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Chemical Oxygen Demand Balance and Energy Recovery in Wastewater Treatment Plant of Pulp and Paper Industry (Corrugated Board)

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Abstract

Pulp and paper mills generate wastewater with high organic content expressed in chemical oxygen demand (COD). The organic material can be converted into biogas/methane at the Wastewater Treatment Plant (WWTP) through an anaerobic process. Besides being used to improve the quality of wastewater, WWTP can also produce energy. This study aimed to develop a model of the wastewater treatment process using the principles of COD balance and carrying out energy recovery. Model development started from COD balance analysis, energy potential calculation, and wastewater treatment process system design with a closed system to fulfill energy independently. The calculation was based on waste volume of 2,500 m^3/day which can produce 1,313 kg of methane (1,970 m^3) equal to 4,398.25 kg COD. By-product in the form of primary sludge was 19,897 kg equal to 3,979 kg of COD containing 2,250 kg of solids equal to 404.84 kg of COD. The resulting effluent has a COD content of 638.37 kg/day equal to 255.35 mg/l and still below the regulatory threshold of 350 mg/l. Methane gas and primary sludge are used as fuel for boiler to generate total actual steam of 43,105 kg/day. The produced energy is able to meet the needs of steam and electricity of WWTP at 773 kg/day and electricity of 1,290 kW respectively with an excess of 827 kW (64.12% surplus).

Keywords: anaerobic process, COD, energy recovery, self-sufficient energy, pulp and paper mill

1. Introduction

The pulp and paper mills (PPM) is one of the world's polluting factories (Thompson et al. 2001; Sumanthi and Hung 2004; Azimvand and Mirshokraie 2016) which produce large amounts of wastewater of 50 m^3/ton of paper product (Pokhrel and Viraraghavan 2004) with the content of organic matter expressed in chemical oxygen demand (COD) of 4,060.7 mg/l (Frijns et al. 2013; Lee et al. 2014; Kamali et al. 2016). This wastewater also contains toxic compounds and compounds that are difficult to degrade (based on the production process used) (Frijns et al. 2013), and highly polluted and dangerous. Therefore, the wastewater needs to be treated at a Wastewater Treatment Plant (WWTP) before being released into the surrounding environment (Pontual et al. 2015).

The wastewater contains energy bearing materials and has the potential as a source of chemical energy in the form of organic carbon that can be converted into biogas in sludge processing (Frijns et al. 2013). It contains almost five times the amount of energy needed for wastewater treatment processes (Werf et al. 2014), so that the WWTP can be designed to improve effluent quality while reducing energy consumption (Zakkour et al. 2002). According to Tao and Chengwen (2012) the average electricity demand of 1,856 WWTPs in China is 0.254 kWh/m^3. Some 55% of energy used is for aerobic processes, 20% for pumps, 8% for lighting, 5% for clarifiers, and 12% for others (Loera 2016).

WWTP with anaerobic process technology can produce methane gas that can be converted into energy (Pontual et al. 2015; Kamali et al. 2016). The use of Blanked Upflow Anaerobic Sludge (UASB) reactor in the effluent of PPM produced 734.40 m^3 CH_4/day (8.846 kcal/m^3) or equivalent to 650 kg of fuel oil (10,000 kcal/kg) (Berni et al. 2014), 520 l biogas/kg of reduced COD (Chinnaraj and Rao 2006), and for pre-hydrolysate liquor produced 0.31-0.33 m^3 of biogas/kg of reduced COD (Rao and Bapat 2005).

WWTP can generate a surplus upto 80% of its energy needs (Nowak et al. 2014). East Bay Municipal Utility District (EBMUD) in Oakland, California with a wastewater flow rate of 264,979 m^3/day produces a total of 11 MW of electricity (120% of electricity needs) (Shen et al. 2015). The Sheboygan Regional Wastewater Treatment Facility is able to supply almost 100% of its own energy needs, which meets 90% of annual electricity needs and meet 85% of annual heat requirements using co-digestion (Sheboygan Regional Wastewater Treatment Facility 2012).

A closed system is a system that is interconnected with a cycle, namely the output of the first system will be the second system input, and the second system output becomes the input of the first system (Astrom and Murray 2009). The closed system is stated in mass and energy balance that is integrated flow of material in the system (Ramadhani 2016). According to Bantacut and Novitasari (2016), a closed system can be applied to agriculture product based industries that process materials containing relatively high carbohydrates, fiber, wood, oil and fat.

The purpose of this research was to design and develop a model of the wastewater treatment process using the COD balance principle and to carry out the recovery energy contained in the waste. The steps taken were calculating the COD balance in the WWTP, calculating the energy needs of the wastewater processing and the energy potential for WWTP byproducts, and designing and developing a model of energy independent wastewater treatment plant of the pulp and paper mill.

2. Method

2.1 Type and Source of Data

The secondary data was used and obtained from literature studies namely books, journals, theses, electronic articles, and other scientific articles. These data include COD flow and waste processing technology, energy requirements, and energy potential of COD flows.

