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Research Article

CASE STUDY ON AIR POLLUTANTS EMISSIONS FROM BOILER STACK OF BIODIESEL PLANT USING ATMOSPHERIC DISPERSION MODELLING

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ABSTRACT
Fossil fuel depletion, global warming issues, and environmental pollution issues, had been encouraging the development of biodiesel industry. Biodiesel is an alternative fuel that is renewable, sustainable, and environmentally friendly. However, several biodiesel plants still utilize fossil fuel as a boiler fuel that can give the negative impact on the environment. The purpose of this study was to analyze the distribution of air pollutants (SO_2, NO_2, and CO) concentration emitted from the biodiesel plant stack using Gaussian Dispersion Equation. To obtain the concentration of air pollutantsdistribution the meteorological condition data from the impact receiving area, such aswind speed, wind direction, and atmospheric stability was required. Dispersion models use mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by a source. The result of this study showed that the SO_2 and NO_2 pollutants emission from the production of biodiesel was below the threshold, which means it did not endanger the surrounding population. Whereas, the concentration ofCO pollutant emission in the radius below 450 m from the emission source, give the negative impacts on the environment. It indicated that the safe distance of biodiesel plant site to the settlements area is out of 450 m radius from the emission source.

Key Words: Biodiesel Plant, Gaussian Dispersion Equation, Human Health and Pollution

INTRODUCTION
Biodiesel is an alternative fuel that could substitute the petroleum diesel fuel. Compared to petroleum-based diesel, biodiesel has a high cetane number (a measure of a fuel's ignition quality) and has a potential to reduce emission because it yields a better combustion emission profile, such as lower emissions of carbon monoxide, particulate matter and soot, unburned hydrocarbons, NO_x and especially, SO_x (Zhang et al., 2003[a]; Zhang et al., 2003[b];Wirawan et al., 2008; Ghosal et al., 2008). Therefore, biodiesel is recommended as a fuel that has impact on thereduction of air pollution and public health risks.

The development of biodiesel industry is currently became very important along with the declining petroleum diesel fuel reserves, global warming issues, as well as the issue of environmental pollution. However, in the industrial process, some of biodiesel plants still use the fossil fuel to produce biodiesel. One issue that caused by the combustion of fossil fuels in energy conversion devices is a decrease of ambient air quality. Therefore, in planning of a biodiesel plant establishment should be considered to the proper location in order to minimize the impact of environmental pollution that may endanger the population's health near by the plant. The quantity of air pollutants that potentially released from the biodiesel plant should be considered, becausehigh concentrations of pollutants in ambient air will affect the recipients particularly humans, animals, plants, and materials or objects which are located in the pollutant sources environment.

The major emission sources associated with the operation of the biodiesel plant is emissions from the boiler stack (ERM, 2007). Some air pollutants like nitrogen oxides (NO_x), carbon monoxide (CO), sulfur dioxide (SO_2), hydrocarbons (HC) and particulate matter (PM), generated from the combustion process from boiler providing steam and energy to the process, directly affects the environment and health risks (Cretu et al., 2010).

Pollution is the act that pollutes the environment that causes instability, disorder, harm or discomfort to the ecosystem, i.e. physical systems or living organisms. Air pollution is one of the major problems of urban environment as a consequence of economic development, urbanization, energy consumption, air and urban road transport and increasing number of urban population. Air pollution has been and continues to be a significant health hazard all over the world. Exposure to air pollution is an issue of concern due to the diversity of these pollutants, adverse effects were observed at different levels of air pollution, and a large number of people at risk. The effects of air pollution can sometimes be observed even when the pollution levels below the level indicated by the air quality guidelines (Brunekreef & Holgate, 2002; Chen & Kan, 2008; Cretu et al., 2010).

Considering the fact that air pollutant has been associated with a series of adverse health effects, it is important to predict air pollution from the biodiesel plant stack. An easy and an inexpensive estimation can be performed through atmospheric dispersion modeling. The purpose of this study was to analyze the distribution of airpollutant (SO_2, NO_2, and CO) concentration from the biodiesel plant stack using Gaussian Dispersion Equation. The result of this study was expected to be used as a consideration in anticipation of possible negative impacts caused by biodiesel plants, and also provided recommendation and information about the safe distance of biodiesel plant site to the settlements area.

