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Design of Biofiltration System for Ammonia Removal from the Storage of Rubber Processed Materials

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ABSTRACT

The processing of natural rubber is one of the potential industries that is growing rapidly in Indonesia. In rubber processing stage, number of pollution problems occur, such as unpleasant odor from the chemical and biological process. Ammonia is one of crucial pollutants resulted. According to Decree of Ministry of Environment No. 50/1996, ammonia levels in air must be less than 2 ppm. Biofiltration becomes one of removal techniques that continues to be developed. In this work, an engineering design for reducing ammonia levels from natural rubber processed materials was prepared for capacity of 10 L. The prototype of the system was prepared for industrial applications. Rubber Processed Materials (RPM) sample was stored in a storage and then connected to the line system to the biofilter. The prototype of multibed biofilter was created and successfully tested to reach the target of ammonia removal efficiency of 98%. The filter media used was activated carbon and compost. The nitrifying bacteria was added with a dose of 2% filter volume. Gas from the rubber storage room flowed at the rate of 12 L/min and the optimal ratio of rubber material to volume of storage room is 0.52-1.81.

Keywords: ammonia, biofilter, odor, nitrification, rubber processed materials

INTRODUCTION

Indonesia is one of the largest producers and exporters of natural rubber in the world. Since the 1980s, the Indonesian rubber industry has experienced stable production growth. Recently, Indonesia's total rubber production is around 3.8 million tons per year. About 85 percent of Indonesia's rubber production is exported abroad. Most of the country's rubber production is produced by small farmers.

Natural rubber (NR) is obtained by tapping latex, the sap from rubber plants. Latex is a suspension of microscopic natural rubber particles in an aqueous medium. These particles scatter light, making the latex solution appear white and homogeneous like milk. Natural rubber latex contains rubber hydrocarbon particles and non-rubber substances dispersed in the serum fluid phase. The content of rubber hydrocarbons in latex is estimated to be between 30-45 percent depending on plant clones and plant age. Non substance-rubber consists of proteins, fatty acids, sterols, triglycerides, phospholipids, glycolipids, carbohydrates, and inorganic salts.

Natural rubber latex constitute the polymer cis, 4 poly isoprene nearly 98% and a significant quantities of proteins. Latex is generally collected in the liquid from stabilized with a small quantity of anticoagulant preservative with bactericidal properties such as ammonia. The industry also collects and processes the after flow which is collected as cup lumps. The lumps are the result of auto coagulation of the latex through bacterial action (Sekhar, 2005).

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The microbial-coagulation, acid–coagulation and natural-coagulation are commonly-used three main methods to coagulate fresh natural rubber latex (Zhang et al., 2017). The NR coagulation aims to tighten the rubber particles contained in the liquid latex to become a clot or coagulum. The change in latex into a coagulum requires a freezing agent (coagulant) such as formic acid or vinegar.

Quality degradation in NR product is caused the activity of organisms which will be a problem in the manufacturing process of smoke sits or wind sheets, crepes and concentrated latex. Quality degradation is usually influenced by enzyme activity, climate, crop cultivation or clone types, transportation, and contamination from outside (Sekhar, 2005). In order to guarantee a consistent high-quality natural rubber product, the stage in coagulating latex is considered important. Formic acid is the preferred choice for coagulating latex. It is cost-efficient and many producers claim that it guarantees a consistent high-quality natural rubber product. The use of stronger acids makes the pH drop too fast and in homogeneously. As a result, the latex coagulates unevenly, which may affect its mechanical properties. Weaker acids, such as acetic acid, are less efficient than formic acid and result in much higher acid consumption (Thomas et al., 2013).

After tapping the rubber tree process, latex is collected into cups to prevent from flowing into other part of the tree. There are two main methods involving rubber field latex; the first one undergo ammoniation (adding high amount of ammonia concentration) for latex preservation before patterned in soft solid slabs rubber, while others by kept the latex in cups for certain period of time until it coagulates by itself or adding formic or acetic acid to faster turn to cup lump (Bhowmick et al., 2000).

Coagulated latex can then be processed into higher-grade forms such as block rubber, ribbed smoked sheet, pale creep and air-dried sheet while naturally coagulated cup lump is used in the manufacture of another grade rubber (Azahar et al., 2016). Meanwhile, the source of odor emissions from several NR processing activities is the storage of rubber processed materials in the form of lumps.

ODOR EMISSIONS AND BIOFILTRATION

Lump and Its Odor

In the manufacturing process of natural rubber, both industrial and traditional, it generates an offensive and unpleasant odor. At a certain level, these odor emissions can cause air pollution and endanger human health. Odor emissions and atmospheric pollution are the most common problems associated with composting of organic materials in this industry.

Lump refers to the small amount of latex that drips in to the cup even after the collection of latex. Cup lumps are oxidised rubber, mostly contaminated with dirt and other extraneous material. Lump that is collected and stored in a storage warehouse will experience accumulation if it cannot be processed on the same day. Large plantations usually store lumps because production capacity is limited or used as a buffer for the next production raw material.