2.2 System Boundary

This research was limited to the treatment process of wastewater generated by pulp and paper mill (raw wastewater) to clear wastewater while producing sludge and gas (biogas/methane). This study focused on processing raw wastewater from the paper production process of corrugated board type. The pulp and paper mills wastewater treatment processes to consist of nine main compartments: fine screener, primary clarifier, equalization tank, anaerobic process, aerobic process, secondary clarifier, thermo-alkaline, hydrolysis tank, separator-belt press filter, and liquid portion tank. The main input is wastewater produced from 50 tons of paper production per day.

2.3 Model Description

The COD equilibrium model was developed based on process flows and compartments that describe wastewater treatment. The model development was based to clear wastewater production according to quality standards and recovering generated energy. Input as independent variable and output as dependent variable. The data used in modeling was the ratio (efficiency coefficient) of the value of dependent and independent variables based on the principle of linear equations. Balance model for analyzing energy potential and independency has been undertaken for many agro-based industries such as white sugar production (Bantacut and Novitasari 2016), rice mill (Bantacut and Nurdiansyah 2017), Crude Palm Oil production (Bantacut and Pasaribu 2015), and corn flours industry (Bantacut and Zuriel 2018). These research results showed that mass balance supported the energy requirement analysis and development of closed production process.

2.4 COD Balance Development

The first step in developing a COD equilibrium model is to identify the compartment. The next important step was formulating the model equation that linking input of raw wastewater, and output of clear wastewater output and by-product of each compartment. The simplest model assumed that the overall process occurs only to one compartment (Figure 1). COD equilibrium general equation:

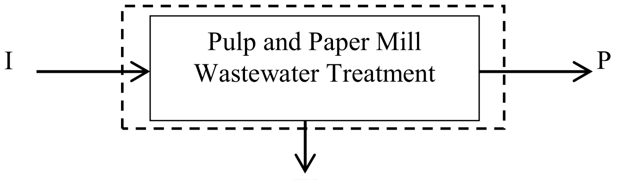

Figure 1. The simplest model Model of COD Balance
Where: I = input; P = product; W = by-product

$$\textit{Input}\ (I) = \text{Product}\ (P) + \text{By-product}\ (W) \quad (1.1)$$

By-product in the form of waste is assumed to be recoverable. Secondary data used are in the form of COD flows in the pulp and paper mills wastewater treatment. This data was used to identify efficiency equations. The efficiency factor value (variable value ratio) can be determined after identifying the COD equilibrium and efficiency equation.

2.5 Energy Potency

Based on the equilibrium model that is suitable for wastewater processing, the converted COD mass into methane and primary sludge were calculated using the following equation (Lobato 2011):

$$V = \frac{C\ x\ R\ x\ (T+273)}{P\ x\ K_{COD}\ x\ 1{,}000} \quad (1.2)$$

V = Volume of methane (m^3)
M = COD Mass (kg)
R = Gas constant (0.08206 atm L mol^{-1} K^{-1})
T = Reactor operation temperature (°C)

P = Atmospheric pressure (1 atm)
Kcod = COD in 1 mol CH_4 (0.064 kg COD CH_4 mol^{-1})

The volume of gas produced is converted to methane gas in kg. Primary sludge mass is obtained from the ratio of the amount of organic matter, minerals, and in the primary sludge according to Bajpai (2015). Energy potential can be calculated using the following equation:

Energy potency (kcal) = mass (kg) x Calorific value (kcal/kg)

The COD calorific value is obtained from literatures and mass from the COD equilibrium calculation. Data from the literature, namely:

(1). Methane gas mass gravity = 0.666 kg/m^3 (Air Products and Chemicals 2017)
(2). Methane calorific value = 56 MJ/kg (Lam dan Lee 2001)
(3). Primary sludge calorific value = 4,200 kJ/kg (Clarke dan Guidotti 1995)

3. COD Balance Model

The COD balance model was developed into two parts, namely a simple model and a complex model. The simple model was based on the assumption that the wastewater treatment system is a single compartment with input (wastewater) and output (products and waste). The complex model were based on detailed steps of the wastewater treatment processes.

3.1 The Simple Model

A balance occurs when the total input are equal to output. Efficiency reaches 100% if all materials in wastewater were converted into products and by-products. There is no perfect conversion, but the efficiency is between 0 and 100% intervals. Based on equation (1.1), the ratio equation (efficiency) is:

$$\text{Efficiency (a)} = \frac{P}{I} \qquad (2.1)$$

This simple model used the basis of calculation of 2,500 m^3/day of wastewater (production of 50 ton paper/day, 50 m^3 wastewater/ton of paper) and equal to 10,151.75 kg COD (content of waste is 4,060.7 kg/m^3).

Ekama et al. (2006) have conducted an experiment to calculate the anaerobic digester output concentration on 37 °C with a residence time of 60 days. The results of this study were converted to kg COD using Lobato formula (2011) resulted methane COD of 1,241.40 kg or 12.23% of incoming wastewater COD. The output of the simple COD balance model can be seen in Table 1.

