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A Study on Applying PID Control to a Downdraft Fixed Bed Gasifier using Wood Pellets

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〈Abstract〉

Biomass is material that is comprehensive of carbonaceous materials from plants, crops, animals, and algae. It has been used as one of heating fuel since the beginning the emergence of human beings. Since biomass is regarded as carbon-neutral energy source, it has recently been attracting attention as an energy source that can replace fossil fuels. The most widely applied field is distributed power generation, and a method of generating electric power by driving an internal combustion engine with syngas produced by gasifier is chosen. While the composition of the syngas produced in gasifiers changes depending on the air flowing into the reactor, commercialized gasifiers so far do not control the air flowing into the reactor. When the inner pressure in reactor increases, the air sucked into the reactor is reduced. That change of amount of air makes the composition of syngas varied. Those variations of composition of syngas cause the incomplete combustion hence the power output of engine drops, which is a critical weakness of the gasification technology. In this paper, to produce the uniformly composed syngas, PID control is applied. The result was shown when the amount of air into the reactor is supplied with the constant amount using PID control, the standard deviation of caloric values of syngas is around 2[%] of its average value. Meanwhile the gasifier without PID control has the standard deviation of caloric values is around 7[%]. Therefore, Adopting PID control to supply constant air to the gasifier is highly desirable.

Keywords : PID Control, Gasifier, Syngas, Downdraft Fixed-bed, Low Heating Value

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1. Introduction

In accordance with the ongoing global warming, each country is making efforts to reduce carbon emissions and cut down the use of finite fossil fuel. The most realistic alternative is to use biomass as an alternative to fossil fuels[7]. Plants convert radiant energy from the sun into chemical energy in form of glucose or sugar and CO_2 is captured in plants and released when burnt[2].

$$6H_2O+6CO_2+radiant\ energy \rightarrow C_6H_{12}O_6+6O_2$$

There are various processes that convert biomass into energy[5].

- Direct combustion to produce heat
- Thermochemical conversion to produce solid(char), gaseous, and liquid fuels
- Chemical conversion to produce liquid fuels
- Biological conversion to produce liquid and gaseous fuels.

Direct combustion is the oldest and common method for converting biomass into energy. Thermochemical conversion embraces pyrolysis and gasification. Both are thermal decomposition and partial oxidation of biomass in closed, pressurized containers called gasifiers or reactors at high temperatures. The main differences between them are temperatures and amount of oxygen. Pyrolysis heats up organic materials in 400~500 [℃] in the absence of oxygen and produces charcoal, bio-oil mainly. Gasification entails heating organic matters to over 700 [℃] to 1200 [℃] with insufficient air or oxygen and CO and H_2 rich combustible gases called syngas or producer gas are produced. A chemical conversion known as trans-esterification utilizes vegetable oils, greases, and animal fats to transform fatty acid methyl esters (FAME), which are later source of bio-diesel. Biological conversion means fermentation to change biomass into ethanol and anaerobic digestion to produce biogas or bio-methane[5].

2. Gasification

Gasification is a thermochemical process that produces syngas. Syngas composes of carbon monoxide (CO), hydrogen(H_2) and small amount of methane (CH_4) and their wt% varies depending on feedstock, temperature, and the amount of oxygen. LHV of syngas produced from biomass with limited air is pretty lower when compared with that of biogas and Natural gas GZ50 shown in Table 1[1].

Table 1. The main properties of fuels

Fuel	Composition	LHV, MJ/Nm^3
Biogas	CH_4≈60%, CO_2≈39% Other: C_2H_6, C_3H_8, C_4H_{10}	21.6
Natural gas GZ50	CH_4≈98.5%, CO_2≈0.1%, N_2≈1% Other: C_2H_6, C_3H_8, C_4H_{10}	35.3
Producer gas	CO≈27%, H_2≈16%, CO_2≈7%, CH_4≈4%, N_2≈46%	6.57

2.1 Types of Gasification

Although there are various types of gasifiers (gasification reactors), different in design and operational characteristics, there are three main gasifier classifications into which most of commercially available gasifiers fall. These categories are as follows[8] :

- · Fixed-or moving-bed gasifiers
- · Fluidized-bed gasifiers
- · Entrained-flow gasifiers

In fixed or moving-bed gasifier, relatively coarse solid biomass is gasified by the gasifying agent such as air, oxygen, and/or steam. For fludized bed gasifier, feedstock and other solid material such as sand are vigorously mixed by the gasifying agent. Entrainted flow gasifier is where finely grinded solid biomass is entrained and quickly converted by the gasifying agent. Their unique desings are shown in Fig. 1.