During the storage process, the lump will experience an aerobic and anaerobic reaction due to bacterial activity which breaks down organic matter and produces foul-smelling and very stinging gases, especially ammonia, hydrogen sulfide and other volatile inorganic compounds. The volatile compounds produced during microbial degradation of carbohydrates, proteins, and other nonrubber components of NR generate the offensive odor.

The microbial populations in the cup lump affect the properties of the raw material during intermediate storage that cannot be avoided. Low quality of rubber processed materials (RPM) is commonly found due to farmers using non-recommended latex freezing materials and soaking RPM in ponds or rivers for 7-14 days. Soaking will trigger the proliferation of natural antioxidant-destroying bacteria in the RPM. A stinging stench also occurs because the growth of decomposing bacteria that bio degradate proteins in RPM becomes ammonia and sulphide (Azahar et al., 2016). The conventional latex freezing agent used cannot prevent bacterial growth.

Odor Emission Control

During the storage process, aerobic and anaerobic reactions will occur in lumps due to bacterial activity which breaks down organic matter and produces odorous and very stinging gases, especially ammonia, hydrogen sulfide and other volatile inorganic compounds. Rubber processing materials produced by smallholder rubber farmers to be processed into crumb rubber until now have low quality and a pungent odor.

The unpleasant odor from the process of raw natural rubber is generated from the biodegradation process by decomposing bacteria which produce ammonia and sulfide. This is due to the immersion process and the accumulation of rubber processed materials with a relatively long time in the storage warehouse in the industry.

Ammonia is one of odorous gas produced in rubber manufacturing process. Ammonia is a colorless, toxic, reactive and corrosive gas with a sharp odor. The traditional treatment of ammonia is based on physical and/ or chemical processes, such as activated carbon adsorption and wet scrubbing condensers.

In the natural rubber processing industry, the surrounding air generally contains a number of gas pollutants including ammonia, hydrogen sulfide, carbon monoxide, carbon dioxide, methane and nitrogen dioxide, and other hydrocarbon gases. Based on the Decree of the Minister of Environment Republic of Indonesia No. 50 of 1996 the ammonia levels in the air must be less than 2 ppm. There are still many NR manufacturing process and industries, especially those managed traditionally by farmers, having unrepresentative technology to reduce ammonia levels before it released into the air. The pungent odor from the processing area can reach hundreds of meters radius so that it may affects the surrounding communities.

Common methods that are mostly used in the process of reducing ammonia concentration are based on physical and chemical processes, but in recent years a method has been focused on reducing the concentration of ammonia by biological processes through the biofiltration method (Zhang et al., 2017; Zhao, 2018). The use of biofiltration methods with biofilter has several advantages, including simple processes, relatively low investment costs, stable use and high decomposition power.

Biofiltration for Ammonia Removal

Biofiltration is a biological air pollution control technology for volatile organic compounds (VOCs) using a bioreactor containing living material to capture and biologically degrade pollutants. Biofiltration technology can effectively remove most of the ammonia content and achieving removal efficiencies over 95%. (Shahmansouri et al., 2005). As an emerging technology biofilter offers many advantages over other traditional methods of air pollution control, particularly for low concentrations of polluted air streams. Besides its high removal efficiency, low capital and operating costs, safe operating conditions, and low energy consumption, biofiltration does not generate undesirable byproducts and converts many organic and inorganic compounds into harmless oxidation products (Chen et al., 2008; La et al., 2005; Shahmansouri et al., 2005; Zhang et al., 2017).

The principle of biofiltration is quite simple and economics. A contaminated air stream is passed through a porous packed bed on which pollutant degrading cultures of microorganisms are immobilized, and air bio-treatment relies on microbial reactions for the degradation of waste compounds (Deshusses et al., 2000). As the odorous and contaminated air passes through the media, the contaminants in the air stream are absorbed by the biofilm. The two basic removal mechanisms occur simultaneously: absorption/adsorption and biological oxidation or biodegradation. The success of bio-filter used for controlling odor is based on both sorption and regeneration (Chen et al., 2008). The contaminants are then oxidized to produce biomass, CO_2, H_2O, NO_3, and SO_4.

Biofilter is commonly recognized as bioreactor filled with wet woodchips or composts that separates Ammonia gas from contaminated air streams through absorption, and then oxidizes it into nitrite and nitrate using microorganisms by that grow on the surface of packing media (Kayyashree et al., 2015).

Biofilter is an adsorption column that works in a biological process where there are growing microorganisms and shoots that stick to the surface of a fixed medium such as activated carbon or soil. The effectiveness of the biofilter process is strongly influenced by the type and shape of the media used in an effort to provide a surface area where bacteria or microorganisms multiply considering the role of bacteria in biofilter media is very important, besides the absorption ability of the media used also has an important role in the ability to maintain water content to keep moisture in the biofilter. The process of biofilter has several capabilities, including changing ammonia to nitrite and finally becoming nitrogen gas, removing organic pollutants, increasing oxygen levels (for aerobic processes), being able to reduce excess nitrogen and other inert gases, and eliminating turbidity and purifying water (Zhang et al., 2019).