ATMOSPHERIC POLLUTANTS

Pollutantsare substances that are not natural constituents ofthe environment, with their adverse effect being caused by concentrations higher than those which would be expected from natural causes (Reeve, 2002). The principal air pollutants resulting from fossil fuel combustion are the following: (a)carbon monoxide (CO); (b) the oxides of sulfur, SO_2 and SO_3 (represented as SOx); (c) theoxides of nitrogen, NO and NO_2 (NOx); and (d) 'particulates', consisting primarily of veryfine soot and ash particles. Air pollution may result also from unburned hydrocarbons;these either pass through energy conversion devices without burning or escape into the airby evaporation before they can be burnt.These primary pollutants can further interact with the environment to generate additionaldeleterious effects. Examples of these effects (secondary pollutants) are acid rain andsmog, the greenhouse effect and the high ozone levels in the air we breathe (Radovic, 1997). The parameters considered in this study are sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide (CO). Sulfur dioxide (SO_2) emissions come from burning of sulfur-containing fossil fuels which may contain up to 6% sulfur. At relatively high concentrations, SO_2 causes severe respiratory problems (Badenhorst, 2007); at sufficiently high concentrations, SO_2 exposure is harmful to susceptible plant tissue. SO_2 is also a source of acid rain, which is produced when SO_2 combines with water droplets to form sulfuric acid (H_2SO_4). Fine particles of H_2SO_4 will be binding in the lungs which can cause respiratory diseases. It can also heighten the risk of skin cancer due to sulfate and nitrate compounds into direct contact with skin. Another impact of acid rain include influence of surface water quality, dissolved heavy metals contained in the soil thus affecting the quality of ground water and surface water, and its corrosiveness damaging materials and buildings. SO_2 and other tropospheric aerosols containing sulfur are believed to affect the radiation balance of the atmosphere, which may cause cooling in certain regions (Cahyono, 2007; Fardiaz, 1992; Matthias et al., 2006).

Nitrogen oxides (NO_x) refers to the mixtures of nitric oxide (NO) andnitrogen dioxide ($NO_{2)}$ that are formed when combustion causesthe nitrogen and oxygen in the atmosphere to combine toform NO, some of which then oxidizes further to NO_2; combustion gases contain about 5 to 10%NO_2 mixed with NO. NO_2, the most toxic of the NO_x,causes damage to lung tissues at concentrations higher thanusually found in ambient atmospheres(Ather et al., 2010). NO_2 is a noxious gas that can cause inflammation of the lungs and, at highconcentrations, even death. In addition, NO_x will react further with water andoxygen to form nitric acid(HNO_3). Like sulfuric acid(H_2SO_4), nitric acid is a very strong acid that easily corrodes or attacks many materials rain (Fardiaz, 1992; Matthias et al., 2006; Pfafflin & Ziegler, 2006). Nitric acid is also a component of acid.

Carbon monoxide (CO) is a product of incomplete combustion ofany fuel. It is both a highly poisonous gas and the principal constituent of photochemicalsmog. CO is poisonous when inhaled because it combines withhemoglobin, the oxygen-carrying substance in red bloodcells and block it. Therefore, the lack of oxygen makescells and tissues to die (Fardiaz, 1992; Matthias et al., 2006; Pfafflin & Ziegler, 2006; Currie et al., 2009).

The people most affected by air pollution are those who are situateddownwind of the major sources. To prevent or minimize damages of atmospheric pollution, a method for predicting a concentration of atmospheric pollutants is urgently needed, which can rapidly and reliably detect and quantify air quality. The study on dispersion of air pollutants from a stack is an effort to develop an environmentally friendly industry.

MATERIALS AND METHODS

Air Pollution Dispersion

Pollutants dispersion in the air can be visualized by looking at the pattern of dispersion (plume) of smoke emitted by the stack continuously. The size of the plume carried by the wind will increase due to dispersion. Dispersion also leads to the decreases of pollutants concentration in the smoke along with the increase of the distance from the emission source.