Table 1. The simple model output of COD Balance (Basis 50 ton paper/day, wastewater 2,500 m^3/day)

Component	(%)	COD (kg)
Input		
Raw wastewater	100	10,151.75[b]
Output		
COD of Gas		
COD of methane gas	12.23[a]	1,241.40[c]
COD of non-methane gas	7.94[a]	806.31[c]
COD of clear wastewater	65.27[a]	6,626.02[c]
Total output		8,673.73
Unidentified mass		1,478.02
Efisiensi of system	85.44	

[a]Ekama et al. (2006); [b]COD total in 2,500 m^3 wastewater (COD concentration is 4,060 mg/L); [c]out of total COD input

The system has an efficiency of 85.44%. which needs to be detailed to find the COD mass flow that is not identified.

3.2 The Complex Model

Development of the COD balance complex model after the steps described below.

3.2.1 Model Description

The complex model are developed based on the previous model and follows detailed wastewater processing stages (Figure 2). This model uses the main process as the compartment.

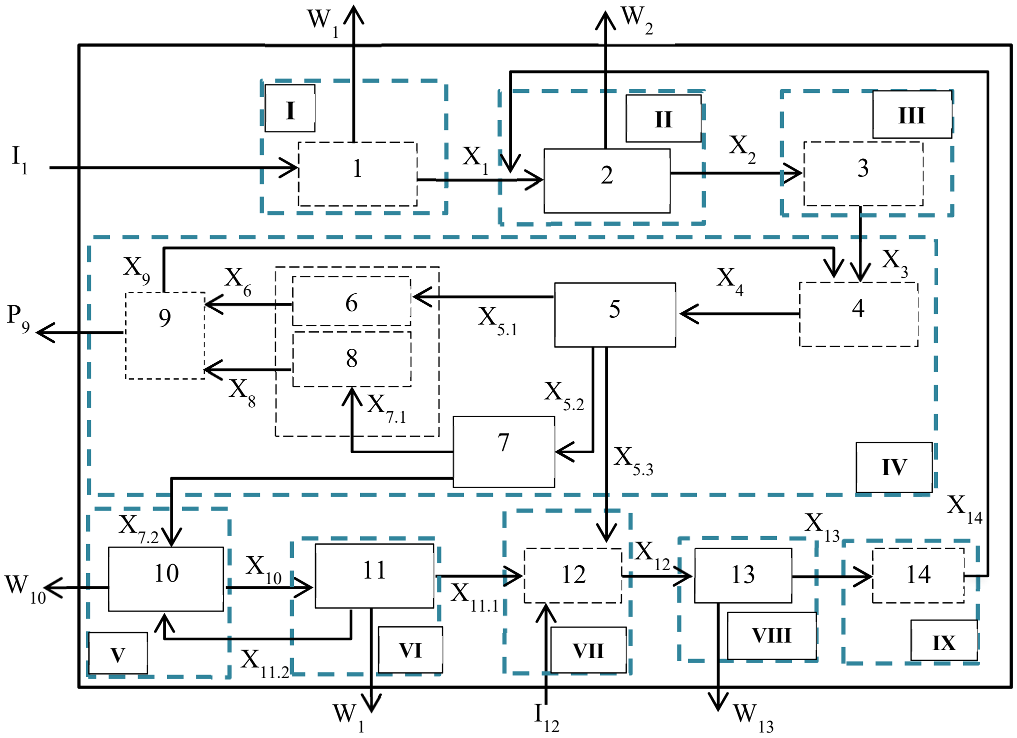

Figure 2. Complex model of COD balance

Notes: Compartment 1, 3, 4, 6, 8, 9, 12, and 14 (doted lines) are neglectable because no mass flow out the system. Symbol explanations are in Tabel 2 and 3.

Table 2. Compartment of COD complex balance model

Symbol	Description
1	Fine screener
2	Primary clarifier
3	Equalization tank
4	Feed and mixing compartment
5	Fluidized bed compartment
6	First recirculation system (RS-1)
7	Polishing compartment
8	Second rercirculation system (RS-2)
9	Three-phase separator
10	Aerated tank
11	Secondary clarifier
12	Thermo-alkali hydrolysis tank
13	Separator-belt press filter
14	Reserve tank for separated liquid portion of wastewater