Typically, biofilters are utilized to reduce the concentration of biodegradable organic compounds that otherwise might result in microbial growth in the distribution system or the formation of disinfection by-products (Kayyashree et al., 2015). There are many conventional physico-chemical methods (e.g. direct oxidation, ozone oxidation, liquid redox and adsorption process) to remove pollutant gas. However, these methods have many problems such as: (i) high initial investment costs associated with high energy requirements, and (ii) the formation of secondary pollutants in most cases, they are not suitable for commercial application because of the low conversion or elimination capacities. Nowadays, the application of biofilter has become popular as a suitable alternative to conventional methods for treating pollutant gas (Tsang et al., 2017).

Biofilter performance are affected by the media characteristics. The characteristic relates to surface area, mechanical properties, buffer capacity, nutrient availability, porosity, and water retention capacity, hence providing an ideal environment for microbial growth (Jinanan & Leungprasert, 2015). There are many types of media used in biofilter. Natural materials including peat, soil and compost, are generally chosen as biofilter media. It is due to they are inexpensive and have a wide diversity of indigenous microorganisms (Tsang et al., 2017).

Biofilters have been successfully used to remove ammonia in polluted air. However, several unavoidable drawbacks found in the use of biofilters such as compaction, channeling, filter degradation and accumulation of acidic or alkaline metabolites. Moreover, biofilters generally operate at a lower contaminant loadings and gas flow rates in terms of unit packing media volume than other biological treatment systems, such as biotrickling or bio-scrubbering systems (Chou & Wang, 2007). That means the improvement of biofilter design is quite crucial.

Many biofiltration techniques studied in order to reduce ammonia concentration in air stream, however it is still in laboratory scale. In this work, a biofiltration system for removing ammonia is designed and produced which oriented to industrial application.

Nitrification

Nitrification is a process of nitrogen compound oxidation (effectively, loss of electrons from the nitrogen atom to the oxygen atoms), and is catalyzed step-wise by a series of enzymes. Nitrifications the first and most crucial step of nitrogen removal (Liang et al., 2000). Nitrification is the process of decomposing ammonia compounds into biologically nitrite and nitrate by certain microorganisms. Nitrification takes place through two reaction stages, in which the first stage of oxidation of ammonia to nitrite is carried out by bacteria such as Nitrosomonas, Nitrosospira, Nitrosovibrio and Nitrosolobus, then in the second stage the oxidation of nitrite becomes nitrate by the Nitrobacter bacteria.

The reaction sequence accomplished by the nitrifying bacteria. It turns toxic compound into nontoxic, as stated as follow:

$$\mathrm{NH_3(toxic)} \xrightarrow[\mathrm{N}]{Nitrosomonas} \mathrm{NO_2^-\ (toxic)} \xrightarrow[\mathrm{N}]{Nitrobacter} \mathrm{NO_3\ (non-toxic)}$$

The living bacteria in organic samples oxidise the ammonia. Then the bacteria use it to grow and convert it to nitrite (NO_2^-). There is oxygen needed due to it is an aerobic process. The bacteria that convert ammonia to nitrite are known as Nitrosomonas. Like ammonia, the nitrite produced by the Nitrosomonas bacteria is toxic to aquatic organisms and must be oxidised further to a less toxic form of nitrogen. This is accomplished by another naturally occurring genus of bacteria referred to as Nitrobacter. These bacteria metabolize and oxidise the nitrite (NO_2^-) produced by Nitrosomonas and convert it to nitrate (NO_3). The presence of oxygen is also important in order to create nitrate. Nitrate is the end product of the conversion of ammonia and nitrite. It may lead to a non-toxic nitrate with low levels.

The oxidation of ammonia into nitrite is performed by two groups of organisms, ammonia-oxidizing bacteria and ammonia-oxidizing archaea. The biofilter houses the nitrifying bacteria and is the primary site where biological nitrification occurs. Nitrifying bacteria process dissolved nitrogenous waste products excreted by the aquatic organisms being cultured.

The microbial population in the packing material is relatively inactive before contact with the ammonia substrate. After the acclimation period has passed, the microorganisms grow in mass and number in the thin layer of water surrounding the support media of the biofilter forming a biofilm (Shahmansouri, 2005).

Media and Biofiltration Design

Some researchers showed the use of biofiltration systems to reduce ammonia levels, with a variety of media and bacterial involvement, various conditions and processing time. It was provided a variety of effects. Das et al. have evaluated the performance of an aerobic biofilter packed with compost and compost and biochar for the removal of gas-phase hydrogen sulfide (H_2S). After 52 days of operation, the biofilter was repacked by replacing a certain portion (25% v/v) of the existing compost with biochar. This study shown that the compost biofilter was the best performance with removal efficiency 99% at the EBRT 119 seconds (Das et al., 2019).

