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Assessment of Chemical Oxygen Demand Balance for Energy Harvesting in Sugar Mills Wastewater Treatment

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ABSTRACT

Sugar production process consumes a substantial quantity of water, and generates a huge amount of wastewater. It requires a lot of energy for the wastewater treatment process. The wastewater contains nutrients and a substantial amount of biomass containing energy as indicated by chemical oxygen demand (COD). The objectives of this study were to analyse the COD (mass) balance, assess the energy content of wastewater and propose an energy recovery model from the sugar mill wastewater treatment process. An Upflow Anaerobic Sludge Blanket (UASB) reactor was used as the basis of model development. The results showed that processing wastewater of 3,000 ton cane per day, sugar mills generate methane as much as 913.94 m^3/day. The energy potential for the methane was about 33,333 kJ/day and able to meet the energy needs of wastewater treatment plant of 478 kWh/day, with an energy excess of 2 kW/day. This study explained that wastewater treatment process of sugar industry can be self-sufficient by optimizing the use of generated biogas.

INTRODUCTION

Sugar factories need water and produce relatively large quantity of wastewater. According to Gunjal & Gunjal (2013), to process one ton of sugarcane, the sugar mill needs about 2 m^3 of water and produces 0.4 m^3 of wastewater, whereas Tanksali (2013) calculated that the volume of wastewater is around 0.2-1.8 m^3 per day. Kolhe (2010) researched a sugar factory with a capacity of 2,500 tons of sugar cane per day (TCD), which produces 1,000 m^3 of wastewater. Characteristics of the wastewater are brown, low pH, high temperature, containing biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS) and high inorganic components (Patil et al. 2015). The wastewater generally contains carbohydrates, nutrients, oils, chlorides, sulphates and heavy metals. These characteristics and composition of the wastewater are influenced by the intended final product, production process and machinery used (Kushwaha 2013).

In practice today, wastewater treatment consumes considerable energy. According to Peter (2011), energy consumption of wastewater treatment ranges from 0.29-1.22 kWh per m^3. Sugar factories in Indonesia have an average capacity of 3,000-7,000 TCD (Bantacut & Novitasari 2016), so that the energy needed to process the wastewater is around 0.35-3.42 MWh per day. This energy can be met with by converting organic content of wastewater to usable energy. Chemically bonded energy of wastewater is indicated by the amount of COD (Cornel et al. 2011), which ranges from 1,000-4,340 mg/L (Hampannavar 2010) or 3,682 mg/L (Tiwari & Sahu 2017, Poddar & Sahu 2015). Garrido et al. (2013) found that the energy potential is 13.88 kJ/g COD. Energy harvesting on wastewater treatment can be done by converting the organic content of biogas in anaerobic processing (Nouri et al. 2006). The wastewater contains relatively high organic matter (Table 1).

The anaerobic treatment that can be used in sugar mills is UASB reactor (Omol 1997) that converts the complex organic compounds into an energy source of CH_4 gas (Powar et al. 2013). Nacheva et al. (2009) found a UASB reactor at a sugar factory with an OLR (Organic Loading Rate) of 16 kg COD/m^3/day can produce biogas of 0.619 m^3/kg COD removal with 65.3% methane content. The calorific value of methane is 55.5 MJ/kg (Janke 2014). The resulting biogas can be harvested and used for energy in wastewater treatment processes (Guest et al. 2009). Biogas can be converted into electrical energy by co-generation system (Premalatha et al. 2008) for pumping needs, aerobic processing, and processing of mud that requires a lot of energy (Libhaber & Jaramillo 2012).

Based on these facts, research on energy harvesting on the sugar mills wastewater treatment processes needs to be done. This study examined the energy potential for organic material in wastewater to develop a COD balance model. The analysis was conducted to determine the energy poten-

Table 1: Physico-chemical characteristics of sugar mill's wastewater.

Characterstics	Value
Color	Dark yellow
pH	5.5
COD	3,682 mg/L
Phosphate	5.9 mg/L
Protein	43 mg/L
Total solid	1,987 mg/L
Suspended solid	540 mg/L
Dissolved solid	1,447 mg/L
Chloride	250 mg/L
Hardness	900 mg/L
Sulfate	419 mg/L

Source: Tiwari & Sahu (2017)

Table 2: Description of sugar mill wastewater treatment units.

Unit	Description
1	Screening and Oil Trap
2	Equalization Tank
3	UASB Reactor
4	Aeration Tank
5	Clarifier
6	Polishing Pond

tial for the biogas produced to meet the energy needs of the sugar mill wastewater treatment plant. This analysis expected that sugar mills wastewater treatment can be energy self-sufficient process. Bantacut & Nurdiansyah (2017) and Bantacut & Zuriel (2018) approved that closed production systems can be applied to develop independent energy agricultural product processing industries.

To achieve this goal, the steps taken were: (1) studying characteristics of the wastewater, energy content, appropriate processing technology and energy requirements in the sugar mills wastewater treatment process, (2) assessing the energy potential for wastewater using the COD balance model, and (3) designing a closed system model on sugar mills energy independent treatment of the wastewater.

