Feature Article *J. Aerosol Res.*, **21** (2), 122-129 (2006)
特集「東南アジア地域の発展途上国における大気環境問題の現状と将来への取り組み」

Environmental Problems Related to Natural Rubber Production in Thailand †

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Received 30 January 2006
Accepted 5 April 2006

Abstract − Thailand is the world leader in natural rubber production and export. Intermediate products from natural rubber industries include ribbed smoked sheets (RSS), air dried sheets (ADS), block rubber, crepe rubber, and concentrated rubber latex. In these production processes, many environmental problems arise. These include air, water, and odor pollutions. In this article, environmental problems and existing control techniques in each rubber production are reviewed. In rubber sheet drying industry, main concern is the smoke particles from fuel wood burning because of the presence of hazardous components such as PAHs (polycyclic aromatic hydrocarbons) associated with the particles. The PAH concentration is very high in the workspace and this could have adverse effect on workers' health. Moreover, the wastewater in rubber drying cooperatives is not treated properly. Appropriate technologies are needed in dealing with both smoke particles and wastewater problems. In rubber latex industry, main concern is wastewater but it is generally well treated. The odor problem arising from ammonia used for latex preservation remains, however, unsolved. In rubber glove industry, main problem is the wastewater and it is treated the same way as in rubber latex industry.

Key Words : Natural Rubber, Pollution, PAH, Wood Burning, Wastewater.

1. Introduction

Thailand is the world leader in natural rubber (*Hevea brasiliensis*) production and export. Total rubber production in 2004 was 2.9 million metric ton (Thailand Rubber Research Institute, Department of Agriculture, Ministry of Agriculture and Cooperatives, http://www.rubberthai.com, 2005). White liquid obtained from rubber trees, called rubber latex, is used as raw material for five intermediate forms of the rubber before they are used in downstream rubber product industries. These intermediate products include ribbed smoked sheets (RSS), air dried sheets (ADS), block rubber, crepe rubber, and concentrated rubber latex. Downstream products of the natural rubber are rubber tires, medical gloves, condoms, rubber bands, flexible tubings, etc. Among the five forms of the intermediate rubber, RSS is the leading product accounting for 43 % of the total product, while the block rubber and concentrated latex account for 36 % and 17 %, respectively.

Production of each form of the natural rubber causes, however, many environmental impacts. These include air, water, and odor pollutions. In this article, environmental problems and existing control techniques in each rubber production will be reviewed.

† タイにおける天然ゴム製造に伴う環境問題

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Suggestion for pollution control will also be given in relevant sections.

2. Environmental Problems

Environmental problems related to natural rubber production include air and water pollutions in dried rubber sheet (RSS and ADS) production. Problems in rubber latex industry are particularly water and odor pollution, while main problem in block rubber is odor. Environmental problems in downstream rubber product industries depend on the type of the product. In this section, problems in dried rubber sheet, rubber latex, and rubber product industries have been reviewed.

2.1 Rubber Drying Industry

Most of the RSS or ADS manufacturers in Thailand reside in the south. At present, the production has been shifted from large-scale industries to community-level rubber cooperatives. These cooperatives reside in the areas where rubber trees are planted. There are totally about 700 such cooperatives throughout the country, mostly in the south as shown in **Fig. 1** (Furuuchi *et al.*, 2006). The capacity of each cooperative is about 500～1,000 metric ton per year. These cooperatives use mainly rubberwood as a source of heat to dry the rubber sheets. **Fig. 2** shows a common layout of a rubber cooperative producing RSS or ADS. In the production process, fresh rubber latex collected in a pool is diluted with water and mixed with formic acid to form solidified tofu-like slabs, as shown in **Fig. 3** (a). These slabs are then transported in a water rail to a squeezing machine and are squeezed to form thin (2 ～ 3 mm) sheets, as shown in Fig. 3 (b). The raw rubber sheets are then hung on a cart to let the water evaporate and then are dried in a heating room. The only difference in RSS and ADS productions is that the rubber sheets are in direct contact with smoke from rubberwood burning in RSS production, while in ADS production, only heat is used to dry the sheets. **Figs. 4** (a) and (b) show a rubberwood burner that supplies heat to the smoking room, and the dried rubber sheets, respectively. Burning of the fresh rubberwood causes a high concentration of smoke particles in the gas (**Fig. 5**). These particles cloud the workspace in the factory of rubber cooperatives, due to poor ventilating system. Moreover, these particles can be transported in atmospheric air and may then cause environmental concern to the residents or cities nearby. Another major source of environmental pollution in rubber drying cooperatives is the wastewater. Water has been used in many rubber sheet production processes. These include dilution of the rubber latex before mixing with formic acid, washing and transporting the rubber slabs, lubricating the rubber sheets when being squeezed, and washing the containers and factory floor, which result in a large amount of wastewater. Appropriate treatment is then needed to avoid environmental effects.

