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 irrigation, 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-thermaloxidation 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, naphthelene	Naphthalene	Asphalt plants	[2]
Lower fatty acid	n-butyric acid	Poultry farm, pet shop, starch manufactoring	[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 througha stationary bed. To achieve the most efficient operation of the carbon filter, substances likedust, 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 fromclogging up the small charcoal pores and thus reducing their adsorption capacity.Also certain metal compounds quickly reduce the char- coal adsorptioncapacity, often as a result of heavy oxidation of the coal and destruction of thepore structure. To improve the adsorption capacity of activated carbon forcertain purposes the coal is impregnated with various agents so that thesubstances intended for retention react chemically with the impregnationagent. Activated carbon can often be regenerated in a process where odorantsare 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 usuallyconducted by means of hot gas or steam. A disadvantageof this technology is the relatively low heat capacityof the regeneration gases, resulting in large regenerationgas 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].

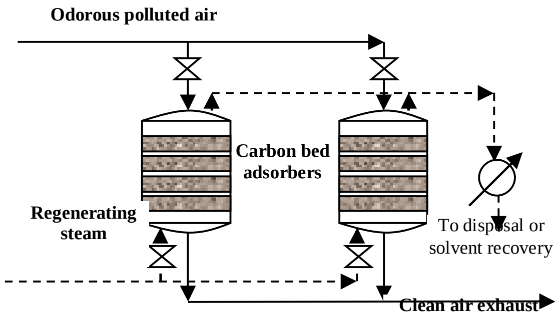

Figure 1.A schematic diagram of odorous adsorption technology

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 control 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 in 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 thanthe original exhaust air which can be treated more efficiency. Aqueous scrubbing liquids can also be biologically regenerated .

Figure 2 presents an absorption technology using a scrubber.

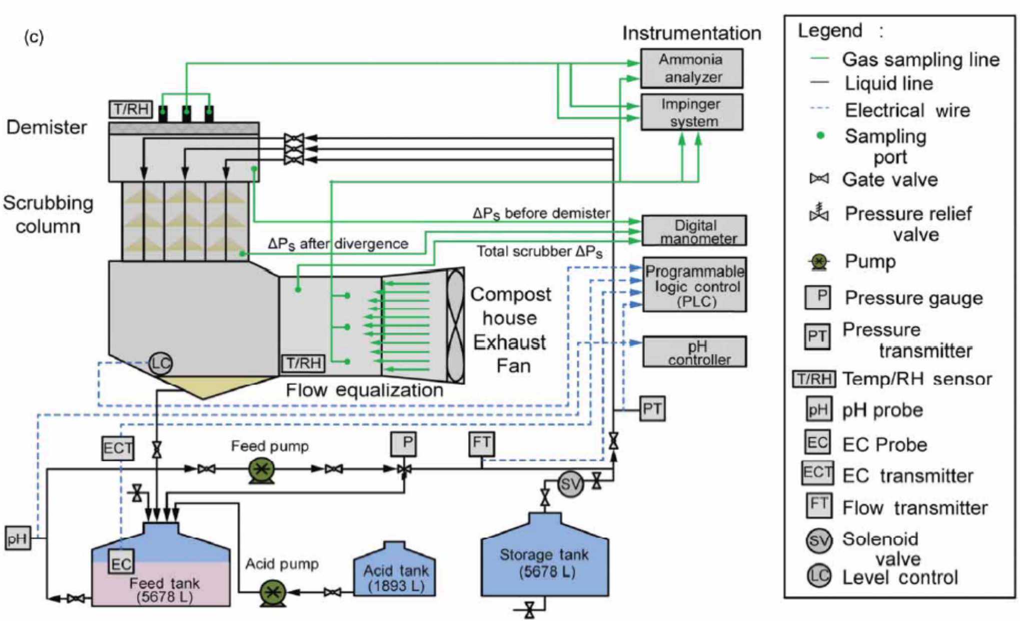

Figure 2. A schematic diagram of ammonia odorous absorption scrubber technology. After Hadlocon (2014)[18]

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 removingodorants 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-smellingacids.

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.

