

Odor pollution treatment technologies: a review

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ABSTRACT

Odor pollution is especially concerned due to its unpleasant smell, human health impacts and the possibility to be dispersed in a very large area. Odor emission sources from typical industries were introduced. The representative technologies for cleaning odor polluted air

stream such as adsorption, absorption, biological treatment, thermal and non-thermal oxidation methods were reviewed in this paper. The advantages and disadvantages of these methods were analyzed and compared.

Keywords: odor pollution, adsorption, absorption, biological filter, thermal oxidation

1. INTRODUCTION

Odor pollution may be caused by a single volatile compound or more typically by a mixture of compounds [1]. It is highly concerned due to its unpleasant smell, human health impacts and the possibility to be dispersed in very large area. The acute human health impacts by odor pollution such as burning eyes and throat, headaches, skin irritation, sleeping problems, etc., were reported [2, 3]. The dispersion ability of odorants can cause environmental problems at the local and regional scale [4].

Odor pollution is difficult to address given that many pollutants cause strong odors at extremely low concentrations [3]. The human nose is very sensitive with on average over 5 million scent receptors at ppb concentrations [1]. In addition, regulations and guidelines to avoid odor annoyance is presently inadequate and differ from country to country [5, 6]. In Vietnam, the national technical regulations in ambient air

and industrial emission, for instances QCVN 06 : 2009/BTMT, QCVN 19 : 2009/BTMT, QCVN 20 : 2009/BTMT, are being applied to control odor pollution.

Complying with these odor pollution regulations, various treatment technologies have been developed. None-treatment technologies such as ventilation, dispersion or cent-covering can be used to mitigate odor pollution, however, these methods do not originally remove the odor pollutants. Detail knowledge of treatment technologies which can separate and degrade odor pollutants from the polluted air stream is therefore highly essential for environmental engineer and manager.

This paper aims to summarize odor pollution emission sources and to review the typical traditional treatment technologies including adsorption, absorption, biofiltration, thermal and non-thermal oxidation which have been efficiently applied in Vietnam and

elsewhere in the world to degrade and remove the odorous compounds from the polluted air stream. Advantages and disadvantages of the considered methods are also assessed and presented.

2. ODOR POLLUTION SOURCES

At first, allodorous sources should be determined and classified. They need to be captured before an adequate treatment method can be applied. A variety of municipal, agricultural, and industrial activities are sources of odorous air emissions. Municipal odor sources include sewage treatment plant (emitting odorants such as hydrogen sulfide [7]), storm drain systems, and sanitary landfills; agricultural sources include livestock feed lots, poultry farms, composting and other biomass operations, and pesticide operations; industrial sources include pulp (emitting odorants such as hydrogen sulfide, methyl mercaptan, dimethyl sulfide, sulfur dioxide [3]), leather tannery (emitting odorants such as hydrogen sulfide, ammonia), latex rubber, tapioca, livestock, fishery, fertilizer, pesticide, etc. mills. Typical main odorants emitting from different sources is

presented in Table 1.

It is important to not only consider obvious sources like air vents and stacks but also sources of fugitive emissions. Especially the later have often been neglected but may very well account for a high portion of the odor problem. Possible sources for fugitive odorous emission may be open delivery, tipping, and storage areas, open doors and windows, as well as leakages in the piping systems. In addition, poorly designed or malfunctioning treatment systems should be considered emission sources [4].

When identifying and recording the emission sources, a company's site plan may be very helpful to mark the discovered sources for future reference. For the recording of the various emission sources, a data sheet that contains all relevant data to describe, classify and characterize an odor emission source. Values of parameters such as odor composition, odor concentration, gas temperature, volume of exhaust gas, frequency of gas emission are essential for the decision of which treatment methods should be chosen for odorous mitigation.

Table 1. Typical main odorants emitting from different sources

Compounds	Main odorants	Emission sources	Ref.
Sulfur-compounds	hydrogen sulfide, methyl mercaptan, dimethyl sulfide, sulfur dioxide	Pulp paper, night-soil treatment, sewage disposal, drain pit of high-rise building, rubber, landfill	[3, 8]
Nitrogen-compounds	ammonia, trimethyl amine	Poultry farm, composting facility, fish-meal, night-soil treatment, anaerobic waste water treatment	[8, 9]
Organic solvent	toluence, xylene, ethyl acetate	Coating factory, laundry, adhesive manufacturing factory, plywood, car repair shop, furniture manufacturing factory	[8]
Aldehyde compounds	acetaldehyde	Metal coating factory, casting, off-set printing, coffee baking	[8]
PAHs, naphthalene	Naphthalene	Asphalt plants	[2]
Lower fatty acid	n-butyric acid	Poultry farm, pet shop, starch manufacturing	[8]

