Automatic Temperature Control of Biomass Gasifier System Using Fuzzy Controller

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Abstract: *Biomass is amongst one of the prominent renewable energy sources. Biomass gasification technology is being used to convert biomass into gas. The greatest challenge to researchers is automation and control of downdraft biomass gasifier systems. This paper exhibits dominance of fuzzy logic controller over conventional proportional integrative derivative (PID) controller in an application to temperature control of the biomass gasification industrial plant. Applying fuzzy logic to non-linear systems control is not only new but real plant applications are still interesting because they need to account for given plant specifics. Controlling the temperature of fixed bed gasifier system using the conventional PID controller with its parameters tuned for specific conditions gives low performance once the tuned conditions change. The system varies non –linearly and the temperature is easily affected by varies disturbances. The proposed fuzzy controller is a very powerful approach to make the gasifier system give a more linear output. The result derived from the fuzzy controller has improved the performance of the gasifier system in terms of low settling time, set point tracking, and without overshoot. The controller's performances have been verified by the simulation.*

Key words: *Biomass, Downdraft Gasifier, Expert controller, Gasification.*

1. Introduction

The control of temperature in fixed bed gasifier is a very important factor to produce the correct composition of syngas. Biomass gasification is a familiar process and widely used for power generation and thermal applications. The obtained gas mixture from gasification is called synthesis gas and it can be used as a fuel. The downdraft gasifier has four different zones as follows, combustion zone, reduction zone, pyrolysis zone and drying zone. The complete view of the zones in which the processes occur is shown in the Figure 1. In the combustion zone, charcoal undergoes combustion with oxygen in the presence of air from inlet air channel at the bottom of the gasifier. Other chemical reactions occur in the chamber, but at a very slower rate. The effects of these reactions in the chamber are insignificant. Reduction process occurs by the release of CO2 and heat on combustion of biomass. The important reaction in the process is the formation of CO from C02 and charcoal. This endothermic reduction reaction occurs only temperatures more than 800 ^{0}C. In the third zone, pyrolysis reaction occurs. Pyrolysis is defined as the degradation of a material under the effect of heat. In this zone, the gasification of the biomass occurs in the absence of air and under the effect of the high temperature of the gas coming from zones beneath [1]. The implementation of these systems in the real world has many issues in their modeling and control [2]. Even though an accurate, model of a nonlinear dynamic system can be developed there are implications in the development of a controller for such a system as controllers are designed to function under some predefined set of conditions or predefined assumptions [28]. These assumptions result in a number of unknown output variables which cannot be handled by the controller design techniques. This problem is because machines, unlike man, do not have the ability to process approximated data or information. To deal with this problem the ability fuzzy logic controller has been introduced and utilized. Fuzzy controllers are a robust in this field of controlling dynamic systems and their output performances are not considerably affected by the variation of parameters [26] [27].

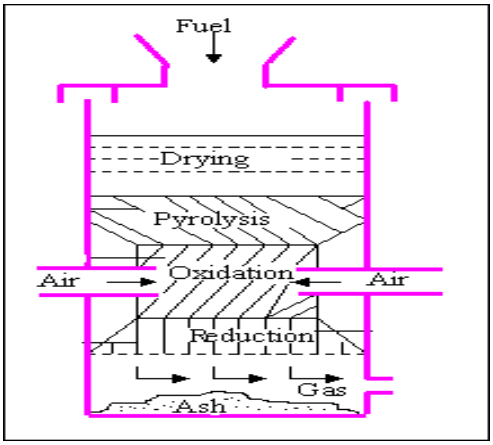


Fig. 1. Downdraft Gasifier producers

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The fuzzy controller can be designed without knowing the mathematical model of system [29] [30]. Fuzzy logic controllers have been successfully used to control variouse complex ,dynamic and nonlinear processes. Fuzzy can operate over a wide range of varing values in the system and has the capacity to keep up with the set point levels in controlling the process.

