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Black Smoke Elimination Via PID Controlled Co-Firing Technique at Palm Oil Mill

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Abstract

Burning of only biomass fuel in a boiler furnace causes uncontrollable black smoke emission into the atmosphere especially during high-power demand in which case, rapid addition of biomass fuel is required. Black smoke discharge can be annihilated by using gaseous fuel through co-firing technique. Adding different type of fuel to the primary fuel as another method of fuel mixing is known as co-firing technique. The objective of the present work is to evaluate a co-firing technique of biomass (palm fibre and palm kernel shell) with PID controllers controlling the biogas input into the boiler. Co-firing techniques consist of direct, indirect and parallel co-firing. Among the three techniques, direct co-firing is chosen to be used because it's the simplest and inexpensive in implementation. The performance obtained from the use of each controller was analysed. Drum pressure results are presented. Based on the result for each controller, P controller was the most suitable controller to be used for the application.

Keywords: Biomass, Biogas, Co-firing, PID controllers

INTRODUCTION

Biomass can be converted into gaseous, liquid and solid fuels such as methane, ethanol and charcoal. After the transformation, these fuels can be burned and used. Carbon dioxide will be released into the atmosphere when oxygen in the air reacts with carbon in the biomass fuels. Carbon dioxide from the air will be used during the growth stage. The similar amount of carbon dioxide will be discharged into the atmosphere when the biomass fuel is fully burned. Thus, biomass is acknowledge as a carbon sink. This is because there is no addition of carbon dioxide (CO_2) to the atmosphere. This is furthermore recognised as the zero carbon emissions or the carbon cycle [18].

Diminishing the greenhouse gases releases into the air by using biomass is recognised as a promising energy source [1-9]. By utilizing biomass at great scale can be great advantages in sustainable growth that include social, economical and environmental [4, 5, 10]. When biomass is managed in a sustainable approach, biomass is a neutral renewable fuel [7,11]. Moreover, by using biomass to produce energy can help to solve a couple of problem such as waste disposal problem and harmful gases release result from decompose landfilling junks that will emit CO_2 , methane and more hazardous greenhouse gases [12]. Currently, the energy need in the entire world contributes by biomass is around 10-15% [10, 13].

There are various prominent profitable crops in many countries and palm oil is one of them. Malaysia produced 47% of the world's palm oil resource alone because of that Malaysia is recognised as leader in producing and exporter of palm oil. After the palm oil fruit harvesting and oil extraction process, there will be a huge volume of palm oil biomass produced. This biomass consists of palm oil trunks, fronds, fibres, empty fruit bunch (EFB) and shells [26].

In 2008, 6 million hectares farm land in Malaysia is covered by palm oil plantations. Therefore, Malaysia continuing maintaining its top spot in palm oil plantation. While, Malaysia become a main producer for palm oil, the processing residues also in an enormous amount. Its remains competing to exploit the biomass produced. This biomass can be utilized for bio-energy industry in commercial scale. Palm oil biomass make up of 85.5% of biomass fraction in the entire country extremely surpassing other remaining biomass sources such as sugarcane (0.5%), rice husks (0.7%) and wood (3.7%) [33].

According to Malaysia Palm Oil Board, palm oil biomass residues annually produce in Malaysia at average of 53 million tonnes with a 5% annual growth projection [30]. Dry palm oil biomass wastes in 2010 were recorded as much as 80 million tonnes, this amounts is expected to increase to 100 million tonnes by the year 2020 [31]. Thus, reliable and consistent policy to exploit the competitive benefit of the palm oil industry is required. Therefore, reinforce its commitment toward reducing carbon footprint in the imminent future [32].

Chemical energy in biomass can be converted into form of electricity, heat or mechanical power. These can be achieved by burned biomass directly using boilers, furnaces or steam turbines. The temperature of hot gases produced from the combustion of biomass is in range of 700-1000°C. The temperature is sufficient for turbine to produce energy. Biomass that will be used for combustion, must contained 50% or less moisture content else the biomass must be dried first before used [34].