3. TREATMENT TECHNOLOGIES

Treatment process can be designed large enough to meet the requirements. Thus, selection and design of suitable treatment processes must aim at finding an optimum where the required treatment efficiency is achieved as cost-effectively and feasible, using a technology that is adapted to the specific conditions. Often, a combination of different treatment methods is

advantageous. Table 2 lists some of the common odor treatment processes along with corresponding design options. Having this variety of treatment options, the main task is to know which system is best applicable for a specific odorous emission. This section reviews the typical treatment technologies including adsorption, absorption, biological treatment, thermal and non-thermal destruction.

Table 2. Overview on odor treatment processes [4]

Process	Options
Adsorption	Different adsorbents (activated carbon, activated alumina, silica gels, zeolites, etc.)
Absorption	Physical absorption; chemical absorption
Biological waste gas treatment	Bioscrubbers; biotrickling filters; biofilters
Waste gas incineration	Thermal afterburners; catalytic incinerators; regenerative thermal oxidation (RTO)
Non-thermal oxidation processes	Ozone, UV, non-thermal plasma

3.1 Adsorption

Adsorption is the process whereby odorants are sorbed on the surface of solid porous materials (adsorbents). Carbonaceous materials such as activated carbon are commonly used as an effective adsorbent [4, 10]. Other adsorbents such as biochar, activated alumina, silica gels and zeolites were also used [4]. Recently, research has focused on the design of engineered and specific adsorbents [11, 12].

In industrial applications, adsorbers are mostly designed as fixed bed reactors, with the polluted air flow passing through a stationary bed. To achieve the most efficient operation of the carbon filter, substances like dust, tar, mineral oil and large quantities of steam must be removed from the polluted gas before it passes through the filter bed to prevent these substances

from clogging up the small charcoal pores and thus reducing their adsorption capacity. Also certain metal compounds quickly reduce the charcoal adsorption capacity, often as a result of heavy oxidation of the coal and destruction of the pore structure. To improve the adsorption capacity of activated carbon for certain purposes the coal is impregnated with various agents so that the substances intended for retention react chemically with the impregnation agent. Activated carbon can often be regenerated in a process where odorants are removed with steam.

Desorption process should also be simultaneously designed and operated along with the adsorption process in order to ensure the continuous treatment. This may be achieved by parallel operation of several adsorbers or by using an adsorber wheel [13]. Regeneration of the adsorbent is usually conducted by means of

hot gas or steam. A disadvantage of this technology is the relatively low heat capacity of the regeneration gases, resulting in large regeneration gas flows, which are re-diluting the desorbate [11]. Figure 1 presents a scheme of activated carbon adsorber. Activated carbon adsorption technology was also used for removing volatile organic carbon odorants [14, 15].

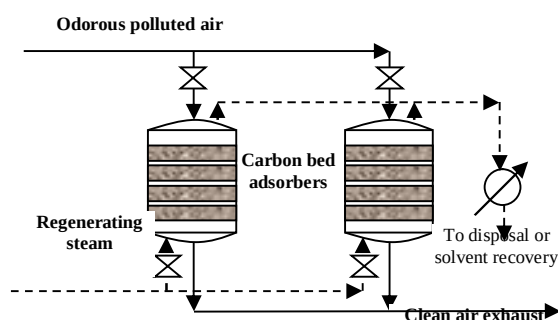


Figure 1. A schematic diagram of odorous adsorption technology

3.2 Absorption

Absorption technology is often used to mitigate odor pollution by dissolving off-gas compounds in a scrubbing liquid. Mass transfer is mainly controlled by the solubility of the substances and the gas-liquid interfacial surface [16]. Hydrogen sulphide, organic sulphur gases, ammonia, organic nitrogen compounds such as amines, organic acids, chlorine, and other

chlorine-containing compounds can be removed by scrubbing [17-19]. In this process, odorous compounds are transferred from a gas phase into a liquid phase. The liquid may be water, an aqueous solution or suspension of a reactive compound, or an organic solvent. The use of oxidants such as ozone (O_3) and hydrogen peroxide (H_2O_2), sodium hypochlorites ($NaOCl$) are often used for removal of odorous compounds from fish and meat meal processing plants and because of their relatively inexpensive and easy to handle [4]. Acid gases are needed for alkaline solutions and vice versa.