MATERIALS AND METHODS

This study includes: (1) analysis of the energy potential for wastewater produced from the production process of the sugar mill with a capacity of 3,000 TCD and wastewater volume of 1,200 m^3/day with a COD content of 3,682 mg/L, (2) COD balance analysis of wastewater based on its removal rate to determine potential harvestable energy, (3) analysis of energy needs based on the wastewater treatment technology adopted to the characteristics and volume of the sugar mill wastewater, and (4) energy harvesting from sugar mills wastewater treatment process by utilizing its organic content to generate biogas from UASB reactor.

Data collection: The data used in this study were secondary data obtained from literature studies in the form of books, journals, research reports, electronic articles, theses and other scientific articles.

System boundary: Sugar mill wastewater treatment processes consist of six stages: screening and oil trap, equalisation tank, UASB reactor, aeration tank, clarifier and polishing pond. The COD balance principle is based on its removal to determine the energy potential for wastewater. Input of the system is 3,000 TCD. Part of COD can be converted to methane and other remaining in final wastewater effluent and in sludge from screening and oil trap unit, UASB reactor, aeration tank, clarifier and polishing pond.

Model description: The COD balance model illustrates the flow of its removal of the sugar mill wastewater treatment processes consisting of several compartments connecting input (I), product (P) and by-product (B). This model was developed using input as independent variable and output as dependent variable by using the input-output ratio (efficiency coefficient) of each compartment based on the principle of linear equation (Bantacut & Pasaribu 2015). A COD balance calculates the harvestable methane in biogas to determine energy potency for further use in wastewater treatment. This is to enable the development of an energy independent process of wastewater treatment.

COD Balance: The first step to establish the balance model is the compartment identification to describe COD flows in the sugar mill wastewater treatment process. The model is formulated from the balance equation of COD and the efficiency equations associated with the inputs and outputs between compartments in the sugar mill wastewater treatment plant (Fig. 1).

The output of COD balances is the amount of convertible COD to methane, while by-products are generated wastes of each process that can be reused. Identification of efficiency equation using secondary data, that is COD removal rates of every stage of sugar mills wastewater treatment processes. After the balance equation of COD and the efficiency coefficient is obtained, the value of COD efficiency and balance factors can be determined.

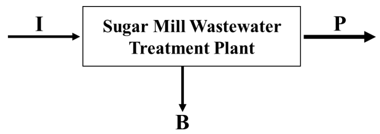

Fig. 1: Concept of COD balance.
The balance equation is I = P + B; and Efficiency (e) = P/I
Where: I = input; P = Product; B = By-product

Energy potency: Based on the COD balance model, the amount of COD methane in biogas can be estimated. Lobato et al. (2012), used the following equation to calculate the mass of methane in biogas:

$$\text{Methane mass (kg)} = \frac{C(kg) \times R \times 273+T)}{P \times Kcod \times 1{,}000} \times \text{specific mass of methane (kg/m}^3\text{)}$$

Where,

C = Convertible COD into methane/CH_4 (kg)

T = Reactor temperature (°C)

K_{COD}= COD in one mole CH_4 (0.064 kg COD_{CH4} mol^{-1})

P = Atmospheric pressure (1 atm)

R = Gas constant (0.08206 atm L $mol^{-1}K^{-1}$)

Janke (2014) applied the methane mass of 0.657 kg/m^3 and methane calorific value of 55 MJ/kg to calculate energy potential using the following equation:

Potential energy (kJ) = Mass of methane (kg) × calorific value (kJ/kg)

Calculation of Total Steam Potential (TSP) using the equation:

TSP (kg steam) = Energy Potency (kJ) / 2,779 kJ/kg steam

The conversion value is taken from the Steam Table showing the energy requirement to produce one kg of steam at a pressure of 10.4 bar and the saturated temperature is 2,779 kJ/kg. The equations for steam factor calculations produced by a boiler (SFB) and electric potential are:

SFB (kg hot steam) = TSP (kg steam) × 80 % (average efficiency of boiler)

Total of electrical potency (TEP) generated:

TEP (kW) = SFB (kg steam)/(20 kg steam/kW)

The conversion of steam to electricity using a single stage conversion turbine is 20 kg of steam/kW (Bantacut & Novitasari 2016).

COD BALANCE MODEL

The COD balance model illustrates the COD flow in the wastewater treatment process in detail that defines the organic content of wastewater (Heidrich et al. 2011). The model is developed according to compartment mass flows as shown in Fig. 2. A compartment describes the processing unit on wastewater treatment of the sugar mill.

Model description: The COD balance model consists of 8 compartments (Table 3), comprising 6 main units (Table 2) illustrating the wastewater treatment process, where compartment II is ignored and in Unit 3 (UASB reactor) divided into 3 sub-compartments (compartments 3, 4 and 5). The COD balance model has 16 variables consisting of one free variable (I_{11}) and 15 independent variables (X_{11}, $X_{21,}$ X_{31}, $X_{41,}$ X_{51}, $X_{61,}$ $X_{71,}$ $W_{11,}$ $W_{31,}$ $W_{41,}$ $P_{51,}$ $W_{61,}$ $W_{71,}$ W81 and W_{82}). The dependent variable X_{21} is omitted, since it is an explanatory process flow from compartment II. Of the 14 dependent variables as indicated in Table 3, we can find equations that can be classified into 7 balance equations of COD and 7 efficiency equations (Fig. 2).