Kavyashree et al. have evaluated the use of a mixture of cattle manure and rice husk as biofilter media to reduce ammonia gas. A bench scale biofilter column was designed and operated to remove ammonia gas in the Municipal Compost Plant. Removal efficiency was found to be 61.5% to 71.45% for different depth of bed. They that the ammonia gas removal efficiency goes on increases as the accumulation of bacteria increases.

Kim et al. have studied biofilter operation on the removal of H2S and NH3 gases using granular activated carbon media and the addition of ammonia decomposing bacteria Thiobacillus thioparus. In this research the removal efficiency was found 92-100% with ammonia removal capacity of 25-75 mg NH3/kg media/Liter.

Liang et al. have conducted a study for ammonia removal by biofilter for a long term (> 8 months) with activated carbon and compost media. Biofilter was operated in counter-current flow that enhances the moisture retention ability of the media. The ammonia removal was normally > 95% it performed a short retention time which is only 0.532 min (Liang et al., 2000).

Yang et al. have studied the impact of Mn and NH3 on nitrogen conversion that simultaneously removes Fe, Mn and ammonia in biofilter. A lab-scale biofilter used Plexiglas column (height: 2.8 m; inner diameter: 9 cm) with matured quartz sand media in 1.5 m bed and cobblestone on the bottom of column. Biofilter was steady operated in >200 days with filtration rate 3-3.5 m/h. From this study, it shown that ammonia was converted 98% by nitrification (Yang et al., 2019).

Baquerizo et al. have evaluated the use of coconut fiber for packing materials in the pilot scale biofilter. The model has been able to predict experimental results for dynamic operation under different loading rates. The pilot unit was operated at an empty residence time (EBRT) 36 seconds. Elimination capacities and removal efficiency reached at the end of each feeding period were 3.2 g NH3/h/m3 and 100% for the 45 ppm input level (Baquerizo et al., 2005).

Shahmansouri et al. have evaluated the uses of mixture of compost, sludge, and piece of PVC as biofilter media to remove ammonia gas. The ammonia removal efficiency of 99.9% was obtained. They also revealed that for concentration level of ammonia input and, biofilter media depths will be considered influenced to the efficiency (Shahmansouri et al., 2005).

Jinanan and Leungprasert have studied the efficiency of design operation of low cost biofilter to remove ammonia gas which is the main odorous gas from livestock farms. They have evaluated the use of mixture of manure fertilizer and rice husk in the ratio 80:20. The results shown that ammonia removal efficiency more than 99% at the flowrate of 2 m3/min (Jinanan & Leungprasert, 2015).

Choi et al. have evaluated the use of mixture of organic material such as compost, bark, and peat was used as the biofilter media based on the small scale column test for media selection. Their biofilter have complete remove ammonia up to 1.0 g N/kg dry material/day. Volume biofilter uses 2.51 L, up to 250 ppm ammonia input and the efficiency of 50% (Choi et al., 2003). While Zhao have studied the use of two biofilters for ammonia odor removal during composting with filter media zeolite or mixture zeolite and composting solids. The biofilters were operated with the same flowrate of 160 L/h gas from composting unit. The biofilter A is filled with zeolite while biofilter B filled with zeolite and composted waste mixture with ratio of 1:1. The results shown that when ammonia concentration was less than 100 mg/m3, removal rate can up to 100%, which can reach the level one of factory standard value (Zhao, 2018).

METHODS

In this study, an ammonia reduction system was carried out with the principle of biofiltration. The design orientation is based on application interests in the small and medium industrial sector. The draft data is based on in-depth literature review that shows the most optimum performance (high removal efficiency). The selection of filtration media is also done by comparative analysis and considering the availability and cost-effective factors. A multi-bed layer biofilter was designed, manufactured, and used in this study. The biofilter was constructed from a cylindrical PVC pipe. The prototype of the biofiltration system was then tested for its ability to reduce the levels of ammonia gas produced from rubber processed materials. The column of biofilter was packed with the mixture of chosen filter media. The decomposing bacterial of Nitrosomonas sp. and Nitrobacter sp were added at the filter media.

