Advanced Research in Electrical and Electronic Engineering
Print ISSN: 2349-5804; Online ISSN: 2349-5812 Volume 2, Number 6 April-June (2015) pp. 69-73

http://www.krishisanskriti.org/areee.html

Automatic Control of Downdraft Gasifier using Fuzzy Controller

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Abstract—*Biomass is a renewable energy resource derived from the carbonaceous waste of human being and natural activities. It is derived from several sources, including the by-products from various industries, raw material from the forest, major parts of household waste, agricultural crops and wood. These by-products are used to produce biofuels either directly or indirectly through different processes. Biomass energy production is competent to other renewable energy resources as it contributes in reducing the green house effect. Therefore, much emphasis is on improving the quality of gas produced by biomass for engines. A fuzzy controller is proposed to improve the quality of gas generated from downdraft biomass gasifier with wood as input. A fuzzy system is a static non-linear mapping between its inputs and outputs by providing a formal methodology for representing, manipulating and implementing a human heuristic knowledge of controlling a system. The controller generates the set points for the process variables (temperature T and* CO/CO_2 *ratio) by controlling air flow rate (*F_A*) and frequency of grate (*f_g*) according to the error value. As a result much better controlling action is performed by fuzzy controller by generating set points automatically than other conventional controllers.*

1. INTRODUCTION

The term "biomass" covers a wide variety of materials which can be used as fuel or as a raw material and the common feature among them is their derivation from recently living organisms. Despite being derived from plant (coal) or animal life (gas and oil), the traditional fossil fuels which took millions or billions of years to get transformed into their present form are not covered under the term biomass. Various sources of biomass are natural and derived materials, agricultural crops and residues, forestry crops residues, industrial residues, animal residues, municipal solid waste, energy crops grown for biomass etc.

A huge amount of energy requirement for energy concentrated processes is mainly contributed by fossil fuels. But due to rise in their prices and their shortage leads to a pragmatic shift in the use of alternative energy resources like solar, biomass, wind etc. However, these alternative energy resources are not economical but still they are widely used for energy production including different processes for converting biomass into usable form. One of them is biomass gasification.

Biomass gasification can be defined as incomplete combustion of biomass which results in production of combustible gases like Carbon monoxide (CO), Hydrogen (H_2) and traces of Methane (CH_4). This mixture of gases is called producer gas. This producer gas can be used in various ways, example to lope internal combustion engine, as alternative for furnace oil in direct heat applications and to produce methanol which is used as fuel as well as chemical feedstock for industries. Unlike ethanol production or biogas, any biomass material can undergo gasification process. The gasification process consists of the following processes:

(1)Drying: The moisture content of biomass ranges from 5%-35%. In this stage, the moisture content of the biomass is reduced up to 5% with a drying temperature 100-200ºC.

(ii)Devolatilisation (pyrolysis): In this process, the biomass is thermally decomposed in the absence of air. The volatile matter is removed and this lead to the release of hydrocarbon gases. Thus biomass is reduced to charcoal.

(iii) Oxidation: In this process, solid charcoal reacts with oxygen and forms carbon dioxide.

Hydrogen present in biomass is oxidised to form water. This oxidation process leads to the release of huge amount of energy.

(iv) Reduction: In this process, various reduction reactions take place in the absence of air which are mostly endothermic. The temperature range is 800-1000 ºC.

Gasification acts as an efficient way of converting low value-residual biomass (such as municipal solid waste) into higher value products including power, steam, hydrogen, and basic chemicals.

2. DESIGNS OF GASIFIER

There are available various reactor designs available for both at small and large scale. Gasifiers can be classified in different ways:

(a) According to the gasification agent: air-blown, oxygen or steam gasifiers.
(b) According to heat for gasification: auto thermal (heat is provided by partial combustion of biomass) or allothermal gasifiers (heat is supplied from an external source).
(c) According to pressure in the gasifier: atmospheric or pressurized gasifiers
(d) According to the design of the reactor: fixed bed, fluidized bed, entrained flow or Twin-bed.

But the major types of gasifiers which exist in the industries are:

(a) Downdraft and updraft gasifiers, which are in the fixed bed category.
(b) Fluidized bed gasifiers, which consist of bubbling fluidized bed biomass gasifiers (BFB)
(c) Circulating fluidized biomass bed gasifiers (CFB).