Table 3. Variable of complex COD balance model

Symbol	Description
I_1	COD of influent raw wastewater
I_{12}	NaOH solution
X_1	COD of screened wastewater
X_2	COD of wastewater after primary settling
X_3	COD of wastewater after equalization
X_4	COD wastewater enter fluidized bed compartment
$X_{5.1}$	COD of methane enter first recirculation system (RS-1)
$X_{5.2}$	COD of wastewater enter polishing compartment
$X_{5.3}$	COD of sludge from IC reactor
X_6	COD of methane enter three-phase separator
$X_{7.1}$	COD of methane enter second rercirculation system (RS-2)
$X_{7.2}$	COD of wastewater out of anaerobic process
X_8	COD of methane enter three-phase separator
X_9	Circulating water and sludge to feed and mixing compartment
X_{10}	COD of aerated wastewater
$X_{11.1}$	COD of waste activated sludge (WAS)
$X_{11.2}$	COD of recycled activated sludge (RAS)
X_{12}	COD of sludge after hyrdolysis
X_{13}	COD of liquid portion out of separator-belt press filter
X_{14}	COD of liquid portion recirculated to primary clarrifier
W_1	Solid and impurities (big size)
W_2	COD of primary sludge
W_{10}	COD of CO_2 emission
W_{11}	COD of clear wastewater
W_{13}	COD of solid portion after separator-belt press filter
P_9	COD of methane gas

The COD complex balance model has 26 variables, consisting of 2 independent variables (I_1 and I_{12}) and 24 dependent variables (X_1, X_2, X_3, X_4, $X_{5.1}$, $X_{5.2}$, $X_{5.3}$, X_6, $X_{7.1}$, $X_{7.2}$, X_8, X_9, X_{10}, $X_{11.1}$, $X_{11.2}$, X_{12}, X_{13}, X_{14}, W_1, W_2, W_{10}, W_{11}, W_{13} and P_9). I_{12} is ignored because it does not affect the amount of COD in the waste, and only 13 dependent variables are used, namely X_2, $X_{5.1}$, $X_{5.2}$, $X_{5.3}$, $X_{7.1}$, $X_{7.2}$, X_{10}, $X_{11.1}$, X_{13}, W_2, W_{10}, W_{11}, and W_{13} because these variables affect the calculation. Therefore 13 equations are needed to solve the probems that consisting of 6 COD equilibrium equations (according to the number of compartments) and 7 efficiency equations.

3.2.2 Equation of COD Balance

There are 6 mass balance equations (3.1-3.6) representing main process stages of wastewater treatment, and 7 efficiency equations (3.7-3.14) that were created by linking certain input and output of each processing stage in the form of ratio.

COD Balance Equations

Compartment 2 : $I_1+X_{13}-X_2-W_2 = 0$ (3.1)
Compartment 5 : $X_2-X_{5.1}-X_{5.2}-X_{5.3} = 0$ (3.2)
Compartment 7 : $X_{5.2}-X_{7.1}-X_{7.2} = 0$ (3.3)
Compartment 10 : $X_{7.2}-X_{10}-W_{10} = 0$ (3.4)
Compartment 11 : $X_{10}-X_{11.1}-W_{11} = 0$ (3.5)
Compartment 13 : $X_{12}-X_{13}-W_{13} = 0$ (3.6)

Efficiency Equations

Compartment 2
COD of *primary sludge* (a_1)

$$a_1 = \frac{W2}{I1} = \frac{\text{COD of primary sludge}}{\text{COD of raw wastewater}} \qquad (3.7)$$

The efficiency of reducing COD content of primary clarifier is 39.20% (Yeshi et al. 2012); the value of a_1 is 0.392.
Compartment 5
Ratio of COD sludge in the reactor IC to COD wastewater to fluidized bed (a_2)

$$a_2 = \frac{X5.3}{X4} = \frac{\text{COD of sludge out of IC reactor}}{\text{COD of wastewater entering fluidized bed compartment}} \qquad (3.8)$$

The amount of COD converted to sludge in the anaerobic reactor is 11.4% (calculated using the formula of Lobato 2011); the value of a_2 is 0.114.
Compartment 5
COD methane entering RS-1 (a_3)

$$a_3 = \frac{X5.1}{X4} = \frac{\text{COD of methane entering first recirculation system (RS−1)}}{\text{COD of wastewater entering fluidized bed compartment}} \quad (3.9)$$

Flow through the first recirculation system (RS-1) includes a large portion of methane, water, and sludge (Phan et al. 2017). The amount of COD methane that passes through RS-1 is 54.9% (calculated using the formula from Lobato 2011); the value of a_3 is 0.549.
Compartment 7
COD methane enter RS-2 (a_4)

$$a_4 = \frac{X7.1}{X5.2} = \frac{\text{COD of methane enter the second rercirculation system (RS−2)}}{\text{COD of wastewater enter the polishing compartment}} \quad (3.10)$$

COD mass flow through the second recirculation system (RS-2) includes a small portion of methane, water, and sludge (Phan et al. 2017). The results of calculations using the Lobato formula (2011), the amount of COD methane that passes through the RS-2 compartment is 13.7%; the value of a_4 is 0.137.
Compartment 10
COD reduction efficiency in aerated tanks (a_5)

$$a_5 = \frac{X5}{X4} = \frac{\text{COD of wastewater out of aerobic treatment}}{\text{COD of wastewater out of anaerobic treatment}} \quad (3.11)$$

In the aerobic process 50-60% of COD content is found in sludge, 10-12% of COD content is contained in the effluent, and the rest is lost (Van Lier et al. 2008); the value of a5 is 0.66.

