Estimation of Carbon dioxide and Methane Emissions Generated from industrial (WWT) plants

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ABSTRACT
The objective of this study is to determine the effect of chemical usage on greenhouse gas (GHG) in wastewater treatment (WWT) plants (WWTP) utilizing Life Cycle Assessment (LCA). Some applications in (WWTP) require the use of chemicals during (WWT) such as disinfection, coagulation, flocculation, precipitation and sludge conditioning. However, the chemical usage during (WWT) may contribute some negative effects to the environment especially emission of (GHG) such as Carbon Dioxide (CO$_2$) and Methane (CH$_4$). (LCA) was performed in order to estimate the emission of CO$_2$ and CH$_4$ from the chemicals used. The amount of CO$_2$ emitted was found to depend on the dosage of chemicals. Figures of 106 kg CO$_2$/ day, for CH$_4$ the CO$_2$ Equivalent for CH$_4$ emission from October 2011 until January 2012 was found to be 7852.20 kg CO$_2$/ year, 6831.00 kg CO$_2$/ year, 5148.09 kg CO$_2$/ year and 5827.74 kg CO$_2$/ year respectively. CH$_4$ emissions were found to depend on the COD of wastewater.

Keywords: GHG, WWT, BOD, COD, Life Cycle Assessment, Bridle method
Nomenclature

HRT is the hydraulic retention time
SRT is the sludge retention time
MLVSS are the mixed liquor volatile suspended solids
BOD is the biological oxygen demand
TSS is the total suspended solids
TOW = total organically degradable material in wastewater, kg COD/yr
S = organic component removed as sludge, kg COD/yr
EF = emission factor, kg CH₄/kg COD
R = amount of CH₄ recovered in inventory year, kg CH₄/yr
EF = emission factor for each treatment/discharge pathway or system, kg CH₄/kg COD
Bₒ = maximum CH₄ producing capacity, kg CH₄/kg COD
MCF = methane correction factor (fraction)
TOW = total organically degradable material in wastewater, kg COD/yr
P = total industrial product, t/yr
W = wastewater generated, m³/t
COD = chemical oxygen demand, kg COD/m³

1. Introduction

Industrial wastewater can be generated from contaminated water from the industrial activities which may contain dangerous components such as heavy metals, ammonia, cyanide and others. The major aim of wastewater treatment (WWT) is to remove as much of contaminants as possible before the “effluent” is discharged to the environment as environmentally safe fluid waste stream. Before the wastewater effluent is discharged, a series of treatments; physical, chemical and biological have to be performed to meet the standards required by the Department of Environment (DOE).

Nowadays, environmental problem are a major concern in (WWT) plants. Most of these treatments focus on cost reduction only with little or no consideration to minimize environmental impacts. Legislations by governments continuously being refined with one aim; that is to control the level of pollutants in treated water in order to avoid industrial wastewater being disposed in a manner that is dangerous to the human health and / or damaging the environment.
Emission reduction of the greenhouse gases (GHG) have become one of the leading factors in combating global warming problem. Not much work has been done on the contribution of wastewater chemicals used in the treatment of industrial wastewaters towards global warming. Generation of (GHG) in the (WWT) plant can be direct or indirect. In order to estimate emissions of (GHG) from (WWT) plants, the Life Cycle Assessment (LCA) analysis with the inventory for the gases can be performed (Colliver, 2000).

(LCA) is a “cradle to grave” method used to evaluate possible environmental impacts of the products, or service from design to disposal by compiling the inventory of relevant inputs and outputs, evaluating the potential environmental impacts associated with those inputs and outputs, and finally interpreting the results of the inventory and impacts phases in relationship of the study.

(LCA) involves the collection and evaluation of quantitative data on inputs and outputs of material, energy, and waste flows associated with a product over its entire life cycle so that the environmental impacts can be determined. The procedures of (LCA) are part of the ISO 14000 environmental management standards which are in ISO 14040: 2006 and 14044: 2006. There are four main stages in conducting the (LCA), namely:

- Goal and scope
- Life cycle inventory
- Life cycle impact assessment
- Interpretation

Goal and scope is the most important stage to identify the (LCA)’s purpose and the expected product of the study. The scope of study usually implies defining the system, its boundaries and any assumptions or limitation based upon the goal definition.