2. Gasification Process

The major part of the biomass gasification system is the reaction chamber or reactor. This is a container into which fuel/biomass/feed stock are combusted in the a limited supply of air. The heat produced from partial combustion of the feedstock is used for gasifying the chamber. This partial combustion leads in to the other chemcial reactions in the feedstock or fuel and produces a combustible gas called the producer gas [3]. The net calorific value of the producer gas ranges between 4.0 and 6.0 MJ/Nm^3 or about 10 to 15 percent of the combustible heating value of natural gas. Producer gas composition in different types of gasifiying systems varies according to the variation in the composition of the fuel or feedstock. However, the producer gas always has the following gases in its composition , namley, Methane (CH_4) ,Carbon Monoxide (CO), Hydrogen (H_2) and other incombustible gases such as Nitrogen (N_2) and Carbon Dioxide (CO_2). The composition of CO in the producer gas makes it toxic. The producer gas obtained in its raw form from the gasifer is highly greasy with major composition of soot ,tar and water . Reactors / gasification chambers can be of fixed-bed type or fluidized bed type. Also, based on the direction of flow of the gas they can be classified into upward gas flow, downward gas flow and horizontal gas flow [4]. Based on the direction of the flow of solid and gas stream , gasifiers can be classified into Co-current flow type, Counter-current flow type and Cross-current flow type. In all the three mentioned type of reactors, the fuel(biomass) is fed into the reactor from the top. The fuel then moves down gradually due to gravity.

The suction blower supplies air for the combustion of fuel during its movement downward .the combustion of fuel results in the production of Producer gas after a series of oxidation,reduction and pyrolysis processes. Ash ,tar and soot is removed from the bottom of the reaction chamber. The biomass gasifier setup is shown in the Figure 2.

The figure shows biomass and air feeding, gas cleaning and conditioning parts of gasifier. The gasifier comprises of two concentric shells made of mild steel body having an outer diameter of 320mm and inner diameter of 200mm respectively. The area between the shells offers channel for secondary air from the gasfier to flow, where the incoming air is then preheated. The boiler with a total volume of 0.243m^3, is split into two parts where the top part is a cylinderical shape with a height of 700mm and the bottom part is in conical shape with a length of 300mm. The inner shell is lined with 3mm thick fire clay and to the bottom of the conical tank is fixed a grating. The hot gas evolving from the reactor is cooled using a cooling tower and the soot particles from the gas is removed using two cyclone separators. To remove the moisture and soot or dust present in the gas, a bed of rice husk and charcoal are used. For removing tar and other fine soot particles, three other bag filters are being used. To stabilize the intial rate of combustion inside the reactor, an eductor is provided. The temperature in the interior of the reactor is measured using four Type-K thermocouples located at four different zones in the reactor.



Fig. 2. Biomass Gasifier Setup

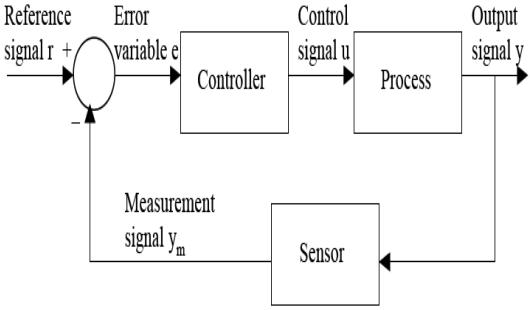


Fig. 3. Block diagram of temperature control system

3. Gasifier Model

The simplified block diagram of the temperature control system shown in the figure 3. Experiments have been done on different developed models of downdraft

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gasifier system to analyze the efficiency of the system with the variation in biomass moisture ,gas composition fluidizing agent ,gasification temperature keeping in note that the temperature at which the chamber is gasified affects the system the most than all the other parameters[5]. For analyzing the nonlinear response of the gasifier, temperature (T) is taken to be the as a controlled variable and the air flow rate (F_A) is taken as a manipulated variable. The momentary response tests are done by step response method. In industrial application, the step response of the system is varied after the initial time of the process [17], [18]. The transfer function can be approximated in a step response system.