Nowadays, renewable energy sources are preferred to be exploited in decreasing carbon dioxide emission into the atmosphere. The renewable resources is utilised through co-firing fossil fuel with biomass in current power plants [14]. Most inexpensive approach that had been recognised is to utilise biomass through co-firing biomass for electric utility industry. Co-firing can reduce greenhouse gases emission and established infrastructural support for fuel resource and delivery in order to transform to profound base for biofuel supplies. Moreover, co-firing also support economic development between wood products and agricultural industries in specified service area. These are the reasons why co-firing is considered practical to compliment global climate challenge plan [15].

Merging biomass co-firing with carbon capture and storage (CCS) in power plants can be a solution to carbon dioxide net elimination from the air [19]. It is known that there are three types of co-firing technologies. These technologies consist of direct co-firing that is the simplest and economical and also indirect co-firing and parallel co-firing [27]. Direct co-firing is chosen because it is also easy to implement.

Due to its high caloric value, palm oil mill wastes such as fibre, shell and empty fruit bunch (EFB) can be exploited as an energy source [24]. Palm oil wastes continue to increase as crude palm oil continues to be produced. Palm oil wastes are made up of 12 -15% fibre, 20- 23% EFB and 5- 7% shell. Due to environmental concerns to resolve the disposal problem, biomass wastes need to be utilised efficiently [24]. The palm oil mill that under assessment employs fibre and palm kernel shell as the boiler feeding. Palm oil milling process produced fibre that be burned in the boiler furnace while there is some amount of palm kernel shell are sold due to its good market price [24]. The energy produced can vary because of inadequate blending between shell and fibre, the amount of moisture content in the material, the air flow and also because of incomplete combustion [29].

THE PID CONTROLLER

PID controller is one of the most acquainted forms of feedback. In the early governors, it was a significant component and developed to standard tool for process control in 1940s [20].

It consists of three controller types that are proportional (P), integral (I) and derivative (D). The small changes in error can results in oscillations that make the system to overreact. This problem can solved with the used of proportional control. One of the characteristic of proportional control was its proportional to control error when the error was small [21]. With proportional control there always a steady state error. By increasing gain the steady state error can be reduce. To make sure the process output match up with set point in steady state is a job for integral controller. No matter how small the error is, positive or negative error will affect the control signal whether to increase or decrease the control signal [21]. When integral control is used it will rise the cause to oscillate but will solved the steady state error problem. In order to improve the closed loop stability, derivative controller can be used. Changes in control variable at process output will take some time to notice because derivative controller will extrapolate the error by tangent to error curve to predict the process output. The controllers can be used individually (P, I, D) or in combination (PI, PD, PID) to produce the desired effect contributed from each individual controller components.

The general algorithm of PID controllers is shown as below:

$$u(t) = k_p e(t) + k_i \int_0^t e(T)dT + k_d \frac{de}{dt} \tag{1}$$

DYNAMIC CHARACTERISTICS OF THE BOILER DRUM PRESSURE

Water-tube boiler was used in this project based on the boiler at West Oil Mill, Pulau Carey. Boiler model developed by Astrom and Bell [22] was used. This boiler model only describes the drum pressure response. Eqn (2) shows the global mass balance for the boiler. Eqn (3) shows the global energy balance for the boiler.

$$\frac{d}{dt}[\rho_s V_{st} + \rho_w V_{wt}] = q_f - q_s \tag{2}$$

$$\frac{d}{dt}[\rho_s h_s V_{st} + \rho_w h_w V_{wt} - pV_t + m_t c_p t_m] = Q + q_f h_f - q_s h_s \tag{3}$$

Where

$$V_t = V_{st} + V_{wt} \tag{4}$$

To obtain the second order model, saturated steam tables were combined with eqns (2), (3) and (4) to yield a simple boiler model. Considering we only interested in drum pressure, eqn (2) can be multiply by h_w and subtracting result from (3) while neglecting small variations we be able to obtain approximate model, eqn (5):

$$e_1 \frac{dp}{dt} = Q - q_f(h_w - h_f) - q_s h_c \quad (5)$$

Where

$$e_1 = h_c V_{st} \frac{\partial \rho_s}{\partial p} + \rho_s V_{st} \frac{\partial h_s}{\partial p} + p_w V_{wt} \frac{\partial h_w}{\partial p} + m_t c_p \frac{\partial t_s}{\partial p} - V_t \quad (6)$$

This model does not describe the distribution of steam and water in the system, thus this model does not concern with drum water level behaviour. The mathematical model above captured the gross behaviour of the boiler.