A Life Cycle Inventory (LCI) includes information on all of the environmental inputs and outputs associated with a product or service such as material and energy requirements, as well as emissions and wastes.

Life Cycle Impact Assessment is used to assess the potential human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.

Interpretation is a systematic technique to evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

The (WWT) plant is an important part in any industry. These plants contribute to the emission of (GHG) worldwide (Copp, 2002). One of the sources of (GHG) emission in these plants comes from chemicals used in the treatment. Most plants rely on the use of several (GHG) generating chemicals.

Chemicals regularly used in industrial (WWT) systems are related to the applications which are coagulation, flocculation, precipitation of dissolved substances, pH control and also sludge conditioning. In our work, the emission of (GHG) from the chemicals usage will be quantified by using (LCA) method. The outcome will be beneficial for better design operation in the future (Corominas, 2010).
2. Research methodology

The study is done in a few stages that involve chemicals used starting from the production of the chemicals, transportation of the chemicals to the (WWT) plant. The study was carried out in order to evaluate the possible environmental impacts of chemical use. Lam Soon Edibles Oils in Pasir Gudang Johor plant specializes in edible oils separation was chosen for our study. In the (LCA) method for this study, a few aspects have been considered. Normally, the input of the system includes all the materials and energy consumption from cradle to grave phases, namely; construction phase, operational phase and demolishment phase. However, our study focuses on production, transportation and operational phase. The daily consumption of chemicals and emission released on other environmental impact from the reaction were accounted and the data used in this study were obtained from the company.

There are few parameters that need to be considered as well for the estimation of the (GHG) emission namely:

- **Dosage of Chemical**
  In (WWT) plants, there are few chemicals used including sulfuric acid, lime, alum, aluminium chlorohydrate and flocculants. The data of doses of chemicals were taken based on daily consumption.

- **Chemical Oxygen Demand (COD)**
  Chemical Oxygen Demand (COD) is a measure of the amount of oxygen, divided by the volume of the system, required to oxidize the organic (and inorganic) matter present in wastewater using an oxidizing agent.

- **Secondary Data**
  The secondary parameter and data were obtained from published works to help in estimation of (GHG) emission (Consulting, 2007).

- **(GHG) estimation methods**
  From data collected from the (WWT) plant, the amount of (GHG) emission were calculated for Carbon Dioxide and Methane. Calculation of Carbon Dioxide emissions were carried out by applying “Bridle model” during chemicals usage for the production of (GHG) from (WWT) plant. While for Methane, the method used is based on the 2006 IPCC Guidelines for National Greenhouse Inventories (IPCC - Intergovernmental Panel on Climate Change).

- **Carbon Dioxide Emission**
  “Bridle model” is one of the methods used in determining the amount of (GHG) emissions in industries. This method relies on five important parts namely:
  
  i. Bio treatment
  ii. Sludge treatment
  iii. Chemical usage
  iv. Power consumption
  v. Biogas produced.
Figure 1 illustrates sources of CH₄ emissions from industrial (WWT).

Figure 1 Tree for CH₄ emission from industrial (WWT)

For every parts of “Bridle method”, emissions were calculated in of kg CO₂/day. CH₄ emissions were calculated in equivalent of CO₂/day. Emissions for CH₄ and CO₂ were next calculated using conversion factors, the daily GHG emission from (WWT) were estimated. The inputs used for this estimation are listed in Table 1.
Table 1 Input Used For (GHG) Estimation

<table>
<thead>
<tr>
<th>Input</th>
<th>Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influent flow</td>
<td>CO2 from bio treatment</td>
</tr>
<tr>
<td>HRT</td>
<td>N2O from bio treatment</td>
</tr>
<tr>
<td>SRT</td>
<td>Biogas, CH4 and CO2</td>
</tr>
<tr>
<td>MLVSS concentration</td>
<td>Amount of sludge</td>
</tr>
<tr>
<td>BOD concentration inlet and outlet</td>
<td>Sludge reuse</td>
</tr>
<tr>
<td>TSS concentration</td>
<td>Power for aeration</td>
</tr>
<tr>
<td>Fractions sludge disposal</td>
<td>Chemicals CO2</td>
</tr>
<tr>
<td>Chemicals</td>
<td></td>
</tr>
<tr>
<td>Non aeration power</td>
<td></td>
</tr>
</tbody>
</table>

The “Bridle model” calculates emitted CO$_2$ from five different chemicals namely; lime, chlorine, caustic, hypochlorite and polymer. Since CO$_2$ is emitted from lime and polymer treatments, thence they were mainly used in our study. Unfortunately limited data is available for CO$_2$ generated from polymer treatment; therefore our calculations relied mainly on lime treatment.

