 150 Lpm respectively, three transfer function models were developed for three regions in the combustion zone. It has been noted from the experimental study that the optimum temperature is only reached during the second model-II transfer function. Compared with the plant's experimental data response to validate the model response, it is observed that the model and the experimental response were similar. And the PID controller for the transfer function model-II was created and contrasted with the Manuel control. The PID controller provides better response in the 700-800 ° C range for the set points. Since biomass gasification is a non-linear method, the various controllers can be introduced to obtain better stable reaction.

SYMBOLS

K- Gain
L- Delay
T- Time constant

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