CONTROL SYSTEM MODEL FOR BLACK SMOKE ELIMINATION AT PALM OIL MILL

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ABSTRACT

In this paper, black smoke released during biomass combustion is eliminated by a proposed PID control system. Black smoke is a result of incomplete combustion of biomass fuel with improper pretreatment. To solve this problem, direct co-firing is used with mixed fuel combustion technology. Mixed fuel technology consists of mixed biomass and biogas. The biogas admission will be controlled by the PID controllers. Analysis is provided on the response of each controller. Simulation results for the drum pressure using the scheme are presented.

Keywords: *Biomass; Biogas; PID controllers; Co-firing; mixed-fuel technology*

INTRODUCTION

Nowadays, energy consumers globally are accustomed to fossil fuels such as oil, coal and natural gas. Although it has been expected that fossil fuels will be dwindling soon, these fuels are still prominent as the essential source of energy in the whole world. Recently, many endeavours have been done to substitute renewable fuels to cut down the dependence on the fossil fuels. The most assuring renewable energy source turns out to be biomass due to its diverse resource and it's environmentally sound distinctive. While the fossil fuel is burned, a net addition of CO_2 was produced in the atmosphere. By combusting enormous portions of fossil fuels, immense quantities of CO_2 will be emitted into the air within a very short time equivalent to about 200 years of CO_2 [1-2]. Malaysia holds a national policy of encouraging the adoption of renewable energy. This policy was declared as a part of the 8th Malaysia Plan in 2001. The aim is to boost the power production using renewable energy sources. This project is in line with the government's policy of fuel diversification and will shift fossil fuel consumption with renewable energy sources such as biomass.

Since Malaysia is an agricultural based tropical country. Many crops such as paddy rice, palm oil and sugar cane are cultivated in this region. Malaysian palm oil industry produce huge amounts of palm solid residue (PSR) biomass such as empty fruit bunches (EFB), shell, palm fibre, trunks and fronds as by products. These biomasses are capable to be taken into account in the energy mix of the country [3]. Biomass can be converted to solid, liquid and gaseous as for example like charcoal, ethanol and methane. When it is burned, it reacts with oxygen in the air to form carbon dioxide and to be released into the atmosphere. The amount of carbon dioxide emitted is equivalent to amount of carbon dioxide taken from the atmosphere during growing stage if it is fully combusted. Biomass also known as carbon sinks as there is no net increase of CO_2. This is also known as zero carbon emissions or the carbon cycle [4-6].

Biomass Co-firing

Complete combustion ensues when a hydrocarbon fuel such as natural gas or oil burns and produces only carbon dioxide, water and heat. If there is insufficient oxygen or poor mixing of fuel and oxygen then incomplete combustion will take place resulting in other products of combustion including carbon monoxide and unburned fuel. When incomplete combustion occurs, the chemical energy of the fuel is not completely released as heat and the combustion efficiency is reduced. This is also a safety concern as unburned fuel could ignite in the stack and cause an explosion. In the process of combustion, the two components such as biomass and oxygen are combined in a high temperature environment to form carbon dioxide, water vapour, and heat [7].

Biomass exploitation as the solitary fuel resource for a large power station may not be an attractive alternative either logistically or economically. However, biomass can be used as a complementary fuel along with the conventional fossil fuel in the plant. Whether as a reburning fuel [8] or been used in a co-firing mode [9-11]. If biomass is used as fuel, it's helps to reduce the greenhouse gases [12-13] and NO production [14] from the plant. There are a lot of advantages by using biomass as fuels. Some of the advantages are biomass is renewable and unlimited fuel source, relatively cheap resource, commonly low content of ash, C, S, N and trace elements, great reactivity during conversion, mitigation of hazardous emissions (CH4, CO2, NOx, SOx and trace elements) and waste separated, restoration of degraded lands and can be co-fired with conventional fossil fuels to reduce emissions while achieving economically benefit. [15-16].