The following equations were used for estimation of GHG emissions.

**Lime**

\[
CO_{2 \text{lime}} = \text{Lime}_{\text{added}} \times \text{Sludge}_{\text{total}} \times \frac{(\text{Lime}_{\text{CO2}})}{1000} \quad (1)
\]

\[
CO_{2 \text{lime}} = \text{CO2 emitted} \ [\text{kg CO2 / day}] \text{ from lime usage.} \quad (2)
\]

\[
\text{Lime}_{\text{added}} = \text{The amount of lime added} \ [\text{kg lime/ kg dry solids}] \quad (3)
\]

\[
\text{Lime}_{\text{CO2}} = \text{The amount of CO2 emitted when one tonne of lime used} \ [\text{kg CO2/ tonne lime}] \quad (4)
\]

**Polymer**

\[
CO_{2 \text{polymer}} = \text{Polymer}_{\text{added}} \times \text{Sludge}_{\text{digested mass}} \times \frac{(\text{Polymer}_{\text{CO2}})}{1000000} \quad (5)
\]

\[
CO_{2 \text{polymer}} = \text{CO2 emitted} \ [\text{kg CO2 / day}] \text{ from polymers usage.} \quad (6)
\]

\[
\text{Polymer}_{\text{added}} = \text{the amount of polymer added} \ [\text{kg lime/ kg dry solids}] \quad (7)
\]
Polymer_{CO2} = CO_2 emitted when a polymer is used [kg CO_2/ tonne lime] \hspace{1cm} (8)

There are several factors affecting CH_4 emission potential from industrial (WWT) plants; the concentration of degradable organic matter, the volume of wastewater and the propensity of the industrial sector to treat their wastewater. Suggestion on completing the inventory by using a top down approach that includes the following general steps:

Step 1: Use Equation 11 below to estimate total degradable organic carbon (TOW) in wastewater for industrial sector.

Step 2: Select the pathway, and use equation 10 to obtain emission factor (EF).

Step 3: Use Equation 9 to estimate emissions, adjust for possible sludge removal and CH_4 recovery.

Step 4: Sum the results.

Total CH_4 Emissions from Industrial Wastewater plants is given by:

\[
\text{CH}_4 \text{ Emissions} = \sum[(TOW - S)EF - R] \hspace{1cm} (9)
\]

\[
EF = B_o (\text{MCF}) \hspace{1cm} (10)
\]

The total degradable organic carbon (TOW) is given by:

\[
TOW = P \cdot W \cdot COD \hspace{1cm} (11)
\]

3. Results and discussions

The dosages of chemicals used in (WWT) plant in Lam Soon Edible Oils Sdn Bhd were obtained from the operation logbook and used in this study. Table 2 lists these quantities.

Table 2 Daily Dosage of Chemical Used In Lam Soon Edible Oils (WWT) Plant

<table>
<thead>
<tr>
<th>Name of Chemicals</th>
<th>Dosage (kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alum</td>
<td>150</td>
</tr>
<tr>
<td>Aluminium chlorohydrate</td>
<td>9</td>
</tr>
<tr>
<td>Lime</td>
<td>50</td>
</tr>
<tr>
<td>Polymer</td>
<td>0.6</td>
</tr>
</tbody>
</table>

The data were taken for 3 month from October till December 2011. These data are contained in Table 3.
Table 3 Water Treated and Chemical Oxygen Demand in Lam Soon Edible Oils (WWT) Plant for the period October 2011 to January 2012.

<table>
<thead>
<tr>
<th>Month</th>
<th>Total Water Treated (m³/ton)</th>
<th>COD (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 2012</td>
<td>0.7626</td>
<td>0.075</td>
</tr>
<tr>
<td>December 2011</td>
<td>0.7424</td>
<td>0.067</td>
</tr>
<tr>
<td>November 2011</td>
<td>0.7500</td>
<td>0.088</td>
</tr>
<tr>
<td>October 2011</td>
<td>0.7440</td>
<td>0.096</td>
</tr>
</tbody>
</table>

By applying “Bridle model” to data in Tables 4 and 5, CH₄ and CO₂ emissions were estimated (Consultin, 2007; Cleemput, 1998).