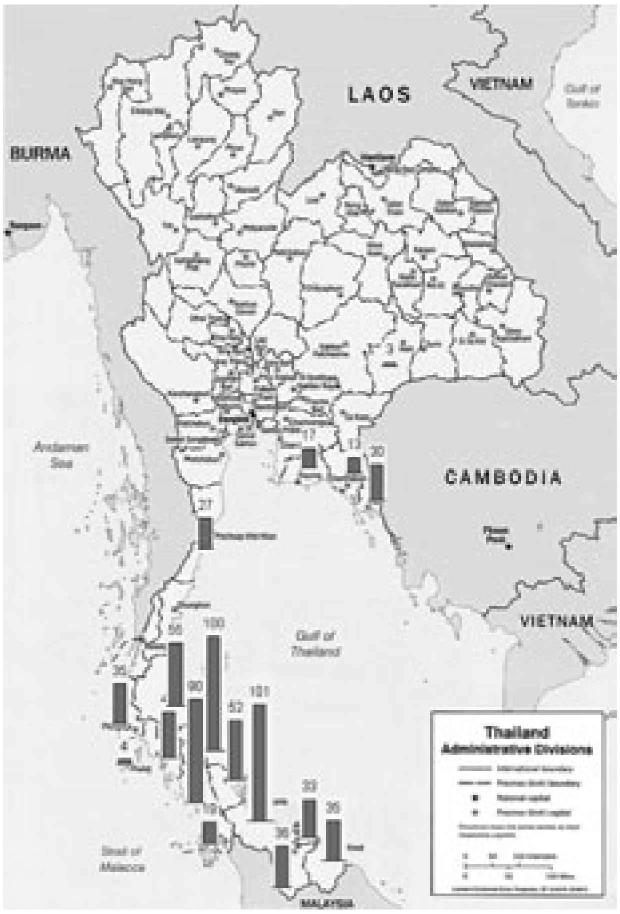

Fig. 1 Map of Thailand indicating locations of rubber cooperatives.

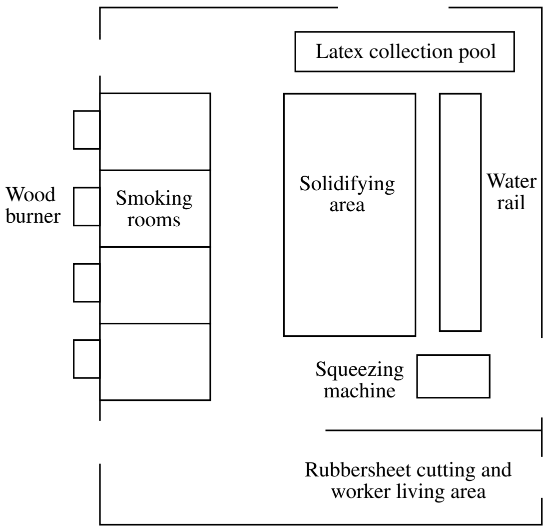

Fig. 2 Layout of a rubber cooperative factory.

(a)  (b) 

Fig. 3 Rubber sheet production process. (a) Rubber slab formation and transportation. (b) Rubber sheet squeezing.

(a)  (b) 

Fig. 4 Rubber sheet drying. (a) Wood burner. (b) Dried rubber sheets.

2.1.1 Particulate Matters : Smoke Particles

Kalasee *et al.* (2003) studied the size distribution characteristics of aerosol particles from rubberwood burning and found that the aerosol is dominantly single mode with average mass median aerodynamic diameter (MMAD) of 0.95 micron, and geometric mean standard deviation (GSD) of 2.51. The mass concentration of the smoke particles was found to depend strongly on the moisture content of the wood; ranging from 47 to 1,358 mg / m^3 for a rubberwood moisture content between 34.5 to 107.5 %.