Biomass co-combustion power generation technology was the finest in term of saving money. Direct-fired power generation technology has a very high efficiency and more reasonable unit investment when it is in scale operation**.** It is described as the simultaneous mixing and combustion of biomass with other fuels such as coal and/or natural gas in a boiler in order to generate electricity [17–21]. There are other constraints of producing power purely from biomass. Such as biomass low heating values and the fuel's low bulk densities, which create the need to transport large units of biomass [17]. Power generation thru biomass co-firing provides an effective way to overcome these challenges [21]. The biomass power generation technology can be characterized into three types. These are biomass co-combustion power generation, direct-fired and biomass gasification. Biomass co-combustion power generation is a technology which the combustion is done between fossil fuel and pre-treated biomass mixed, which produces the steam to driven the steam turbine. This technology comprises of three types: direct co-combustion, indirect co-combustion and parallel connection co-combustion [19].

a. Mixed fuel combustion

In this project a direct co-combustion is used. Palm oil biomass such as palm kernel shell (PKS) and palm fibre is burned with biogas to generate electricity for a palm oil plant usage. The biogas is obtained through anaerobic digestion of palm oil mill effluent (POME) from the same palm oil plant. This method of burning is to help achieve complete combustion state. This technology is also known as mixed fuel technology. Biogas is supplied when the pressure in the boiler drops below the target pressure, which is 1800kPa. Black smoke is normally released to the atmosphere when the pressures drop below the target pressure as biomass fuel is manually added to increase the boiler pressure back to normal. Black smoke is produced due to incomplete combustion as the biomass fuel is not properly mixed [22].The black smoke contained small particle such as airborne particles and liquid droplets composed of acids (such as nitrates and sulphates), ammonium, water, black (or "elemental") carbon, organic chemicals, metals, and soil (crustal) material [23]. Black smoke can be reduced by having a more uniform mix of biomass, or by burning a cleaner fuel such as biogas to achieve a combustion process close to complete combustion.

PROPORTIONAL – INTEGRAL – DERIVATIVE CONTROLLER

A proportional (P), integral (I), derivative (D) controller also known as PID controller is a generic control loop feedback mechanism (controller) broadly used in the industrial control systems. A PID controller is the most commonly used feedback controller. PID controller computes an error value as the difference between a process variable and a desired set point. The controller attempts to minimize the error by adjusting the inputs for the control process. In the absence of knowledge of the underlying process, PID controllers are the best controllers. However, the PID parameters used in the calculation must be tuned according to the nature of the system for best performance. While the design is generic, the parameters depend on the specific system. The PID controller computation (algorithm) involves three types of parameters. This controller also sometimes called three-term control. These constants are K_p, K_i and K_d; whose subscripts p, i and d denote proportionality, integrative and derivative control, respectively The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing. Heuristically, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. By tuning the three constants in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. Some applications may require using only one or two modes to provide the appropriate system control. This is achieved by setting the gain of undesired control outputs to zero [24-25]. Below is the control algorithm for the PID controller:

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

There are four types of controllers that can be obtained from using proportional, integrative and derivative controller. Those controllers are P controller, PI controller, PD controller and last but not least PID controller. In this project, automatic tuning algorithm from Control System Toolbox Simulink MATLAB is used to find the controller parameters.

THE PROPOSED MODEL

a. Dynamic Characteristics of the Boiler Drum Pressure

The boiler parameters used in this project are based on water-tube boiler available at the West Oil Mill, Pulau Carey. The gross behaviour of the boiler was captured in the mathematical model below [26]. This model does not acquire the behaviour of the drum level because it does not describe the distribution of steam and water in the system. The equation gives good understanding into nonlinear characteristics of the pressure response in the boiler. Because this model did not capture the drum level, the feed water flow rate will be constant. In this project, we are focusing on the drum pressure of the boiler. Fig. 1 shows the block diagram of the boiler.

