PAPER • OPEN ACCESS

Potential of Biomass Utilization in Rotary Kiln of Nickel Processing Plant

View the article online for updates and enhancements.

IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Potential of Biomass Utilization in Rotary Kiln of Nickel Processing Plant

B C Pamungkas[1,a] and H Hadi[1,b]
[1] Engineering Physics Department, Faculty of Industrial Technology, Sepuluh Nopember Institute of Technology

[a] bcpamungkas@gmail.com, [b] hadiharsono00@gmail.com

Abstract. Global energy-related CO2 emissions rose by 1.4% in 2017 and reached a historic high of 32.5 Gigatonnes (Gt). One of the biggest contributors to CO2 emission is coal combustion that emits 96.1 kg CO2 for each GJ energy production. Top consumers of coal in the world are the iron-steel industry (28.5%) and the non-metallic minerals (21.4%). Rotary kiln is one of the most energy consuming equipment in nickel pyro-metallurgy processing plant. The specific energy consumption for calcine production is determined to be 2.26 GJ/ton calcine. In the rotary kiln, coal is used as fuel and a reducing agent. Charcoal from palm kernel shell has similar characteristics with coal and very suitable to substitute coal. Charcoal from PKS has many advantages compared to other biomass: high fixed carbon content, high heating value, and low ash content. Charcoal from palm kernel shell can be used as fuel and a reducing agent. Potential 9.9% reduction of CO2 emission can be achieved by using 20% PKS charcoal as fuel and 5% PKS charcoal as a reducing agent with minimum impact on the current operation.

1. Introduction

Global energy-related CO2 emissions rose by 1.4% in 2017 and reached a historic high of 32.5 Giga-tonnes (Gt) (International Energy Agency, 2018). One of the biggest contributors to CO2 emission is coal combustion that emits 96.1 kg CO2 for each GJ energy production. Top consumers of coal in the world are the iron-steel industry (28.5%) and the non-metallic minerals (21.4%). Rotary kiln process is widely used in the iron-steel industry, cement industry, and non-ferrous mineral processing plant. Production of nickel by pyrometallurgical process considered energy-intensive because of high intensity of heat required for all stages: ore drying, calcination, smelting, and purifying. One of the highest energy consumption is the chemical reaction for calcination and reduction process that takes place inside the rotary kiln. At this stage, semi-dried laterite ore heated up to temperature 800-900 degree Celcius. Currently, the main source of energy in most kilns are fuel oil and coal that emit a high amount of greenhouse gas emissions. To reduce the pollution two type of improvements can be made: the first option is using more environmental-friendly fuels, such as natural gas, biofuel, biomass, solar, and the second option is by improving the energy efficiency of the kiln. From an economic point of view, renewable resources such as biomass and solar are more promising for future energy because fossil fuel price will increase when the resources exhausted in the future.

Biomass has been applied in the iron and steel metallurgical processes and cement manufacturing process [1,2]. Biomass mainly comprises of five organic elements, such as carbon (C), hydrogen (H), oxygen (O), nitrogen (N) sulfur (S); and inorganic elements such as aluminium (Al), silica (Si),

potassium (K), calcium (Ca), sodium (Na), etc in its ash. The objective of this paper is to study the potential of biomass utilization in the rotary kiln of nickel processing plant.

2. Methodology and mass and energy flows in rotary kiln process

2.1. Process description

The main function of the rotary kiln is to remove all water content of semi-dried laterite ore and to perform the calcination process and reduction reaction of metallic oxide. Semi-dried ore from rotary dryer contained water in the form of residual free moisture, crystal water, and chemically bonded water. Evaporation of free moisture occurred immediately in the front section of the kiln where the temperature is lowest. Removal of crystal water and chemically bonded water require higher temperature and occurred afterward in the pre-reduction process. Reduction process of nickel oxide and other metallic oxides occurred near the outlet section of the kiln where carbon monoxide formed because of the oxygen-starved combustion environment. Oxygen required for complete combustion delivered into kiln from four air pipes installed in the middle section of the kiln to burn out remaining carbon monoxide and other combustible gases.

The rotary kiln for which this paper studied is 135 m long cylinder fabricated steel-plate with 6 m outer diameter and 0.8-0.9 rpm rotation speed. The kiln can process 241 ton per hour of semi-dried lateritic ore with an average output of 3500 ton calcine per day. The kiln has four supports with 3.1% inclination with the horizontal plane between inlet and outlet. Support number #1 is the one has the lowest elevation and located near the discharge end of the kiln.