The principal factor dictating performance is the solubility of the pollutants in the solvent. Accumulation of the waste gas components in the scrubbing liquid would result in a cease of mass transfer after establishment of equilibrium according to Henry's law. Thus, the scrubbing liquid must be exchanged or regenerated.

Regeneration of the scrubbing liquid can be conducted by means of stripping with air or steam. As in adsorption, the aim is to obtain a desorbate flow with considerable higher concentration than the original exhaust air which can be treated more efficiently. Aqueous scrubbing liquids can also be biologically regenerated.

Figure 2 presents an absorption technology using a scrubber.

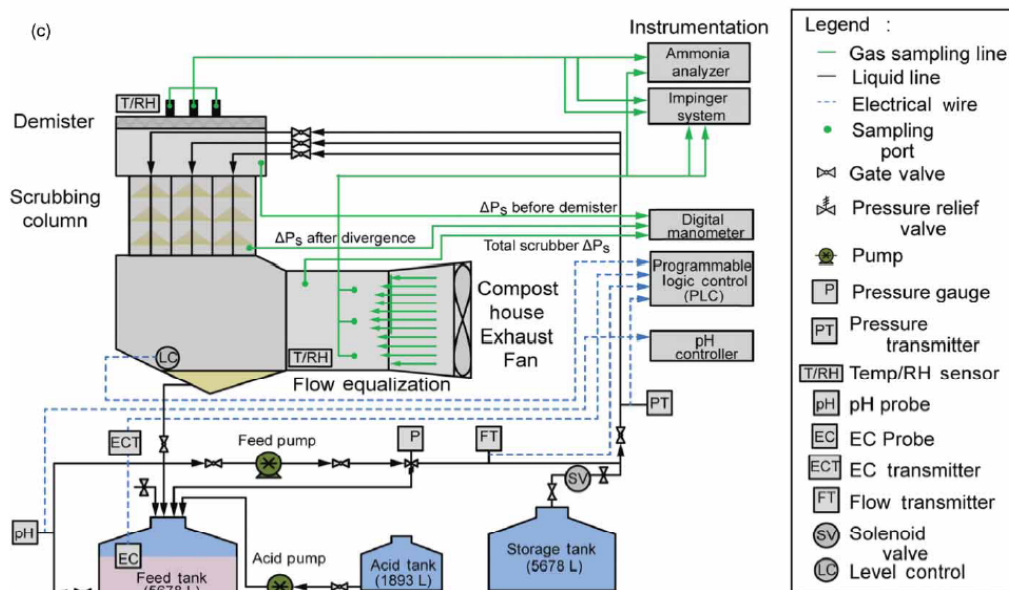


Figure 2. A schematic diagram of ammonia odorous absorption scrubber technology. After Hadlocon (2014)[18]

There are different types of scrubbers, for instance packed tower scrubbers, spray and venturi scrubbers. A common characteristic is the effort to make the efficient contact area between air and liquid as large as good. A scrubber is a fairly simple device, which is able to treat large volumes of air. Gas washing in a scrubber is, therefore, often a cheap way of removing odorants from process gases. Chemicals should be added very carefully to prevent overloading of the plant. In a well-operated scrubber the reaction products are often salts and non-smelling acids.

3.3 Biological treatment systems

Biological odor treatment technology relies on the activity of microorganisms which are able

to degrade the organic odorous compounds from the waste gas stream [20]. The catabolic process of microorganisms will oxidize the odorous compounds to the odorless compounds or to the final products of CO_2 and H_2O . One of the important advantage of the biological method is therefore its capacity to completely degrade an odorant and do not transfer the pollution from the air phase into the liquid or solid phases like the absorption and adsorption methods. In addition, no toxic chemicals and high energy are required because they are operated at atmospheric pressure and ambient temperatures. Accordingly, investment and operational costs for biological waste gas treatment systems are comparably low [21, 22]. Figure 3 presents four typical biotreatment methods.