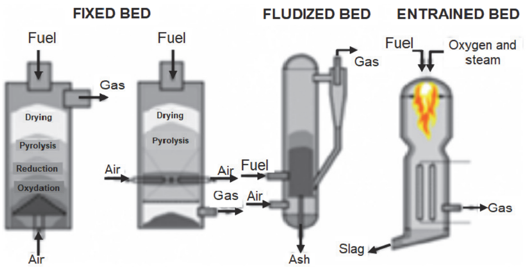

Fig. 1 The types of gasifier

2.2 Reactions in Gasification

The chemical reactions of gasification can progress to different extents depending on the gasification conditions such as temperature and amount of oxygen. Combustion reactions take place in a gasification process, but, in comparison with conventional combustion which uses a stoichiometric excess of oxidant, gasification typically uses one-fifth to one-third of the theoretical oxidant. As a "partial oxidation" process, the major combustible products of gasification are carbon monoxide (CO) and hydrogen. Within a gasification process, the major chemical reactions are those involving carbon, CO, CO_2, Hydrogen(H_2), water(steam) and methane (CH_4), as follows[6] :

The combustion reactions:

$$C + \frac{1}{2}O_2 \rightarrow CO \qquad (-111\ MJ\ /\ kmol)$$

$$CO + \frac{1}{2}O_2 \rightarrow CO_2 \qquad (-283\ MJ\ /\ kmol)$$

$$H2 + \frac{1}{2}O_2 \rightarrow H_2O \qquad (-242\ MJ\ /\ kmol)$$

Other important gasification reactions include:

$$C + H_2O \leftrightarrow CO + H_2 \qquad (+131\ MJ\ /\ kmol)$$

$$C + CO_2 \leftrightarrow 2CO \qquad (+172\ MJ\ /\ kmol)$$

$$C + 2H_2 \leftrightarrow CH_4 \qquad (-75\ MJ\ /\ kmol)$$

$$CO + H_2O \leftrightarrow CO_2 + H_2 \qquad (-41\ MJ\ /\ kmol)$$

$$CH_4 + H_2O \leftrightarrow CO_2 + 3H_2 \qquad (+206\ MJ\ /\ kmol)$$

The heat produced by the partial oxidation provides most of the energy required to drive the endothermic gasification reactions.

2.3 Equivalent Ratio

Equivalent Ratio (ER) is defined as the ratio of the actual amount of oxidant to stoichiometric oxidant for complete combustion as in Equation (1).

$$ER = \frac{m\,air/m\,biomass}{(m\,air/m\,biomass)stoichiometric} \qquad (1)$$

This parameter is the most important operating parameter in gasification process because it affects syngas composition, tar content, gas yield, and its chemical energy. The pyrolysis process is operated at close to ER zero, and the combustion process is operated at more than ER one for complete combustion. Fig. 2 shows the molar fraction of H2, CO, CO_2, N_2, and CH4 in the syngas depending on ER. (YunYongseung, 2018)

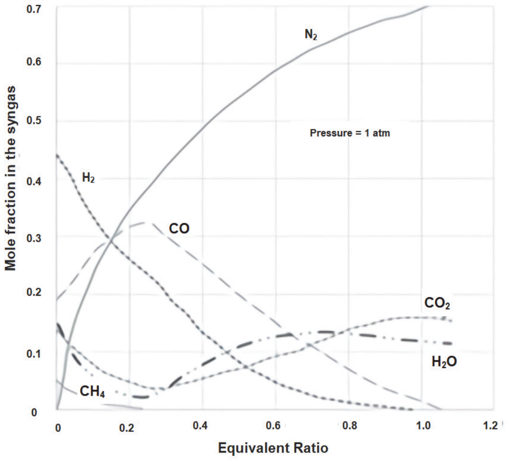

Fig. 2 Syngas composition at chemical equilibrium as a function of ER for gasifiers

3. PID Control

The term PID represents Proportional, Integral, and Derivative Control. As implied in the name, PID controllers have three control modes:

- · Proportional Control
- · Integral Control
- · Derivative Control

Each of the three modes reacts differently to the error. The amount of response produced by each control mode is adjustable by changing the controller's tuning settings. A PID controller, like most of the control system, has a Set Point(SP) that the operator can set to the desired value. The Controller's Output(CO) sets the value of the actuator or controller. The measured value from sensros, called the Process Variable (PV), gives the controller its feedback.