Table 3: Description of the COD balance model compartment.

Unit	Compartment	Description
1	I	Screening and Oil Trap
3	III	Sludge Bed
	IV	Sludge Blanket
	V	Gas Separator
4	VI	Aeration Tank
5	VII	Clarifier
6	VIII	Polishing Pond

Table 4: Description of the COD balance model symbols.

Symbol	Description
I_{11}	COD of wastewater in Screening and Oil Trap
X_{11}	COD of wastewater out of Sludge Bed compartment
X_{31}	COD of wastewater in Sludge Blanket compartment
X_{41}	COD of wastewater in Gas Separator compartment
X_{51}	COD of wastewater in Aeration Tank
X_{61}	COD of wastewater in Clarifier
X_{71}	COD of wastewater in Polishing Pond
W_{11}	COD of sludge in Screening and Oil Trap
W_{31}	COD of wastewater that convertible into sludge
W_{41}	COD of wastewater to reduce sulfate
P_{51}	COD of wastewater that convertible to methane in biogas
W_{61}	COD of sludge from Aeration Tank
W_{71}	COD of sludge from Clarifier
$W_{81}W_{82}$	COD of sludge from Polishing Pond COD of effluent

The process of compartment I is screening and oil trap to eliminate large solids, oils and lubricants carried by the wastewater from sugar mills (Patil et al. 2015). The tool used to separate the solid is fine screen, resulting in some COD removal. The oil removal processes use the principle of specific gravity difference between water and oil so that the wastewater will be at the bottom and towards equalisation tanks (Awarese et al. 2015). The next stage (compartment II) is equalisation tank which aims to stabilise wastewater characteristics such as discharge, temperature and pH, so there is no COD removal (negligible compartment). Sugar mills wastewater has a low pH, so the lime is added to rise the pH for easier handling in the next treatment (Patil et al. 2015). The wastewater temperature is about 40°C, so it needs to be lowered to about 35°C before it is processed in UASB reactor (Nacheva 2009). Equalisation tanks need stirrer, mixer, agitator or diffused water to homogenise the wastewater before being flowed to the next process (Shelavale & Shinde 2016).

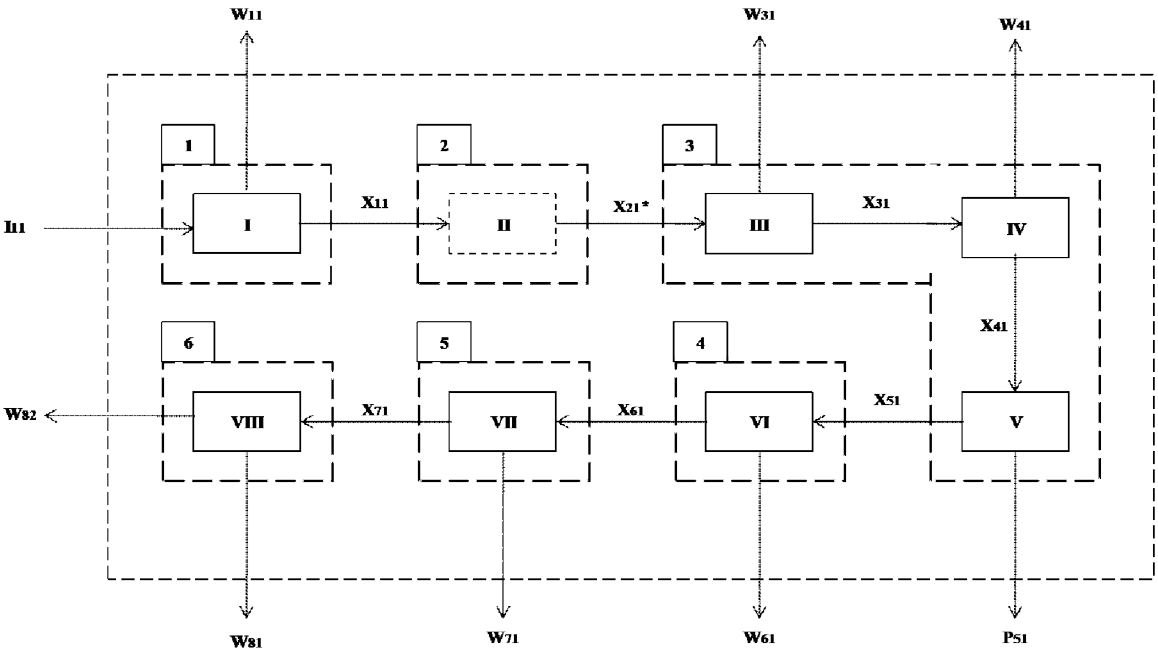

Fig. 2: Basic structure of COD balance model (symbols description in Tables 2, 3 and 4)
Notes: Compartment II is deleted because no COD flow out of the systems.