Furuuchi *et al.* (2006) investigated characteristics of smoke particles from the rubberwood burning and evaluated their influences on workspace environment in a rubber cooperative as well as surrounding atmosphere in the city of Hat Yai, hailand. The size distribution of aerosol at the burning source agrees with results from Kalasee *et al.* (2003) as shown in **Fig. 6**. The size distributions at workspace and ambient in Prince of Songkla University are, however, bi-modal with influence of aerosol from other anthropogenic sources.

Fig. 5 Rubber cooperative factory workspace showing cloud of smoke from wood burning.

Values of total suspended particulates concentration (TSP) are shown in **Table 1**. Concentration of particles inside workspace is quite high even though it is in the acceptable limit of 0.330 mg / m^3 regulated by the Thailand Department of Pollution Control. The concentrations at urban areas are very well within the limit for atmospheric air.

Tekasakul *et al.* (2005) and Furuuchi *et al.* (2006) investigated the concentration of 15 different PAH components (**Fig. 8**) associated with aerosol particles. The PAHs mass fraction in particles in each size range is shown in **Fig. 7**. The smoke particles from rubberwood burning are found to contain 10～100 times higher portion than in the ambient particles almost regardless to the particle size. This indicates that rubberwood burning is a serious emission source of PAHs. The PAH concentration in the workspace is still high enough, more than ten times higher than that in the ambient for some PAH components, so that the working environment may be in the serious situation even though the mass concentration is within the limit of the regulation.

Figs. 9 and **10** show the mass ratios between PAH compositions in the source and workspace, respectively. Fractions of PAHs with larger molecular sizes with 4 ～ 6 aromatic rings are high in the source particles probably because these compositions are usually generated from combustion. However, the fractions of these compositions are still large in the workspace but low in the ambient particles (not shown). The high temperature in the oven may be the reason why the fraction of semi-volatile PAHs compositions with 2 ～ 3 aromatic rings from the source is reduced.

2.1.2 Wastewater

Wastewater from rubber sheet production in the cooperatives comes from four sources; remainder of the water in the rubber sheet formation containers, transporting of the rubber sheets in a water rail to the squeezing machine, spraying of the rubber sheets during a squeezing process, and washing of the containers and factory floor. The wastewater from rubber cooperatives is about 5.2～13.4 m^3 / ton of dry product (Boonchuay, 1998). The production capacity of rubber cooperatives is generally in the range of 450 ～2,600 kg / day. Hence, wastewater effluent from a single cooperative can be as high as 35 m^3 / day.

Boonchuay (1998) also analyzed the wastewater from the four sources mentioned above in three rubber cooperatives and found that the water is acidic because formic acid is used during the rubber sheet

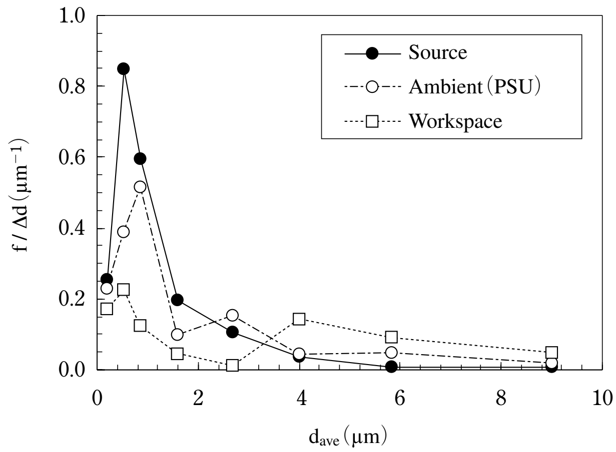

Fig. 6 Size distribution of aerosol particles from source and workspace samplings.