3.1 Proportional Control Mode

The proportional control mode is the main driving force in a controller. It changes the controller output in proportion to the error in Fig. 3.

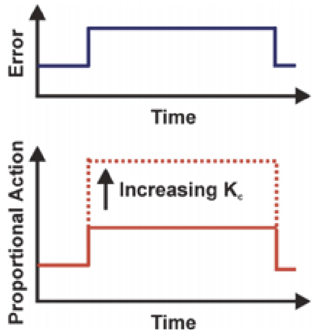

Fig. 3 The proportional control action

If the error increases, the control action increases proportionally. Since more control action is needed to correct large errors, this is very useful. The adjustable setting for proportional control is called the Controller Gain (Kc). A higher controller gain will increase the amount of proportional control action for a given error. If the controller gain is set too high the control loop will begin oscillating and unstable. If the controller gain is set too low, it will not respond adequately to disturbances or set point changes[3].

3.2 The Proportional-only Controller

A PID controller can be configured to produce only a proportional action by turning off the integral and derivative modes. Proportional controllers are simple to understand and easy to tune. The controller output is simply the control error times the controller gain, plus a bias in Fig. 4.

The bias is needed so that the controller can maintain a nonzero output while the error is zero (process variable at set point).

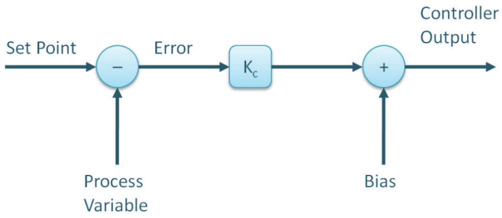

Fig. 4 The proportional-only controller algorithm

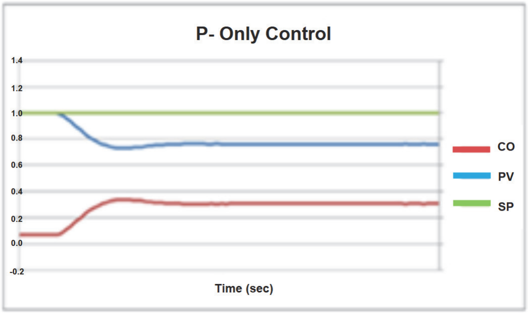

Fig. 5 The proportional controller's response to a disturbance

The use of proportional-only control has a large offset. Offset is a sustained error that cannot be eliminated by proportional control alone. Under proportional-only control, the offset will remain present until the operator manually changes the bias on the controller's output to remove the offset. It is said that the operator manually resets the controller in Fig. 5.

3.3 Integral Control Mode

The need for manual reset in the proportional only controller led to the development of automatic reset or the integral control mode, as known today. The function of the integral control mode is to increment or decrement the controller's output over time to reduce the error, as long as there is any error present. Given enough time, the integral action will drive the controller output until the error is zero. If the error is large, the integral mode will increment/decrement the controller output at a fast rate; if the error is small, the changes will be slow. For a given error, the speed of the integral action is set

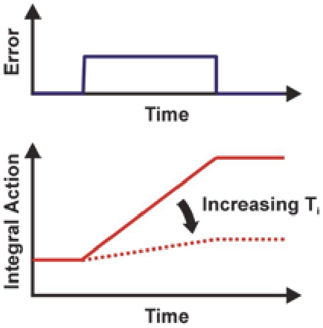

Fig. 6 Integral control action

by the controller's integral time setting (Ti). A large value of Ti (long integral time) results in a slow integral action, and a small value of Ti(short integral time) results in a fast integral action in Fig. 6. If the integral time is set too long, the controller will be sluggish; if it is set too short, the control loop will oscillate and become unstable.

3.4 Proportional Integral Controller

Commonly called the PI controller, the proportional + integral controller's output is made up of the sum of the proportional and integral control actions in Fig. 7.

Fig. 8 shows how, after a disturbance, the integral mode continues to increment the controller's output to bring process value to its set point. Compared to Fig. 5, it is clear how integral control continues to drive the controller output until it has eliminated all offset.