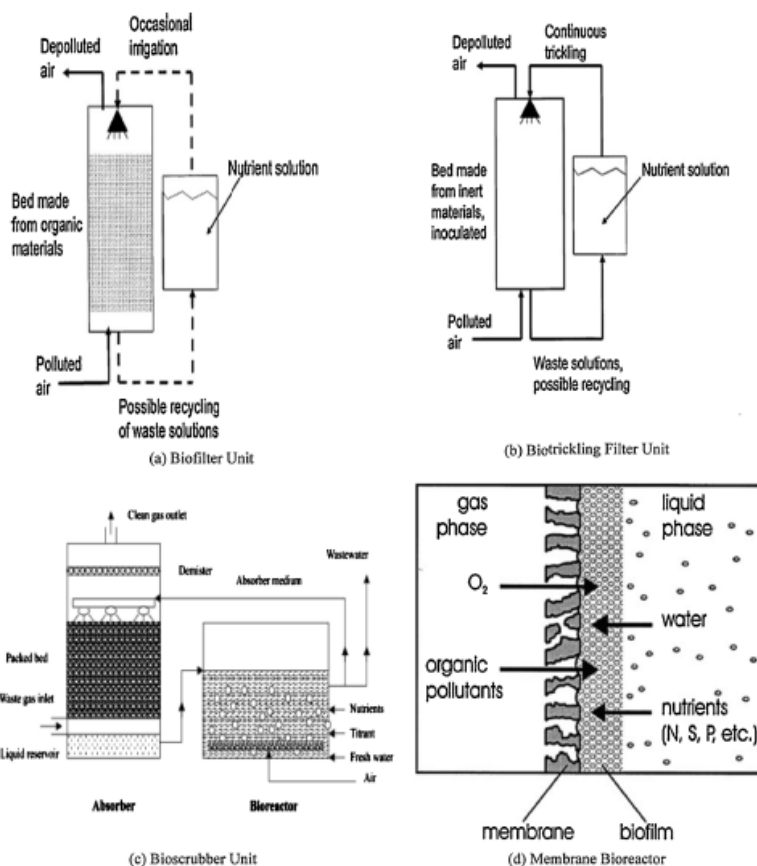


Figure 3. A schematic diagram of odorous biotreatment methods: (a) biofilter; (b) biotrickling filter; (c) bioscrubber; and (d) membrane bioreactor. After Giri (2014)[23]

3.3.1 Biofilters

Biofilters can be described as biochemical fixed bed reactors where the waste gas is treated while passing a biofilter bed. Microorganisms settle on its surface and form a biofilm in which the airborne substances are absorbed. An important criterion for biofilter media is to provide optimum environments for the microorganisms, thus an essential property is the ability to store water. Additional criteria are a low pressure drop to assure an even air distribution and a large specific surface for the mass transfer and the microorganisms to settle on. Frequently used biofilter media are compost, peat, root wood,

bark, wood chips (normally used as bulking agent) and different kinds of combinations [24].

In most of these cases, the biofilter material already provides stable mixed cultures of microorganisms, which mostly adapt to the condition and composition of the waste gas. The adaptation phase may range from several days to several weeks [24, 25]. Inoculation of the biofilter with e.g., biosolids or specialised microorganisms especially for inorganic media can be considered to shorten the starting phase [26].

One of the key parameters of biofiltration is the moisture content of the biofilter material. The optimal range for biologically active organic

media is between 40% and 60% [24, 26, 27]. To avoid drying of the filter media, the waste gas should be saturated with water vapor. Usually the air is humidified using wet scrubbers or even bioscrubbers. However, not only dry air streams can cause drying of the biofilter material. If the passing waste gas is heated within the filter due to a high microbial activity, water will evaporate into the gaseous phase, as the ability of air to hold water vapour rises with an increase of its temperature. That is why even if the waste gas initially is saturated with water, the biofilter media may still dry out. An additional irrigation system for the filter may be installed to ensure the optimal moisture content. Anyway, adding too much water should be avoided as it results in clogging and consequently in an increasing pressure drop, a limitation of the mass transfer, and possibly in anaerobic zones [26].

Biofilters may be designed as open to the atmosphere or enclosed [24]. Biofilter beds are up to 2 m deep. In open biofilters the air passes through the bed in an up-flow direction. A problem with open biofilters is the direct exposure of the biofilter media to climatic conditions which may influence its functionality. A hot and dry climate may result in a drying of the filter media. The opposite problems have been reported from places with very humid climate. In this case, heavy rainfall forced the operator to cover the filter [28]. Enclosed biofilters are less affected by weather conditions than open filters, and also offer a better moisture distribution, as they can be operated under down-flow conditions. In these cases the water from the saturated air stream moisturises the first layers of the biofilter material while excess water trickles down by gravity to deeper levels. However, typically the waste gas is not saturated with water, resulting in a drying of the media right where the exhaust is distributed. Consequently, additional sprinklers should be installed at the inlet of the waste gas [29, 30].