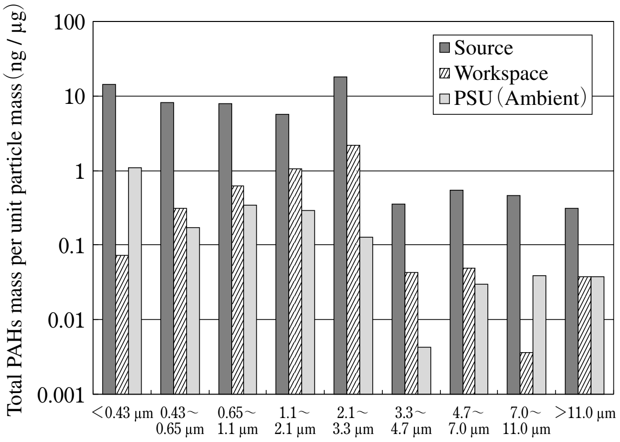

Fig. 7 Total PAHs mass fractions in particles in each size rage sampled at source, workspace and PSU (ambient).

Table 1 TSP concentration at each sampling site

Location	TSP (mg / m^3)
Source	199.2
Workspace	0.186
Urban (PSU)	0.067
Urban (downtown)	0.045

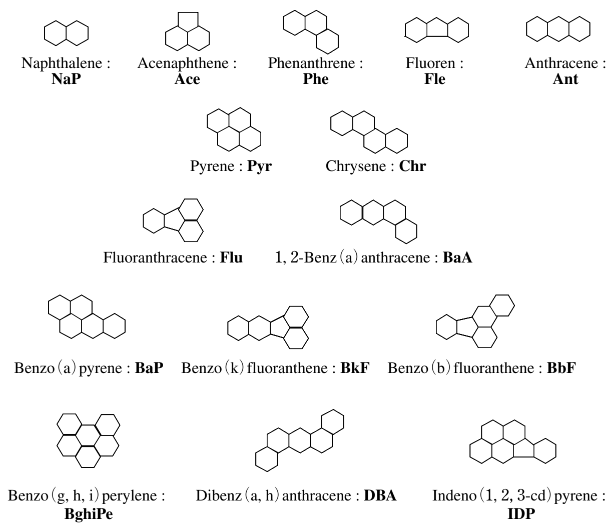

Fig. 8 Chemical structures of the PAHs considered.

coagulation process, as shown in **Table 2**. The values of BOD_5, COD, TKN, NH_3-N, TP and sulfate are extremely high, especially for the remainder of the water in the rubber sheet formation containers. This is because the water leftover in the containers contains higher amount of rubber serum than water from other sources.

2.2 Rubber Latex Industry

The natural rubber latex contains about 25 to 45 % of the dry rubber content (DRC). This latex has been centrifuged to increase its DRC to about 60 % by removing water and other impurities in the rubber latex industry. The concentrated latex is used as raw material for rubber product industries, for instance, rubber gloves. The latex is usually treated by ammonia solution (0.2 or 0.7 %), tetramethyl triuram disulfide (TMTD), zinc oxide (ZnO) and diammonium phosphate (DAP) to extend its life, and to remove the magnesium by sedimentation prior to the centrifugation (Tekprasit, 2000). The leftover from centrifugation is called skim latex which contains 5 ~10 % of rubber content (Intamanee, 1997). The ammonia is removed from the skim latex and H_2SO_4 is added to recover the rubber content prior to the processes to make skim crepe or skim block. The skim latex and wastewater from the skim latex production contain pollutants and other substances as shown in **Table 3** (Thongpradistha, 1999).

The ammonia solution added to the rubber latex causes a strong smell environment, near the centrifugation area in particular. This can have adverse effects on workers' health, especially the respiratory system. Solid rubber waste is usually accumulated in

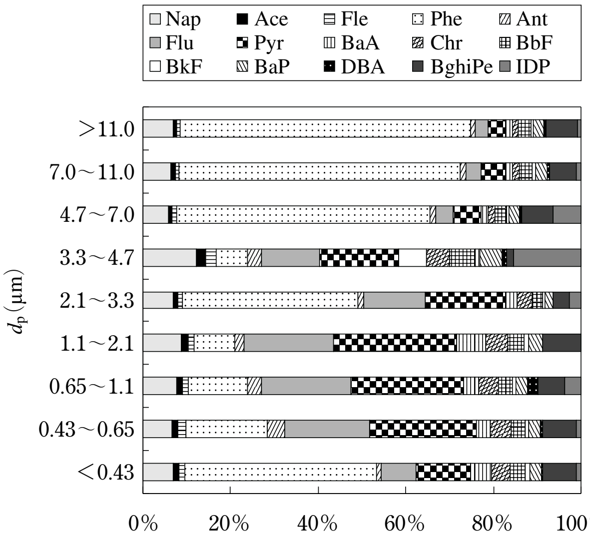

Fig. 9 PAHs mass ratios in each size range (source).