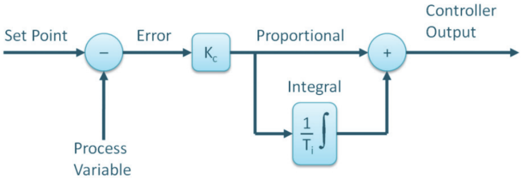

Fig. 7 The PI controller algorithm

3.5 Derivative Control Mode

The third control mode in a PID controller is the derivative control mode and it is used often in motion control. Using the derivative control mode of a controller can make certain types of control loops respond a little faster than with PI control alone. The derivative control mode produces an output based on the rate of change of the error in Fig. 9. Because of this, derivative mode was originally called rate. The derivative mode produces more control action if the error changes at a faster rate. If there is no change in the error, the derivative action is zero. The derivative mode has an adjustable setting called Derivative Time (Td). The larger the derivative time setting, the more derivative cation is produced. A derivative time setting of zero effectively turns off this mode. If the derivative time is too long, oscillations will occur and the control loop

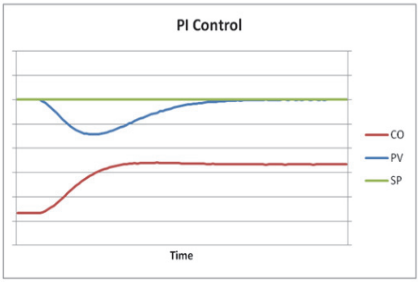

Fig. 8 The PI controller's response to a disturbance

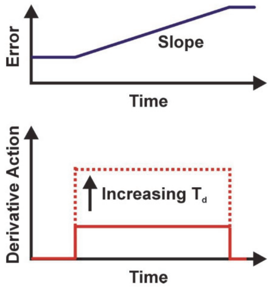

Fig. 9 Derivative control action

will run unstable.

3.6 Proportional Integral Derivative Controller

Commonly called the PID controller, the proportional, Integral, Derivative controller's output is made up of the sum of the proportional, integral, and derivative control rapidly response. Fig. 10 shows the noninteractive PID controller algorithm and Fig. 11 shows the parallel controller algorithm. The derivative mode of the PID controller provides more control action sooner than it is possible with P or PI control. This reduces the effect of a disturbance and shortens the time it takes for the level to its set point in Fig. 12[3][4].

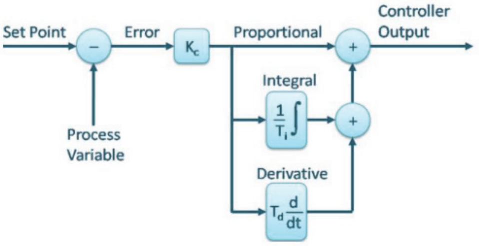

Fig. 10 The non-interactive PID controller algorithm

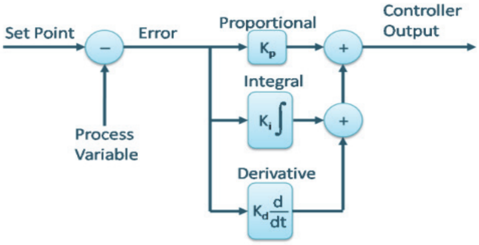

Fig. 11 The parallel PID controller algorithm

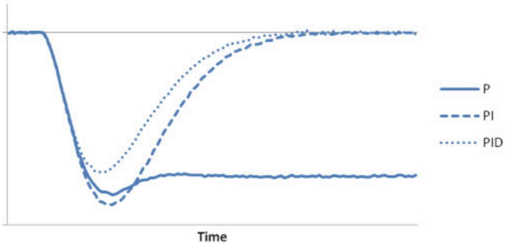

Fig. 12 P, PI and PID controllers' response to a disturbance

4. Methodology & Experimental Apparatuses

4.1 Material

The feedstock, wood pellet that is commercially sold in South Korea, was used. ultimate analysis and proximate analysis have been carried out and the composition of the feedstock is as in Table 2.