RESULT AND DISCUSSION

Drop in pressure in the drum pressure will caused black smoke to be released during combustion. Black smoke that be released consists of small particles, carbon monoxide, carbon dioxide as well as water vapour, hydrocarbons and many more hazardous gases. Incomplete combustion of solid fuel is one of the reasons for black smoke emission. Increasing the drum pressure is considered as one of the solutions for black smoke released. Using a cleaner fuel also help in eliminating black smoke released and also by properly blend the biomass to aid in attaining combustion close to the complete combustion. By using biogas as supplementary fuel, its can help in combustion process as well as increasing the drum pressure. Fig.1 shows that the density of the smoke released from the boiler stack can be affected by the drum pressure. Based on the observation, when the pressure in the drum is high, the density of the smoke released is low and vice versa. This result is obtained from the real time testing at the West Oil mill to proof the concept of mix fuel combustions [35]. Combustion done in high pressure is more effective than combustion in low pressure based on the thermodynamic view. This will result in intensified the combustion thus improved fuel efficiency. Result in tremendously reduced the emissions from combustion such as carbon dioxide and other pollutants [28].

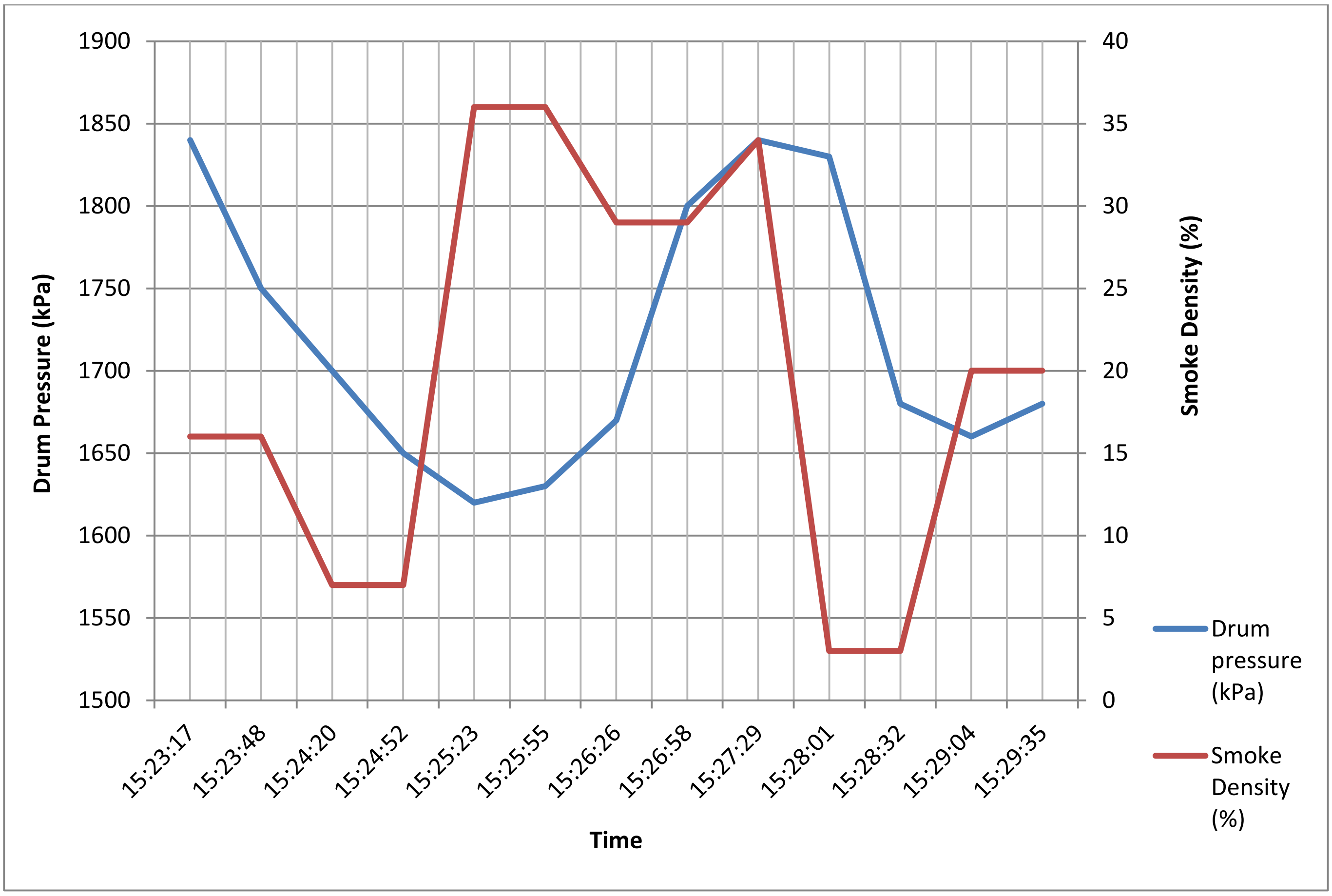

Figure 1: Drum pressure to the smoke density relationship

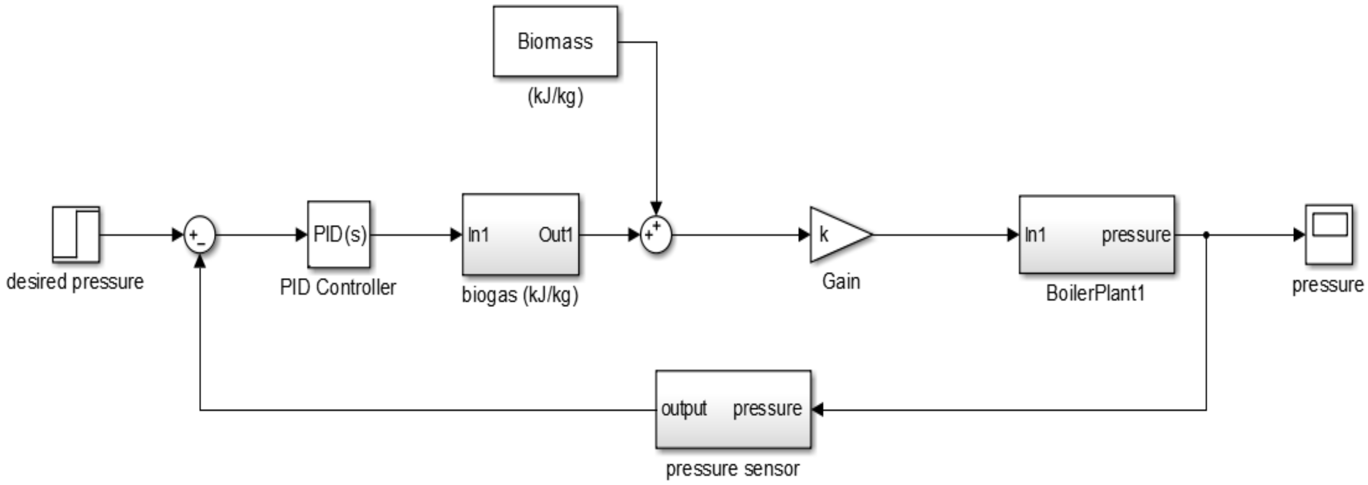

Figure 2: Block diagram of the feedback control