Fossil fuel is the main source of energy input for the rotary kiln with consumption of 9140 kg per hour and 7224 kg per hour, respectively. High sulfur fuel oil used as fuel at the main burner and lance burner located on the outlet side of Kiln, meanwhile medium to high-grade coal used as reducing agent that mixed with semi-dried lateritic ore before conveyed into Kiln inlet. The heating value of high sulfur fuel oil and coal are 40,271 kJ/kg and 25,995 kJ/kg, respectively. Energy consumption of the Kiln influenced by several factors: lateritic ore chemistry and moisture, temperature distribution, rotational speed, and condition of kiln internal components.

2.2. Mass and energy balance

Mass and energy balances were carried out on the system as shown in Figure 1. Mass and energy balances implemented around the control volume of the inlet side, outlet side and kiln shell. According to the rotary kiln process flow diagram, there are six material inflow and two material outflows. Material mass balance in the rotary kiln can be expressed in material conservation equation below:

$$M_{K,in} = M_{K,fo} + M_{K,st} + M_{K,bc} + M_{K,ca} + M_{K,ap} + M_{K,rkf} \qquad (1)$$

$$M_{K,out} = M_{K,c} + M_{K,ogk} \qquad (2)$$

where $M_{K,in}$ and $M_{K,out}$ denote the total inflow and outflow material in rotary kiln, respectively; $M_{K,fo}$, $M_{K,st}$, $M_{K,bc}$, $M_{K,ca}$, $M_{K,ap}$, $M_{K,rkf}$, $M_{K,c}$, $M_{K,ogk}$ are the mass of high sulfur fuel oil, steam, bituminous coal, combustion air, air pipe, rotary kiln feed ore, calcine and off-gas kiln, respectively. Refer to process flow diagram for kiln feed rate of 241 ton per hour, the result of material flow analysis of rotary kiln are shown in mass balance in Table 1.

Energy balance in rotary kiln can be expressed in energy conservation equation below:

$$E_{K,in} = E_{K,fo} + E_{K,st} + E_{K,bc} + E_{K,ca} + E_{K,ap} + E_{K,rkf} \qquad (3)$$

$$E_{K,out} = E_{K,c} + E_{K,ogk} + E_{K,cr} + E_{K,ev} + E_{K,hl} \qquad (4)$$

where $E_{K,in}$ and $E_{K,out}$ denote the total inflow and outflow energy in rotary kiln, respectively; $E_{K,fo}$, $E_{K,st}$, $E_{K,bc}$, $E_{K,ca}$, $E_{K,ap}$, $E_{K,rkf}$, $E_{K,c}$, $E_{K,ogk}$, $E_{K,cr}$, $E_{K,ev}$, $E_{K,hl}$ are the energy of main oil, lance oil, bituminous coal, combustion air, air pipe, rotary kiln feed, calcine, off-gas kiln, chemical reaction, evaporation

and heat loss from outer surface of kiln shell, respectively. Refer to process flow diagram for kiln feed rate of 241 ton per hour, the result of energy flow analysis of rotary kiln are shown in energy balance in Table 2.
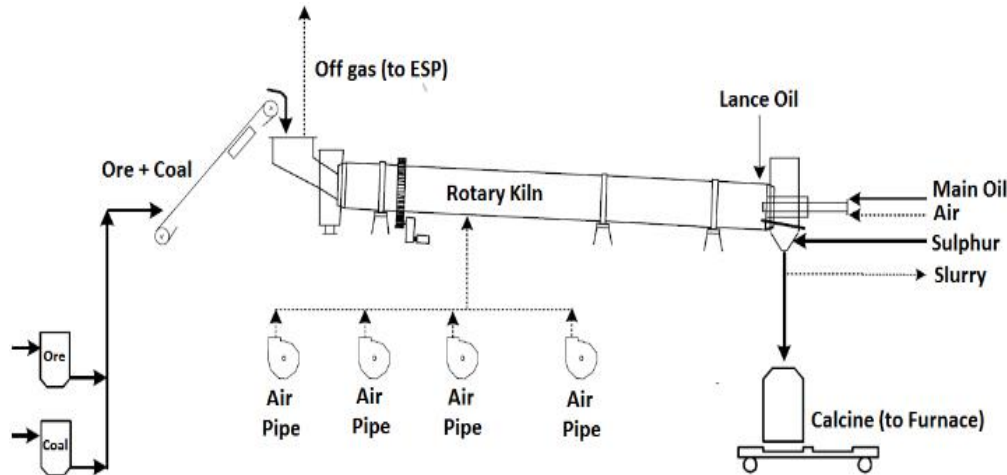

