Obnoxious Odor Problem of Standard Thai Rubber 20 Industry: An Overview Related to Recent Evidence in Southern Thailand

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ABSTRACT

The Standard Thai Rubber 20 (STR20) industry is a very important part of natural rubber manufacturing in southern Thailand. This type of rubber industry has been identified as being an important source of air pollution, and in particular of obnoxious odor problems. This paper reports on the offensive odor problems of the STR20 industry in the South of Thailand. The study was conducted by field survey, air and absorbent sample analyses, and literature review. Current information on raw rubber materials used, STR20 processing, dryer exhaust gas characterization, and odor treatment technology of the factories are reported in this paper. There were 52 types of volatile organic gases characterized from dryer exhaust gases, effluent gases from absorbers, STR20 products, and the cup lumps of raw rubber used in STR20 factories. H_2S, NH_3, and volatile fatty acids (VFAs) including of acetic acid, propionic acid, butyric acid, isobutyric acid, valeric acid and isovaleric acid were the major gases causing offensive odor problems to STR20 factories. Packed bed absorbers with treated effluent wastewater utilized as absorbent were a common technology used to reduce such odors. The limitations of odor reduction technology used in STR20 industry are discussed. In addition, recommendations and suggestions in order to abate the obnoxious odor problems produced by STR20 factories are given.

1. INTRODUCTION

Hevea brasiliensis is the rubber tree originating in Brazil. This tree was being planted throughout the Malayan peninsula by the 1890s, and has led to the dominance of the rubber industry in Southeast Asia. Presently, not only Indonesia and Malaysia but also Thailand are the major producers of natural rubber in the world [1]. Thailand has been the largest natural rubber producer since 1991. [2]- [3]. Raw rubber manufacturers can be divided into 3 groups, namely of concentrated latex, air dried sheets/smoked rubber sheets, and block rubber. Block rubber is a technically specified rubber (TSR). In Thailand, the TSR is known as Standard Thai Rubber (STR). STR is classified into many grades, i.e., STR5L, STR5CV, STR5, STR10, STR10CV, STR20, and STR20CV which can be processed from fresh latex or field coagula. All STR products are guaranteed according to the technical specifications of national schemes of Thailand or ISO 2000:2003 [4]. Of the various grades of STR, STR20 is the most exported type of block rubber from Thailand [5].

There were 105 block rubber factories distributed throughout Thailand in 2014. However, 50 of these were for STR20 and 44% of them (22 factories) were located in southern peninsular Thailand. The rest of them, consisting of 18, 7 and 3 STR20 factories were in the northeastern, eastern, northern Thailand, respectively [6]. The processing of STR20 commonly generates offensive smells from exhaust gases of STR20 drying, a consequence of which is public complaints [7] [8] [9]. Understanding the current malodor pollution could allow the environmental personnel to control and eventually abate the obnoxious odor problem of the STR20 industry. In this article, obnoxious odor problems and existing odor control technologies in STR20 factories in the southern Thailand are investigated. This paper discusses the sources of odor, characterization of odor pollutants, measures taken to control odor in the STR20 industry, and their limitations; and it also gives suggestions on malodor control. Although odor is a human experience, it is defined as sensations perceived by the brain when volatile compounds interact with the olfactory system [10]. The measurement of odor falls into methods that 1) determine type and intensity, or 2) determine the threshold concentration of odoriferous gases [11]. This study investigated malodor by determination of type and intensity of odoriferous gases emitted from STR20 rubber dryers, and

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the gases after treatment with the odor reduction units of the STR20 factories.

2. MATERIALS AND METHODS

2.1 Field survey and secondary data obtained

This research deeply investigated the malodor problem of the STR20 industry in southern Thailand. The study was undertaken in 2012-2014 by field survey, air sampling and analysis, and also used secondary data from research reports. Field survey was conducted in 7 large size STR20 factories (32% of total STR20 factories in Southern Thailand) in Surat Thani, Nakhon Si Thammarat, Songkhla, and Pattani provinces. Interviews with environmental personnel and in-plant investigations were carried out during STR20 factory visits. The survey aimed to collect information on raw materials used, STR20 processing, odor reduction technologies used, and their limitations. In addition, secondary data relating to the odor problem of STR20 industry, especially the odoriferous gases emitted from rubber dryers, were obtained from various research reports that were reviewed and used for discussion in the study.