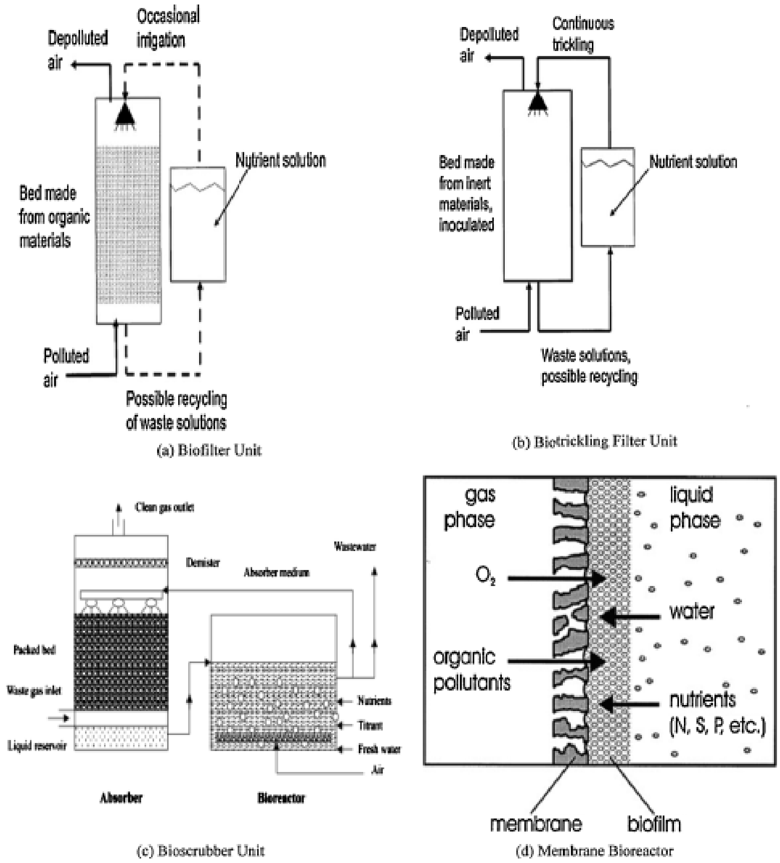

Figure 3. A schematic diagram of odorous biotreatment methods: (a) biofilter; (b) biotrickling filter; (c) bioscrubber; and (d) membrane bioreactor. After Giri (2014)[23]

3.3.1 Biofilters

Biofilters can be described as biochemicalfixed bed reactors where the waste gas is treatedwhile passing a biofilter bed. Microorganisms settleon its surface and form a biofilm in which the airbornesubstances are absorbed. An important criterion for biofiltermedia is to provide optimum environments for themicroorganisms, thus an essential property is the abilityto store water. Additional criteria are a low pressuredrop to assure an even air distribution and a large specificsurface for the mass transfer and the microorganismsto settle on. Frequently used biofilter media arecompost, peat, root wood, bark, wood chips (normallyused as bulking agent) and different kinds of combinations[24].

In most of these cases, the biofilter material alreadyprovides stable mixed cultures of microorganisms,which mostly adapt to the condition and compositionof the waste gas. The adaptation phase may range fromseveral days to several weeks [24, 25]. Inoculation of the biofilter with e.g., biosolidsor specialised microorganisms especially for inorganicmedia can be considered to shorten the startingphase [26].

One of the key parameters of biofiltration is the moisturecontent of the biofilter material. The optimal rangefor biologically active organic media is between 40% and60% [24, 26, 27]. To avoid drying of the filter media, thewaste gas should be saturated with water vapor. Usuallythe air is humidified using wet scrubbers or evenbioscrubbers. However, not only dry air streams cancause drying of the biofilter material. If the passingwaste gas is heated within the filter due to a high microbialactivity, water will evaporate into the gaseousphase, as the ability of air to hold water vapour riseswith an increase of its temperature. That is why evenif the waste gas initially is saturated with water, the biofiltermedia may still dry out. An additional irrigationsystem for the filter may be installed to ensure the optimalmoisture content. Anyway, adding too much watershould be avoided as it results in clogging and consequentlyin an increasing pressure drop, a limitation ofthe mass transfer, and possibly in anaerobic zones[26].