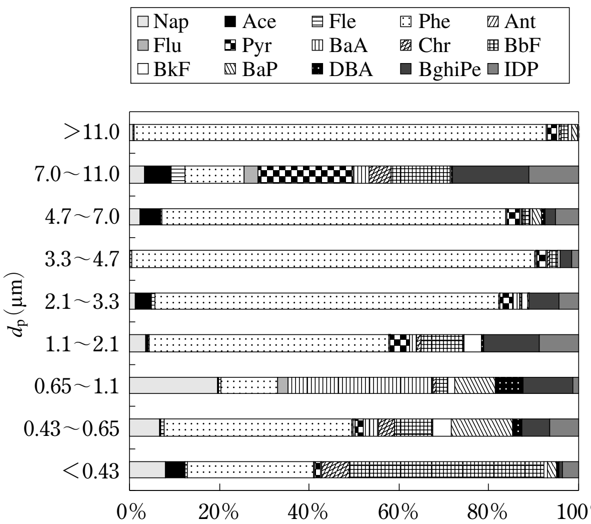

Fig. 10 PAHs mass ratios in each size range (workspace).

Table 2 Average values of wastewater characteristics from rubber sheet production in rubber cooperatives (Boonchuay, 1998)

Property	Source				
	A	B	C	D	E
pH	5.0	5.3	5.3	5.8	5.9
Temperature (℃)	26.0	26.7	26.7	27.1	26.3
DO (mg / L)	1.13	0.45	3.92	0.58	2.08
BOD_5 (mg / L)	9,433	3,433	7,016	1,391	4,783
COD (mg / L)	15,069	5,137	11,344	1,928	6,673
SS (mg / L)	164	93	195	525	167
TKN (mg / L)	162.1	79.5	190.9	60.2	132.0
NH_3-N (mg / L)	85.1	45.0	110.0	38.7	75.9
TP (mg / L)	21.6	20.0	17.8	19.4	14.9
Sulfate (mg / L)	472.6	225.8	445.2	136.0	188.1
Acidity (mg / L as $CaCO_3$)	986.5	347.8	581.8	130.1	391.7
BOD_5 leading (kg BOD_5 / d)	29.4	7.8	5.8	1.0	37.3

Note: DO is the dissolved oxygen, BOD_5 is the biochemical oxygen demand, COD is the chemical oxygen demand, SS is the suspended solids, TKN is the total kjeldahl nitrogen, and TP is the total phosphorus.
A is the remainder of the water in the rubber sheet formation containers.
B is the water in the transport rail that moves rubber slabs to the squeezing machine.
C is the water used in spraying the rubber sheets in the squeezing machine.
D is the water used in washing the containers and factory floor.
E is the overall water from the rubber sheet production factory.

Table 3 Properties of wastewater from rubber latex industry

Property	Skim latex	Wastewater from skim latex production
pH	6.3	4.8
Suspended solid (mg / L)	8,000	42,550
COD (mg / L)	–	32,690
BOD_5 (mg / L)	11,830	13,760
Total nitrogen (mg / L)	750	4,620
NH_4^+ (mg / L)	540	3,430

a rubber trap, drains, latex container, and wastewater treatment ponds. It has high impurity due to contamination. Centrifuged residue is a white sludge obtained from sedimentation in latex container and from centrifugation. It contains high content of plant nutrients, i.e. nitrogen, phosphorus, potassium, magnesium and alkaline pH.

2.3 Rubber Product Industry

In this section, only the environmental problem in rubber glove industry will be mentioned. Rubber gloves are manufactured from the concentrated rubber latex. The hand-shaped model, so-called former, is dipped into a compound latex bath. Thin layer of latex is formed on the former and is then brought into several steps in the production of a glove. Major environmental problem in rubber glove industry is wastewater as in the case of the latex industry. Two main sources of wastewater are from washing the maturation container and from the production processes. Maturation is the process of pretreatment of rubber latex by chemicals. Wastewater from washing the maturation container contains suspended latex particles. Calcium chloride solution is added to the water to form large-size lumps that can be wiped off easily. However, a large portion of fine suspended particles still remains in the water and makes it highly polluted. Wastewater from the production processes is, however, much less polluted. The COD from container washed water is as much as twenty times higher than that from the process water, while the BOD_5 is about 2.2 times higher (Bunnual *et al.*, 1995 ; Srisuwan, 1996).