2.2 Air samples and analysis

Air sampling of STR20 factory was undertaken during factory visits. Air samples from the exhaust gases from the factories' rubber dryers and outlet gases after treatment with odor reduction units (scrubbers) were collected. The following characteristics of air samples were analyzed: H_2S, NH_3 and 6 types of VFAs including acetic acid, propionic acid, butyric acid, isobutyric acid, valeric acid and isovaleric acid. Air samples for VFAs, H_2S and NH_3 determinations were separately collected with an activated carbon tube, cadmium sulfide absorbent solution and sulfuric acid solution via an air sampling pump with a rate of 0.5 l/min. The H_2S and NH_3 of air samples were determined per the protocols described by [12] [13] respectively. For VFAs determination, the analysis followed the method described by [7] [9]. After air sampling for VFAs examination, the activated carbon adsorbent was eluted into 5-10 ml of ethyl acetate solvent for 15 minutes to extract the air pollutants into the solution. The ethyl acetate extract was then further evaporated to reduce the volume down to 2 ml and this was used in analysis with gas chromatography (GC). The GC (HP model 6850) with a flame ionization detector and with capillary column Stabilwax, 30 m, film thickness 0.25 mm., ID. 0.25 mm., was used for VFAs analysis. GC technique was used to identify individual volatile fatty acids of low molecular weights with up to five carbon atoms, and to determine the concentrations by using known standards of the VFAs acetic acid, propionic acid, butyric acid, isobutyric acid, valeric acid and isovaleric acid.

2.3 Analysis of absorbent solutions used in odor reduction units.

In order to evaluate the existing odor reduction units used in STR20 factories, samples of absorbent solutions, both before and after passing through the units, were collected to analyze for physical, chemical and biological characteristics. The liquid samples were determined for temperature, pH, conductivity, turbidity, DO, TDS, SCOD (soluble COD), SS, VFAs, TKN, H_2S, SO_4^{2-}, S^{2-}, TP, organic and inorganic sulfate degradation bacteria, and total plate count (TPC). The absorbent solution sample characteristics were determined according to protocols described by [14].

3. RESULTS AND DISCUSSION

3.1 Raw materials used and STR20 production processes relating to malodor generation.

Raw natural rubber used in STR20 factories comes from field coagula blended or not with low grade rubber sheets (ribbed smoked sheets and/or unsmoked sheets). Field coagula are freshly coagulated rubber and their quality depends on the origin and collection methods in tapping and processing [1]. The mixing ratio of field coagula and rubber sheets depends on the STR20 product control during the process. However, cup lumps and smallholder's lumps (cup coagula) are the major field coagula used in STR20 production. Cup lumps are coagulated rubber obtained from the collection cup on the tapped rubber tree. Cup lumps are mainly formed by auto-coagulation of the latex in the cup, or by biological coagulation in the collection cup, and is collected after 3-7 days depending on the frequency of tapping [2]. Smallholders' lumps are generated by the smallholders that take latex from trees, with acidic materials used to induce coagulation in the latex [1].

It is noted that both coagulation and maturation are the key steps before starting the STR20 production process, but they contribute to the malodor problem of the STR20 industry. Coagulation and maturation are known to involve complex phenomena that modify the structure of field coagula. Coagulation eliminates most of the serum and non-rubber contents. A commonly adopted practice today is to allow natural coagulation of rubber in cups, after which it is taken out of the cups. In earlier stages of tapping, microorganisms can enter the rubber latex [15]. Since rubber latex contains all the nutrients that microorganisms need, it is very susceptible to bacterial growth. The bacteria action can spontaneously coagulate fresh latex to form solid coagula.

The rubber coagula were commonly collected and stored for 1-2 weeks by the middle man for extended periods before factory processing [2]. Then they were transferred to the factory. In industrial practice, the coagula were again kept in the shade or exposed to the sun for a period of 15-45 days before processing. This storage time is called the maturation period. Maturation is the phenomenon that occurs in the coagula before processing of STR20 rubber [16]. Maturation reactions are based on microbial activity. During the maturation period, microbes develop in the coagula, and bacterial decomposition of proteins and other non-rubber content in the coagula occurs [17].