Dispersion models use mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by a source. Using observations and/or simulated meteorological fields, dispersion models can predict concentrations at selected downwind receptor locations (Matthias et al., 2006). The Gaussian Dispersion Equation, a mathematical approximation that simulates the steady-state dispersion of pollutants from a continuous point source is given below (Turner, 1994; Matthias et al., 2006).

$$C_{(x,y,z,H)} = \frac{Q}{2\pi\sigma_y\sigma_z\bar{u}} \times exp\left(-\frac{y^2}{2\sigma_y{}^2}\right) \times \left[exp\left(-\frac{(z-H)^2}{2\sigma_z{}^2}\right) + exp\left(-\frac{(z+H)^2}{2\sigma_z{}^2}\right)\right] \quad (1)$$

Where:
C = point concentration at receptor, in µg/m^3;
(x, y, z) = ground level coordinates of the receptor relative to the source and wind direction, in meters;
H = effective release height of emissions, in meters (m);
Q = mass flow of a given pollutant from a source located at the origin, in µg/s;
$\bar{u}$= wind speed, in m/s;
σ_y and σ_z= standard deviation of plume concentration distribution in y and z plane, in meters.

Value of σ in the above equation is estimated from several empirical formulas that connectedσ with the distance of the wind flow and the stability conditions of the airflow (equation 2). The formulas were developed by *Brookhaven National Laboratory* (BNL).

$$\sigma_y = ax^b \quad \text{and} \quad \sigma_z = cx^d \quad (2)$$

Where values of a, b, c and d are parameters that depend on the stability conditions of the airflow (Matthias et al., 2006). It is assumed that the total reflection of the plume at ground level (z = 0 conditions). Gaussian dispersion model has been widely used for predicting pollutants dispersion and concentration (Laskarzewska & Mehrvar, 2009; Cretu et al., 2010; Latha & Shanmugam, 2010; Suryani et al., 2010; Teleaba & Mihai, 2012).

Scenario

The study was limited to a small scale biodiesel plant and used the data of emission from the boiler stack of biodiesel plant, then the distribution of pollutants concentration were analyzed using Gaussian models (equation1). The air qualities were measured based on Air Pollutant Standard Index (*Indeks Standar Pencemar Udara*/ ISPU) based on KEP 45 / MENLH / 1997 and KepKa. Bapedal No. 107 in the year of 1997 (Tabel 1). ISPU is numbers that do not have a functional unit which describes the condition of ambient air quality in certain locations and times, that based on the impact on human health, aesthetic values and other living things**.**

Table 1: Air Pollutant Standard Index (*Indeks Standar Pencemar Udara*/ ISPU)

Index Number	**Category**	**SO_2 (24 hours)**	**(NO_2)1 hours**	**CO (8 hours)**
		µg/m^3	**µg/m^3**	**µg/m^3**
1 - 50	Good	SO2 ≤ 80	*)	CO ≤ 5
51 - 100	Medium	80 < SO2 ≤ 365	*)	5 < CO ≤ 10
101 - 199	Unhealthy	365 < SO2 < 800	*)	10 < CO < 17
200 -299	Extremely unhealthy	800 ≤ SO2 < 1600	1130 ≤ NO2 < 2260	17 ≤ CO < 34
≥ 300	Dangerous	SO2 ≥ 1600	NO2 ≥ 2260	CO ≥ 34

*) *There is no index to be reported at low concentrations with short-term exposure*

Pollutants concentration from the combustion of fossil fuel in Boiler was directly measured from the boiler stack of a small scale biodiesel plant located in Research Development Engineering Operation (RDEO) in the region of Research Centre for Science and Technology, Serpong, South Tangerang Manucipality, Indonesia. The plant capacity is 1 ton/day with a compact design and small size boiler for steam generator.

The simulated pollutant gases consist of three types, namely sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide (CO). To obtain the concentration of pollutantsdistribution required the physical condition of the biodiesel plant, such as height anddiameter of stack, gas velocity that emitted from stack, and also the meteorological condition data from the impact receiving area. The data included wind speed, wind direction and atmospheric stability.

The meteorological condition datathat were obtained from the first class of Geophysics Station in the Meteorology, Climatology, and Geophysics Agency Tangerang, on the official site of South Tangerang Manucipality Government, were as follows: the wind speed average is 3.8m/s, with the wind direction in January to April and November to December is to the West, while May to October is to the North (South Tangerang Manucipality Government, 2012).

