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Management and control of malodour atmospheric pollutant of public concern

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Abstract: Unpleasant odour or malodour is of intense public concern all over the world. It had attracted attention scientists and managers since later half of 20th century. Many countries developed standard methods of measurement and regulation of odour, though there is no uniformity among them, as those were based on local conditions, culture and public perception. In India, the guidelines for odour monitoring and management have been developed by Central Pollution Control Board (CPCB- Ministry of Environment, Forests and Climate Change) in 2008 and 2017. Odours are caused due to volatile compounds of varied nature and emitted from large number of sources. Different malodours have graded intensity of pungent or undesirable unpleasant smell. Odours are recognized as atmospheric pollutants and subject to control and regulation in many countries. The issues of odour chemistry, monitoring, management and dispersion modeling are discussed in this paper.

Key Words: Odor, Chemistry, Sources, Regulation, Monitoring, Control, Modeling

Introduction

Air quality is affected not only due to conventional air pollutants but also due to unpleasant odor which has been considered as an important environmental pollutant. The odor may be classified into pleasant odor and unpleasant or malodor odor. Pleasant odor is not considered as air pollutant. Odor, which is used to denote malodour in this article, has distinctly different characteristics and has the most complex chemical nature. Till date, not much attention has been paid towards odor problems due to poor awareness in developing countries, but attracted attention of scientists and managers in many developed countries in the world. The malodors are emitted from everyday activities of industrial and commercial units, haphazard community waste disposal habits. Odour may have health problems of different intensities.

Malodours are major cause of public complaints concerning air quality to the competent authorities, thus odors are recognized as atmospheric pollutants and are subject to control and regulation in many countries [1]. The work on characterization, environmental monitoring and management of malodors have been ongoing in developed countries as U.S.A. and European countries right from 1980.

Public Health Importance of Malodor

Odor emissions induced by various activities led to environmental problems that can affect moods and have psychological and physiological impacts on people’s daily lives. High intensity odour may create public health problems like vomiting, headache, nausea leading to stress, anxiety and frustration. This may create more problems with elderly people, children and due to toxic action of odour [2]. Odor nuisance issues are particularly worrying when more industrial activities exist near residential areas [3].

Strong offensive smells can interfere with a person’s enjoyment of life especially if they are frequent and/or persistent. Major factors relevant to perceived odor nuisance are offensiveness, duration of exposure, frequency of occurrence, tolerance and expectation of the receptor etc. [4]. Undesirable odor contributes to air quality concerns and affect human lifestyles and social life of the neighbors. Foul odor may not cause direct damage to health, but toxic stimulus of odor may cause ill health or respiratory symptoms like nausea, insomnia, discomfort, nasal irritation, and breathing problems or asthma. The value of public property near odor causing industries and odorous environmental is greatly reduced. It is the duty of the local authority to set up a management strategy to control this nuisance.

Olfactory Sensation of Odor

CPCB [4] in their guidelines on odor pollution and control defines odor as the perception of smell as a sensation resulting from the reception of stimulus by the olfactory sensory system. CPCB further states that odorous substances emitted from any source will be regarded important in the context of odor pollution if they are dispersed in the surrounding area. Both the pleasant or unpleasant odor is sensed by human nose after inhaling air-borne volatile organics or inorganic.

Odor nuisance in surrounding area are caused by odorant molecules dissolved in air. There are two hypotheses of odor – the one maintaining that chemical reactions are the cause of olfactory stimulation and the other pointing out that there are physical causes which set the olfactory nervous process into operation. Several variants are proposed in each group.

The first older conception is that osmogenic stimulation is chemical in nature. Most chemical hypotheses confirmed that a substance or chemical has specific shape that make it odor. This shape will fit on certain available molecular sites in the olfactory receptors, giving sensation of odor. Odor sensory elements in olfactory epithelium has complementary surface structure, may be assumed as pockmarked or pitted, having defined regularity. Those molecules having overall configuration identical or similar to the shape of certain of these pits, will fit wholly or partly into the appropriate depressions in the epithelium, giving specific odor. This is called "lock and Key" organization.