3. Pollution Control Techniques

In this section, existing techniques for the pollution control in relevant industries as well as attempts to solve the problems are reviewed.

3.1 Rubber Drying Industry

3.1.1 Particulate Matters

Currently there is no control techniques implemented to remove smoke particles from the emission of rubberwood burning for environmental purpose. However, Tekasakul *et al.* (2006) used a simple wire-cylinder type electrostatic precipitator (ESP), shown in **Fig. 11**, to trap a part of smoke particles from rubberwood burning in rubber cooperative before entering rubber smoking room in order to improve rubber smoked sheet color. Reduction of the amount of smoke particles results in lighter and more desirable color of RSS. A portion of smoke is still needed because it contains phenolic acid which helps preserve the life of the rubber sheets. They found that with ESP collection efficiency higher than 40 % during 10 hours of operation, the color of the dried RSS was quite satisfactory. However, to efficiently remove smoke particles for the environmental point of view, the ESP must be improved to increase its collection efficiency. Moreover, an appropriate cleaning mechanism for collected particles on the electrode surface needs to be taken into consideration because accumulation of smoke particles reduces the collection efficiency of the ESP. Currently, we are modifying the rubber smoking to reduce energy usage, and we have found that by simply adjusting the flow pattern inside the smoking room and reduce loss of energy through the draft tube, energy usage can be saved up to about 31 %. The saving of energy means reduction of rubberwood to be burned and, as a result, reduction of emission of smoke particles. Another way to reduce the use of fuel wood is by using alternative energy to assist the drying of rubber sheets. Solar energy is an environment-friendly energy source. It can be used to initially reduce the moisture content of the rubber sheets to a certain level before fuel wood is subsequently used to completely dry the sheets. Solar energy can be used as a direct or indirect heat source. Direct solar drying involves direct exposure of the rubber sheets to the sunlight. This can be achieved by means of a transparent chamber. Moreover, solar-heated air flowing through the chamber can enhance the drying rate. Indirect solar drying employed a use of solar collector to heat the flowing air that eventually passes through the rubber sheets and carries the moisture with it (Ekechukwu and Norton, 1999; El-Sebaii *et al.*, 2002). Optimal condition, i.e. suitable temperature and air velocity, needs to be explored

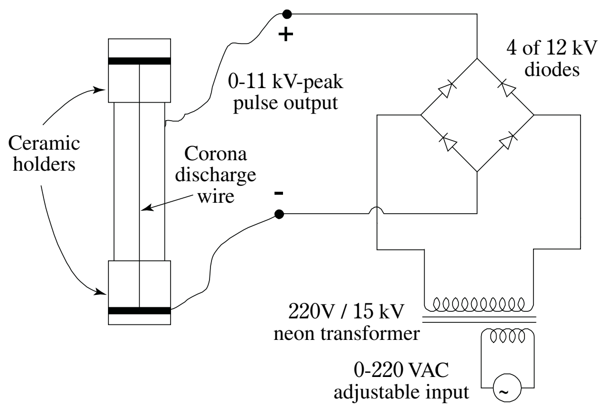

Fig. 11 Diagram of the ESP and electric circuit.

when designing the solar drying system. Currently, we are testing the drying in a chamber to simulate solar drying for this purpose.

3.1.2 Wastewater

Wastewater treatment system of all rubber cooperatives is identical. It contains three consecutive ponds receiving wastewater from the rubber production sheet area. These three ponds are not actually the water treatment ponds. They are merely sedimentation ponds where wastewater from rubber production flows to pond 1 and is allowed to slowly transport to ponds 2 and 3, respectively, via small tubes. Sedimentation takes place in each pond. In general an aerated paddle wheel system is installed in Pond 1 to add oxygen to the wastewater but almost all of the cooperatives do not use the system as it simply add electricity cost to the production of the rubber sheets. In the rainy season, wastewater ponds will be flooded and the wastewater will flow to the neighboring agricultural areas. This causes complaints from farmers in the vicinity area affected by the flood.