Compartment 11
COD in sludge formed at the aerated tanks (a_6)

$$a_6 = \frac{X6.1}{X5} = \frac{\text{COD of waste activated sludge (WAS)}}{\text{COD of wastewater out of aerobic treatment}} \quad (3.12)$$

According to Van Leur et al. (2008), as much as 50-60% of COD content is converted to biomass in aerobic process; the value of a_6 is 0.55.

Compartment 13
COD reduction in liquid portion in separator-belt press filter (a_7)

$$a_7 = \frac{X8}{X6.1} = \frac{\text{COD of liquid portion out of hydrolysis}}{\text{COD of waste activated sludge (WAS)}} \quad (3.14)$$

Kaluza et al. (2014) reported that thermo-alkaline hydrolysis processed waste activated sludge has a high level of solubility (sCOD / tCOD> 0.9). Separation process produces a liquid portion of 70-80% COD content; the value of a_7 is 0.75.
Table 4 summarizes the coefficient value of each equation. Microsoft Excel was used to calculate values of dependent variables.

Table 4. Equation coefficient

Symbol	Value	Reference
a_1	0.392	Yeshi *et al.* (2012)
a_2	0.114	Authors calculation (Appendix 1)
a_3	0.549	Authors calculation (Appendix 1)
a_4	0.137	Authors calculation (Appendix 1)
a_5	0.660	Van Lier *et al.* (2008)
a_6	0.550	Van Lier *et al.* (2008)
a_7	0.750	Kaluza *et al.* (2014)

4. Result and Discussion

The results of this study are the COD equilibrium model, energy requirements, and closed systems of pulp and paper mill wastewater processing.

4.1 COD Balance

The complex balance model was developed after the wastewater treatment process as the compartment and identifying detailed flows in each compartment. The output of the complex balance model is shown in Table 5.

COD methane produced from the complex model is 43.33%, greater than simple model. The increase in the amount of methane due to reprocessing of wastes namely WAS ($X_{7.2}$) and sludge of the anaerobic process ($X_{5.3}$) which are fed back to the initial processing. The by-product is treated with a thermo-alkaline hydrolysis, then separation of the solid and liquid portion. The liquid portion (X_{13}) is fed back to Compartment 2 to be mixed with raw wastewater. All flows were identified and generate 100% system efficiency. COD contained in clear wastewater is 638.37 kg/day equal to 255.35 mg/l. This value is below the threshold standard of 350 mg/l (Figure 3).

Table 5. *Output* of the complex balance model
(50 ton paper/day, 2,500 m^3 wastewater/day)

Component	Mass (kg COD)	(%)^b
Raw wastewater^c	10,151.75	
Output		
COD of methane gas	4,398.26^a	43.33
COD of *clear wastewater*	638.37^a	6.29
COD *of primary sludge*	3,979.49^a	39.20
COD of *solid portion*	404.84^a	3.99
COD of CO_2 emission	730.79^a	7.20
Total *output*	10,151.75	
Unidentified mass	0	
System Efficiency		100