Figure 1. Flow diagram of rotary kiln

The main reference to this study is operating design data in the process flow diagram from kiln manufacturer that complemented with plant data. Plant data were obtained from the continuous measurement value recorded in the process information management system and manual measurement using appropriate tools. Analysis of mass and energy flows was conducted based on the following assumptions: rotary kiln operates at steady state conditions, the composition and the average temperature of material can be considered constant, outer shell temperature of the kiln can be divided into 44 sections and average temperature of these sections can be considered constant, ambient temperature of 27 °C can be considered constant and air supply to the rotary kiln and off-gas kiln are assumed to be ideal gases.

Table 1. Rotary Kiln Mass Balance

	Mass In [kg/h]		Mass Out [kg/h]
Ore	241,000	Calcine	148,931
HSFO	9,140	Off-gas	249,500
Coal	7,224	Dust in off-gas	27,726
Steam	980		
Combustion air	21,300		
Air pipe	146,521		
Total in	426,165	Total out	426,157

Table 2. Rotary Kiln Energy Balance

	Energy In [GJ/h]		Energy Out [GJ/h]
Ore	4.82	Calcine	83.76
HSFO	368.08	Evaporation heat	150.59
Coal	176.36	Off-gas	138.93
Steam	2.72	Heat loss	24.94
Combustion air	6.39	Chemical reaction	204.12
Air pipe	43.96		
Total in	602.33	Total out	602.33

3. Results and Discussion

3.1. Coal and biomass properties comparison

Coal specification that currently used in the rotary kiln is shown in Table 3. Coal that used as a reducing agent mixed directly with kiln feed, meanwhile coal for fuel must be ground and pulverized in the coal mill system before injected as fuel to the kiln burner system. As a reducing agent, coal addition to kiln feed influenced by nickel grade and chemical composition of laterite ore. Volatile matter portion of the coal will be burned out initially and release heat for drying process inside the rotary kiln. Subsequently, in the remaining length of the rotary kiln, fixed carbon content will form carbon monoxide and react with metallic oxide in the laterite ore. High fixed carbon content is required in the rotary kiln to ensure reduction process accomplished properly, otherwise many valuable metals will be discharged with furnace slag and wasted.

Table 3. Coal Specification For Rotary Kiln

Parameters	Unit	Test Results
Total Moisture	%wt	8.9
Total Moisture ADB	%wt	3.5
Ash Content, ADB	%wt	6.6
Volatile Matter, ADB	%wt	38.6
Fixed Carbon, ADB	%wt	51.3
Total Sulfur, ADB	%wt	0.42
Gross Caloric Value, ADB	kcal	7288
Gross Caloric Value, AR	kcal	6880
Ultimate Analysis		
Carbon ADB	%wt	76.2
Hydrogen ADB	%wt	5.6
Nitrogen ADB	%wt	1.6
Oxygen ADB	%wt	9.5

As a fuel, coal must be dried and pulverized in the coal mill system to burn completely. Primary factor for this application is heating value. Lower heating value will increase quantity of material required for same amount of energy. Secondary factor to be considered is milling requirements that indicated by Hardgrove Grindability Index (HGI) and product consistency.

Palm kernel shell charcoal selected as biomass source in this study because of leading properties compared to other biomass: high carbon content, high heating value, low ash, standard mill requirement and the finally, its abundance resources in Indonesia.

Main characteristics of biomass is high moisture and high volatile matter. High moisture will reduce heating value. Palm kernel shell as waste from palm oil mill facility contain approximately 15% of moisture and 75% volatile matter. These characteristics are not suitable for utilization in the rotary kiln as a reducing agent or fuel. Palm kernel shell need to be transformed to charcoal via carbonization or pyrolysis to increase heating value (lower moisture) and higher fixed carbon content (low volatile matter). Typical specification of palm kernel shell charcoal is shown in Table 4.

Indonesia is the largest palm oil producer in the world. Total crude palm oil (CPO) production in 2017 has reached 41.98 million ton. From one unit of fresh fruit bunch only 22.5% wt.% extracted to crude palm oil, the remaining mass will be discharge as waste unless reused as biomass energy or other utilization. Palm kernel shell portion is about 6 wt.% of fresh fruit bunch or approximately 10 million

ton in 2017. Palm oil mill facility can utilize about half of the biomass as waste and remaining half will be discharged as waste.