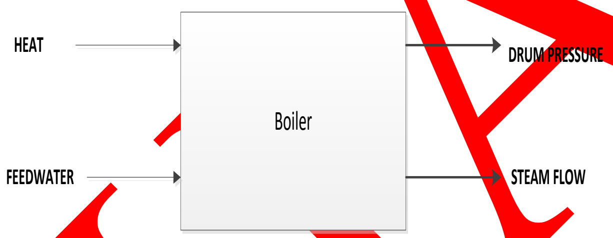

Figure 1 Block diagram of a boiler

$$e_{11} \frac{dV_{wt}}{dt} + e_{12} \frac{dp}{dt} = q_f - q_s \qquad (2)$$

$$e_{21} \frac{dV_{wt}}{dt} + e_{22} \frac{dp}{dt} = Q + q_f h_f - q_s h_s \qquad (3)$$

Where

$$e_{11} = Q_w - Q_s \qquad (4)$$

$$e_{12} = V_{st} \frac{\partial Q_s}{\partial p} + V_{wt} \frac{\partial Q_w}{\partial p} \qquad (5)$$

$$e_{21} = Q_w h_w - Q_s h_s \quad (6)$$

$$e_{22} = V_{st}\left(h_s \frac{\partial Q_s}{\partial p} + Q_s \frac{\partial h_s}{\partial p}\right) + V_{wt}\left(h_w \frac{\partial Q_w}{\partial p} + Q_w \frac{\partial h_w}{\partial p}\right) - V_t + m_t C_p \frac{\partial t_s}{\partial p} \quad (7)$$

$$V_t = V_{st} + V_{wt} \quad (8)$$

MODEL SIMULATION

a. Simulation of the boiler without controller control.

Fig. 2 represent the Simulink representation of the boiler model based the mathematical model above. The calorific value (CV) of the biomass is used as the input for the heat [27].

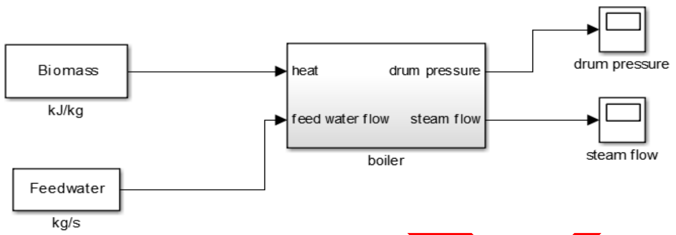

Figure 2 Boiler block diagram simulation

Based on Fig. 3 the boiler pressure only reached to 1368kPa when 85kg biomass is used as the solid fuel for the boiler combustion. When the boiler pressure was low, the black smoke will be emitted from the boiler stack. This pressure is categorised as low pressure hence producing high amount of black smoke. One of the solutions in eliminating black smoke emission was to increase the boiler pressure. The pressure needed in order to eliminate black smoke emission was around 1800kPa [28].

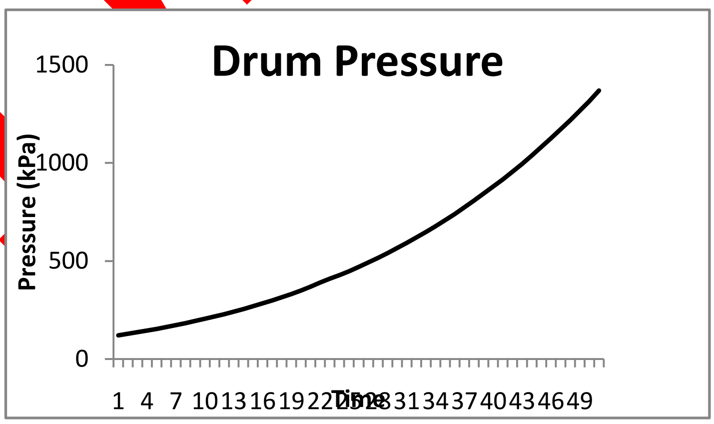

Figure 3 Drum pressure responses when using only biomass as combustion fuel

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b. Simulation of the boiler with Controller Control.

Fig. 4 represents the Simulink representation of the boiler model with control. The variation of PID controllers is used. Biogas will be supplied to aid the combustion in the boiler. The biogas admission will be controlled by the controllers. Direct co-firing technique is used.