^{a}Appendix 2, ^{b}Percentage (%) to *raw wastewater*; ^{c}Based on Table1

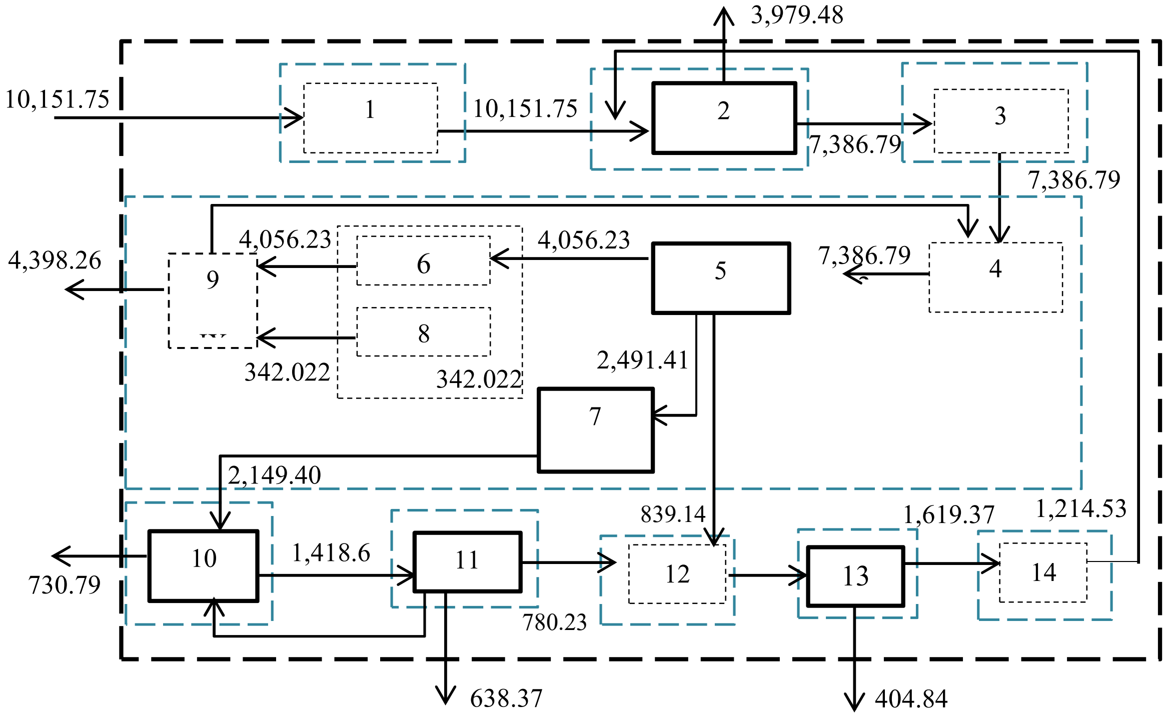

Figure 3. *Output* of complex model (kg COD/day)

Notes: Compartments 1, 3, 6, 7, 8, 9, 12, and 14 were ignored due to no mass flow out the system

4.2 Energy Harvesting

The products of WWTP wastewater treatment are methane gas, primary sludge, and solid portion resulting from thermo-alkaline hydrolysis (TA-H). Several studies explain further handling of these materials such as landfill, composting, incineration, recovery of raw material, animal feed, anaerobic digestion, and others (Bajpai 2015). The most potential use is as an energy source of anaerobic digestion and incineration. However, not all byproducts can be converted into energy for several special reasons.

Methane is a strong greenhouse gas with a global warming potential 34 times higher than CO_2, produced in the anaerobic process, can be used as an energy source (Ashrafi et al. 2015). The complex Balance model calculated the yield of 1,313 kg of methane gas with a volume of 1,970 m^3 equal to 4,398.25 kg of COD. The model results are similar to Borja and Banks (1994), namely the yield of methane is 0.395 m^3/kg COD, equal to 1,737.30 m^3 methane/day.

Methane (55-75% of biogas) can be used for heating processes, converted to other natural gas, and used to heat co-generators to generate electricity (De Mes et al. 2003). The calorific value of methane is 1,384.34 kcal /kg (Lam and Lee 2001). Methane gas can be converted to electricity through boiler heating with 80% combustion efficiency (Yingjian et al. 2011).

Primary sludge (50% dry solid) has 40% organic matter and 60% mineral material (CEPI 2011), has a heating value of 4,200 kJ/kg (Clarke and Guidotti 1995) equal to 1,003.38 kcal/kg at 63% moisture content and 20% ash content. Primary sludge can be burned to heat a steam-producing boiler which then generates electricity at efficiency of 73% (Bora and Nakkeeran 2014). The complex model calculated 19,897 kg of primary sludge equal to 3,979 kg of COD per day.

Solid portion is separated dregs in the separation process. This solid is used again in the corrugated board production process as raw material for middle layer fillers (Kaluza et al. 2014). The complex model calculated 2,250 kg of solid portion which is equal to 404.84 kg of COD per day.

Methane and primary sludge are used as boiler fuel. The resulting steam is flowed to the turbine to drive a generator that produces electric current. The single stage conversion turbine will convert 20 kg of hot steam to 1 kW of electrical energy (Bantacut and Pasaribu 2015). The methane gas and primary sludge produced 43,105 kg steam/day.

The energy produced is used to meet the energy needs of the wastewater treatment process. The need for electric and steam energy in pulp and paper wastewater treatment for production capacity of 50 ton paper/day and wastewater capacity of 2,500 m^3/day is 1,290 kW and 773 kg respectively. WWTP energy needs are 0.52 kWh/m^3. This value is in the range of energy requirements for wastewater treatment according to Tao and Chengwen (2014) namely 0.26-2.5 kWh/m^3.

Some compartments use the gravitational force to drain wastewater, ie flow into equalizing tanks and aerobic tanks, clear wastewater flows out of the secondary clarifier into the environment, and waste streams enter the separator-belt press filter. Equipment in the waste source compartment should be placed in a higher position than the waste recipient compartment, so that wastewater can flow. This is to save energy cunsumption.

Calculations using complex model showed that the energy produced is greater than the energy requirements of the wastewater treatment process. The energy produced is 2,117 kW (after being reduced by steam requirements), the conversion results from 42,332 kg of steam, while the total electricity required is 1,290 kW (Table 6). The system is able to meet the needs of steam and electricity per day with a surplus of electrical energy of 827 kW or 64.12% .