Table 2. Ultimate and proximate analysis of the feedstock

Ultimate Analysis	Wt %	Proximate Analysis	Wt %
C (d)	48.88	Moisture (ar)	9.34
H (d)	6.02	Ash (ar)	0.29
N (d)	0.2	Volatile matter (ar)	73.71
S (d)	0.02	Fixed Carbon (ar)	16.66
O (d)	44.53		
LHV: 4070 kcal/kg			
Ar: As received basis, d: Dried basis			

4.2 Gasifier

In this study, SBI-W-30 (manufactured by Sunbrand Industrial Inc, South Korea in 2020)

Fig. 13 SBI-W-30 Gasifier

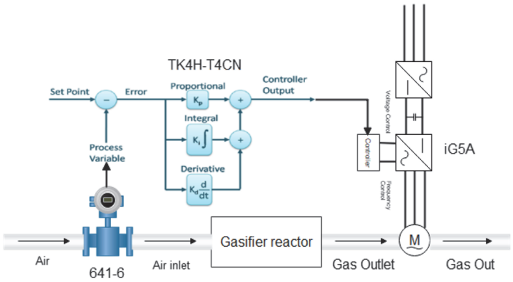

Fig. 14 Control Scheme

has been used shown in Fig. 13. The gasifier is adopted downdraft fixed-bed methods. The air is used as gasifier agent and the air-blower located at the rear end of the facility sucks air and is designed to introduce air into the reactor situated at the front end. The amount of air introduced into the reactor is determined by the rotation speed of the air-blower, and the rotation speed of the air-blower is determined by the inverter(iG5A-LS Electroci). There is a flow meter(641-6, Dwyer Instrument. Inc) at the reactor inlet, and the flow meter displays the amount of air flowing into the reactor in Fig. 14. The PID controller (TK4H-T4CN, Autonics) calculates the difference between Set Point and Process Variable, then computes the Controller Output, and feedbacks the value to the invertor.

Fig. 15 Gasboard-3110P analyzer

4.3 Syngas Analyzer

To monitor the components of the syngas generated in the gasifier in real time, Gasboard-3110P in Fig. 15 has been used. Gasboard-3110P is a portable type analyzer that can read the CO, CO_2, H_2, O_2, CH_4 in the syngas. In order to check the degree of the measured value of the gas analyzer, a sample of syngas was collected and analyzed by Gas Chromatography. When compared with two values, it did show meaningless difference.

5. Results and Discussion

The experiment was conducted over two days. On the first day, the PID control was disabled in Fig. 16, and on the second day, the PID control was enabled in Fig. 17. the data were logged every 10 minutes and the

Table 3. Average value & standard deviation of syngas w/o PID

	CO (%)	CO2 (%)	CH4 (%)	H2 (%)	O2 (%)	LHV (kcal/m3)	%.....
Average	23.9	17.7	5.86	13.09	0.32	1558.84	
Standard deviation	1.85	2.52	0.78	0.98	0.19	109.97	7.05

Table 4. Average value & standard deviation of syngas with PID

	CO (%)	CO2 (%)	CH4 (%)	H2 (%)	O2 (%)	LHV (kcal/m3)	%
Average	26.15	11.19	5.77	11.99	0.09	1589.56	
Standard deviation	0.75	0.59	0.40	0.43	0.08	35.59	2.26%

values were compared with each other. Both graphs show typical changes in the LHV of syngas produced in the gasifier. In that one of the main characteristics of fuel for internal combustion engine is the uniformity of the calorific value, the fluctuation of LHV of syngas is the main drawback of the gasification technology and causes the variation of voltage and frequency when the syngas feeds into a internal combustion engine.

When PID is disabled, the average caloric value is 1558.84 kcal/m^3 and its standard deviation is 109.96 kcal/m^3, which means the caloric value of syngas fluctuates within 7 [%] Table 3. The maximum value is 2,113 [kcal/m^3] and the minmum value is 1273 [kcal/m^3] which the difference between min and max values is 840 [kcal/m^3]. While PID is activated, the average caloric value is 1589.56 kcal/m3 and its standard deviation is 35.59 [kcal/m^3] and it can be translated that the caloric value of syngas fluctuates within 2.26 [%] Table 4. The maximum value is 1,647 [kcal/m^3] and the minimum value is 1,504 [kcal/m^3], which the difference is 143 [kcal/m^3].