Biofilters may be designedas 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 anup-flow direction. A problem with open biofilters is thedirect exposure of the biofilter media to climatic conditionswhich may influence its functionality. A hot anddry climate may result in a drying of the filter media.The opposite problems have been reported from placeswith very humid climate. In this case, heavy rainfallsforced the operator to cover the filter [28].Enclosed biofilters are less affected by weather conditionsthan open filters, and also offer a better moisturedistribution, as they can be operated under down-flowconditions. In these cases the water from the saturatedair stream moisturises the first layers of the biofiltermaterial while excess water trickles down by gravity todeeper levels. However, typically the waste gas is notsaturated with water, resulting in a drying of the mediaright where the exhaust is distributed. Consequently,additional sprinklers should be installed at the inlet ofthe waste gas [29, 30].

Traditionally, biofilters were used to treat off-gasesfrom sewage treatment plants, composting facilitiesand rendering plants, which mainly contain biologicalintermediate degradation products [31-34]. In recent years, further applications have beenopened to this technology including in food and tobaccoproducing and processing industries [35-37], as well as the treatmentof waste gases containing industrial solvents and othervolatile organic compounds[38-40].Problematic substances regarding biofiltration aresulphurous and nitrogenous organic or inorganic compounds,as they cause acidification of the biofilter mediadue to their oxidization products, sulphuric and nitricacid [41, 42]. For these applications, a combination with othertreatment processes should be considered.Applicable filter loads usually range between 40 and150 m^3 m^{-3} biofilter material per hour[29, 43, 44] but also filter loads of up to 500 m^3 m^{-3} $h^{-1}$are recorded [24].

3.3.2 Bioscrubbers and biotrickling filters

In bioscrubbersand biotrickling filters, the microorganisms generallyare suspended in a scrubbing liquid but mayadditionally be immobilised on packing material. Themost important component of these devices is theabsorption column where the mass transfer between gaseousand aqueous phase takes place, and thus the airbornesubstances are made available to themicroorganisms. Usually packing materials are installedto enhance the contact surface of both phases. In mostapplications the gaseous and the aqueous phases are distributedin counter flow to each other. However, if nopacking materials are installed, cross-flow systems oftenare used.

Once the odorous substances are dissolved in thescrubbing liquid, if degradable they are removed bythe microorganisms. The degradation process may takeplace in the liquid, usually water, or in the biofilm thatgrows on the packing materials. These internals not onlyenhance the surface for the mass transfer but also providean additional surface for the microorganisms to settle.

During the adaptation phase the microorganismsstart to grow and form a biofilm which has a large effecton the degradation efficiency of the scrubber. Attentionhas to be paid to the fact that clogging of the scrubbermight be a problem. To avoid clogging, the packedbed should have large pores and should be cleanedfrequently.The scrubbing liquid is subsequently drawn off andcontinuously cycled. An activation tank may be implementedinto this cycle to allow further regeneration time[45]. The degree of regeneration can beinfluenced by the size of the activation tank and consequentlythe retention time of the scrubbing liquid. Itmay be necessary to install an additional aeration systemto provide a sufficient amount of oxygen [46, 47]. Furthermore, nutrients may beadded to the scrubbing liquid to provide lacking elementslike phosphorous, nitrogen, potassium, etc., forthe microorganisms. The superficial air velocity in abioscrubber should be in the range of 0.5–2.5 m s^{-1}.Packed towers operate at liquid irrigation rates of about20–60 m^3 m^{-2} h^{-1} of packing surface.

3.3.3 Bioscrubber/biofilter combination

This biologicalsystem combines the advantages of both technologies.The bioscrubber acts as a humidifier and degrades ahigh portion of the odour load. It also shows a bufferingeffect[31], which prevents highconcentrations of odorous substances from enteringthe biofilter, which otherwise might lead to a rise in temperaturein the biofilter material due to increasing degradationprocesses.

3.4 Thermal waste gas treatment

Thermal treatment can be basically applied to anyexhaust air (Figure 4). However, since the concentration of VOCsis 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 combustionis a concentration of organic compounds of1 g m^{-3}.