Table 4 CH₄ Emission from October 2011 until January 2012

<table>
<thead>
<tr>
<th>Sector</th>
<th>Edible Oil waste treatment plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>CH₄ Emission Estimation</td>
</tr>
<tr>
<td>Water treated (m³/ton of oil)</td>
<td>COD (kg/m³ of treated water)</td>
</tr>
<tr>
<td>TOW (kg COD/yr)</td>
<td>CH₄ Emission (kg CH₄/yr)</td>
</tr>
<tr>
<td>January 2012</td>
<td>0.7626</td>
</tr>
<tr>
<td></td>
<td>0.075</td>
</tr>
<tr>
<td></td>
<td>3431.7</td>
</tr>
<tr>
<td></td>
<td>257.38</td>
</tr>
<tr>
<td>December 2011</td>
<td>0.7424</td>
</tr>
<tr>
<td></td>
<td>0.067</td>
</tr>
<tr>
<td></td>
<td>2984.4</td>
</tr>
<tr>
<td></td>
<td>223.83</td>
</tr>
<tr>
<td>November 2011</td>
<td>0.7500</td>
</tr>
<tr>
<td></td>
<td>0.088</td>
</tr>
<tr>
<td></td>
<td>3960.0</td>
</tr>
<tr>
<td></td>
<td>297.00</td>
</tr>
<tr>
<td>October 2011</td>
<td>0.7440</td>
</tr>
<tr>
<td></td>
<td>0.096</td>
</tr>
<tr>
<td></td>
<td>4285.4</td>
</tr>
<tr>
<td></td>
<td>341.40</td>
</tr>
</tbody>
</table>

The following assumptions were made in our estimations:
1- Water treated was assumed to be identical to wastewater generated.
2- Default values for S and R = 0 (Kiyoto Tanabe,(NGGIP)
3- The IPCC COD – default factor for B₀ = 0.25 kg CH₄/kg COD.

Table 5 CO₂ Emission from October 2011 until January 2012

<table>
<thead>
<tr>
<th>Data</th>
<th>CH₄ Emission (kg CH₄/yr)</th>
<th>CO₂ Equivalent (kg CO₂/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 2012</td>
<td>257.38</td>
<td>5919.74</td>
</tr>
<tr>
<td>December 2011</td>
<td>223.83</td>
<td>5148.09</td>
</tr>
<tr>
<td>November 2011</td>
<td>297.00</td>
<td>6831.00</td>
</tr>
<tr>
<td>October 2011</td>
<td>341.40</td>
<td>7852.20</td>
</tr>
</tbody>
</table>
Based on these results, the quality of wastewater for each month can be predicted. If the value of COD is high, it means that the wastewater quality from the chemical plant is highly polluted and need to treat carefully both chemically and biologically. Actually, there are no standard emissions for CO₂ and CH₄ in industry because there are several influencing factors which must be considered such as process selection, chemical use, transportation and others that contribute to the (GHG) emission.

Conclusion

Our study shows that the use of the chemicals in (WWT) plant have contributed to the emission of (GHG) such as Carbon Dioxide (CO₂) and Methane (CH₄). The consideration of the emission of the greenhouses gases in this research was started from the production of the chemicals and also during the operational of the (WWT) plant. The results also shows that the impact of CO₂ emission depends on the amount of dosage of the chemicals and the sludge produced in the (WWT) plant. While for CH₄ emission, the value depends on the quality of the wastewater in the plant. The amount of the CH₄ emitted is proportional to the value of COD of wastewater. Finally, industries must consider their contribution towards (GHG). It is well established that (GHG) affects the environment and it is our moral duties to minimize their effects.

References

Tanabe, K., Technical Support Unit, IPCC National Greenhouse Gas Inventories Programme (NGGIP).
The IPCC assesses the scientific, technical and socio-economic information relevant for the understanding of the risk of human-induced climate change. Available online: IPCC - INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE,WWW/IPCC.CH/