6. Conclusion

Biomass gasification technology is being commercialized in the direction of generating and distributing electric power by driving an internal combustion engine with syngas produced in gasifiers. Since the caloric value of syngas is 30.4 [%] and 18.6 [%] of those of biogas and Natural gas GZ50 respectively, fluctuations in the calorific value of syngas directly tansfer an additional load to the generator[1]. The generators connected to the load play a role in supplying stable frequency and voltage to users in response to changes in the load. Syngas generated from the gasifier to which PID control is not applied has a fluctuation range of 7 [%], which can be considered to cause an additional load fluctuation of approximately 14 [%] during generator operation, which adversely affects the power quality of the generators. On the other hand, it was found that a relatively uniform fuel can be supplied to the generator with a standard deviation of 2 [%] of caloric value fluctuation of the syngas generated from the PID-applied gasifier. Therefore, it is highly desirable to apply PID control to supply constant air into the gasifier.

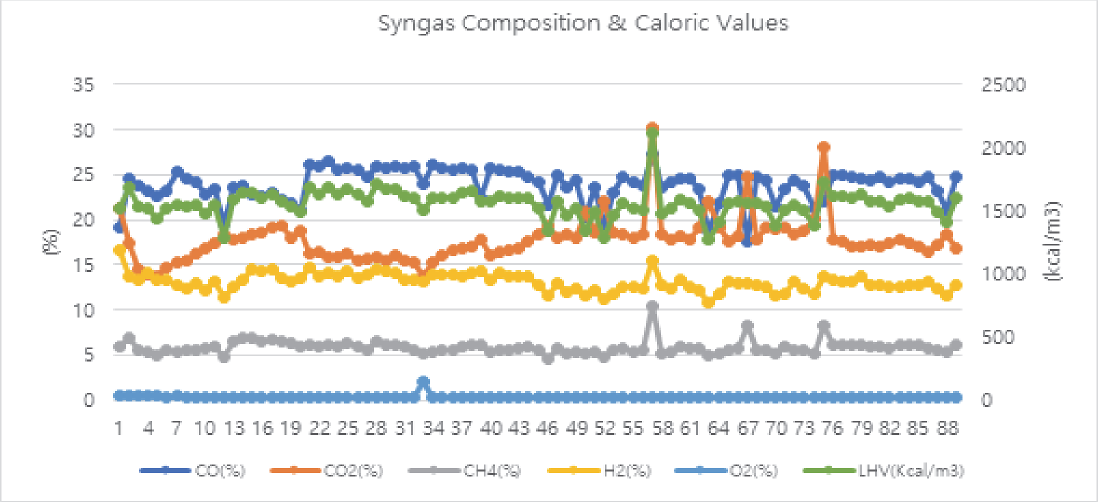

Fig. 16. The PID disabled

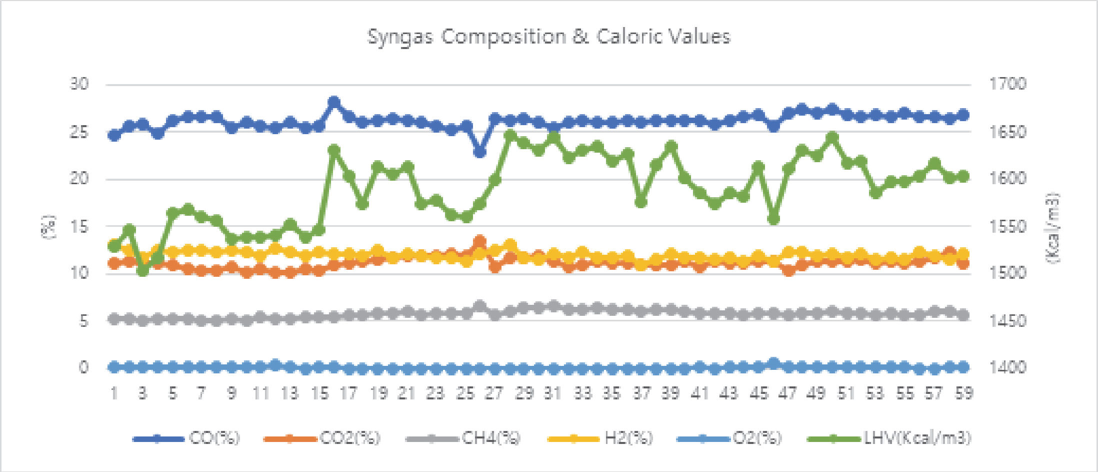

Fig. 17. The PID enabled

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