It has been demonstrated that the assisted biological coagulation is an auto-coagulation process, but the rubber coagula achieved often have an offensive smell due to obnoxious volatile air pollutants arising from the breakdown of non-rubber content in the coagula. Also, at the maturation period in STR20 factories, due to bacterial activities, the non-rubber, especially in the wet coagula is broken down into obnoxious volatile fatty acid compounds which contribute to the malodor problems of STR20 factories [2] [7] [14]. Therefore, the coagula storage areas in STR20 factories are one source of offensive odors.

The STR20 process is shown in Fig.1. The process is commonly divided into 3 lines: the pre-cleaning line, the STR20 preparation line and the drying line. After maturation, the raw coagula are cut into small pieces, soaked and cleaned with water in a tank. Next, they are transferred to cutting, shredding and creping machines and also mixed with rubber sheets. After that the mixture is fed to a series of crepers which make the rubber into a blanket, and it is then crumbed through a shredder to small granules that are called wet crumbs. The final crumbs are dried in a forced–air dryer at temperatures of 110-130^{o}C for 2-4 hours. Finally, the dried crumbs are pressed into blocks. The finished STR20 product is wrapped with plastic film. Among these operations, the drying step generates odoriferous gases into the exhaust that is then discharged into the air via the dryer stack. These gases have several volatile compounds from the breakdown of non-rubber content in the raw rubber, and have offensive smells which contribute to the malodor problem of STR20. Therefore, the major source of malodor generation of the STR20 industry is at the dryer, besides the storage area of the rubber coagula.

In addition, the STR20 process consumes a lot of water and energy. Normally, electricity and LPG (liquefied petroleum gas) are the main sources of energy used in the STR20 processing line. STR20 factories generate large amounts of wastewater and commonly use a combination of physical and biological treatments in their wastewater treatment system. The aerated lagoon, pond system, activated sludge process and sequencing batch reactor are the most popular systems utilized for wastewater treatment of STR20 factories in southern Thailand [2]. The wastewater treatment plants of STR20 could be considered sources generating malodor, if the treatment technology used is the pond system. However, the STR20 process is not similar to the concentrated latex process; sulfuric acid is not used in the process and does not result in high sulfate concentrations of wastewater. If the wastewater is treated by the pond system, malodorous H_2S gas does not pollute the environment while that is the case with the concentrated latex industry

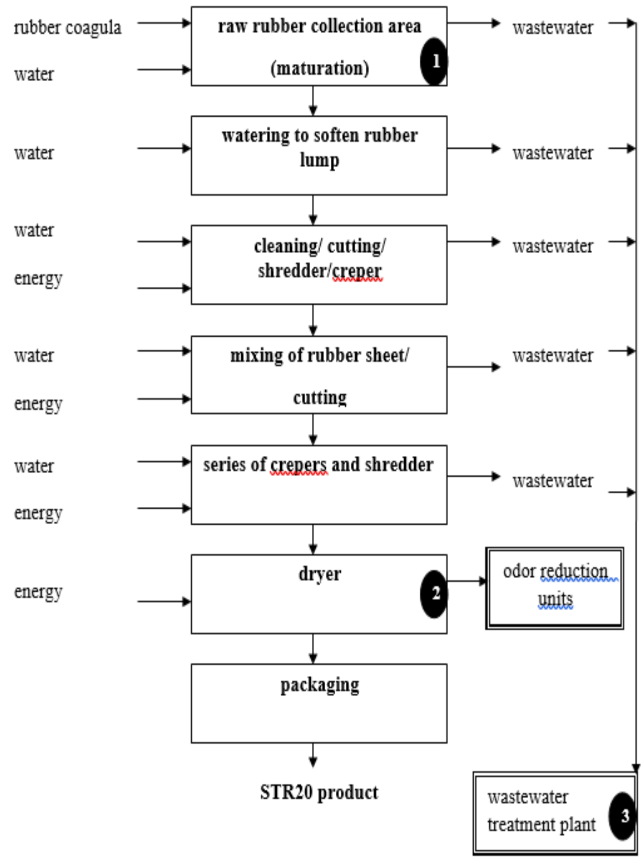

Fig.1 Flow chart of STR20 processing (1, 2, 3 mark the originating sources of malodor.).