The wind is one of the most important meteorological parameters for the transport and dispersion of air pollutants. The wind acts either by speed and direction, its influence on air pollution being high variable, depending on the source position. Generally, wind speeds increases with altitude; the dispersion is being facilitated by the wind. More wind will be stronger; the pollution levels will be lower whereas, a wind with a low speed supports the local accumulation of pollutants (Cretu et al., 2010).

RESULTS AND DISCUSSION

Based on the research that was conducted at the RDEO biodiesel plant, boiler stack emitted 25.362µg/s SO_2 pollutant, 0.227µg/s NO_2 pollutant, and 178.478 µg/s CO. The analysis result for pollutants concentration from biodiesel plant using Gaussian Dispersion Model (equation 1) is given in Table 2. The highest pollutant concentration value found at a radius of 25 m from the stack.

Table 2: The value of pollutants concentration distribution

Distance by the wind direction, x (m)	Pollutant Concentration (µg/m^3)		
	SO_2	NO_2	CO
25	69.418	0.623	488.516
50	27.196	0.244	191.390
100	8.920	0.080	62.775
200	2.772	0.025	19.508
300	1.387	0.012	9.763
400	0.848	0.008	5.964
500	0.578	0.005	4.067

The results showed that based on the atmospheric dispersion modelingusing Gaussian Dispersion Model, the distribution of concentrations in ambient air for parameter SO_2 and $NO_2$are under the threshold. It means the SO_2 and NO_2pollutants didn't affect to the air quality around the biodiesel plant, which based on the ISPU, a radius of 25 meters from the emission source (boiler stack) for those twopollutants, already in 'good' category, with the ISPU number below 50. At this air quality level, therewasno adverse effects neither on the health of humans, animals, and plants, nor on the building and aesthetic value. Pollutants distribution model can be seen in Fig. 1 and Fig. 2 for parameter SO_2 and NO_2, respectively.