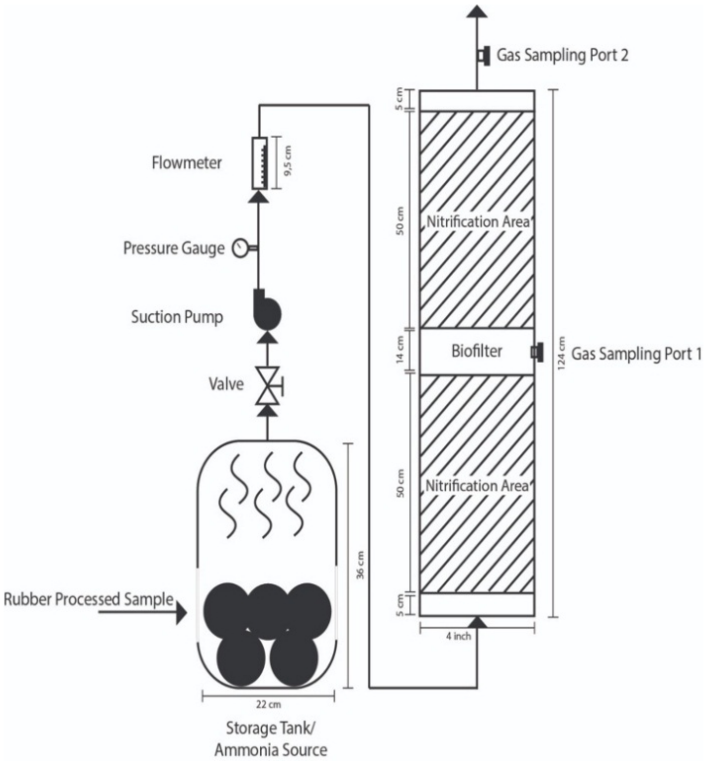

Figure 1. Scheme of Biofiltration System for Ammonia Gas Removal from Rubber Process Materials

The dose of decomposing bacteria added is determined based on the data of the previous tests considering the size and ratio of the filter column, gas flow rate, type of filter media chosen and the efficiency resulted.

Samples of processed rubber material were obtained from rubber farmers in the South Sumatra region. The rubber processed material taken is in cup lump formation. The sample was taken and observed in wet and dry conditions and placed in a storage room (glass vessel). Ammonia levels are measured in the air that occupies the storage space and the air flowing through the pipe is connected to the biofilter column. Ammonia levels were measured using Ammonia Gas Detector and ammonia test kit. In order to perform good nitrification process, the temperature of the system was controlled intensively, due to it has a very important role in microorganisms' life. Therefore, the average temperature was maintained at 28-32 °C during the operation of the system.

The efficiency of biofiltration is calculated based on differences in ammonia levels measured in the air in the storage room for rubber processed materials compared to the ammonia levels coming out of the biofiltration column. Empty Bed Residence Time (EBRT) is one of indicator of biofilter performance. It is related to the flowrate and volume of the biofilter column.

RESULTS AND DISCUSSION

The Design of Biofiltration System

For applications in the industrial sector, the ammonia reduction with the principle of biofiltration needs to be specifically designed. It is conducted by modifying and enriching a biofiltration system that is generally applied on a laboratory scale.

Rubber processing materials may cause different levels of ammonia gas influenced by the pre-treatment applied to the material before it is stored (selection of methods and types of coagulation agents), storage time and comparison of weight or volume of material to storage space. It means that the ratio of the amount of material to the storage space and the measurement system for ammonia levels in the important storage zone are prior to be considered.

It is important to prepare the suitable capacity of the biofilter with optimum performance. A biofiltration system for ammonia gas generated from rubber processed materials can be carried out by first localizing the rubber processed materials in the storage zone which is then connected to the biofiltration system (**Figure 1**).