3.2 Characterization of odoriferous gases of STR20 processing

Knowledge of the types of odoriferous gases streaming from STR20 factories is needed in order to provide suitable treatments for odor reduction. Even though the offensive odor problem of STR20 is receiving serious attention, there is not much information on the characterization of such gases. Since the major source of offensive odor in the STR20 industry is the STR20 dryer, there have been some efforts to characterize the odoriferous gases contained in the dryer exhaust gases, as well as gas effluent after its treatment with absorbers. Also, there have been some reports of the characterization of gases emitted from STR20 products and cuplumps used as raw material in STR20 processing. All of these have been analyzed by GC/MS (gas chromatography-mass spectrometry). From the literature review, it was found that the types of organic volatile gases contained in exhaust gases from dryers, the gas effluent after being treated with absorbers, gases emitted via head space technique from STR20 products and cup lumps had in total 52 components, as given in Table 1 [9] [18] [19].

Table 1. Volatile contents detected by GC-MS of air samples from STR20 industry

Volatile component	A* report		B* report	C*report	
	Dryer	Absorber	Dryer	STR 20	Cuplump
acetic acid	✓	✓	✓	✓	✓
behenic acid, methyl ester		✓			
benzothiazole				✓	
sec-butyl acetate			✓		
t-butyl acetate			✓		
butyric acid	✓	✓	✓	✓	✓
m-cresol		✓			
p-cresol	✓				
p-cymean			✓		
N,N-dimethyl formamide				✓	
decene			✓		
eicosenoic acid, methyl ester		✓			
ethanol					✓
2-(2-ethoxyethoxy)-ethanol				✓	✓
ethyl pentanoate			✓		
N-glycyl-L-alanine					✓
glycylglycine ethyl ester					✓
heptanoic acid					✓
hexadecanoic acid	✓	✓			
hexanoic acid					✓
isobutyl phthalate/ butyl phthalate/ n-butyl isobutyl phthalate	✓	✓			
isobutyric acid	✓	✓	✓	✓	✓
isobutyric acid-2-D1				✓	
isovaleric acid	✓	✓	✓	✓	✓
limonene			✓		
linoleic acid, methyl ester		✓			
methyl butanoate					✓
methyl hexanoate					✓
methyl laurate	✓				
methyl cis-6-octadecenoate	✓				
methy palmitate	✓				
methyl pentanoate			✓		
3-methyl-2-pentanone			✓		
4-methyl-2-pentanone			✓		
octadecanoic acid, methyl ester	✓				
octadecanoic acid/ stearic acid		✓			
2-octanone			✓		
oleic acid		✓			
oleic acid, methyl ester	✓	✓			
pentanal				✓	
1-pentanol				✓	
phenol	✓	✓			
α-pinene			✓		
propanamide				✓	
propionic acid	✓	✓	✓	✓	✓
propyl acetate			✓		
terpene			✓		
tetrachloroethylene			✓		
tetratetracontane				✓	
tricosane		✓			
undecane			✓		
valeric acid	✓	✓	✓	✓	✓

Note: A*: Danteravanich, S. (2007); B*.: Isa (1991) C*: Sakdapipanich and Insom (2006)

Note: A*: Danteravanich, S. (2007); B*: Isa (1991) C*: Sakdapipanich and Insom (2006).

It was noted that the odoriferous gases from the STR20 industry consisted of mainly volatile fatty acids of low molecular weights, with up to five carbon atoms. These acids are acetic acid, propionic acid, butyric acid, isobutyric acid, valeric acid, and isovaleric acid. Besides having low molecular weight volatile fatty acids, other volatile organic compounds were also identified by the GC-MS technique. Those compounds were mainly methyl esters of fatty acids, alcohols, and carboxylic acids. The diversity of the detected volatile components might be due to the different phases of biochemical reactions occurring inside the coagula within different stages of coagulation and maturation. The latex derived from a rubber tree is a mixture of many chemicals, some inorganic, but mostly organic. The major soluble carbohydrates in latex were determined to be glucose, sucrose, and quebrachitol [20]. The rubber particles also contain 90% rubber and are associated with phospholipids, proteins, neutral lipids, as well as enzymes [21] [22] [12]. Up to 3.2% total lipids and 2.1% neutral lipids were found in rubber particles. At least 14 different substances could be separated from neutral lipids. Triglycerides were about 45% and another 40% were sterols, sterol esters and fatty acid esters, and the rest were diglycerides, monoglycerides, free fatty acids, tocotrienols and some phenolic substances [21]. Proteins were found as indigenous components of the film enclosing the rubber particles including one of the major proteins in latex - α-globulin. The coagula of coagulated latex are an extremely favorable medium for the development of bacteria. Microorganisms use enzymes in the biochemical pathways for growth, and some of these enzymes may have participated in the initiation of coagulation. [15] reported the regular occurrence in natural rubber latex of micro-aerophilic bacteria species usually producing acids. He isolated both Streptococcus and Lactobacillus in natural latex. Therefore, the volatile components detected from air samples of STR20 industry via GC-MS were probably caused by oxidation of unsaturated fatty acids or triglycerides (lipid oxidation), carbohydrate fermentation/oxidation, and microbial esterification of alcohols and organic acids. In addition, not only lipid oxidation in the coagula occurred due to enzymes, but also nonenzymatic phenomena such as photo-xidation happen during maturation of the coagula under sunlight [19]. Therefore, the methods of latex coagulation and the later conversion of coagula into STR20 products affected the malodor problems of the factories.