Traditionally, biofilters were used to treat off-gases from sewage treatment plants, composting facilities and rendering plants, which mainly contain biological intermediate degradation products [31-34]. In recent years, further applications have been opened to this technology including in food and tobacco producing and processing industries [35-37], as well as the treatment of waste gases containing industrial solvents and other volatile organic compounds [38-40]. Problematic substances regarding biofiltration are sulphurous and nitrogenous organic or inorganic compounds, as they cause acidification of the biofilter media due to their oxidation products, sulphuric and nitric acid [41, 42]. For these applications, a combination with other treatment processes should be considered. Applicable filter loads usually range between 40 and 150 m³ m⁻³ biofilter material per hour [29, 43, 44] but also filter loads of up to 500 m³ m⁻³ h⁻¹ are recorded [24].

3.3.2 Bioscrubbers and biotrickling filters

In bioscrubbers and biotrickling filters, the microorganisms generally are suspended in a scrubbing liquid but may additionally be immobilised on packing material. The most important component of these devices is the absorption column where the mass transfer between gaseous and aqueous phase takes place, and thus the airborne substances are made available to the microorganisms. Usually packing materials are installed to enhance the contact surface of both phases. In most applications the gaseous and the aqueous phases are distributed in counter flow to each other. However, if no packing materials are installed, cross-flow systems often are used.

Once the odorous substances are dissolved in the scrubbing liquid, if degradable they are removed by the microorganisms. The degradation process may take place in the liquid, usually

water, or in the biofilm that grows on the packing materials. These internals not only enhance the surface for the mass transfer but also provide an additional surface for the microorganisms to settle.

During the adaptation phase the microorganisms start to grow and form a biofilm which has a large effect on the degradation efficiency of the scrubber. Attention has to be paid to the fact that clogging of the scrubber might be a problem. To avoid clogging, the packed bed should have large pores and should be cleaned frequently. The scrubbing liquid is subsequently drawn off and continuously cycled. An activation tank may be implemented into this cycle to allow further regeneration time [45]. The degree of regeneration can be influenced by the size of the activation tank and consequently the retention time of the scrubbing liquid. It may be necessary to install an additional aeration system to provide a sufficient amount of oxygen [46, 47]. Furthermore, nutrients may be added to the scrubbing liquid to provide lacking elements like phosphorous, nitrogen, potassium, etc., for the microorganisms. The superficial air velocity in a bioscrubber should be in the range of 0.5–2.5 m s⁻¹. Packed towers operate at liquid irrigation rates of about 20–60 m³ m⁻² h⁻¹ of packing surface.

3.3.3 Bioscrubber/biofilter combination

This biological system combines the advantages of both technologies. The bioscrubber acts as a humidifier and degrades a high portion of the odour load. It also shows a buffering effect [31], which prevents high concentrations of odorous substances from entering the biofilter, which otherwise might lead to a rise in temperature in the biofilter material due to increasing degradation processes.

3.4 Thermal waste gas treatment

Thermal treatment can be basically applied to any exhaust air (Figure 4). However, since the concentration of VOCs is often low, the addition of natural gas or a pre-concentration, e.g., by adsorption, is usually required. As a general rule, the lower limit for autothermal combustion is a concentration of organic compounds of 1 g m⁻³.

For thermal treatment, catalytic and non-catalytic techniques are applied. Catalytic processes can be operated at lower temperatures, resulting in considerably lower energy demand. On the other hand, the costs for the catalyst itself have to be taken into account. In addition, for non-catalytic processes, energy costs can be significantly reduced by using advanced systems with heat recovery (recuperative thermal oxidisers, regenerative thermal oxidisers).

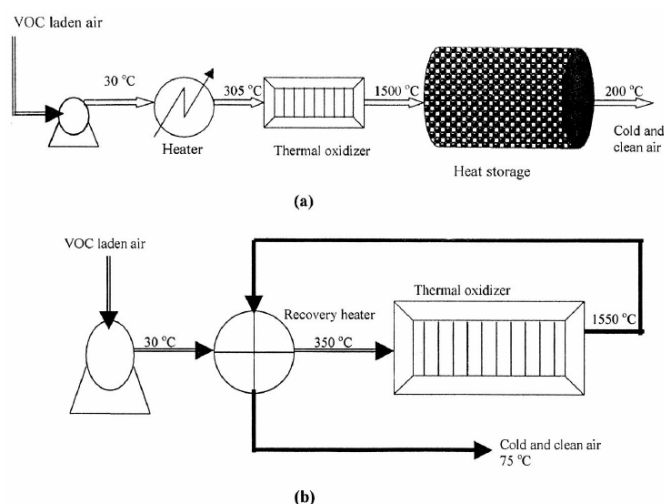


Figure 4. A schematic diagram of thermal oxidation: (a) regenerative thermal oxidation; (b) recuperative thermal oxidation. After Faisal (2000)[48]