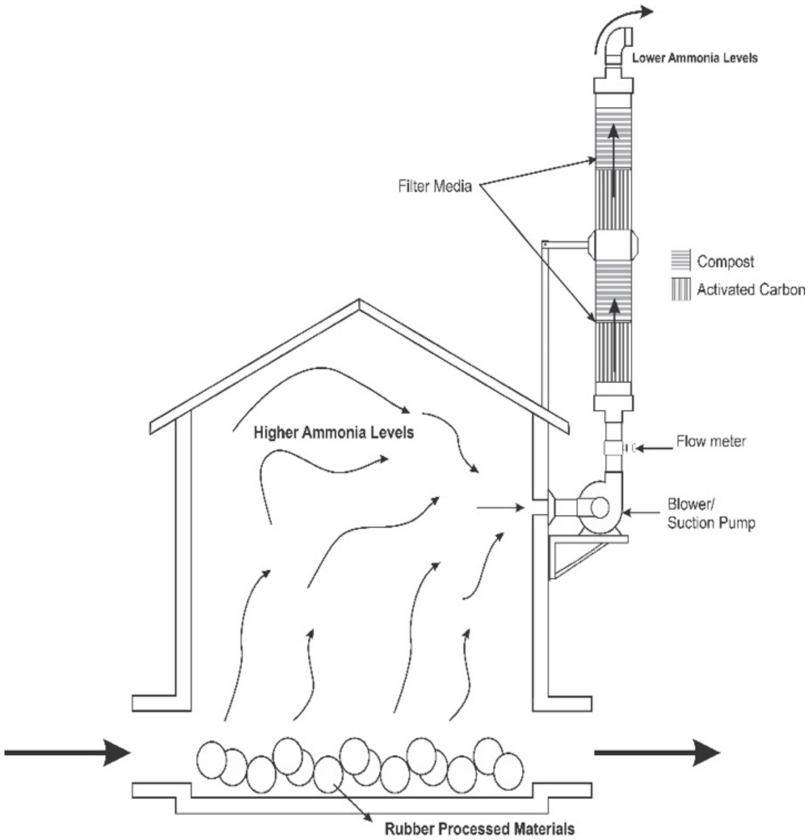

Figure 2. Proposed biofiltration system application in the rubber industry

To ensure optimum efficiency, the column size, type and configuration of filter media and its content as well as the dose of decomposing bacteria used will be adjusted to the concentration of ammonia produced in the storage room. The gas flow rate from the storage space of the rubber processed material is controlled by the suction pump and the valve opening arrangement. It aims to optimize the capacity of biofilter removal to provide a longer service life and be able to handle pollutants produced in the common rubber industry.

The proposed biofiltration system to reduce ammonia levels in the air produced from natural rubber processing can be shown in **Figure 2**. Furthermore, this biofiltration system will be designed with compact but effective for storage and processing patterns in the industry.

The Prototype of Biofiltration

The biofiltration system design was then realized in the form of a prototype for the storage capacity of 10 L. The rubber processed materials (RPM) in the form of cup lump is placed in the cylindrical tank, while the ammonia concentration is detected. In **Figure 3**, the prototype of biofiltration system for ammonia removal for RPM is installed and further be tested to reduce ammonia concentration entered to the system.

Filter media in the form of activated carbon and compost are loaded into the biofilter column with a predetermined ratio for each bed together with ammonia decomposing bacteria, Nitrosomonas sp. and Nitrobacter sp. The top and bottom side of the biofilter column are connected to a ½ inch-ID PVC pipe. The gas seal and valve are installed to prevent leakage. A vacuum pump was used with maximum pressure of 60 psi and motor of 1/8 HP to transport the gas containing ammonia form storage room to the biofilter column. The gas flow was set co-current from the bottom of the column. The line or pipe of gas output from the storage tank is created near to the biofilter column in order to reduce losses and friction. At the bottom of the biofilter column, a PVC sieve plate is installed. This element provided in order to distribute the air containing ammonia may spread evenly. The size of each hole is ½ cm with total of 21 holes on the plate.

The apparatus

1. Storage [glass storage tank]
2. Ammonia Detector Port 1
3. Pipe
4. Gate valve
5. Suction Pump
6. Flow Meter
7. Biofilter Column
8. Thermocouple
9. Ammonia Detector Port 2

Figure 3. The prototype of biofiltration system

Table 1. Biofilter column specification

	Specification	unit
Materials	PVC	-
Height	123.3	cm
Diameter	4.0	inch
Width	4.1	mm
Surface area	12.6	$inch^2$
Volume	10.0	liter

The biofilter column is arranged to be able to treat odor emissions on medium scale rubber processed materials according to the material load and the average concentration of ammonia concentration in the air. In this test the biofilter column specifications are shown in **Table 1**. Ammonia levels in the air around the storage area of this rubber material are measured in the range of 38-79 ppm.

The selection of media to be used in the biofilter column is based on the performance test data as presented in **Table 2**. It shown that type of media is concern about absorption capacity, the input of ammonia concentration to be treated and its impact to the removal efficiency.

Table 2. Filter Media Selection and its performance at lab-scale

Media	Ammonia concentration input (ppm)	Efficiency (%)	Ref
Soil and sludge	11.36	85-99	(Mc Kie et al., 2019)
Activated carbon	6.03	85	(Yang et al., 2019)
Activated carbon & compost	20	95-99	(Baquerizo et al., 2005)
Wood chips	35-200	50-98	(Shahmansouri et al., 2005)
Compost & wood chips	17.9-21.1	25-90	(Zhao, 2008)
Compost and peat	>250	50	(Gopal et al., 2014)
Activated carbon & cocopeat	3.66	93	(Sun et al., 2000)
Granular activated carbon (1)	25-500	92-100	(Jinanan & Leungprasert, 2015)
Granular activated carbon (2)	35-200	30-92	(Kim et al., 2002)

Table 3. Media Filter Specification

Activated Carbon	
Type	Standard
Granular size	8-12 mesh
Composition	
C	73.3 %
H	1.4 %
S	0.6 %
Compost	
Type	Compost Bokhasi Fertilizer
pH	7
C/N ratio	15.20 %,
Composition	
N_2	0.85 %
P_2O_5	0.82 %
K_2O	3.45 %
Ca	1.72 %,
Water content	17.7%.
C-Organic	21.36%

The chosen media used for this research is presented in **Table 3**. The media is a mixture of activated carbon and compost. Activated carbon has a large surface area, 1 gram of activated carbon has a surface area of 500 m^2, has a very large absorption capacity, which is 25-100% of the weight of the activated carbon itself. Activated carbon has the greatest efficiency in reducing ammonia levels and easy availability (Baquerizo et al., 2005; Yang et al., 2019).