The next process of UASB reactor, which is an anaerobic wastewater treatment plant. A UASB reactor has four main compartments, namely sludge bed, sludge blanket, gas separator and settlement compartment (Patyal & Lallotra 2015). The working principle of UASB reactor is wastewater that has been separated from large solids, oil and lubricants, and resolved pH and temperature with reactor condition entering at the bottom of the reactor, entering through the bottom of reactor that is sludge bed and contact with an anaerobic microorganism. The process that occurs in the reactor, that is the process of hydrolysis, acidogenesis, acetogensis and methanogenesis, thus producing biogas. During the process of overhauling the organic content occurring in sludge bed (compartment III) and sludge blanket (compartment IV), there is COD in the wastewater converted to sludge, COD in wastewater used to reduce sulphate, COD converted to CH4 in the biogas (Lara et al. 2007). The biogas produced from the methanogenesis stage will exit from the top of the reactor, the gas separator (compartment V), to separate the gases, liquids and solids (Lobato et al 2012).

Wastewater from the UASB reactor enters aerobic post-treatment in aeration tank unit (compartment VI) to remove biodegradable organics and odour (H_2S) contents arising from anaerobic treatment, resulting in COD removal (Bula 2014). Furthermore, the sludge from the aeration tank is separated out the clarifier unit (compartment VII), resulting in COD removal (Patil et al. 2015). Wastewater from the clarifier is then channelled into a polishing pond (compartment VIII) aimed at reducing microbial content, resulting in COD removal (Augusto & Chernicharo 2007). Wastewater treatment of polishing pond can be used to irrigate sugarcane plantation (Yang et al. 1991).

Equations: There are 14 dependent variables involved in COD balance; thus 14 equations are needed for solving the problems. One mass balance equation is made from each compartment, resulting in 7 equations of COD balance (1 to 7) and 7 efficiency equations (8 to 14).

Mass balance equations of COD:

Compartment I : $I_{11}-X_{11}-W_{11}=0$ ...(1)
Compartment III : $X_{11}-X_{31}-W_{31}=0$ ...(2)
Compartment IV : $X_{31}-X_{41}-W_{41}=0$ ...(3)
Compartment V : $X_{41}-X_{51}-P_{51}=0$ ...(4)
Compartment VI : $X_{51}-X_{61}-W_{61}=0$ ...(5)
Compartment VII : $X_{61}-X_{71}-W_{71}=0$ ...(6)
CompartmentVIII : $X_{71}-W_{81}-W_{82}=0$ ...(7)

Efficiecny equations:

Compartment 1
COD removal at Screening and Oil Trap unit (a_1)

$$a_1=\frac{\text{COD of sludge out of Screening and Oil Trap unit}}{\text{COD of wastewater in Screening and Oil Trap unit}} \quad ...(8)$$

Screening is the initial stage of sugar mill wastewater treatment, so that it is easier to be processed in the next unit. According to Patil et al. (2015), the efficiency of COD removal of Screening and Oil Trap unit is 37.33%; the value of a_1 is 0.37.

Compartment 3

COD of wastewater converted to sludge out of the UASB reactor (a_2)

$$a_2 = \frac{\text{COD of } \textit{sludge}}{\text{COD of wastewater at } \textit{Sludge Bed}} \quad ...(9)$$

Based on calculations, the COD in the wastewater entering the UASB reactor unit is 2,783.59 kg per day, the COD content in the sludge that comes out of the UASB reactor unit is 142.30 kg per day. This can be interpreted as a percentage of COD sludge of 5% of COD in the wastewater entering the UASB reactor unit; the value of a_2 is 0.05.

Compartment 4

COD of sulphate reduction process in the UASB reactor unit (a_3)

$$a_3 = \frac{\text{COD of reducing sulphate}}{\text{COD of wastewater in Sludge Bed}} \quad ...(10)$$

The reduction of sulphate in H_2S formation affects the productivity of microorganisms in the reactor to produce methane, where reduction of 1.5 gram sulphate is associated with the use of 1 gram of COD (Lara et al. 2007). The calculation showed that the amount of COD to reduce sulphate is 33.96 kg out of 2,783.59 kg COD per day in the wastewater entering UASB reactor unit. This can be interpreted as a percentage of COD to reduce sulphate by 1% of COD in the wastewater entering the UASB reactor unit; the value of a_3 is 0.01.

Compartment 5

COD of wastewater converted to methane in the UASB reactor unit (a_4)

$$a_4 = \frac{\text{COD of wastewater converted to methane}}{\text{COD of wastewater at Sludge Bed}} \quad ...(11)$$

Based on the calculation, COD in the wastewater entering the UASB reactor unit is 2,783.59 kg per day which is partially converted into methane that equals to 2,329.40 kg COD per day. This can be interpreted as a percentage of COD of methane in biogas is 84% of COD in the wastewater entering the UASB reactor unit; the value of a_4 is 0.84.