Table 6. Electrical energy needs in wastewater treament plant

Treatment	Equipment	Volume (m^3/day)	Power (kW)[b]	No. of equipment	Energy (kW)	Energy of each process (kW)[c]	Time of one cycle process (hour)[d]
Fine screener	influent pump	2,500 [a]	22[d]	2	44	289.47	6.58
	Motor	2.836 [b]	1.1[e]	1	1.1	7.24	6.58
Primary clarifier (PC)	influent pump	2,497.1633	22[d]	2	44	289.15	6.57
	primary sludge pump	10.9027 [b]	1.5[f]	1	1.5	1.64	1.09
Equalizing tank	influent pump	2,486.26	0	-	0	0	-
IC reactor	influent pump	2,486.26	22[d]	1	22	287.8	13.10
Aerobic tank	influent pump	2,486.26	0	-	0	0	-
	Aerator	2,486.26	-	-	-	122[g]	-
Secondary clarfier	influent pump	2,486.26	22[d]	3	66	287.8	4.37
	effluent pump	2,476.30	0	-	0	0	-
	RAS pump	4.98[h]	0.37[f]	2	0.74	0.74	1.00
Thermo-alkaline hydrolysis tank (TA-H)	WAS pump	4.9846[b]	0.75[f]	3	2.25	0.75	0.19
	NaOH pump	0.0399[b]	0.37[f]	2	0.74	0.0059	0.33
	IC sludge pump	2.583[b]	0.37[f]	1	0.37	0.38	1.03
Separator	input pump to belt press filter	7.6074	0	-	-	0	-
	solid portion pump	1.959[b]	0.37[f]	1	0.37	0.29	1.52
	Belt press filter	7.6074	0.37[h]	1	0.37	0.57	0.78
Tank liquid portion	input liquid portion pump	5.4899	1.5[f]	2	3	0.85	0.28
	input liquid portion to PC pump	5.4899	1.5[f]	2	3	0.85	0.28
					Total	1,290	

Notes: Power consumption 0 (zero) means that wastewater flow using gravity.
[a] Wastewater based volume; [b] Author calculation; [c] Energy multiplied with time per cycle; [d] Xylem Water Systems Australia Pty.Ltd (2012); [e] Jiangsu BOE Environmental Protection Technology Co., Ltd (2017) ; [f] ABEL Pump (2017); [g] Larsson (2011); [h] FRC System International, LLC (2015).

4.3 Closed System Model of Wastewater Treatment Process of Pulp and Paper Mills

Energy generated from the utilization of by-products of wastewater treatment of the pulp and paper mill with a capacity of 50 ton/day and 2,500 m^3/day of wastewater can meet the needs of steam and electricity with a surplus of 827 kW. Therefore, the WWTP of pulp and paper mill can be developed into an energy independent system (Figure 4).

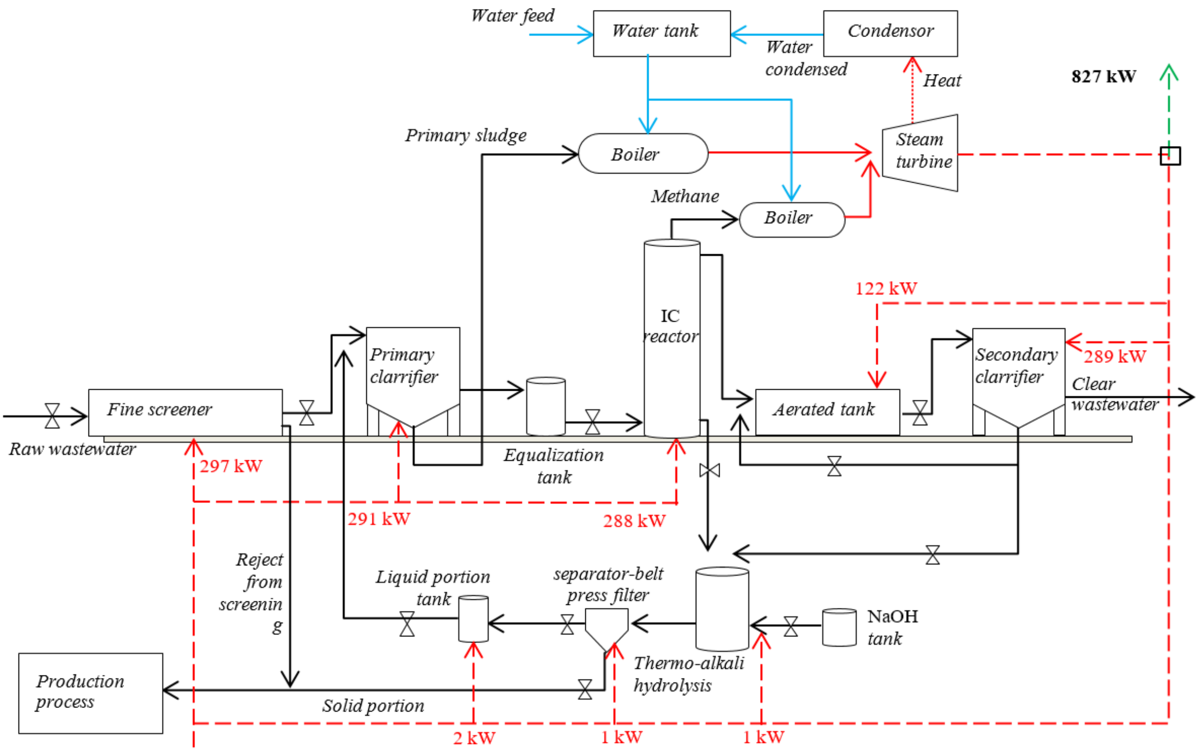

Figure 4. Closed system model of pulp and paper wastewater treatment plant of pulp and paper mill (red and blue lines denote water and energy flows and green line denotes energy surplus)