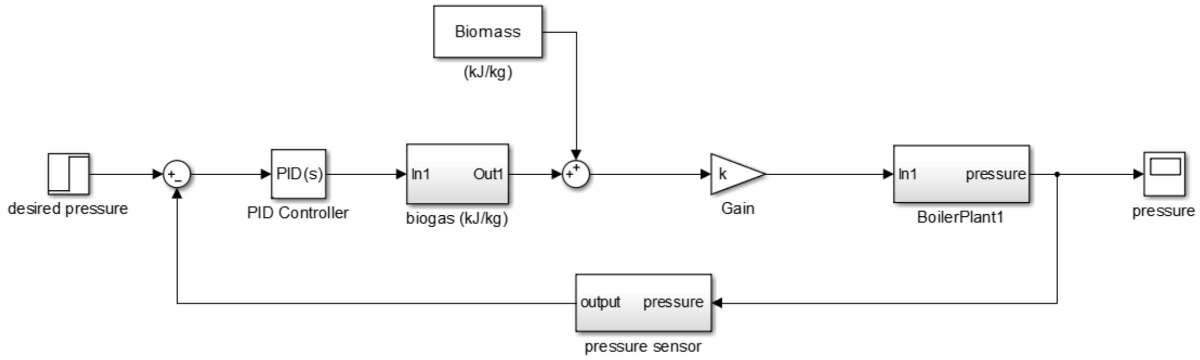


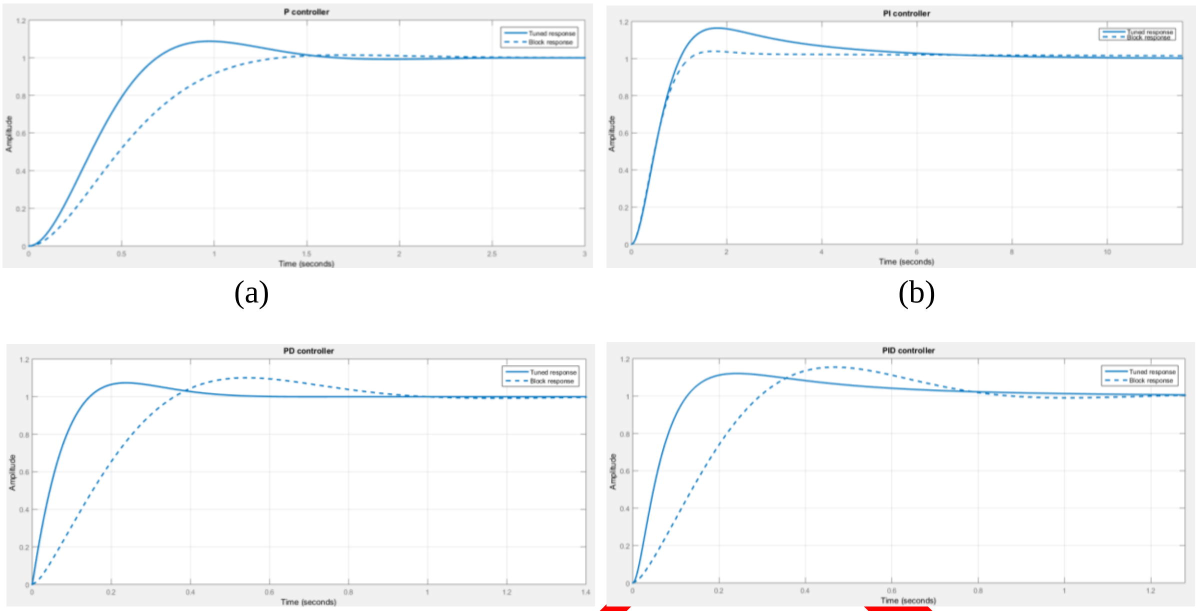
Figure 4 Block diagram mixed fuel combustion control by PID controllers

Table 1 shows the simulation tuning result obtained.