From the data obtained on temperature values at different intervals from the gasifier system, the steady state response is plotted as shown in the Figure 4. By the response from the biomass process, the system is approximated as a first order system along with the dead time. The general transfer function of a first order system is given by the equation, $G(s) = (k/ \tau s+1)\, e^{-\theta S}$. Where the terms k, τ, and θ meant that static gain, time constant and delay respectively.

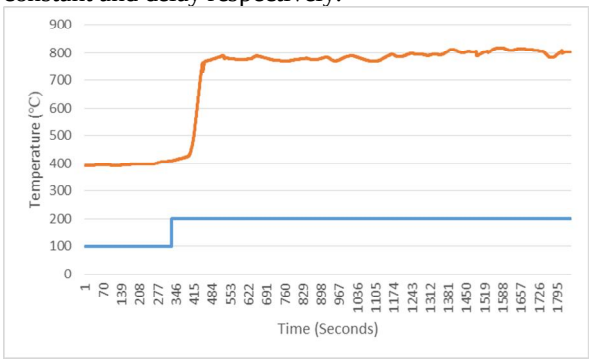


Fig. 4. Temperature versus time curve

The parameters were found from real time biomass gasifier response:

i) Gain (K) = (Final Temperature- Initial Temperature) / change in Airflow
= (802-421) / (100-50)
= 383/ 50
= 7.66

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

T1 = 63.2 % of (change in process variable) + offset
= 63.2 % of (804-421) +421
= 663 ^{0}C

Time constant = 115 seconds

Then substituting the values of K and τ in the Transfer function $G(s) = [8/ (115\ s + 1)]\, e^{-3s}$. The step change from 50-100 lph is in the efficient region for controlling the particular gasifier.

4. PID Controller Design

Proportional-Integral-Derivative (PID) algorithm is one of the most common control algorithm in industries nowadays. The control signal provided by PID controller is in need of three prameters and is specified by:

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

Control Variable G(s)
System Error e(t)
proportional gain (K_p)
integral time constant (T_i)
derivative time constant (T_d)

The S-shaped reaction curve can be considered by two constants, delay time *L* and time constant *T*, which are determined by drawing a tangent line at the inflection point of the curve and finding the intersections of the tangent line with the time axis and the steady-state level line. Figure 5 shows the S-shaped response curve for the step input [19].

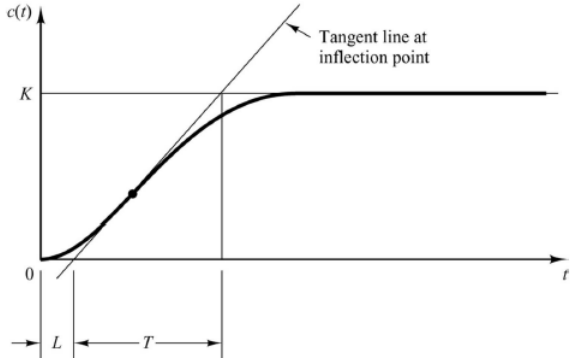


Fig.5. S-shaped Step Input Response Curve

Using Zeigler- Nichols tuning method, the setting of PID contollers are designed for proportional gain (K_p), integral time constant (T_i) and derivative time constant (T_d) . The Ziegler–Nichols Tuning Rule Based on Step Response of Plant has been shown in Table 1.

Table 1: Ziegler–Nichols Tuning Rule

Controller	K_p	T_i	T_d
P	$\frac{T}{L}$	∞	0
PI	$0.9\ \frac{T}{L}$	$\frac{L}{0.3}$	0
PID	$1.2\ \frac{T}{L}$	2L	0.5L

Ususally , PID to controllers are used in heating and cooling systems, fluid level monitoring, flow control and pressure control. PID controllers are not very adaptive , therfore, it should be tuned frequently and uploaded with changes [6]. It is very diificult to auto tune these

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controllers for comlex systems .In this paper,the PID controllers are designed to set the desired nominal operating temperature for contolling and regulating the temperature in the gasifier such that the system maintains the nominal operating tmperatures even with the disturbances such as set point variation or noise .