Although mainly volatile fatty acids were detected in the dryer exhaust gases and effluent gases after treatment with absorbers in STR20 factories, also H_2S and NH_3 were detected. Table 2 presents the concentrations of VFAs, H_2S and NH_3 in air samples from dryer exhaust gases, before scrubbing and after scrubbing. Variations in detected concentrations of individual VFAs, H_2S and NH_3 were observed throughout the drying process and scrubbing. However, the VFA concentrations detected in this study were not consistent with Idris and team's study in Malaysia in 2012. They reported higher concentrations of acetic acid, propionic acid, isobutyric acid, butyric acid, isovaleric acid and valeric acid in the scrubber inlet with average values of 977, 549, 307, 108, 132 and 11 ppm, respectively [8]. This might have been due to the different methods of analyses. In this study, the volatile organic compounds were adsorbed in activated carbon tube and desorb in ethyl acetate, concentrated, and then analyzed by GC, but the study of Idris and team used thermal desorption-gas chromatography technique. This active technique made the absorbed volatile organic compounds directly desorb in a thermal desorption unit for analysis by the GC. Therefore, this technique could cause less losses of components during the analysis and give more sensitive detection results. With reference to the H2S concentrations detected, they were consistent with [23] in which H_2S from block rubber processing was determined at up to 11.5 ppm.

Table 2. Concentrations of VFAs, H_2S, and NH_3 detected in air samples before and after scrubbing at STR20 factories (Unit: ppm)

Type of gases	Before scrubbing	After scrubbing
Acetic acid	0.5 - 75	0.1 - 23
Propionic acid	0.1 - 8.9	0.1 - 3.7
Isobutyric acid	0.1 - 3.4	0.05 - 0.6
Butyric acid	0.1 - 42	0.03 - 11
Isovaleric acid	0.1 - 38	0.1 - 2.4
Valeric acid	LD - 54	0.05 - 11
Ammonia	1.7 - 254	3.7 - 30
Hydrogen sulfide	0.8 - 39	1.7 - 20

Note; LD: lower than detection limit

VFAs, H_2S and NH_3 gases generated from STR20 industry are odoriferous gases with smell characteristics as shown in Table 3. The very low concentrations of an odoriferous chemical that can produce an odor sensation is called the odor detection threshold. It was observed that isovaleric acid and valeric acid, which are higher molecular weight VFAs, gave lower odor detection thresholds with considerably stronger malodor intensity. With respect to odor threshold values, the odor intensity of VFAs detected in STR20 industry seems to be directly proportional to the molecular weight. However, the odor threshold of H_2S is the third lowest, suggesting that H_2S is also the most important gas contributing to the obnoxious odor problem of STR20 industry.

3.3 Odor reduction technology used in STR20 industry and its limitations

STR20 factories are constant sources of obnoxious odor. The bad smell can originate from the STR20 dryer and cup lump storage, which is raw material used to produce STR20 products. However, the STR20 dryer is the main source of offensive odor. Highly odorous waste gases should normally be fed to waste gas purification units based on adsorption or absorption/scrubbing before discharge to the atmosphere. Absorption is applicable when the odorous vapors are soluble in a liquid or react chemically in solution. The addition of an oxidizing agent to a circulating water stream has proved effective in some cases. [9]

Table 3. Odor thresholds and smell characteristics of odoriferous gases in STR20 industry