Table 1 Parameters of the controllers

Controller	Value	Response Time (s)	Settling Time (s)	Overshoot (%)
Proportional (P)	P = 516.9431	0.6929	1.46	8.77
Proportional & Integral (PI)	P = 278.2907 I = 92.9308	1.158	6.85	16.5
Proportional & Derivative (PD)	P = 4178.8264 D = 431.1452 N = 1786.964	0.1279	0.426	7.32
Proportional, Integral & Derivative (PID)	P = 3771.4944 I = 6157.6535 D = 436.5943 N = 85.2801	0.1279	0.836	12

Fig. 5 shows the step response of each controller in time domain after tuning. The figure shows that the responses improve much better after the controllers were tuned.

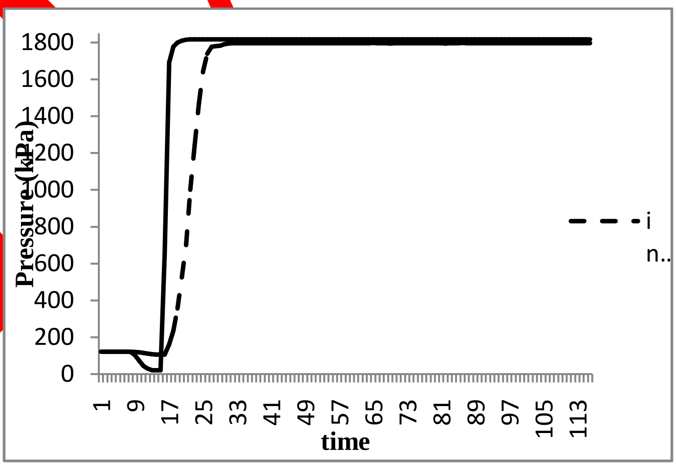


(a) (b)

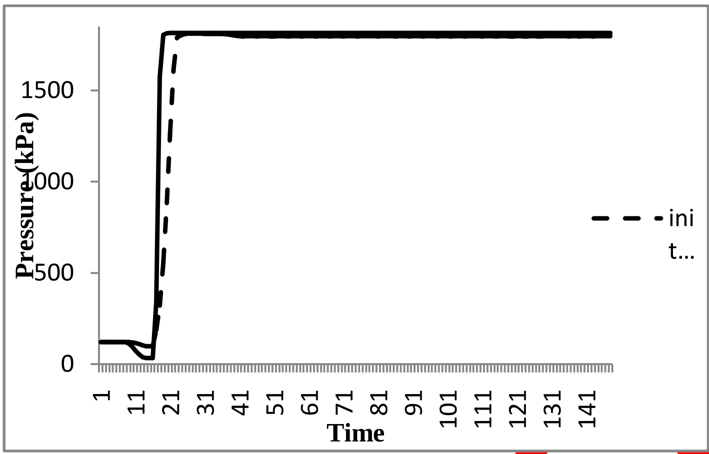
(c) (d)

Figure 5 Step responses (a) P controller, (b) PI controller, (c) PD controller and (d) PID controller.

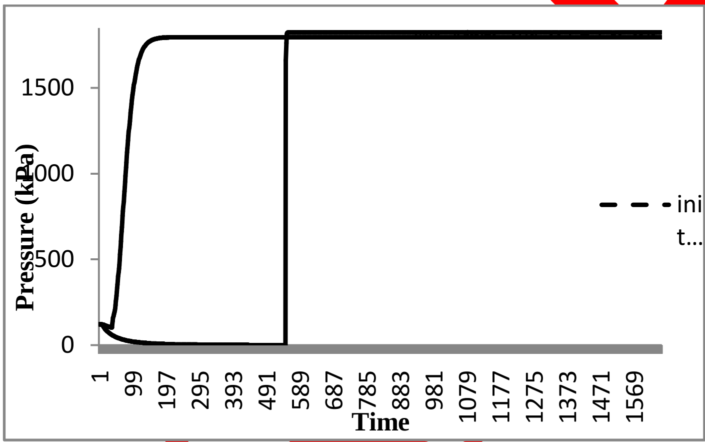
The parameter of the controllers is obtained using MATLAB® automatic tuning tools. The algorithm finds the gains by balancing between performance and robustness. Based on the observation the fastest response time belongs to PD controller and PID controller that is 0.1279s but PID controller rise time was faster than PD controller even though PID controller settled later than PD controller. PI controller took the longest time to settle. The lowest values of overshoot between all the controllers belong to PD controller with 7.32% while the highest overshoot belongs to PI controller. After the controller responses are known, the pressure response can be observed through Fig. 6.