The compost is chosen due to it has adequate nutrition for microbes and may accommodate a diverse of microbial to grow. It has a dense structure, good in holding water capacity and air permeability. No less importantly, it is economics, easy to handle and widely available.

The media filter is placed in ratio of 2:1 that equal for each bed in the biofilter column. The filter bed conditioning is simultaneously occur with the preparation of the nitrification zone through the addition of decomposing bacteria.

The Performance Tests

The initial ammonia level in the storage room is measured when the rubber materials performed in dry or wet conditions. It is represented the common treatment used in the rubber manufacturing industries. The more and the longest rubber processed material available in the storage room the concentration of ammonia in the surrounding air is certainly increasing.

In the current research, rubber processed materials in dry and wet conditions are placed in 2/3 part of storage space or 4 kg solid weight. In wet conditions the concentration of ammonia in the air in the storage room is 55.5 ppm while the dry rubber sample shows an ammonia level of 53.5 ppm. The ammonia levels produced in samples in wet conditions are always higher than dry samples. Samples of dried and wet natural rubber lumps are assumed to have a density of 921 kg/m3 (Kim et al, 2000) and 970 kg/m3 (Cracium, 2016). It shows that the microbial decay process in rubber material is higher in conditions with lots of water. The

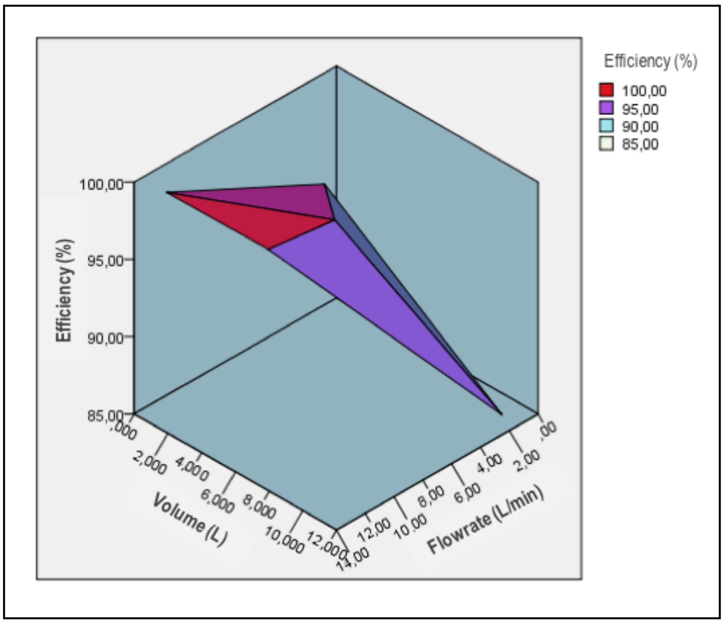

Figure 4. Relation of ammonia gas flow rate and biofilter volume to biofilter efficiency

presence of water triggering the activity of decomposing bacteria which causes protein degradation in natural rubber to produce ammonia and acid sulfides.

In order to comply the maximum standard of ammonia level in the air, the biofiltrations is designed to reduce the ammonia concentration reach to lower than 2 ppm. So that the removal efficiency target was set in 96-97%.

The media placed in the biofilter column is divided into 2 (two) beds. In each bed, the ratio of activated carbon: compost is set at 2:1. This ratio was chosen because in several lab scale tests it gave the best performance in the aspect of ammonia removal efficiency. For this work, the biofilter column was filled with 387 gr activated carbon and compost of 193 gr by each bed. Each bed is 50 cm height or occupied for 4 L volume of media by each.

In the biofilter, ammonia can be removed or transformed by nitrifying bacteria. In the first step, nitritation, ammonia is oxidized to nitrite by Nitrosomonas sp. and in the second step, nitratation, nitrite is oxidized to nitrate by Nitrobacter sp. Denitrification is assumed to be as the environment in biofilters is aerobic. To measure for nitrogen mass balance, biofilter operation should be in a stationary water phase and in steady state condition. Biofilter is only effectively operated by managing and controlling the seeding of nitrifying bacteria cells in the filter media.

The right quantity nitrifying bacteria aims to increase the efficiency of ammonia removal in the biofilter. The bacterial for nitrification process used in this work is typical King Prawn Super-N. Nitrifying bacteria can be introduced with water or bits of biofilter media from an already operating system. Initially, 100 mL nitrifying bacterial was put in 250 gal of water and then mixed with media on each filter bed. To maintain the stability of growth, every day a bacterial solution is added in proportion to ½ of the initial dose by injection. This is done for 5 (five) days. Air flow should begin within 24 to 48 hours after bacterial inoculation and loading (Devinny et al., 2017).