Classification of Sources of Odor

Odor sources are classified as point sources, area sources, building sources, and fugitive sources. *Point sources* are confined emissions from vents, stacks and exhausts with a known flow rate. *Area sources* may be unconfined like swine operations, sewage treatment plant, waste water treatment plants, solid waste landfills, composting, household manure spreading and settling lagoons or a cattle feedlot etc. *Building sources* of odor may be like those from hog confinement, chickens and pig sheds. *Fugitive sources* of odor emission include bed or bio-filter surface.

Odorous Compounds or Odorants

Most of the odorants are gaseous under normal atmospheric conditions or at least have a significant volatility. They are generally of low molecular weight such as volatile organic or inorganic substances. Odor is the most complex air pollutant and is a mixture of diverse chemical compounds and thus, is difficult to be assessed qualitatively by olfactory sensations of human nose. The odors largely consist of organic compounds although some inorganic substances, such as hydrogen sulphide (having rotten egg odor) and ammonia (with sharp pungent odor). Most of the odorants which are derived from anaerobic decomposition of organic matter contain sulfur and nitrogen [5]. Carbon disulphide (CS2) - colorless, flammable, poisonous volatile liquid - and mercaptans are products of decomposition of proteins (especially of animal origin). Phenols and some petroleum hydrocarbons are other common odorants. Very offensive odor is created by the anaerobic decay of wet organic matter such as flesh, manure, fodder or silage. Odor originating from livestock manure is the result of 168 odor-producing compounds. Warm temperatures enhance anaerobic decay and production of foul odor. Table 1 shows odorous compounds, properties, exposure, type of odor and its health impact.

Table I: Odorous Compounds, Properties, Exposure, Type of Odor and Its Health Impact [6]

Compound	Properties	Exposure & Odor	Health Impact
Ammonia	Colorless, stable at room temp	TWA-50 ppm, Ammoniacal strong, high corrosive in presence of Cu and its alloys	Exposure can cause coughing, chest pains difficulty in breathing
Chlorine	Greenish yellow gas, extremely reactive	TLV- 0.5 ppm, pungent suffocating bleach like odor	Can cause itching and burning of the eyes, nose, throat
Hydrogen sulphide	Colorless gas, stable, highly inflammable	TWA- 10 ppm, smell of rotten eggs	High toxic, may be fatal if inhaled. Skin Contact may cause burns
Ethyl mercaptan	Colorless gas, stable under normal storage condition	Odor threshold is 0.001 ppm	Highly toxic, affects the central nervous system
Sulphur dioxide	Colorless gas, stable, incompatible with strong reducing or oxidizing agents	TWA - 2 ppm, irritating pungent odor	Can cause fatal

TWA: time-weighted average; TLV: threshold limit value

Emission of Odorants from Different Activities

The sources of odor are largely man-made such as putrefaction of improperly dumped garbage, unscientific design of landfill, increased sewage production & improper sewage treatment practices emitting

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unpleasant odor. Large livestock operations, poultry farms, slaughterhouses, vehicular traffic, and bone mills are other major sources of odor pollution. Agricultural activities like decaying of vegetation, production and application of compost etc. also contribute to odor pollution. Industries such as pulp & paper, fertilizer, pesticides, tanneries, sugar & distillery, chemical, dye & dye intermediates, bulk drugs & pharmaceuticals, food & meat processing industries etc are some of the major industries responsible for odor pollution (Table 2).

Table II: Sources and Chemical Nature of Odor [7]

S.N.	Industry	Odorous Chemical Material
1.	Pulp and Paper	Mercaptans, Hydrogen sulphide
2.	Tanneries (Hides, Flesh)	Ammonia, H2S, VOC, Methane
3.	Fertilizers	Ammonia, Nitrogen compounds
4.	Petroleum	Sulphur compounds from crude oil, Mercaptans
5.	Chemical	Ammonia, Phenols, Mercaptans, Hydrogen sulphide, Chlorine, Organic products.
6.	Foundries	Quenching oils
7.	Pharmaceuticals	Biological extracts and wastes, meat products, packing house wastes, fish cooking odors, and coffee roaster effluents.
8.	Food industry	Cannery waste, dairy waste, meat products, packing house wastes, fish cooking odors, Coffee roaster effluents.
9.	Detergents	Animal fats
10.	Sugar & Distillery	Ammonia, Hydrogen sulphide
11.	Dye & Dye intermediates	Ammonia, hydrogen sulphide, Sulphur dioxide, Mercaptans
12.	Bulk Drugs & Pharmaceuticals	Hydrogen sulphide, Sulphur dioxide, Mercaptans
13.	General	Burning rubber, solvents, incinerator, smoke.
14.	Swine Operations	Hydrogen sulphide and Ammonia
15.	Slaughter houses	Methane, Hydrogen sulphide, Mercaptans
16.	Water Treatment Plants	Hydrogen sulphide
17.	Municipal Solid Waste Landfill	Hydrogen sulphide