Compartment 6

COD sludge removal from the Aeration Tank unit (a5)

$$a_5 = \frac{\text{COD of sludge of Aeration Tankunit}}{\text{COD of waswaterin Aeration Tank unit}} \quad ...(12)$$

According to Patil et al. (2015), an aeration tank serves to degrade the organic content by using aerobic microorganisms. The efficiency of COD removal of the aeration tank unit is 80%; the value of a_5 is 0.8.

Compartment 7

COD sludge removal from Clarifier unit (a_6)

$$a_6 = \frac{\text{COD of sludge from Clarifier unit}}{\text{COD of wastewater air entering Clarifier unit}} \quad ...(13)$$

According to Patil et al. (2015), COD removal efficiency on clarifier unit is 39%; the value of a_6 is 0.39.

Compartment 8

COD sludge removal from Polishing pond unit (a_7)

$$a_7 = \frac{\text{COD of sludge from Polishing pond unit}}{\text{COD of waswater in Polishing pond unit}} \quad ...(14)$$

Patil et al. (2015) described that the wastewater passes through the clarifier then processed in a polishing pond. The efficiency of COD removal of the polishing pond unit is 20%; the value of a_7 is 0.20.

Following the efficiency factor equations, the values of efficiency coefficient are obtained as in Table 5. Coefficient values are used to calculate the COD balance.

RESULTS AND DISCUSSION

COD balance model: The COD balance model was used to calculate the energy potential generated in the sugar mill wastewater treatment. Outputs of the model based on sugar mill capacity of 3,000 TCD is given in Table 6.

The model calculated that COD in the effluent was 27.17 kg or 22.64 mg/L which is less than the maximum limit of Indonesia National Standards of sugar mills wastewater of 100 mg/L (PERMEN LH No 5/2014). The $COD_{removal}$ value of the wastewater treatment system was 99.38%. This is in accordance with Yang et al. (1991) research finding that the efficiency value of $COD_{removal}$ in wastewater sugar mills for anaerobic-aerobic treatment reached 99.3%. COD is also obtained in sludge, consisting of W_{11}, W_{31}, W_{41}, W_{61}, W_{71}

Table 5: Efficiency factor of COD balance model.

Symbol	Value	References
a_1	0.37	Patil et al. (2015)
a_2	0.05	Author calculation
a_3	0.01	Author calculation
a_4	0.84	Author calculation
a_5	0.80	Patil et al. (2015)
a_6	0.39	Patil et al. (2015)
a_7	0.20	Patil et al. (2015)

and W_{81} of 2.028.30 kg per day or 45.91% of the total COD in the wastewater input.

The COD balance model details the COD flows in the UASB reactor unit to obtain a more accurate COD of methane, so the calculation represents the actual condition. The UASB reactor unit is divided into three compartments where COD is converted to sludge (W_{31}), COD in the wastewater to reduce sulphate (W_{41}) and COD methane (P_{51}) of 2,329.40 kg per day or 52.72% of total COD input. According to Cornel (2011), the amount of COD in wastewater that can be converted anaerobically into methane is generally 61% of the total COD input. There is a difference that may be due to COD removal of the screening and oil trap unit, an anaerobic process in UASB reactor or COD in the effluent from UASB reactor. Thus, the COD calculation in the wastewater to methane conversion rate can be used to calculate the energy potential. The COD balance based on the COD removal of the sugar mills wastewater treatment as a whole can be seen in Fig. 3.

Energy harvesting in sugar mill wastewater treatment: Organic content of the wastewater consists of carbohydrates, proteins and fats (Yao 2015, Rais & Sheoran 2015). These organic materials can be used to generate energy by anaerobic processing to convert them into biogas that contains some energy (Nouri et al. 2006). The energy value can be calculated from the COD content depicting the substrate that can be converted to methane. Based on stoichiometry, every 4 kg COD is equivalent to 1 kg CH_4, following the equation:

$$CH_4 + 2O_2 \Rightarrow CO_2 + 2H_2O$$

$$(16g) + 64\ (g) \Rightarrow (44g) + (36g)$$

Thus, one mole of methane requires 2 moles of oxygen to oxidize it to carbon dioxide and water, so that 16 grams of CH_4 produced are equivalent to the removal of 64 g of COD in wastewater (Lara et al. 2007).

UASB reactor is the most effective against wastewater treatment of sugar mills (Omol 1997). Anaerobic wastewater treatment produces biogas consisting of CO_2 and CH_4. The basic work of UASB is that the wastewater containing complex organic matter (can be known from the content of COD) entered through sludge bed at the bottom of the reactor. Organic matter is degraded into simple compounds through four stages of hydrolysis, acidogenesis, acetogensis and methanogenesis.