The simulink model of PID controller for downgraft gasifier is shown in the Figure 6. Also, PID controllers of the PID controlled temperature of gasification system has longer oscillating and settling time compared to the reference temperature .The conventional controllers are not suitable for such highly slow and non-linear process. For improving the gasification control process,intelligent control techniques are to be designed.

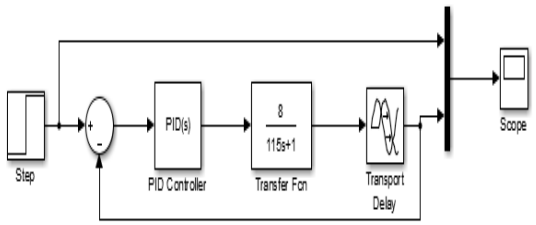


Fig. 6. PID controller for downdraft gasifier

5. Design of FLC

The fuzzy logic controller is the key idea for stability analysis and control design of nonlinear system.The structure of fuzzy logic control system shown in Figure 7 [23] [24].

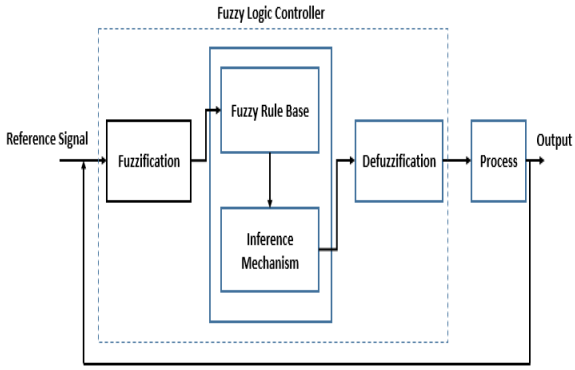


Fig.7. Structure of Fuzzy Control System

A logic system on the two truth values 'True' and 'False' is sometimes insfficient for describing in human reasoning. While, Fuzzy logic uses the entire interval between 'True' and 'False' statements to describe human reasoning [8][25].

Therefore , fuzzy logic is used only in rule based automatic controllers. In rule based fuzzy logic controller, it interpts the rules in a ligustic style that can be comprehened and understood by human [9]-[10].

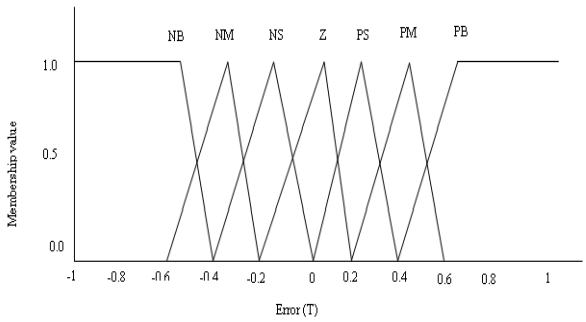


Fig. 8. Membership function of errorT

A fuzzy logic controller was developed for the transfer function model of the biomass process. In this controller, the inputs were error T and change in error ΔT. The output of the controller has air flow rate. Figure 8 shows the triangular membership function for error T, Figure 9 shows the membership function for change in error of ΔT. Figures 10 shows the membership function of air flow rate [11]-[13].