Table 1: System performance parameters

Controller	**Proportional (P)**	**Proportional & Integral (PI)**	**Proportional & Derivative (PD)**	**Proportional, Integral & Derivative (PID)**
Response Time (s)	0.6929	1.158	0.1279	0.1279
Settling time (s)	1.46	6.85	0.426	0.836
Overshoot (%)	8.77	16.5	7.32	12
Phase Margin (°, rad/s)	60@2.89	60@1.73	75.6@15.6	69@15.6

Fig. 2 represents the Simulink block diagram of the feedback control. The biogas consumption into the boiler is controlled by PID controllers. Direct co-firing is used.

MATLAB® automatic tuning tools were used to obtain the controller gains that yields the required system performance parameters. Table 1 shows the simulation tuning result obtained.

Balancing between performance and robustness was the main focused of the tuning algorithm. Ideal gain for a system is at 60° phase. Based on the parameter obtained, systems with P and PI controller are quite stable as they are able to achieve gain at 60°. PI controller response time, overshoot and settling time were the highest compared to other controllers. Although settling time and response time for controller PD and PID quite fast but their system not stable if compared to two other controllers. Fluctuation can be minimizes by using P controller but can produce a large offset. As for I controller, small offset can be obtained in expense of slower response time. While for D controller, it can keep the consistent setting if it's paired with other controller as it's cannot be used alone. Fast responses can be given by PID controller but this controller will be costly.