Thermal waste gas treatment has gained in importance due to more stringent exhaust air requirements in recent years. For example, the German ordinance on mechanical–biological pre-treatment of waste [49] sets a limit of 20 mg m^{-3} of organic carbon in the exhaust air, which can hardly be achieved by biofilters. Furthermore, thermal waste gas treatment may be considered on sites where a combustion facility is operated anyway, e.g., for steam generation. However, corrosion and deposits on the combustion unit may occur depending on the composition of the waste gas. Drawbacks of thermal waste gas treatment are the high operating costs in the case of natural gas addition and the formation of secondary emissions like nitrous and sulphur oxides.

3.5 Non-thermal oxidation technologies

Besides thermal oxidation, several “cold” oxidation techniques for the treatment of odorous exhaust air, like UV treatment or non-thermal plasma, have been investigated in the last few years. UV treatment is successfully used for sterilization of drinking water or treatment of persistent wastewater components. The

technology is based on the UV induced formation of highly reactive radicals and ions which can oxidize organic molecules. Repeated efforts were conducted to apply the positive experience from water and wastewater treatment to waste gas treatment. However, significant efficiencies were only measured when high performance UV radiators were used, resulting in a very high energy demand not considered suitable for treatment of odorous waste gas [50, 51].

The non-thermal plasma technology uses strong alternating electrical currents or microwave radiation to induce highly activated molecules. Like with UV radiation, reactive radicals and ions are subsequently formed and react with odorous compounds. The “ionised air” can be generated in an additional air flow that is merged with the main waste gas flow, or directly in the main flow. Both non-thermal plasma and UV radiation result in the formation of excess ozone, which has to be removed by a subsequent catalyst [13].

In investigations at several plants using non-thermal plasma technology, [51] measured efficiencies between 0% and nearly 100%. The results were strongly depending on the

composition of the waste gas and process technology. The results of applying a non-thermal ionisation system show that a removal of the identified main odour-causers (limonene, α -pinene and dimethyl disulfide) in the waste gas of the biological waste treatment is possible under optimal process configurations [52].

At higher concentrations, the required electrical power increases strongly, implying an application of this technology in low concentration range $<100 \text{ mgC m}^{-3}$. These findings correspond to results obtained with a microwave reactor, where high efficiencies for the treatment of a gas containing 10% ethanol were only obtained at an electrical power corresponding to 14.5 kWh m^{-3} [53].

4. CONCLUSION

There are many treatment technologies to remove odorous compounds from industrial polluted air stream. However, odor problems require a systematic approach towards a sustainable solution. Thus, a strategic odor management plan is essential.

Basing on initial site assessment and due diligence investigation of the polluted air stream,

a combination of the above treatment technologies should be normally suggested to remove/reduce various odorous compounds from one or many emission sources. The following step is to thoroughly assess the local situation. According to the emission sources considered, the available area for the treatment plan and the composition and condition of collected waste gas streams, an abatement strategy should be developed. Once the odor specific data base is handled, it will provide helpful information for this purpose. Results should provide sufficient data for the design and dimensioning of a full-scale treatment process and, additionally, input data for the data base. This continuously growing pool of knowledge about odor abatement strategies and treatment technologies should be used as a tool to effectively and economically solve odor problems in industry or various other facilities.

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Tổng quan một số kỹ thuật xử lý ô nhiễm mùi

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TÓM TẮT

Ô nhiễm mùi được đặc biệt quan tâm do đặc tính hôi, tác hại đến sức khỏe con người và khả năng phát tán rất rộng của nó. Nguồn phát sinh mùi từ một số ngành công nghiệp đặc trưng được giới thiệu. Các kỹ thuật xử lý ô nhiễm mùi tiêu biểu

như hấp phụ, hấp thụ, xử lý sinh học, và oxy hóa nhiệt sẽ được tổng hợp. Các ưu, nhược điểm của các phương pháp này cũng được phân tích và so sánh.

Từ khóa: Ô nhiễm mùi, hấp phụ, hấp thụ, lọc sinh học, oxy hóa bằng nhiệt

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