5. Conclusion and Recommendation

5.1 Conclusion

The complex mass balance model was chosen as the basis of calculating energy potential for the WWTP product and by-product because it produced the largest yield of methane. WWTP products in the form of methane gas is 1,313 kgs or 1,970 m^3 equal to 4,398.25 kg COD. In addition, the WWTP produced a byproduct of 19,897 kg of primary sludge equals to 3,979.49 kg COD and a solid portion of 2,250 kg equal to 404.84 kg COD. The total calories produced from methane and primary sludge is 37,535,014.85 kcal/day with actual steam of 43,105 kg/day equal to 2,155 kW. The electricity and steam energy requirements on WWT is 1,290 kW and 773 kg of steam per day respectively. The energy produced is able to meet the needs of steam and electricity with an electricity surplus of 827 kW or 64.12% per day. Therefore, the processing of wastewater of the pulp and paper mill can be developed into an energy-independent system.

5.2 Recommendation

Some continuing and advancing researches are recommended, such as:

a. Modeling with anaerobic reactor technology and other method of sludge processing technology to check best use of mass and energy generation.
b. Research to corrugated board with higher content of COD is recommended to proof that the higher COD will generate higher energy.
c. The use of other electricity generating technology such as gas turbine is recommended future research to find a better way of producing energy.
d. Calculation of economic benefit (profitability) would give better consideration for development of closed wastewater processing technology.

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Appendix 1. Calculation of efficiency factor of complex balance model (using formula ofLobato 2011)

Description	Equation	Value	Unit	Reference
Wastewater volume		2,500	m^3/day	
COD mass removal from system per day	$COD_{removed} = Q \times E_{COD}$	4,937.811	kg COD/day	Appendix 2
	Q = $COD_{influent}$ (COD of entering wastewater)	6,172.264	kg COD/day	
	E_{COD} = COD removal efficiency	80	%	Speece (1996)
Converted COD to *sludge*/biomassa per day	$COD_{sludge} = COD_{removed} \times Ycod$ $Ycod = Y \times K_{tvs\text{-}COD}$	701.169	kg COD_{sludge}	Foladori *et al.* (2010); Tchobanoglous *et al.* (2003a)
	*Ycod = *sludge yield* as COD	0.142	kg COD_{sludge} / kg $COD_{removal}$	
	Y = *sludge yield* as *Total Volatile Solid* (TVS)	0.1	kg TVS/kg $COD_{removed}$	
	$K_{tvs\text{-}COD}$ = Conversion Factor (1 kg TVS = 1.42 kg COD_{sludge})	1.42	kg COD_{sludge}/ kg TVS	Lobato (2011)
Converted COD to methane per day	$COD_{CH4} = COD_{removed} - COD_{sludge} - COD_{SO4}$	4,236.64	$kgCOD_{CH4}$/day	
Methane generation/day	$Q_{CH4} = (COD_{CH4} \times R \times (273+T)/(P \times K_{cod} \times 1,000)$	1,645.95	m^3/day	
	R = gas constant	0.0820	atm.L.mol^{-1}.K^{-1}	Lobato (2011)
	T = reactor temperature	30	°C	Cruz *et al.* (2016)
	K_{cod} = COD of one mol CH_4	0.064	$kgCOD_{CH4}$. per mol	Lobato (2011)

Appendix 2. Model output of COD flows

Variable	Description	Value (kg COD/day)
X_2	COD of wastewater out of primary settling	7,386.79
$X_{5.1}$	COD of methane out of first recirculation system (RS-1)	4,056.23
$X_{5.2}$	COD of wastewater entering ke polishing compartment	2,491.42
$X_{5.3}$	COD of sludge out of IC reactor	839.14
$X_{7.1}$	COD of methane out of second rercirculation system (RS-2)	342.02
$X_{7.2}$	COD of wastwater out of anaerobic process	2,149.40
X_{10}	COD of wastewater out of aeration	1,418.60
$X_{11.1}$	COD of waste activated sludge (WAS)	780.23
X_{13}	COD of liquid portion out of separator-belt press filter	1,214.53
W_2	COD of primary sludge	3,979.49
W_{10}	COD of CO_2 emission	730.79
W_{11}	COD of clear wastewater	638.37
W_{13}	COD of solid separated portion	404.84