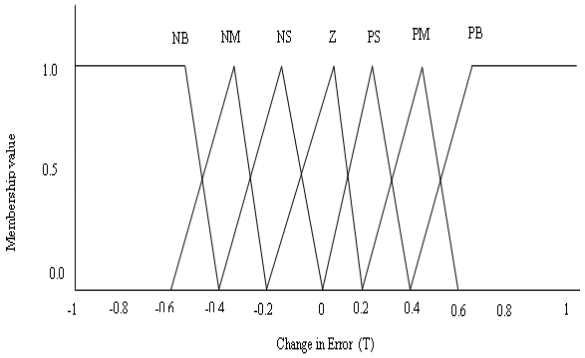


Fig. 9. Membership function of change in error ΔT

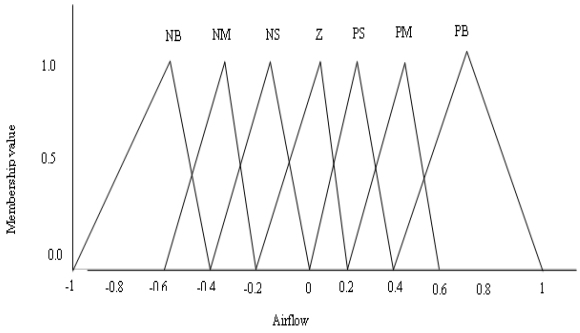


Fig. 10. Membership function of Air flow

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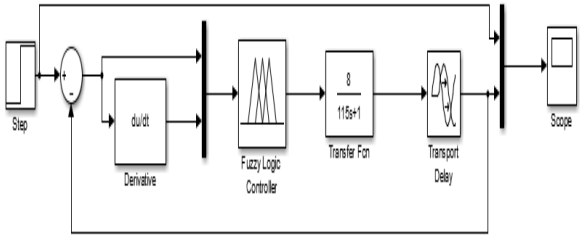


Fig. 11. Fuzzy logic controller for gasifier temperature control system

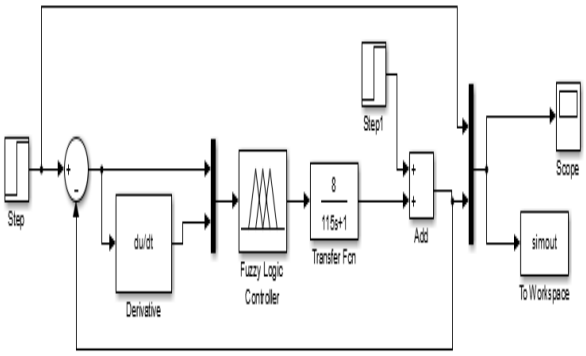


Fig. 12. Fuzzy logic controller for gasifier temperature control system with distrubance

Fuzzy membership functions were tuned with a ramp function as set points [14]. The fuzzy input domain was empirically assigned to {-1, 1}[15]-[16]. The fuzzy sets of inputs and output values were seperated into seven membership functions according to seven linguistic variables (Positive Big ,negative Big, Zero, negative Medium, negative small, positive small and positive Medium).

The Fuzzy logic controller for gasifier temperature control system is shown figure 11. The Fuzzy logic controller for gasifier temperature control system with distrubance is shown figure 12.

The rules used in the fuzzy controller has been represented in Table 1. Where, e(t), Δe(t) and u(t) meant that error, change in error and control signal respectively. The linguistic values has been defined for the input temperature error, change in temperature error and output airflow such as Positive Big(PB), Negative Big (NB), Zero(ZO), Negative Medium (NM), Negative Small(NS), Positive Small(PS) and Positive Medium (PM) .

The fuzzy inference system has been developed based on rules reported in Table 2.The rules decision making is automatically done by fuzzy inference system [20] [21].

Table 2: Rules for fuzzy logic controller

u(t)		e(t)						
		NB	NM	NS	ZO	PS	PM	PB
Δe(t)	NB	NB	NB	NB	NB	NM	NS	ZO
	NM	NB	NB	NB	NM	NS	ZO	PS
	NS	NB	NB	NM	NS	NS	PS	PS
	ZO	NB	NM	NS	ZO	ZO	PM	PM
	PS	NM	NS	ZO	PS	PS	PB	PB
	PM	NS	ZO	PS	PM	PM	PB	PB
	PB	ZO	PS	PM	PB	PB	PB	PB

6. Results and Discussion

The PI and PID controller responses for the transfer function developed from the plant data were checked in MATLAB, by Zeigler- Nichols tuning method. Figure 13 show the response of the plant to PI controller and Figure 14 show the response of the plant to a PID controller.