Fig.3 shows each controller response in drum pressure. The set point pressure was at 1800kPa. This set point pressure was the minimum pressure for black smoke cease to exist [23]. Based on the observation on the drum pressure, P and PI controller give similar response. PD controller took the longest time to rise to set point and settle. The set point pressure is achieved by all the controllers. The only concern was the time. Based on the result obtained, the choice of suitable controllers to be used depends on the user requirement and preferences.

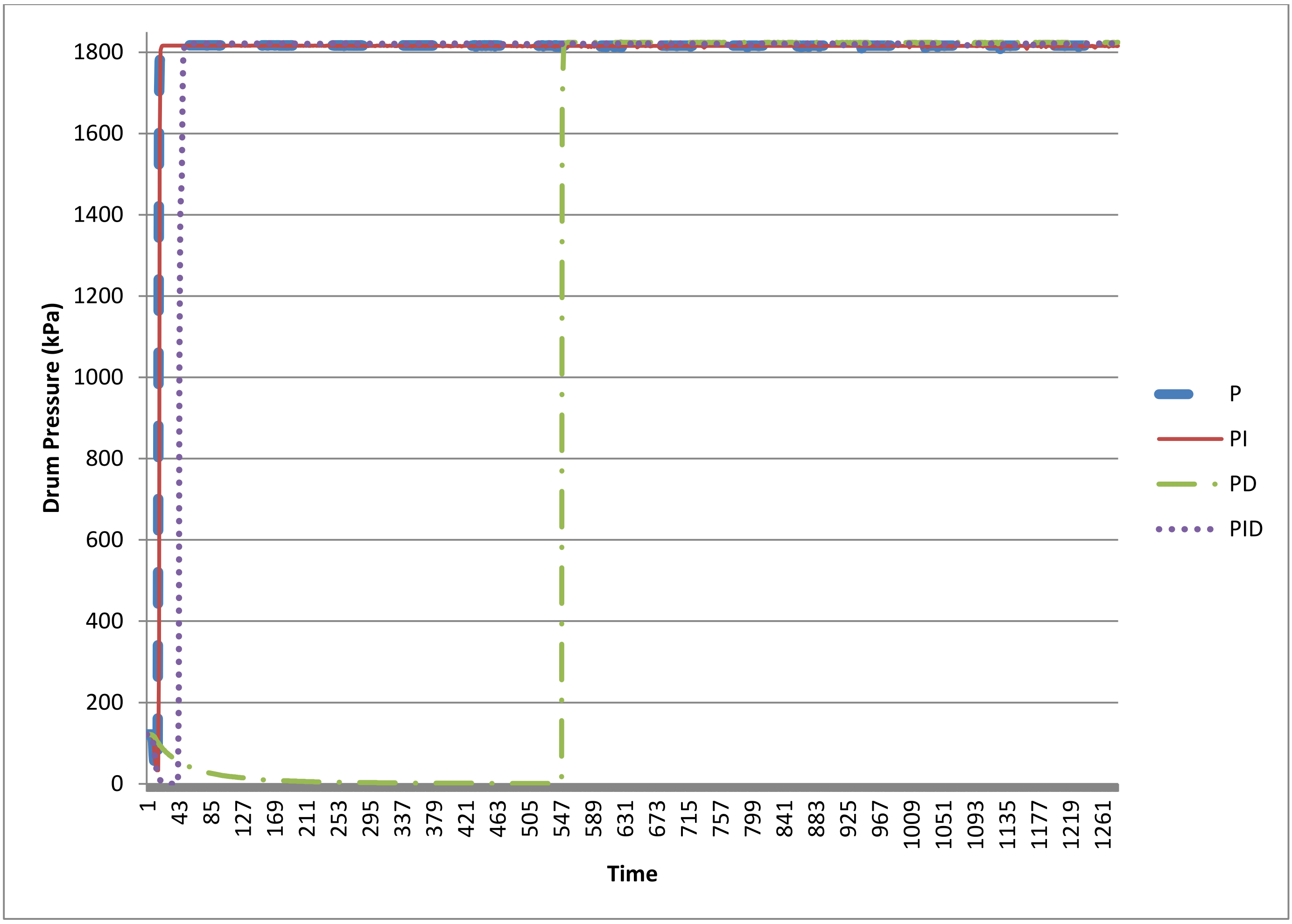

Figure 3: The boiler pressure responds of P controller, PI controller, PD controller and PID controller