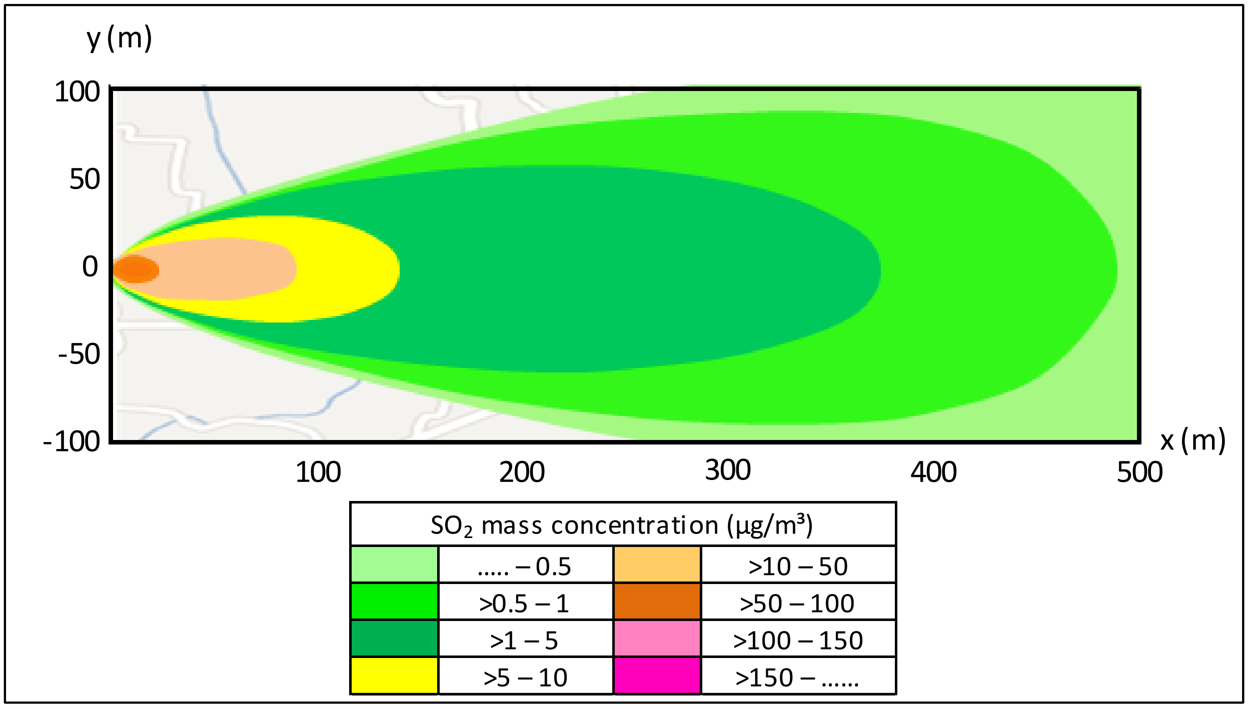

Figure 1: SO_2 Pollutant distribution model

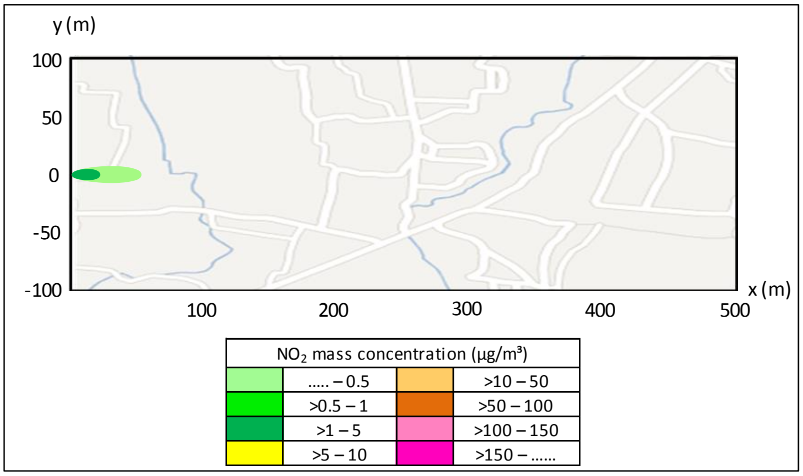

Figure 2: NO_2 Pollutant distribution model

The result of CO pollutant modeling showed that CO concentration in a radius of 100 m from the emission source was intheISPU 'dangerous' category, which the concentration of COwas 62.775 µg/m^{3}with ISPU number was higherthan 500. Air quality level in this condition could harm the health of humans, animals, and plants, seriously.In a radius of 200 m from emission source, the concentration of COwas19.508µg/m^3 with ISPU number was 215, which mean that it was in 'extremely unhealthy'category. At this air quality level, the concentration of CO could be harm to the health of populations exposed. In a radius of 400 m from emission source, the concentration of COwas5.964 µg/m^3 with ISPU number was 60, which mean that it was in 'medium'category. The level of air quality in these conditions had no negative impact on human or animal health, but could affect tothe sensitive plants that could cause injury to some plant species and could affect to the aesthetic value. The 'good' category was obtained at a radius of 450 m from the emission source.Pollutants distribution model for parameter CO can be seen in Fig. 3.

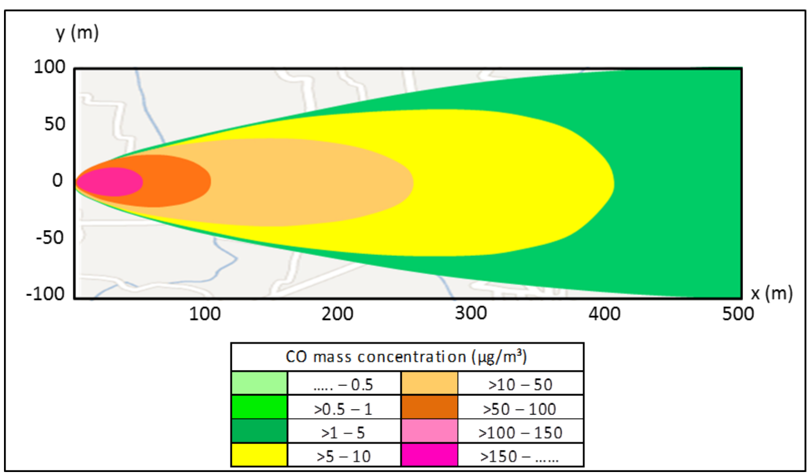

Figure 3: CO Pollutant distribution model

Graphical illustration of simulated results from the biodiesel plant stacks are presented in Fig. 4. The simulated results show that the CO concentration was much higher than SO_2 and NO_2. It observed that the concentrations of SO_2 and NO_2 are below the Indonesian regulatory standards, whereas, due to the high concentrations of CO pollutant from the biodiesel plant, a simulated safety distance beyond 450 m from the plant is recommended for human settlement and activities.