Boonchuay (1998) investigated performance of anaerobic filter and anaerobic digester in the treatment of wastewater from rubber cooperatives and found that the anaerobic filter is more efficient for several values of hydraulic retention time (HRT) in BOD_5 removal. These methods are, however, difficult to implement and operate, and not cost-saving. A more appropriate method for wastewater treatment needs to be explored.

Sdoodee *et al.* (2005) studied possibility of using the wastewater from the last pond in rubber cooperatives in watering several kinds of plants. They have found that the plants treated with mixtures of wastewater and tap water had higher yields than those treated by tap water and are safe from minerals and metals.

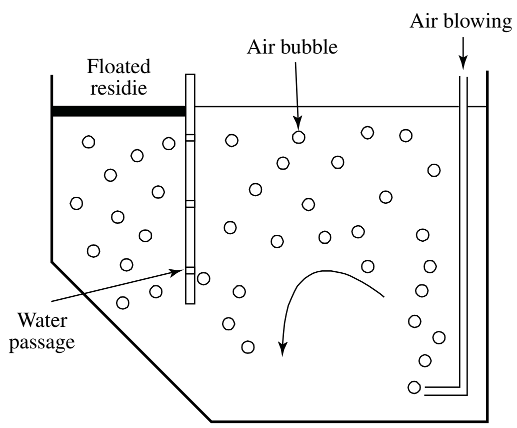

Fig. 12 Dissolved air floatation.

3.2 Rubber Latex Industry

To treat the wastewater, latex industry usually installs a rubber trap pond to separate rubber particles prior to discharging it to another anaerobic or biological wastewater treatment system. Efficiency of this trapping method is quite low. A better method of rubber particle separation system is by trapping using flocculation and floatation (Prabnakorn, 2000). In this method, rubber latex particles are flocculated to form larger size particles. The floatation can be accomplished by one of the following three methods ; dissolved air floatation, air floatation, or vacuum floatation. The dissolved air floatation is the simplest and most economical method. It involves blowing of air bubbles in the wastewater at the atmospheric pressure to move the sediment upward to the water surface as shown in **Fig. 12**.

Anaerobic digestion is used as initial wastewater treatment to reduce concentration of organic compounds before an appropriate oxygen (aerobic) treatment to remove the remaining organic compounds. Anaerobic digestion of sulfate contents results in formation of hydrogen sulfide (H_2S) which causes bad odor. Rucksapram (1996) found that pH adjustment to alkaline condition can reduce generation rate of H_2S.

Aerobic pond is used to treat wastewater that has low organic concentration using organic bacteria in digesting organic compounds (Wittayakul, 2001).

Wittayakul (2001) studied performance of biofilter in reducing concentration of H_2S and found that using the composted material results in the highest efficiency in H_2S removal at 63.7 % for 20-cm thick bed. Increasing the depth of the bed increases the removal efficiency. He also studied performance of the wastewater treatment system of five rubber latex industries in Songkhla province, Thailand, consisting of rubber trap, anaerobic pond, facultative pond, and aerobic pond. It was found that the overall removal efficiencies of COD, BOD_5, suspended solids, and sulfate are 93.9～99.7 %, 84～98.7 %, 45.7～97.8 %, and 87.5～99.7 %, respectively.

3.3 Rubber Product Industry

Since the fine suspended latex particles are the main source of pollutant of the wastewater in rubber glove industry, Bunnual *et al.* (1995) and Srisuwan (1996) attempted to remove these particles using flocculation and flotation. Srisuwan (1996) showed that optimum amount of 5 mg / L of alum and 4 mg / L of polyacrylamide resulted in 96.4 %, 98.9 % and 99.6 % removal efficiencies of COD, suspended solids and turbidity, respectively. When tested in the continuous process using the preceding condition (5 mg / L of alum and 4 mg / L of polyacrylamide), it was found that the minimum hydraulic retention time is 15 minutes. The COD, BOD_5, suspended solids and turbidity can be reduced by 96.0 %, 72.9 %, 97.3 % and 96.2 %, respectively.