3. STATIC MODEL OF GASIFIER

The development of a precise model is very difficult because the gasification process is highly non-linear and slow process. The gasifier model must represent its non-linear dynamic characteristics. Based on the plant data of the gasifier in a typical biomass gasification process, a steady state model is proposed. Four sub-systems is developed using the MATLAB. The plant data is shown in the Table 1. The Tuning of controller is one of the objectives of the control model.

(a) Biomass consumption (Fhb)

It is the amount of biomass consumed for the gasification process which is being considered for monitoring purpose. It depends upon the air flow rate (FA), frequency of rotation of the grate (fg) and moisture content (Hp). The mathematical expression for biomass consumption is:

$$Fhb = [0.077\ F / H\ 1/3] + 1.5 + fg$$

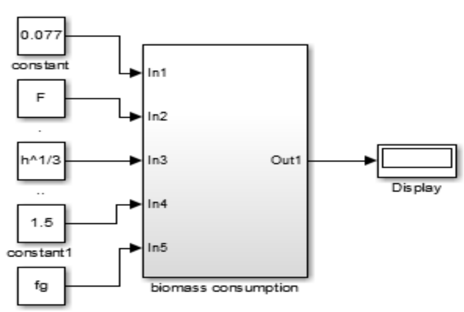

Fig. 1: Subsystem of biomass consumption

(b) Equivalence ratio (ER)

Equivalence ratio depends on Fhb, FA, Hp and material factor mb which represents the amount of air needed to obtain combustion of 1 kg of dry biomass. The mathematical expression for ER is:

$$ER = [F / (254.7\ Fh\ (H-1)\ mb)]\ 100$$

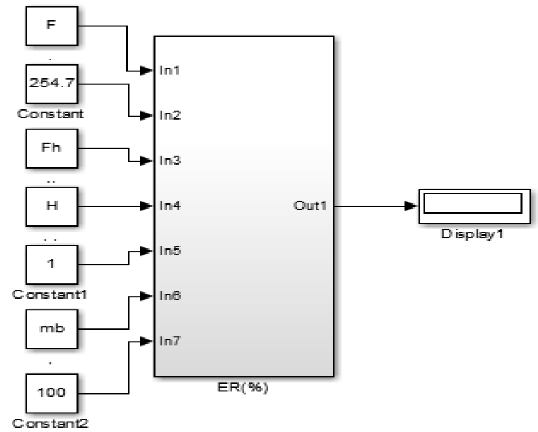

Fig. 2: Subsystem for equivalence ratio

(c) CO/CO2 ratio

It depends upon ER and Hp. Whenever Hp is low, the ratio increases with ER to reach a maximum. The expression derived for the ratio is

$$CO/CO2\ ratio = (0.3\ H + 0.5)\ ER - 0.2761$$

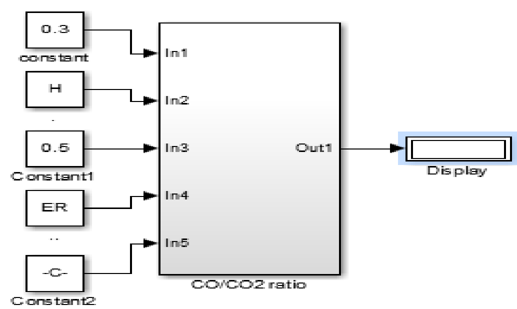

Fig. 3: Subsystem for CO/CO2 ratio

(d) Temperature (T)

Temperature is very closely related to the quality of produced gas. It depends on hp, ER and Fg. The value of T first decreases with ER, then increases and finally, again decreases. The expression for T is:

$$T = mc\ ER + 33/H + ma + 220 + 100\ ER + 100\ fg$$

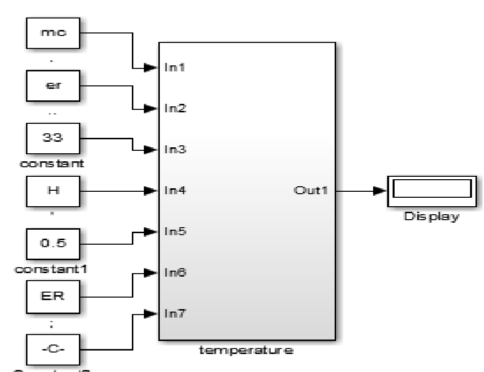

Fig. 4: Subsystem for temperature

In above equations, some constant values are assumed in order to fit with experimental data like here ma=473 and mb=0.03384. The complete steady state model of the biomass gasifier is developed using the simulink models of four subsystems and then it is controlled by fuzzy controller.