Biogas produced from anaerobic fermentation in the UASB reactor will go to the gas separator at the top of the reactor (Lobato et al. 2012). Kaviyarasan (2014) has researched that UASB reactor performance is influenced by several parameters including pH, temperature, hydraulic

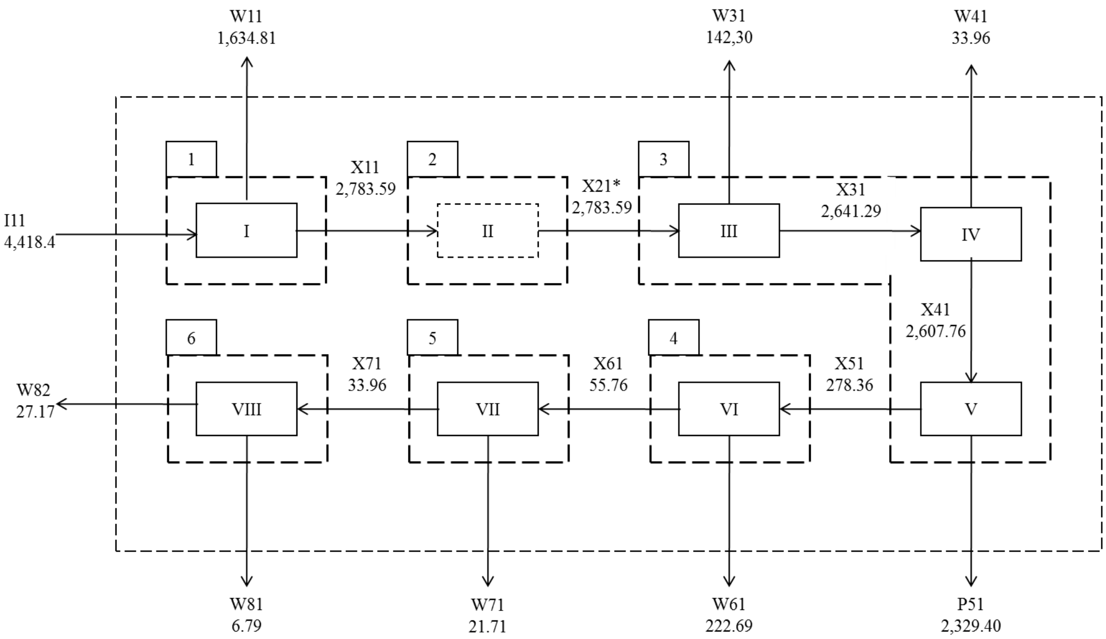

Fig. 3: The COD balance model calculation results (symbols description in Tables 2, 3 and 4) (kg/day)
Notes: Compartment II is deleted because no COD flow out of the systems.

Table 6: Outputs of COD balance model.

Mass	%	kg/day
INPUT		
COD of influent	100.00	4,418.40
OUTPUT		
Product		
Converted COD to methane in biogas	52.72	2,329.40
By-product		
Converted COD into sludge	45.91	2,028.30
COD of effluent	0.61	27.17
$COD_{removal}$ Efficiency	99.38	

retention time (HRT) and organic loading rate (OLR).

UASB reactor has been applied for sugar mill wastewater treatment. Generally, the start-up time for the UASB reactor is 4-6 months, but by adding seed sludge to the reactor, it will cut the start-up time to 2-3 weeks. The optimum conditions for the reactor are at temperatures of 33-35°C, pH 6.8-7.2, and appropriate addition of nutrients (N, P, S and micronutrients) (Lara et al. 2007). Hampannavar et al. (2010), found that the start-up time of UASB reactor using anaerobic non-granular sludge for sugar mill waste treatment was 99 days.

The result of Nacheva (2009) showed that UASB reactor for sugar mills wastewater with OLR 16 kg COD/m^3/day and HRT 11.4 hours produced biogas of 0.619 m^3/kg $COD_{removal}$ with 65.3% methane or methane yield of 0.355 m^3/kg $COD_{removal}$. According to Janke (2014), the calorific value of methane is 55 MJ/kg or equivalent to 55,000 kJ/kg. The potential energy for biogas is calculated based on the heating value multiplied by mass. Calculation of potential energy using formula: energy (kJ) = Mass CH_4 (kg) x Heat value (kJ /kg) (Table 7).

Biogas can be harvested from sugar mill wastewater treatment process to produce heat and is renewable energy (Abdelgair et al. 2014). The biogas can be converted into heat energy and electrical with a co-generation CHP (Combined Heat and Power) unit (Zuza et al. 2015). Biogas is used as a fuel in boiler (biogas fired boiler) to produce steam at a pressure of 1.04 MPa (saturated steam) or equivalent to 10.4 bar with 80% boiler efficiency (Yingjian et al. 2011). The steam generated from the boiler drives the wheels on a single stage steam turbine. The turbine generator converts mechanical energy into electrical energy where every 20 kg of steam generate 1 kW electricity (Bantacut & Novitasari 2016). The calculation of conversion from biogas to electrical energy is given in Table 8.

The energy potential generated from biogas is 480 kW per day which can be utilised to supply energy in sugar mill wastewater treatment. The energy requirements for wastewater treatment vary depending on the size (volume of wastewater, organic loading rate or hydraulic loading rate), type of wastewater treatment and effluent quality (Gu et al. 2017). Sugar mills waste treatment process begins from the first unit of the screening and oil trap to polishing pond. General use of electrical energy is for pump and aeration (Libhaber & Jaramillo 2012). The calculation of energy requirement for each process of wastewater treatment can be seen in Table 9.