CONCLUSION

In this paper, Matlab/Simulink tools were used to design a model of water-tube boiler. In order to eliminate black smoke emission from the boiler stack at palm oil mill, co-firing technique is used. Direct co-firing is chose because of its simplicity and inexpensive to implement. The co-firing method is simulated using a feedback control. Four types of controller are used such as P controller, PI controller, PD controller and PID controller. The biogas intake is controlled by the controller. The drum pressure reading for each controller was recorded. All controllers were able to control the biogas input into the boiler to increase the pressure in the drum. There were delays in the pressure response for PD and PID controllers. P and PI controllers had the fastest response to achieve set point pressure. The type controller suitable to use was depending on the system requirement. For this system, P controller is most the suitable controller to be used to control the biogas intake. In the future, fuzzy logic controller will be considered to be used to improve the system performance

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REFERENCES

[1] F. Okasha , G. Zaater, S. El-Emam, M. Awad & E. Zeidan, "Co-combustion of biomass and gaseous fuel in a novel configuration of fluidized bed: Thermal characteristics", Energy Conversion and Management, vol. 84, pp. 488–496, 2014.

[2] M.F. Demirbas, M. Balat, H. Balat, "Potential contribution of biomass to the sustainable energy development", Energy Convers Manage, vol. 50, pp. 1746–60, 2009.

[3] L. Zhang, C. Xu, P. Champagne, "Overview of recent

advances in thermo-chemical conversion of biomass", Energy Convers Manage, vol. 51, pp. 969–82, 2010.

[4] C.N. Hamelinck, R.A.A. Suurs, A.P.C. Faaij, "International bioenergy transport costs and energy balance", Biomass Bioenergy, vol. 29, pp. 114–34, 2005.

[5] C.N. Hamelinck, A.P.C. Faaij, "Outlook for advanced biofuels", Energy Policy, vol. 34, pp. 3268–83, 2006.

[6] E. Kırtay, "Recent advances in production of hydrogen from biomas", Energy Convers Manage, vol. 52, pp. 1778–89, 2011.

[7] A.A. Khan, W. de Jong, P.J. Jansens, H. Spliethoff, "Biomass combustion in fluidized bed boilers: potential problems and remedies", Fuel Process Technol, vol. 90, pp. 21–50, 2009.

[8] Z. Al-Hamamre, A. Al-Mater, F. Sweis, K. Rawajfeh, "Assessment of the status and outlook of biomass energy in Jordan", Energy Convers Manage, vol. 77, pp. 183–92, 2014.

[9] J.S. Lim, Z. Abdul Manan, S.R. Wan Alwi, H. Hashim, "A review on utilisation of biomass from rice industry as a source of renewable energy", Renewable Sustainable Energy Reviews, vol. 16, no. 5, pp. 3084–94, 2012.

[10] W.C. Turkenburg, "World Energy Assessment: renewable energy technologies", United Nation Development Programme, New York, USA, 2000.

[11] A. Faaij, B. Meuleman, W. Turkenburg, A. vanWijk, A. Bauen, F. Rosillo-Calle, "Externalities of biomass based electricity production compared with power generation from coal in the Netherlands", Biomass Bioenergy, vol. 14, no. 2, pp. 125–47, 1998.

[12] E. Hughes, J.R. Benemann, "Biological fossil CO_2 mitigation", Energy Convers Manage, vol. 38, pp. 467–73, 1997.

[13] A.P.C. Faaij, "Biomass combustion", Enc Energy, vol. 1, pp. 175–9, 2004.

[14] C. YIN, "Biomass co- firing", chapter 5, Aalborg University, Denmark, Woodhead Publishing Limited, 2013

[15] D.A. Tillman, "Biomass co-firing: the technology, the experience, the combustion consequences", Biomass and Bioenergy, vol. 19, pp. 365-384, 2000.