3.2. Biomass utilization in rotary kiln

Fuel combustion characteristics, such as ignition performance, thermal reactivity and kinetic, influenced by ratio of blending between pulverized coal and biomass. Composition of 60 w.t% pulverized has the lowest activation energy and better combustion characteristics for the co-combustion of pulverized coal and palm kernel shell charcoal (Wang, et al., 2018).

Currently high sulfur fuel oil is the main source of fuel for rotary kiln and raw coal is used as the reducing agent. Pulverized coal can be used as fuel for the kiln burner up to 50% but at the moment the coal mill capacity is limited. Energy input for kiln main burner and for reducing agent is 368.08 GJ/h and 176.36 GJ/h, respectively. CO_2 emission from the fossil fuel is 118.21 kg-CO2/ton-calcine and 70.32 kg-CO2/ton-calcine, respectively, which give total 188.54 kg-CO2/ton-calcine. CO_2 emission with current fuel scheme is shown in Table 5.

Table 4. Typical Palm Kernel Shell Charcoal Specification

Parameters	Unit	Test Results
Total Moisture	%wt	1-5
Ash Content, ADB	%wt	0.8-3
Volatile Matter, ADB	%wt	10-12
Fixed Carbon, ADB	%wt	80-87
Gross Caloric Value, AR	kcal	6500-7000

Biomass utilization for fuel requires co-combustion with pulverized coal in ratio 60:40 of pulverized coal and pulverized PKS charcoal. Proposed fuel configuration with biomass utilization for the main burner of the rotary kiln is shown in Table 6. High sulfur fuel oil supply still maintained at the proportion of 50% input energy according to current process guideline. Pulverized coal and pulverized PKS charcoal will supply 30% and 20% of input energy, respectively. Proposed reducing agent configuration with biomass utilization is 95:5 of coal and PKS charcoal. CO_2 emission from the oil, coal, and biomass is 59.11 kg-CO2/ton-calcine, 110.84 kg-CO2/ton-calcine, and zero, respectively. Total CO_2 emission from the rotary kiln with biomass utilization is 169.95 kg-CO2/ton-calcine, or 9.9% lower compared to existing current fuel configuration.

Table 5. CO2 Emission With Current Fuel

Fuel type	GJ/h	kg CO2 / ton-calcine
Fuel oil	368.08	118.21
Reductant Coal	176.36	70.32
Total	544.44	188.54

Table 6. CO2 Emission With Biomass Utilization

Fuel type	GJ/h	kg CO2 / ton-calcine
Fuel oil	184.04	59.11
Pulverized coal	110.42	44.03
Pulverized charcoal	73.62	0.00
Reductant Coal	167.54	66.81
Reductant charcoal	8.82	0.00
Total	544.44	169.95

4. Conclusion

Potential of biomass utilization in the rotary kiln of nickel processing plant is promising in order to reduce CO2 emission. In the rotary kiln, coal is used as fuel and a reducing agent. Charcoal from palm kernel shell has similar characteristics with coal and very suitable to substitute coal. Charcoal from palm kernel shell can be used as fuel and a reducing agent. Potential 9.9% reduction of CO2 emission can be achieved by using 20% PKS charcoal as fuel and 5% PKS charcoal as a reducing agent with minimum impact on the current operation.

5. References

[1]   International Energy Agency 2018 Global Energy & CO2 Status Report 2017
[2]   Mousa E , Wang C, Riesbeck J and Larsson M 2016 Biomass application in iron and steel industry: An overview of challenges and opportunities *Renewable and sustainable energy reviews* **65** 1247-1266
[3]   Rahman A, Rasul M G, Khan M, and Sharma S 2015 Recent development on the uses of alternative fuels in cement manufacturing process *Fuel* **145** 84-99
[4]   Wang P, Wang G, Zhang J, Lee J Y, Li Y and Wang C 2018 Co-combustion charateristics and kinetic study of anthracite coal and palm kernel shell char *Applied Thermal Engineering* **143** 736-745
[5]   Wei R, Zhang L, Cang D, Li J, Li X and Xu C C 2017 Current status and potential of biomass utilization in ferrous metallurgical industry *Renewable and Sustainable Energy Reviews* **68** 511-524