Odoriferous gases	Formula	Smell characteristic	Odor threshold * (ppm)
Acetic acid	CH_3COOH	Pungent/vinegar	0.006
Propionic acid	CH_3CH_2COOH	Pungent/intense vinegar	0.0057
Isobutyric acid	$CH_3CH(CH_3)COOH$	Rancid/ unpleasant/fecal	0.0015
Butyric acid	$CH_3CH_2CH_2COOH$	Unpleasant/ rancid	0.0001
Isovaleric acid	$CH_3CH_2CH(CH_3)COOH$	Stinky feet/strong pungent	0.000078
Valeric acid	$CH_3CH_2CH_2CH_2COOH$	Unpleasant/fecal	0.000037
Ammonia	NH_3	Acrid	1.5
Hydrogen sulfide	H_2S	Rotten eggs	0.00041

* After : Nagata, (1993) and Nagata, (2013)

From surveys, it was found that each STR20 factory had 2-3 dryers. Each dryer had the capacity to produce 30-40 tonnes of STR20 rubber per day, or the equivalent of a production capacity of 3-3.5 tonnes/dryer/hr. The dryers had controlled temperature in the range of 110-130^{o}C and each batch operation took about 3.5 hr. All STR20 factories installed odor reduction units to treat odoriferous gases from dryers before discharging them into the atmosphere. In southern Thailand, the malodor emitted from STR20 dryers is commonly treated by wet scrubber. These existing systems are based on the absorption of odoriferous gases from the dryer exhaust gases to water, in particular using treated wastewater or river water. The absorbers commonly used in the STR20 industry are of packed bed type. The packing in columns disperses the scrubbing liquid over the packing media providing a large surface area for gas-liquid contact. There are 2 types of packed bed absorbers classified by the direction of gas-to-liquid flow, used in STR20 industry in southern Thailand. They are 1) counter-current flow absorbers in which the liquid and gas streams flow in opposite directions and 2) co-current or cross-current flow absorbers in which gas and liquid flow in the same direction. The STR20 factories commonly use one unit of cross-current flow packed bed absorber type, but for the factories facing public complaints on malodor, a series of packed bed absorbers with cross-current flow and counter-current flow types are used. In addition, a few of them are changing to chemisorption with utilization of NaOCl and NaOH to dissolve odoriferous gases through chemical reactions, so that they cannot return to the gas phase.

The packing media used in the absorbers were found to be plastic type, but with different shapes. Fig.2 shows some types of used packing media including Pall rings and Tellerette rings as examples. The packed bed towers were fed gases from dryers at the rate of 240-410 m^3/min or equal to the gas velocity in the towers of 13-23 m/sec. As mentioned above, treated wastewater or river water was used as absorbent. Liquid flow through the packed bed tower was determined to be in the range of 6-40 m^3/hr driven by 3-5 hp pumps for water circulation. The water circulation was conducted for 1-6 days per batch before discharge from the absorbent storage tank.

The packed bed absorber was operated depending on the production period. However, each absorber was observed to operate for about 8-20 hr/day. In practice, every week after running the absorber, packing media needed to be cleaned once in order to remove sludge occurring inside the tower (see sludge in the packing media in Fig. 2). Otherwise, the odor removal efficiency would be limited. The maintenance by cleaning the packing media inside the absorber tower was labor intensive and costly. In addition, running the packed bed absorber also generated wastewater. Table 4 shows the wastewater characteristics obtained from running the absorbers of STR20 factories. After the liquid passed through the tower, temperature, turbidity, SS, TDS, COD, SO_4^{2-}, S^{2-}, VFAs, and total plate count bacteria were determined to have increased compared to before scrubbing. However, pH and DO seemed to be lower after scrubbing. This was because of the absorption of odoriferous gases from dryer exhaust gases into the liquid absorbent and as a result of heat transfer. The results show that liquid after use as absorbent in a packed bed absorber of STR20 industry was polluted with quite high concentrations of several pollutants, in particular organic matter. Therefore, this liquid needed to be treated before discharge into a watercourse.

Fig. 2. Packing media used in the packed bed absorbers of STR20 industry.

From the survey, it was found that packed bed absorber used in the STR20 factory could remove 48-93 % of each VFA, and the average removals of NH_3 and H_2S were determined to be 87% and 45%, respectively. This result was similar to a previous study in Malaysia conducted by Idris and team in 2012. They reported that the absorber used for block rubber industry in Malaysia could remove the total VFAs by on average71%.