Table 1: Biomass plant data calculated from gasifier equations

Sr. no.	Fa (airflow)	Fg (frequency of grate)	Hp (moisture content)	Fhp(biomass consumption)	ER(equivalence ratio%)	Temperature(°C)	CO/CO2 ratio
1.	5.7	0.006	7.15	1.733	0.620	762.7	0.034
2.	6.3	0.050	7.15	1.825	0.7132	776.7	0.080
3.	12	0.050	7.15	2.029	1.116	818.6	0.281
4.	18	0.080	7.15	2.298	1.478	859.2	0.4627
5.	21	0.080	7.15	2.418	1.639	875.9	0.543

Table 2: Error values for the controller input

Sr. No.	Error Hp	Error T	Error CO/CO2
1.	1	-133.5	0.45
2.	1.1	-143.4	0.42
3.	1.1	-49.2	0.318
4.	1.1	-0.8	0.67
5.	1.01	+24.1	0.456

4. FUZZY LOGIC CONTROLLER

Fuzzy logic is very much closer to the human thinking and language than the traditional logic system. The controller based on the fuzzy logic gives the linguistic control conversion from the expert knowledge in automatic control strategies. The first fuzzy logic based controller application was designed by Assilian and Mandani. The basic configuration of FLC are represented in four parts, which are given below as,

- **Fuzzification**

Under this module, the input variables are measured and then the transformation of measured numerical values in to the corresponding linguistic variable is done.

- **Knowledge base**

It consists of two parts 'Data base' and 'Rule base'. The membership function defining the procedure for the control variable is done by the data base. Where the necessary rule that characterized the control goals by means of the linguistic variable set are done, that is by rule base.

- **Inference engine**

Under this module, the simulation of decision make by human being take place and also the control action are influenced based on fuzzy logic concept.

- **Defuzzification**

Defuzzification is the process in which the inferred decision is converted back to the crisp numerical values from their corresponding linguistic variables. There are several methods for defuzzification but the most widely used methods are centroid method, bisection of area and mean of maxima.

As the process of gasification is highly non-linear and slow, it is very difficult to formulate an accurate model for it. To fuzzy system capable of dealing with the indistinguishable and inaccurate biomass conditions, the expert's knowledge about gasification process is used to determine if/then rules. Here, fuzzy system is modeled with three inputs (Error T, error CO/CO2 and Hp(moisture content)) and two outputs (airflow and frequency of grate). Fuzzy rules are formulated based on error temperature , error CO/ CO2 ratio and Hp (moisture content) which are converted to non-fuzzy values by defuzzification,. These values are fed to the final control element for control action.

Table 3: Rules for adjusting frequency of grate

Sr. No.	If hp	And error T	And error CO/CO2	Then grate
1.	Low	Very low	Very low	F4
2.	Low	Very low	Low	F3
3.	Low	Very low	zero	F1
4.	Low	Very low	High	F3
5.	Low	Very low	Very high	F1
6.	Low	Low	Very low	F3
7.	Low	Low	Low	F2
8.	Low	Low	Zero	F2
9.	Low	Low	High	F2
10.	Low	low	Very high	F1

Table 4: Rules for adjusting air flow rate

Sr. No.	If hp	And error T	And error CO/CO2	Then flow
1.	Low	Very low	Very low	EH
2.	Low	Very low	Low	VH
3.	Low	Very low	Zero	VL
4.	Low	Very low	High	VH
5.	Low	Very low	Very high	VL
6.	Low	Low	Very low	VH
7.	Low	Low	Low	VH
8.	low	Low	Zero	B
9.	Low	Low	High	B
10.	Low	low	Very high	VL
11.	Low	Zero	Very low	VH
12.	Low	Zero	Low	B
13.	Low	Zero	Zero	VL
14.	Low	Zero	High	VL
15.	Low	zero	Very high	EL
16.	Low	High	Very low	B
17.	Low	High	Low	B
18.	Low	High	Zero	VL
19.	Low	High	High	VL
20.	Low	high	Very high	EL

21.	Low	Very high	Very low	VH
22.	low	Very high	Low	B
23.	Low	Very high	Zero	VL
24.	Low	Very high	High	VLL
25.	Low	Very high	Very high	VL
26.	Low	Very low	Very low	EH
27.	Low	Very low	Low	EH
28.	Low	Very low	Zero	EH
29.	Low	Very low	High	EH
30.	Low	Very low	Very high	EH
31.	low	Low	Very low	EH
32.	Low	Low	Low	EH
33.	Low	Low	Zero	EH
34.	Low	Low	High	VH
35.	Low	Low	Very high	VL
36.	Low	Zero	Very low	VH
37.	Low	Zero	Low	B
38.	Low	Zero	Zero	VL
39.	Low	Zero	High	VL
40.	Low	Zero	Very high	VL
41.	Low	Very high	Very high	VL