Table 9 shows that the need for electrical energy is 478 kWh per day or equivalent to 0.40 kWh per m^3. The calculation of energy requirements is in accordance with Peter (2011), which states that energy consumption for wastewater treatment ranges from 0.29-1.22 kWh per m^3. The potential energy that can be generated is 480 kW, so it can meet the energy of wastewater treatment process. Surplus energy can be used as backup and supplies other purposes. Thus, sugar mills wastewater treatment system can be self-sufficient in energy; it does not require energy input from outside the system by utilising the energy potential contained in the wastewater optimally. Therefore, a closed system model can be developed in a sugar mill wastewater treatment process (Fig. 4).

Closed system of sugar mills wastewater treatment: Sugar mills wastewater treatment systems in addition to producing products of biogas, also produce final effluent and by-products in the form of sludge. Final effluent can be used for cane sugar irrigation. Biogas is used as energy input in wastewater treatment process, which is converted into electrical energy with co-generation system. Electrical energy is channelled into wastewater treatment units for pump and aerator needs. The sludge can be dried using a sludge drying bed unit which then produced compost to fertilise the cane sugar plantation. A closed system of sugar mills wastewater treatment that does not require input from outside the system and all outputs of the system can be recovered is shown in Fig. 5.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions: Sugar mills wastewater treatment process can be developed for harvesting energy to utilise the energy potential contained in the biogas. The energy potential for wastewater treatment of a capacity of 3,000 TCD is 33,333,022 kJ/day. This energy can generate electrical energy of 480 kW per day to meet the need of electrical energy in wastewater treatment of 478 kWh per day with a surplus of 2 kW per day. Thus, this study explained that the wastewater treatment process of sugar mills can be a self-sustaining energy by utilizing produced biogas optimally to develop a closed wastewater treatment system.

Table 7: Potential energy content of biogas.

Parameter	Amount	Unit	Reference/explanation
Convertable COD to methane[a]	2,329.40	kg/day	from COD balance
Volume of CH_4[b]	913.94	m^3/day	
Specific gravity CH_4	0.657	kg/m^3	(Janke et al. 2014)
CH_4 mass	600	kg/day	
Calorific value of CH_4	55,555	kJ/kg	(Janke et al. 2014)
Energy potency	33,333,022	kJ/day	

[a]Milling capacity of 3,000 TCD; effluent 1,200 m^3/day; COD content of 3,682 mg/L
[b]Temperatureof UASBreactorwas 33

Table 8: Biogas to electrical energy conversion.

Parameter	Unit	Total	Reference
Milling capacity	ton cane/day	3,000	Factroy Data
Wastewater volume	kg/day	1,200,000	Factory Data
Energy Content			
COD methane	kg/day	2,329.40	Model Calculation
CH_4 Volume	m^3/day	913.94	
CH_4 mass	kg/m^3	0.657	(Janke et al. 2014)
CH_4 mass	kg/day	600	
Total Energy			
CH_4 calorific	kJ/kg	55,555	(Janke et al. 2014)
Total generated energy	kJ/day	33,333,022	
Total Steam			
Heat to generated 1 kg of steam (saturated at 10.4Bar)	kJ/kg	2,779	Steam table
Generated steam	kg/day	11,996	
Boiler efficiency	%	80	(Yingjian et al. 2011)
Actual steam	kg/day	9,597	
Total of electrical energy			
Steam conversion with Single Stage Steam Turbine	kg steam/kW	20	(Bantacut & Novitasari 2016)
Total generated energy	kW/day	480	

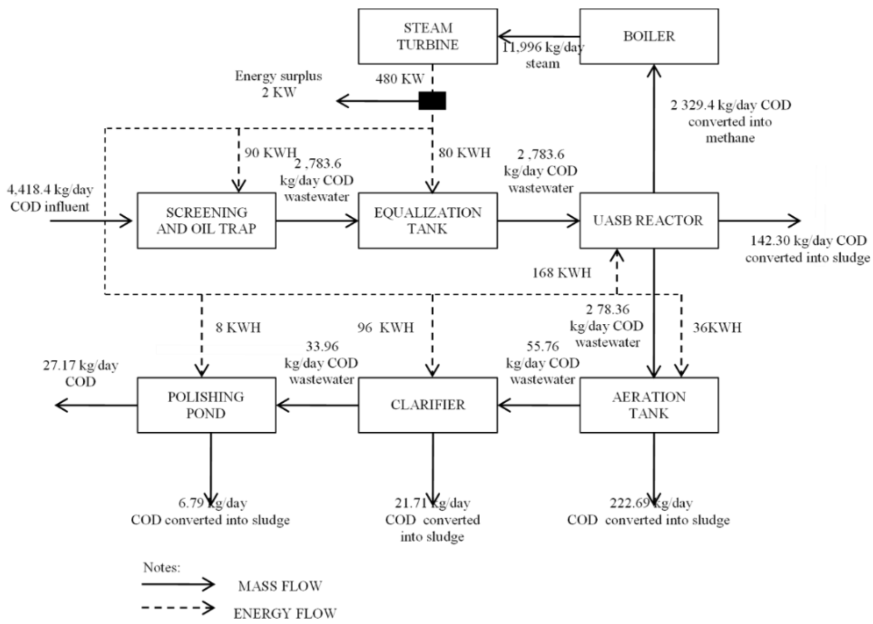

Fig. 4: Process flow model of independent energy sugar mills wastewater treatment.