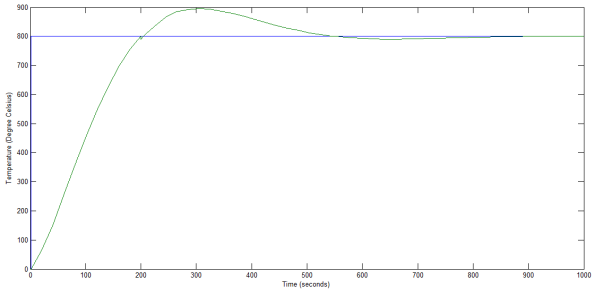


Fig. 13. Response of process to PI controller

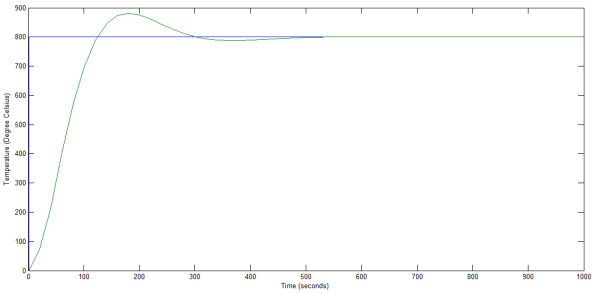


Fig. 14. Response of process to PID controller

From the responses, it is observed that with a PI controller, the response of the process settles down, at 750seconds, but the response is oscillating. But, for PID controller, though the response settles down, at 480 seconds, it has little bit oscillations. But, the responses for both these controllers settle only very slowly. Thus, the need for fuzzy logic controller arises.

As the conventional controllers have limitations, a better controller is chosen and it is the fuzzy logic controller. Figures 15 show the responses of the plant to this controller for the set point 800□. From the response of

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the process to fuzzy controller, it is clear that the response settles at about 100 seconds and the response settles at a value almost equal to the set point.

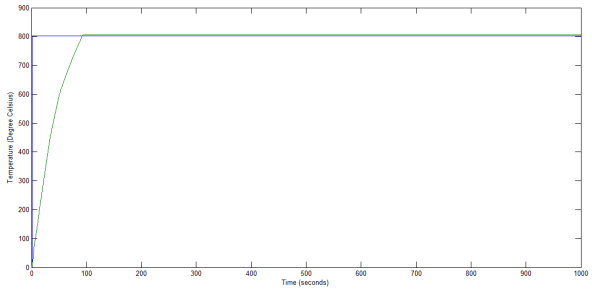


Fig. 15. Response of process to fuzzy controller

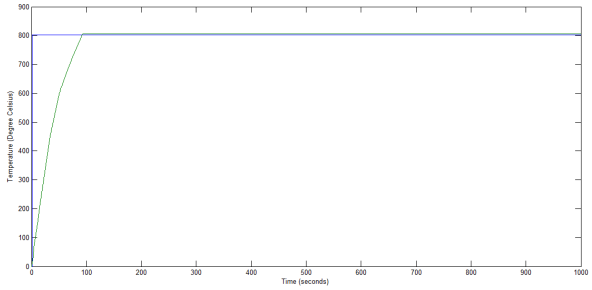


Fig. 16. Response of process to fuzzy controller with distrubance

The performances of the controllers were given in table 2. The fuzzy logic controller also tested with distrubance is shown in Figure 16. From the results, the fuzzy controller was found to be the better controller among the other controllers. It was clear that fuzzy controller was better than conventional controllers like PI and PID controllers, with respect to overshoot, undershoot, rise time and settling time..

Table 2. Comparison of controllers in temperature process

Controller	Undershoot (%)	Overshoot (%)	Rise time (sec)	Settling time (sec)
PI	1.25	12.5	200	750
PID	1.87	10	110	480
FLC	Nil	Nil	80	90

7. Conclusion

A first order transfer function model was developed for the biomass plant with the data available from the plant, by plotting the steady state response. The responses were settling at 750 seconds for PI controller and at 480 seconds for PID controller. Then, a fuzzy logic controller for the transfer function model was developed and the response for the set point have been observed. The responses showed that the settling time of the process is 90 seconds. Thus, the fuzzy controller is better. Introduced this type of controller for the gasifier system the correct gas composition may be produced. Once the gas quality has maintain properly the power generation efficiency also improved. A self-tuning fuzzy controller will be proposed which may proves that self-tuning controller is even better than fixed fuzzy controller.

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