4. Conclusion

Environmental situation in rubber production varies according to the nature of each industry. In rubber sheet drying industry, smoke particles contribute to pollution in workspace and neighboring atmosphere. The PAH concentration is very high for the source aerosol and quite high for the workspace aerosol. This could have adverse effects on workers' health. No aerosol collection techniques have been employed to reduce this problem so far. The wastewater in rubber cooperatives is not treated properly as well. Appropriate and low-cost methods need to be explored in dealing with both smoke particles and wastewater. Wastewater in rubber latex industry is generally treated suitably because latex industry involves large-scale factories in which capital and maintenance costs are not of big concern and they have to strictly comply with the environmental law. The odor problem arising from ammonia used for latex preservation remains, however, unsolved. In rubber glove industry, main problem is the wastewater and it has been treated the same way as in the rubber latex industry.

References

Boonchuay, C.: "Rubber Sheet Wastewater Treatment by Anaerobic Process," Thesis, Prince of Songkla University (1998) (in Thai)

Bunnual, P., Srisuwan, N., Arrykul, S. and Danteravanich, S.: Treatment of Waste Water from a Rubber-gloves Plant Songkla Province, Thailand, *Proc. the Thailand-Japan Joint Conference and Exhibition on Solid-Fluid Separation Technology*, Bangkok, Thailand, 48-53 (1995)

Ekechukwu, O. V. and Norton, B.: Review of Solar-Energy Drying Systems II : An Overview of Solar Drying Technology, *Energy Conversion and Management*, **40**, 615 (1999)

El-Sebaii, A. A., Aboul-Enein, S., Ramadan, M. R. I. and El-Gohary, H. G.: Experimental Investigation of an Indirect Type Natural Convection Solar Dryer, *ibid*, **43**, 2251 (2002)

Furuuchi, M., Tekasakul, P., Murase, T., Otani, Y., Tekasakul, S. and Bai, Y.: Characteristics of Particulates Emitted from Rubber-wood Burning, Accepted for Publication Towards, *Journal of Ecotechnology Research* (2006)

Intamanee, J.: Treatment of Latex Industry Wastewater by Aneaerobic Digestion, *Research Report, Prince of Songkla University, Hat Yai, Thailand* (1997) (in Thai)

Kalasee, W., Tekasakul, S., Otani, Y. and Tekasakul, P.: Characteristics of Soot Particles Produced from Rubberwood Combustion, *Proc. 2nd Asian Particle Technol. Symp.*, Penang, Malaysia, 2003, **2**, 103-10 (2003)

Prabnakorn, P.: "Primary Treatment by Air Floatation in Rubber Trap Tank for Latex Rubber Plant Wastewater Treatment," Thesis, Prince of Songkla University (2000) (in Thai)

Rucksapram, G.: "Assessment of Hydrogensulfide Problem in Anaerobic Ponds of Rubber Wastewater Treatment System," Thesis, Prince of Songkla University (1996) (in Thai)

Sdoodee, S., Chaiprapat, S. and Ovatlarnporn, C.: Assessment of the Impact of Using Partially Treated Rubber Sheet Wastewater for Cultivation, *The Thailand Research Fund (TRF) Research Report* (2005)

Srisuwan, N.: "Rubber Gloves Plant Wastewater Treatment by Floatation," Thesis, Prince of Songkla University (1996) (in Thai)

Tekasakul, P., Furuuchi, M., Otani, Y., Tekasakul, S. and Sakano, T.: "Size Distribution and PAH Composition of Particulate Matters Emitted from Rubberwood burning and Effect on Atmospheric Air in Hat Yai," *Proc.* 4*th Asian Aerosol conference : AAC-2005*, Mumbai, India, 688-690 (2005)

Tekasakul, S.,Tantichaowananl, M.,Otani, Y., Kuruhongsa, P. and Tekasakul, P.: Removal of Soot Particles in Rubber Smoking Chamber by Electrostatic Precipitator to Improve Rubber Sheet Color," Accepted for publication towards *Aerosol and Air Quality Research* (2006)

Tekprasit, V.: "The Utilization of the Centrifuged Residue from Concentrated Latex Industry as a Soil Conditioner," Thesis, Prince of Songkla University (2000) (in Thai)

Thongpradistha, J.: "Isolation, Identification, and Cultivation of Photosynthetic Bacteria in Wastewater from Concentrated Latex Processing Factory," Thesis, Prince of Songkla University (1999) (in Thai)

Wittayakul, P.: "Treatment of Sulfate and Hydrogen Sulfide in Latex Rubber Wastewater by Using Anaerobic and Biofiltration," Thesis, Prince of Songkla University (2001) (in Thai)