Fishing Ports

The fishing ports and fishery industrial complexes show significantly high emission of offensive odorants such as ammonia (NH3), along with mean concentrations of hydrogen sulfide (H2S), methyl mercaptan (CH3SH) and trimethylamine (CH3)3N, greatly exceeding the odorant emission guideline regulated at the industrial area. Such high odor pollution would be a health risk for the people who work or live nearby. The methyl mercaptan and the trimethylamine are considered to be the major odorants at the major fishery facilities and the border area in the fishery industrial area [3].

Pesticide Industry

The odorants from pesticide industry were observed to be HCl (acephate industry), H2S (dimethoate industry), Cl2, HCl & SO2 (cypermethrin industry), NH3 (isoproturon industry), H2S & C2H5SH (ethion industry), H2S (malathion industry), and H2S & C2H5SH (phorate industry) [6].

Guidelines and Mandatory Regulations

In the 1980's countries in Europe began developing standards for olfactometry, some of which are given below:

- France AFNOR X-43-101, Method of the Measurement of the Odor of a Gaseous Effluent, Bureau de Normalization, Paris, France (drafted in 1981 & revised in 1986)
- Germany VDI 3881, Parts 1-4, Richtlinien, Olfactometry, Odour Threshold Determination, Fundamentals. Verein Deutsche Ingenieure Verlag, Dusseldorf, Germany (drafted in 1980 & revised in 1989)
- Netherlands NVN 2820, Provisional Standard: Air Quality. Sensory Odour Measurement using an Olfactometer, Netherlands Normalization Institute, The Netherlands (drafted in 1987 & issued in 1995). The comparative study organized in 1989 used N-butanol and hydrogen sulfide as standard odorants for the study.

- The European Union of 18 countries is bound by the CEN/CENELEC International Regulations to implement. This European Standard EN 13725 has been adopted in Australia, New Zealand, and much of the Pacific Rim, so it will be an International Standard.

The odor legislations have been developed in many countries, but there is no unanimity or similarity among them. Various inter-laboratory studies as well as collaborative projects involving multiple odor testing laboratories in the 80's showed that laboratory results still differed significantly even with these standards in practice. The reason may be found in the fact that these legislations are based on local cultural, educational and other factors that determine the degree of perception of malodors [8, 1].

Recently odor legislative regulations are being made stricter and stricter in several countries at Europe, North America and Asia. These include restriction on levels of odor emission from different sources.

There is variety of approaches to regulate odor in ambient air. Most common approach is to use guidelines based on concentrations. These guidelines are again variable in different sectors/factors such as the nature of the impacted region, the averaging time over which the odor concentration is measured, odor concentration, substance concentration, minimum distance, duration and frequency, odor intensity, odor index, nuisance prevention, and quantitative emission, nature of the source of the odor and the frequency for which compliance is required [1]. In India, there are no mandatory guidelines for odor applicable for occupational working environment or in residential open atmosphere, except for CPCB's Guidelines on odor pollution, its control, monitoring and management [4, 9].

Standard Practices of Odor Testing

Two standard practices for sampling and testing point, area and volume emission sources are published by American Society of Testing and Materials (ASTM E679-79 and E544-99) and by European Union [10]. In 1979, ASTM "Standard Practice for Determination of Odor and Taste Thresholds by a Forced-Choice Ascending Concentration Series Method of Limits" was published. The edition of this odor-testing standard was approved on August 15, 1991, and published in October 1991, as ASTM [11]. This standard defines a method of dynamically diluting the odor sample with an instrument called an olfactometer. "Odor Intensity" is used to measure and quantify ambient odor intensity using an "Odor Referencing Scale (OIRS)". The observations are made on the ambient odor and compared with intensity using an Odor Intensity Referencing Scale (OIRS) (a series of concentrations of a reference odorant, i.e. n-butanol).