The offensive odor problem of STR20 industry is growing and not much has been solved. The chronic odor problems of the factories are the most common cause of air pollution complaints by the public. Although there has been an odor regulatory standard in Thailand imposed by the Department of Industrial Works, Ministry of Industry, since 2005, this regulation has not been easily enforced. The main reason has been the lack of generally accepted methods for quantifying the obnoxiousness of a given odor as allowable odor units. Only experience will show the effectiveness of this approach. Therefore, most control authorities have resorted to nuisance laws to control odors, but nuisance regulations are notoriously ineffective, except in obviously intolerable situations. In addition, the survey results illustrated that most STR20 factories did not use professional personnel to control and operate the absorbers, so the odor treatment units were inconsistently operated and could not accomplish high treatment efficiency. It was also found that the most investigated sites lacked specific data used to control and operate the absorbers, such as gas flow rates, data of concentrations and types of odoriferous gases, removal efficiency, and schedules to make up liquid availability and liquid flow, and so on.

Table 4. Characteristics of absorbent before and after scrubbing in the packed bed absorbers of STR20 factories

Parameters	Absorbent solution	
	Before scrubbing	After scrubbing
Turbidity (NTU)	12 - 45	14 - 56
pH	5.90-7.97	6.54-7.81
Temperature (°C)	32.2 - 36.1	38.2 – 43.0
DO (mg/l)	3.68 - 4.0	2.33 - 2.57
SS (mg/l)	3 - 29	15 - 53
TDS (mg/l)	3,680 - 4,670	3,600 - 4,712
COD (mg/l)	263 - 467	457 - 1,453
SO_4^{2-} (mg/l)	12 - 123	15 - 274
S^{2-} (mg/l)	0.11 - 0.22	0.25 - 0.65
TN (mg/l)	12 - 46	14 - 43
TP (mg/l)	0.8 - 2.37	1.09 - 2.06
VFAs (mg /l as acetic acid)	22 - 31	37 - 143
Organic sulfate degradation bacteria (MPN/ml)	170 - >1600	350 - >1600
Inorganic sulfate degradation bacteria (MPN/ml)	6.8-170	33-350
Total plate count bacteria (CFU/ml)	6.1×10^3 - 4.89×10^5	4.9×10^2 - 8.79×10^5

3.4 Recommendations and suggestions

This overview pointed out that the obnoxious odor problem from the STR20 industry in Southern Thailand needs to be further resolved. Any odor reduction technology which can be applied to the STR20 industry should be an improvement towards getting high treatment efficiency, improved economy, as well as without further effects from technologies used. In this regard, related recommendations and suggestions are offered as follows:

- Qualified and professional operators/personnel who can control and run the absorber technology should be employed in STR20 factories. Increasing technical expertise of operators/personnel is necessary and should be promoted by different training courses/ programs.

- It is suggested that clean water be used in packed bed absorbers. The effluent can be reused further in rubber coagula cleaning processes.

- Regular maintenance and cleaning of packing media in the absorbers is recommended in order to reduce the malodor self-pollution from sludge occurring inside the absorbers.

- Monitoring the performance of the packed bed absorbers of each STR20 factory should be consistently conducted.

- The STR20 factory should get specific data for use to control, operate and evaluate the absorbers' performance.

- Promote more good housekeeping, especially at the rubber coagula storage area, as well as use of a better quality of rubber coagula such as standard cuplumps or cup coagula in the production process of STR20 factories.

- Undertake research and development on appropriate treatment of malodor in the STR20 factories, including from coagula, raw material used, to the end of pipe technology. Chemisorption, biotrickling filter or bioscrubber are recommended to further development and adoption for upgrading the odor reduction in the STR20 industry.

- The sanitary authority regulations on obnoxious odors in STR20 industry should aim at limiting emissions of H_2S, NH_3 and VFAs compounds

4. CONCLUSIONS

Offensive odor abatement for the STR20 industry is receiving serious attention. The production process of STR20 factories includes cutting, washing and crumbling of the rubber coagula, and drying and packing of the crumbs. From the results overview, it can be concluded that most volatile fatty acids of low molecular weight with 2-5 carbons, along with H_2S and NH_3, are the odoriferous gases causing malodor problems in the STR20 industry. The origins of the malodor problem are not only in the production process, but also in the raw rubber coagula used in the industry. This overview indicates that for more efficient odor reduction alternative approaches should be further considered to improve the malodor abatement of the STR20 industry.

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