The media chosen are materials that have large amounts of surface area for nitrifying bacteria cells can colonize. To make biofilters more compact, material that has a large surface area per unit volume is usually chosen, as like activated carbon and compost. The gas from the storage room for rubber processing materials (containing ammonia) is flowed at a volumetric rate adjusted to the available biofilter capacity. In some tests, it is known that the relationship between the volume of the biofilter column and the efficiency of reducing ammonia levels can occur at the most appropriate flow rate, as shown in **Figure 4**.

Based on the correlation as shown in **Figure 4**, the flow rate considered optimal for this case is 12 L/min. Technically, the valve opening and suction pump were adjusted to ensure the flow rate of the gas containing ammonia from the storage room to the biofilter column.

Table 4. Performance Test Result

	Wet Sample	Dry Sample
Initial Ammonia concentration (ppm)	55.5	53.5
Volume of air (containing ammonia) in storage room (L)	5.88	5.66
Outlet Ammonia concentration (ppm)	0.70	0.90
Removal Efficiency (%)	98.73	98.31

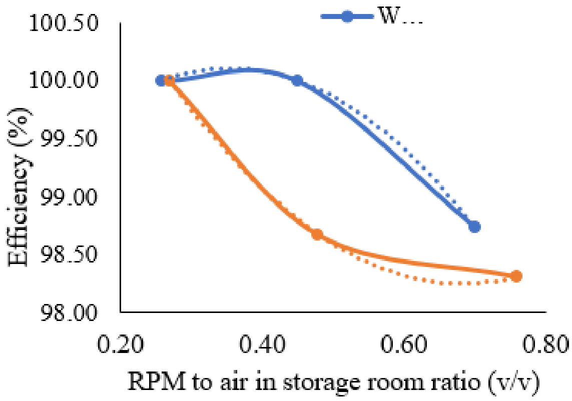

Figure 5. Relationship between RPM volume and air volume ratio to biofilter efficiency

Empty Bed Residence Time (EBRT) is a measurement of relative time for the gas in filter bed to estimate the filter size for a given air flow. EBRT is one of important design and operating parameter (Dessushes et al., 2000). It can be calculated directly by dividing filter bed volume with air volumetric flow rate. In this work, the EBRT is 50 second. According to Devinny et al., EBRT in the range of 25-60 seconds is most commonly used for industrial and commercial applications, especially in controlling odor emissions.

The high EBRT value is equivalent to a large volume of biofilter. In this study, the biofiltration devices is intended for continuous operation over a longer period of time, according to the potential of the higher gas flow rate, so that EBRT can be reduced at the same volume of biofilter.

The results of the biofiltration system performance test can be seen in **Table 4**. The decrease in ammonia levels shows an achievement exceeding the efficiency target of 96-97%. This shows that the capacity of 10 L biofilter with specified media is able to handle a reduction in ammonia concentration. Meanwhile, with low EBRT the lifetime of biofilter can be longer with the same dose of decomposing bacteria. The condition is influenced by the conditioning of the sample in a smaller and compressed tank volume in a closed space. For the purposes of the application, it can be concluded that the capacity of the biofilter per kg of mass of the sample can be determined based on the ratio of sample volume to the volume of gas space/empty space in the storage area as shown in **Figure 5**.

In industrial application of RPM storage, it is very important to determine the ratio of the amount of load of rubber processed materials to the volume of storage space so that the concentration of ammonia in the air can be controlled and the use of biofilter in a certain configuration and capacities can operate effectively.

The ratio of sample volume and air space (v/v) shows the number of samples available to the air space contained in a storage tank with a total volume of 10 L. The regression equation of the relationship in the wet and dry sample can be written respectively as y = -11,545x2 + 8,1973x + 98,649 for RPM wet sample, and y = 10,301x2 – 14,059x + 103,05 for RPM dry sample. The optimum ratio (v/v) of the rubber processed materials placed in the storage room is 0.52 -1.81.

CONCLUSION

The odor emission resulted from rubber processed materials contains ammonia gas. It can be reduced by the principle of biofiltration. The design of a biofiltration device can be made and applied to the rubber processing unit commercially and/or industrially. A multibed column with a volume of 10 L can be used as a biofilter, it filled with activated carbon and compost at a ratio of 2:1, the gas flow rate is maintained at 2 L/minute. The added bacterial of Nitrosomonas sp. and Nitrobacter sp. should be following some mechanisms of starting biofilter, bacterial inoculation and stabilization to ensure the success nitrification process. In order to be applied effectively in the industry, some adjustments in the system of biofiltration required. The RPM storage space need to be adjusted for suitable capacity of the biofilter. The operation parameters should be fit to the best performance of the biofilter in order to produce output ammonia levels that meet the specified quality standards (less than 2 ppm). The volume ratio of RPM to the ideal volume of storage space for biofilter with a capacity of 10 L is 0.52-1.81 (v/v).

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Disclosure statement

No potential conflict of interest was reported by the authors.

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