[16] L. Baxter, "Biomass-coal co-combustion: opportunity for affordable renewable Energy", Fuel, vol. 84, pp. 1295–302, 2005.

[17] H. Haykiri-Acma, S. Yaman, S. Kucukbayrak, "Co-combustion of low rank coal/ waste biomass blends using dry", Appl Therm Eng, vol. 50, pp. 251–9, 2013.

[18] R. Saidur, E.A. Abdelaziz, A. Demirbas, M.S. Hossain, S. Mekhilef, "A review on biomass as a fuel for boilers", Renewable and Sustainable Energy Reviews, vol. 15, pp. 2262–2289, 2011.

[19] W. Schakel, H. Meerman, A. Talaei , A. Ramírez, A. Faaij, "Comparative life cycle assessment of biomass co-firing plants with carbon capture and storage", Applied Energy, vol. 131,pp. 441–467, 2014.

[20] K.J. Astrom, "Control System Design", 2002.

[21] K. Astrom & T. Hagglund, "PID controllers: Theory, Design, and Tuning", 2nd edition, Instrument society of America, Research Triangle Park, ISBN 1-55617-516-7, 1995.

[22] K.J. Astrom and R.D. Bell, "Drum-Boiler Dynamics", Automatica, vol. 36, pp. 363-378, 2000.

[23] R. Mohamed, N.A. Abdullah, W.M.F. Wan Mahmood, M.T. Mohd Nor, M.M. Mustafa, M.U. Mustafa, Z. Atan, M.A. Abdullah, A.J. Asis and N.M. Hashim, "Proof of Concept of Mixed-fuel system for Black Smoke Elimination in the Palm Oil Mill", Prosiding KTP, vol. 31, pp. 293-299, 2014.

[24] M.A. Nasution, T. Herawan, M. Rivani, " Analysis of Palm Biomass as Electricity from Palm Oil Mills in North Sumatera", Conference and Exhibition Indonesia Renewable Energy & Energy Conservation [Indonesia EBTKE CONEX 2013], Energy Procedia, vol. 47, pp. 166 – 172, 2014.

[25] M. S. Umar, P. Jennings, T. Urmee, "Strengthening the palm oil biomass Renewable Energy industry in Malaysia", Renewable Energy, vol. 60, pp. 107-115, 2013.

[26] M.A.A. Mohammed, A. Salmiaton, W.A.K.G. Wan Azlina, M.S. Mohammad Amran, A. Fakhru'l-Razi, Y.H. Taufiq-Yap, "Hydrogen rich gas from oil palm biomass as a potential source of renewable energy in Malaysia", Renewable and Sustainable Energy Reviews, vol. 15, pp. 1258–1270, 2011.

[27] S. Zafar, 2015, "Cofiring of Biomass", http://www.bioenergyconsult.com/tag/direct-cofiring/ [15 August 2016]

[28] NASA Office of Biological and Physical Research (OBPR), 2001, Combustion Under Pressure - A New Understanding Revealed, http://www.spaceref.com/news/viewsr.html?pid=4051 [29 September 2016]

[29] Z.Husain, Z.A. Zainal, M.Z. Abdullah, " Analysis of biomass-residue-based cogeneration system in palm oil mills", Biomass and Bioenergy, vol. 23, pp. 117-124, 2003.

[30] Malaysian Palm Oil Board. Palm oil development and performance in Malaysia, 2010.

[31] Agensi Inovasi Malaysia. National Biomass Strategy

2020: New Wealth Creation for Malaysia's Palm Oil Industry. MIGHT, 2011.

[32] K.H. Solangi, M.R. Islam, R. Saidur, N.A. Rahim, H. Fayaz, "A review on global solar energy policy", Renewable and Sustainable Energy Reviews, vol. 15, pp. 2149-63, 2011.

[33] S. Ahmad, M.Z.A.A. Kadir, S. Shafie, "Current perspective of the renewable energy development in Malaysia", Renewable and Sustainable Energy Reviews, vol. 15, pp. 897-904, 2011.

[34] C.N. Hamelinck, A. Faaij, "Future prospect for production of methanol and hydrogen from biomass", Journal of Power Sources, vol. 111, pp. 1–22, 2002.