For the Error CO/ CO2 variable, five linguistic values are defined: very low, low, zero, high, very high, and for the Error T variable, five linguistic values, very low, low, zero, high, very high, are also defined. For the output variable Airflow five fuzzy values, extremely low, very low, base, very high, extremely high and for the Grate variable, the values f1, f2, f3, f4, f5, are defined. The membership functions are shown below:

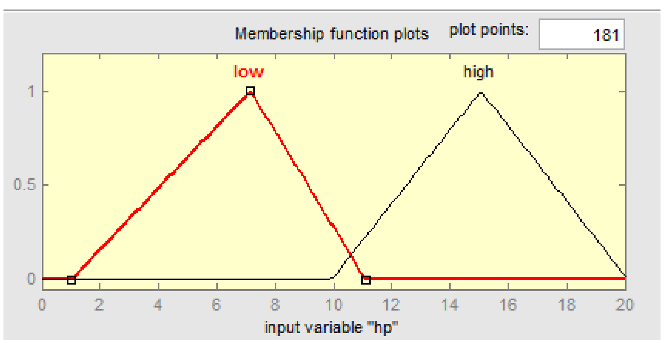

Fig. 5: Membership function of Hp

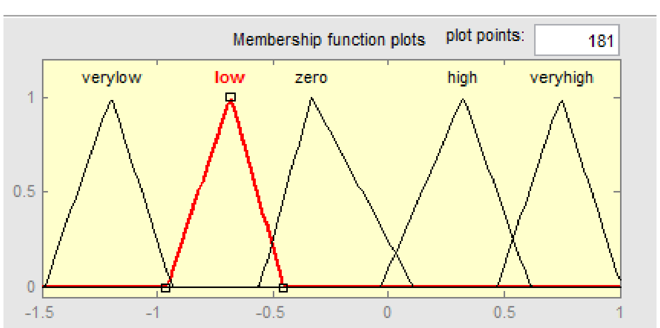

Fig. 6: Membership function of error CO/CO2 ratio

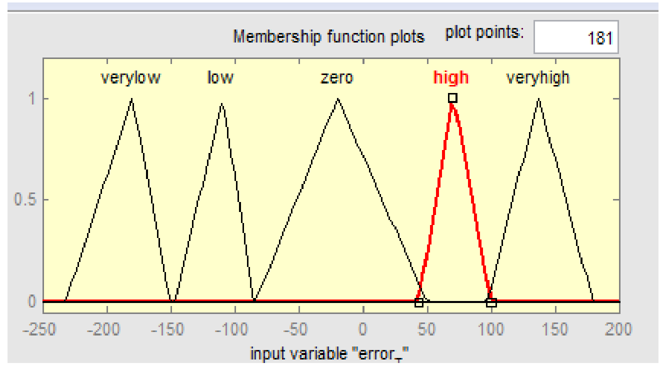

Fig. 7: Membership function error T

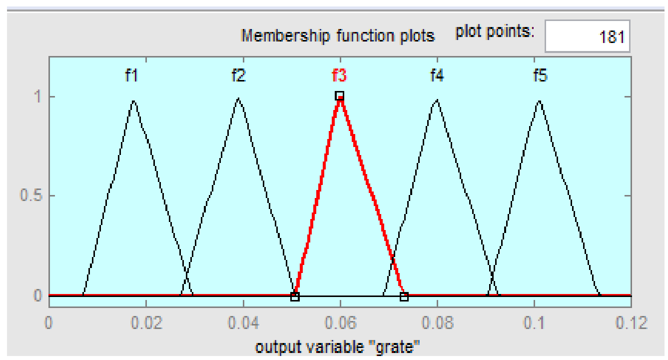

Fig. 8: Membership function of frequency of grate

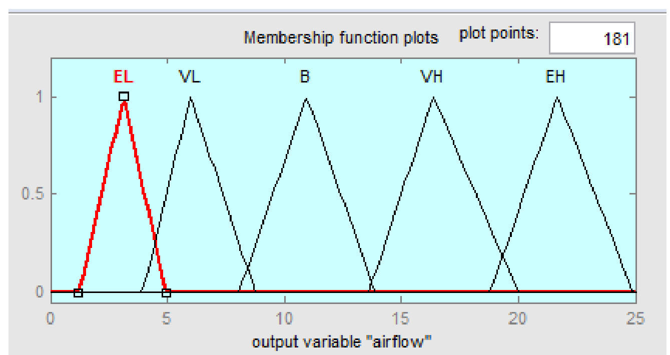

Fig. 9: Membership function of airflow

The static model of the gasifier which has been proposed is used in tuning the controller by developing a fuzzy logic controller of MIMO system of gasifier.