The wind speed is one of the parameter that influence the transport and dispersion of air pollutants. The simulation results show that the increase of wind speed could caused the decrease of pollutant concentration, whereas the decrease of wind speed lead to the increase of pollutant concentration and broaden radius safety from emission source.

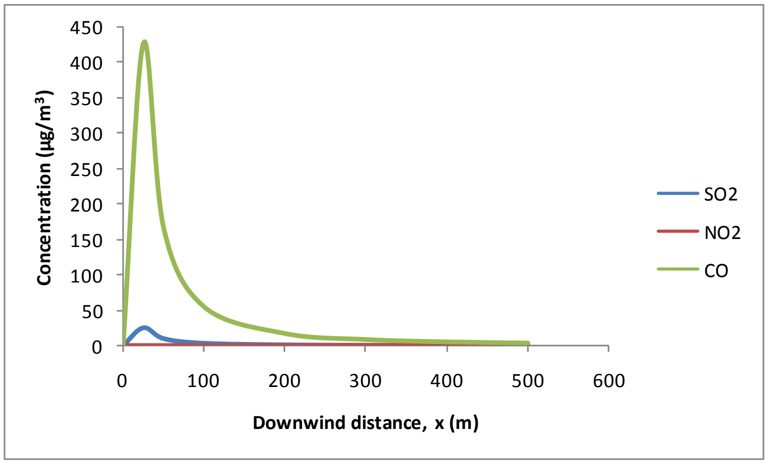

Figure 4: Pollutants concentration estimated by Gaussian Dispersion Model

The high concentration of CO pollutant was due to many incomplete combustion of fossil fuel in boiler. Incomplete combustion can also result in the reduction of boiler efficiency. In order to minimize the negative impacts of the air pollutants emitted from the biodiesel plant being studied, it is necessary to do the prevention attempt, such as installing the scrubber in the stack, maintaining the burner/boiler and doing periodic testing to keep it operating properly.

Boiler startup, shutdown, and load changes can causes the increase of CO emissions due to unstable combustion conditions. CO emissions are also sensitive to boiler operating conditions. Changes in operating conditions, such as rapid changes in load, can have a significant, though temporary, impact on emissions. During boiler startup, boiler itself is relatively cool, and the low air flow rates make it difficult to obtain good air/fuel mixing. For these reasons, CO emissions could radicaly increase when transient conditions occur during boiler startup and shutdown. Tuning of the combustion system and optimizing the boiler performance to maximize the combustion efficiency, can overcome this problem. Tuning of the combustion system and optimizing the boiler performance requires a visual check by an experienced boiler or stationary engineer to ensure that everything is in good working condition and set according to the manufacturer's recommendations or the optimum settings developed for the particular boiler (US EPA 2010).

Juszczak (2002) stated that The increase in CO concentration is caused by two factor: temperature reduction in the combustion chamber and a considerable oxygen concentration increase. To avoid a radical increase of CO concentration, it is necessary to gradually reduce fuel stream as water temperature in the boiler approaches its maximum value.

CONCLUSION

The atmospheric dispersion modeling can be used to predict the downwind concentration of air pollutants emitted from stationery sources, such as biodiesel plant.The prediction result helps us to anticipate air pollution events that might pose a healthhazard forthe receptors. The result of the distribution model of SO_2, NO_2 and CO pollutants concentration derived from the boiler stack of biodiesel plant using Gaussian Dispersion Model showed that the concentration of SO_2, NO_2 and CO pollutants emission from the production of biodiesel was below the threshold, which means it didnot influence the air quality around the biodiesel plant and did not endanger the surrounding population. Whereas, CO pollutant concentration from the biodiesel plant gave the negative impacts to the environment in the radius below 450 m from the boiler stack (emission source). This implied that the safe distance of biodiesel plant site to the settlements area is in the radius of 450 m from the emission source.

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