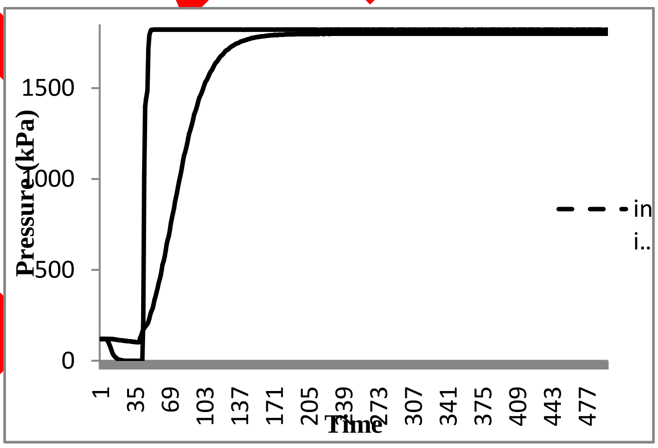
(a)



(b)



(c)



(d)

Figure 6 The boiler pressure responds (a) P controller, (b) PI controller, (c) PD controller and (d) PID controller

Based on the observation, the boiler pressure rising to 1800kPa faster using P controller than PI controller. Both PID and PD controllers took longer time to rise to 1800kPa. All four of the controllers be able to reach the target pressure. It's just the matter of time. Based on the result obtained user can determined which controller they prefer based on the requirement of the plant. Whether the delay in responses will be destructive on the plant or can be tolerated.

CONCLUSION

In this paper a co-firing combustion in a water tube boiler has been implemented using Simulink. A Simulink model of water tube boiler is developed and PID controller is implemented. There are four types of controllers under consideration which are P controller, PI controller, PD controller and PID controller. PD controller give the fastest settling time while PI controller the longest. PI controller also gives the highest overshoot among all the controllers. PD and PID controllers result in the fastest response time compare to others two controllers. All the controllers can be used to control the biogas input into the boiler. The target pressure can be archive by using each controller. It's up to the user to choose which controller to be chosen to be implemented at the site.

In the future, implementation of fuzzy logic controller to continue improving the performance of the control will be considered.

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REFERENCES

[1] T. Abbasi and S.A Abbasi. "Biomass energy and the environmental impacts associated with its production and utilization". Renewable and Sustainable Energy Reviews vol. 14, 2010, pp. 919–937.

[2] J.Y. Tock, C.L. Lai, K.T. Lee, K.T. Tan and S. Bhatia, "Banana biomass as potential renewable energy resource: a Malaysian case study", Renewable and Sustainable Energy Reviews vol. 14, 2010, pp. 798–805.

[3] S.E. Hosseini and M .Abdul Wahid, "Utilization of palm solid residue as a source of renewable and sustainable energy in Malaysia", Renewable and Sustainable Energy Reviews vol. 40, 2014, pp. 621–632

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

[5] A. Bhattacharya and A. Datta, "Effects of supplementary biomass firing on the performance of combined cycle power generation: A comparison between NGCC and IGCC plants", biomass and bioenergy vol. 54, 2013, pp. 239-249.

[6] R. Kaewmai, A.H. Kittikun and C. Musikavong, "Greenhouse gas emissions of palm oil mills in Thailand", International Journal of Greenhouse Gas Control vol. 11, 2012, pp. 141–151.

[7] D. Ciolkosz, "Introduction to biomass combustion" . http://articles.extension.org/pages/31758/introduction-to-biomass-combustion [1 Mac 2016].

[8] W. Zhou, L. Swanson, D. Moyeda and G. Xu, "Process evaluation of biomass co-firing and reburning in utility boilers", Energy Fuels vol. 24(8), 2010, pp. 4510-7.