5. SIMULATION RESULT AND CONCLUSION

Fuzzy logic controller has been implemented for the gasifier model. To control the biomass residence time inside the reactor, the CO/CO2 ratio has been effectively controlled with fuzzy logic controller by adjusting the frequency of motion. Similarly by adjusting the airflow rate, the temperature has been effectively controlled with fuzzy logic controller. The simulink model of the plant is shown in Fig. 10.

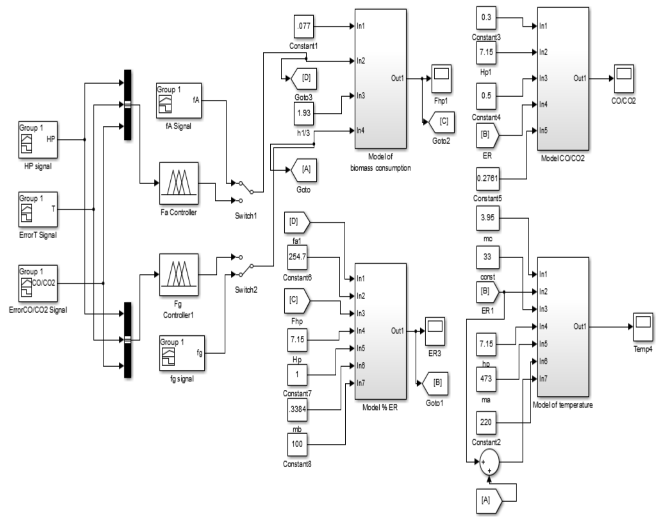

Fig. 10: Simulink model of gasifier controlled by fuzzy controller

As the MIMO system of the gasifier does not have proper model, the performance of MIMO system of the gasifier cannot be verified by simulation. As a result, the controlled values of temperature and CO/CO2 ratio for the five error values of temperature, moisture content and co/co2ratio at t=0,1,2,3,4 are shown in Fig. 11 and 12.

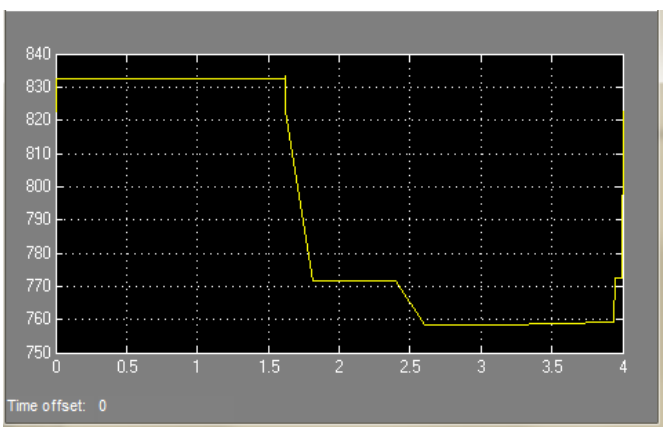

Fig. 11: Controlled temperature values

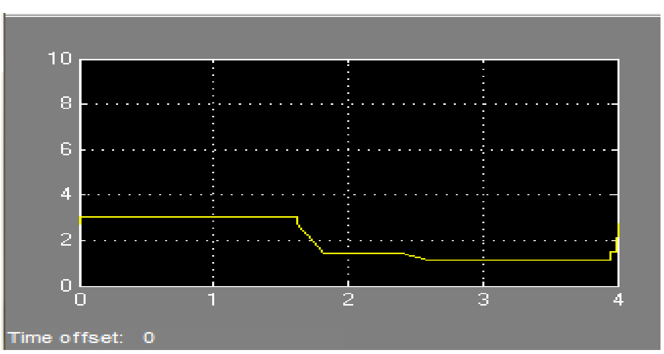

Fig. 12: Controlled CO/CO2 RATIO

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