Table 9: Energy requirements for sugar mills wastewater treatment of 3,000 TCD.

Process Unit	Tool/machine	Power (kW)	Operation time(hour)	Total energy (kWh)
Screening and oil separator tank	Sewage pump	3[a]	24	72
	Fine Screen	0.75[b]	24	18
Equalisation tank	Floating Aerator	0.35[c]	24	8
Pump		3[a]	24	72
UASB reactor	Slurry Pump	4[d]	24	96
Pump		3[a]	24	72
Aeration tank	Air Blower	1.5[e]	24	36
Clarifier	Slurry pump	4[d]	24	96
Polishing pond	Floating Aerator	0.35[c]	24	8
	Total Energy			478

Source: [a]http://www.bedu.eu/products/centrifugal+pumps/dwo+series; [b]http://www.foxenviro.com.au/specifications/FXP1000; [c]http://www.linn.eu; [d]www.directindustry.com/prod/tsurumi-pump/product-30418-1227699.html; [e]http://www.roots-blower.com

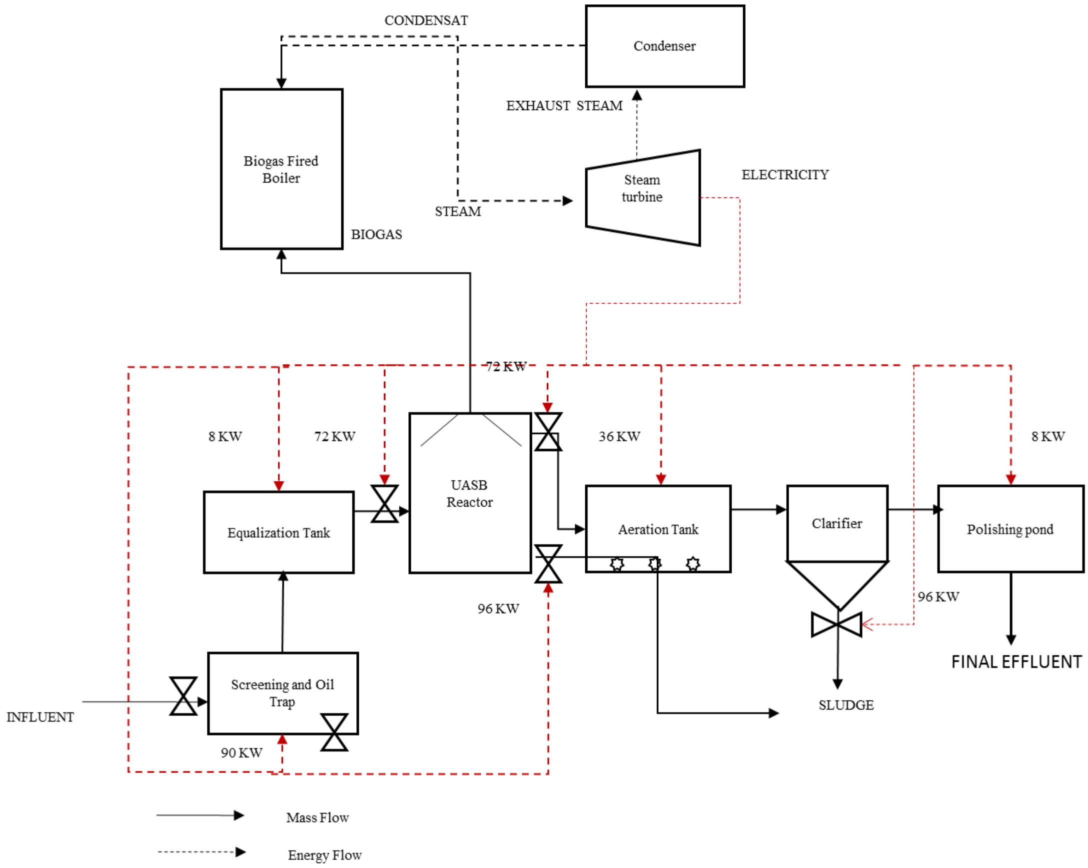

Fig. 5: Closed system of sugar mills wastewater treatment.

Recommendation: Some suggestions that need to be considered to improve the research results are:

a. Development of a more detailed COD balance model in each unit process stage to improve calculation accuracy.

b. It needs to adjust energy requirement with different wastewater treatment plants due to variation of processing units and specifications, so the energy needs are also different.

c. A different technology assessment is required to analyse the mass-to-energy conversion efficiency with improved calculation accuracy.

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