[9] E.A. Sondreal, S.A. Benson, J.P. Hurley, M.D. Mann, J.H. Pavlish and M.L. Swanson, "Review of advances in combustion technology and biomass cofiring", Fuel Process Technol vol. 71(1-3), 2001, pp. 7-38.

[10] A. Demirbas, "Combustion characteristics of different biomass fuels", Prog Energy Combust Sci vol. 30(2), 2004, pp. 219-30.

[11] B. Damstedt, J.M. Pederson, D. Hansen, T. Knighton, J. Jones and C. Christensen, "Biomass cofiring impacts on flame structure and emissions", Proc Combust Inst vol. 31, 2007, pp. 2813-20.

[12] F. Sebastian, J. Royo and M. Gomez, "Cofiring versus biomass-fired power plants: GHG (Greenhouse Gases) emissions savings comparison by means of LCA (Life Cycle Assessment) methodology", Energy vol. 36(4), 2011, pp. 2029-37.

[13] D.R. McIlveen-Wright, Y. Huang, S. Rezvani, J.D. Mondol, D. Redpath and M. Anderson, "A techno-economic assessment of the reduction of carbon dioxide emissions through the use of biomass co-combustion", Fuel vol. 90(1), 2011, pp. 11-8.

[14] N.S. Harding and B.R. Adams, "Biomass as a reburning fuel: a specialized cofiring application", Biomass Bioenergy vol. 19(6), 2000, pp. 429-45.

[15] M. Varela, Y. Lechon and R. Saez," Environmental and socioeconomic aspects in the strategic analysis of a biomass power plant integration", Biomass Bioenergy vol. 17, 1999 , pp. 405–413.

[16] J. Ingraham, J. Marshall and R. Flanagan, "Practical Considerations for Converting Industrial Coal Boilers to Natural Gas", Electric Power, http://www.powermag.com/practical-considerations-for-converting-industrial-coal-boilers-to-natural-gas/ [03 Jan 2014]

[17] D. Tillman, D.N.B. Duong and N.S. Harding," Solid fuel blending: Principles, Practices, and Problems". Elsevier, 2012. UK/Waltham, MA.

[18] J. Tumuluru, S. Sokhansanj, C.T. Wright, R.D. Boardman and N.A. Yancey, "A review on biomass classification and composition, co-firing issues and pre-treatment methods", In: Proceedings of the ASABE annual international meeting. Louis- ville, (Kentucky), 2011, pp. 1-32, INL/CON-11-22458.

[19] S. Van Loo and J. Koppejan, "The handbook of biomass combustion and co-firing", London: Earthscan, 2008, pp. 203-207.

[20] IEA-ETSAP,IRENA. Biomass co-firing. Available at: ⟨http://www.irena.org/ Document Downloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E21% [14 Nov 2014]

[21] E. Agbor, X. Zhang and A. Kumar, "A review of biomass co-firing in North America" Renewable and Sustainable Energy Reviews vol. 40, 2014, pp. 930–943.

[22] S. Zafar," Palm Kernel Shells as Biomass Resource", BioEnergy Consult, http://www.bioenergyconsult.com/tag/palm-oil-biomass/ [2 Mac 2016].

[23] T. Nussbaumer, C. Czasch, N. Klippel, L. Johansson and C. Tullin, "Particulate Emissions from Biomass Combustion in IEA Countries", International Energy Agency(IEA) Bioenergy Task 32 Swiss Federal Office of Energy (SFOE), 2008, pp. 1-40.

[24] M. Salazar and F. Mendez, "PID control for a single-stage transcritical CO2 refrigeration cycle", Applied Thermal Engineering vol. 67, 2014, pp. 429-438.

[25] R. Malhotra and R. Sodhi, "Boiler Flow Control Using PID and Fuzzy Logic Controller", IJCSET vol. 1(6), 2011, pp. 315-319.

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

[27] B.B. Nyakuma, A. Johari and A. Ahmad, "Thermochemical analysis of Palm Oil Mill Wastes as Fuel for Biomass Gasification", Jurnal Teknologi 62(3), 2013, pp. 73-76.

[28] 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, 2014, pp. 293-299.