For thermal treatment, catalytic and non-catalytictechniques are applied. Catalytic processes can be operatedat lower temperatures, resulting in considerablylower energy demand. On the other hand, the costs forthe catalyst itself have to be taken into account. In addition,for non-catalytic processes, energy costs can be significantlyreduced by using advanced systems with heatrecovery (recuperative thermal oxidisers, regenerativethermal oxidizers).

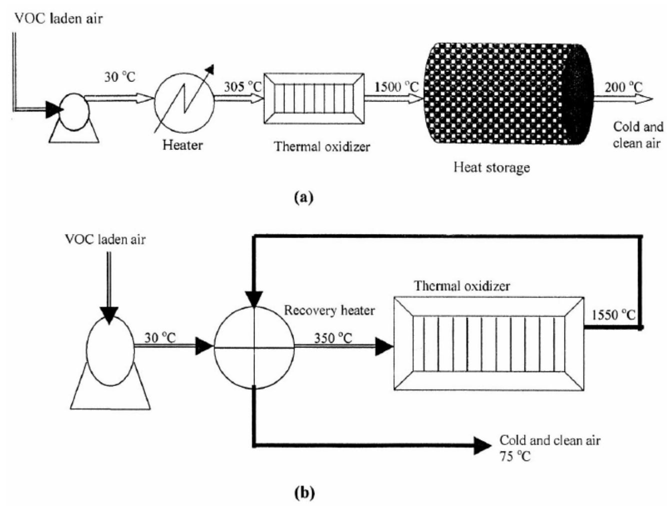

Figure 4. A schematic diagram of thermal oxidation: (a) regenerative thermal oxidation; (b) recuperative thermal oxidation. After Faisal (2000)[48]

Thermal waste gas treatment has gained in importancedue to more stringent exhaust air requirementsin recent years. For example, the German ordinanceon mechanical–biological pre-treatment of waste[49] sets a limit of 20 mg m^{-3} of organiccarbon in the exhaust air, which can hardly be achievedby biofilters. Furthermore, thermal waste gas treatmentmay be considered on sites where a combustion facilityis operated anyway, e.g., for steam generation. However,corrosion and deposits on the combustion unitmay occur depending on the composition of the wastegas.Drawbacks of thermal waste gas treatment are thehigh operating costs in the case of natural gas additionand the formation of secondary emissions like nitrousand sulphur oxides.

3.5 Non-thermal oxidation technologies

Besides thermal oxidation, several ‘‘cold’’ oxidationtechniques for the treatment of odorous exhaust air, likeUV treatment or non-thermal plasma, have been investigated in the last few years.UV treatment is successfully used for sterilization ofdrinking water or treatment of persistent wastewatercomponents. The technology is based on the UV inducedformation of highly reactive radicals and ionswhich can oxidize organic molecules. Repeated effortswere conducted to apply the positive experience fromwater and wastewater treatment to waste gas treatment.However, significant efficiencies were only measuredwhen high performance UV radiators were used, resultingin a very high energy demand not considered suitablefor treatment of odorous waste gas [50, 51].

The non-thermal plasma technology uses strongalternating electrical currents or microwave radiationto induce highly activated molecules. Like with UVradiation, reactive radicals and ions are subsequentlyformed and react with odorous compounds. The ‘‘ionisedair’’ can be generated in an additional air flow thatis merged with the main waste gas flow, or directly inthe main flow. Both non-thermal plasma and UV radiationresult in the formation of excess ozone, whichhas to be removed by a subsequent catalyst[13].

In investigations at several plants using non-thermalplasma technology, [51]measured efficienciesbetween 0% and nearly 100%. The results were stronglydepending on the composition of the waste gas and processtechnology.The results of applying a non-thermal ionisation systemshow that a removal of the identified main odourcausers (limonene, *a*-pinene and dimethyl disulfide) inthe waste gas of the biological waste treatment is possibleunder optimal process configurations [52].

At higher concentrations, the required electricalpower increases strongly, implying an application of thistechnology in low concentration range <100 mgC m^{-3}.These findings correspond to results obtained with amicrowave reactor, where high efficiencies for the treatmentof a gas containing 10% ethanol were only obtainedat an electrical power corresponding to14.5 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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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 oxi 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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