The second standardized method (U.S. Public Health Service Project Grant A-58-541) for measuring and quantifying odor in the ambient air uses a portable odor detecting and measuring device known as a field olfactometer (e.g. scentometer). The field olfactometer dynamically dilutes the ambient air with carbon-filtered air in distinct dilution ratios known as "Dilution to Threshold" dilution factors (D/T's), i.e. 2, 4, 7, 15, etc.

Odor Measuring Instruments

To measure the odor pollution, different methods like instrumental methods and sensory methods (olfactometry) are famous.

E - Nose

The e-nose is a highly specialized complex instrument having a small number of sensors and is capable of recognizing and discriminating between a variety of different gases and odors. The comprehensive range of sensors and quality of individual sensor are important features of any e-nose. The interaction of volatile odor compounds with sensor surfaces cause change in certain chemical and physical properties of sensor which are converted into an electronic signal which is sent to data processing system [12].

The e-nose has been used in variety of conditions for quality control of food products, safety and security, environmental monitoring, medical diagnosis and lately for environmental monitoring. The e-nose is able to monitor gas emissions in real time in the field and to link them to the odor concentration expressed in odor units [13]. The sensors of e-nose are first set up by training or validation for monitoring odors in the same area using the sensorial techniques, based on the detection of odors by means of the human nose. For this case study, 6 panel members made observations every 4 seconds (response time of e-nose) for duration up to ten minutes at a few alert points of the continuous electronic nose odor monitoring system (Odowatch from Odotech),with samples collected at the monitored major sources of odor nuisance and information on the prevailing wind [14]. The e-nose does not recognize the individual odor-generating compounds, but rather provides an olfactory signature (fingerprint) of the analyzed air [15].

Olfactometer

This instrument detect and measures odour dilution and to measure the odor detection threshold of substances. To measure the intensity of odour, an odorous gas is introduced in olfactometer as a baseline against which odors are compared. A new generation of dynamic dilution olfactometer quantifies odors using a panel and can allow different techniques. Olfactometer can be used for a variety of purposes as given below apart from site diagnostics (multiple odor sources) performed with the goal of establishing odor management plans.

- odor concentration and odor threshold determination
- odor supra threshold determination with comparison to a reference gas
- hedonic scale assessment to determine the degree of appreciation
- evaluation of the relative intensity of odors
- allow training and automatic evaluation of expert panels

VOC Meter

VOC meter works on photo-ionization detection (PID) technology to calculate VOC content in the air. When air enters the end of a VOC meter, a UV light interacts with the molecules in the air. Organic compounds release positively charged ions when they pass through the light, which are then captured by a negatively charged plate producing a measurable electrical current. The current is measured by the PID device, which is then used by the VOC sensor to determine the type and quantity of the detected VOCs. The higher the electrical current, the more pollutants in the air, and the UV lamp used by the manufacturer of the VOC meter determines what contaminants can be detected by the VOC sensor.

VOC meters are used for both personal and professional purposes. HVAC and indoor air quality experts routinely use VOC monitors to detect pollutant concentrations in buildings. VOC meters are also used to detect VOC pollutants in ambient air and in houses. These monitoring results will be much useful to the people with allergies, constant headaches, sinus irritation, asthma, or any breathing disabilities.

Monitoring of Odour

Monitoring of Odor in U.S.

Monitoring of odor is required to take effective measures to eliminate/control odor and to measure the effectiveness of odor control programme. The most common odor parameter determined during odor testing is “Odor Concentration” (odor strength). This determination is made by an instrument “Olfactometer”. Odor can also be measured and quantified directly in the ambient air using and “Odor Intensity Referencing Scale (OIRS) (ASTM E544-99). Another standard method is to measure odor by portable field Olfactometer (e.g. Scentometer). OIR Scale is expressed in parts per million (ppm) of n-butanol indicating intensity of odor as given in Table 3. Using this scale odor can be measured in dependable and repeatable data.

Table III: A 5 - Point OIRS in Relation to n-Butanol (ppm) in Air

Reference Level	n-Butanol (ppm) in Air
0	0
1	25
2	75
3	225
4	675
5	2025

In 1958-1960, U.S. Public Health Service used “dilution factor” as Dilution to Threshold (D/T) using the field olfactometer to denote ambient odor concentration. The field olfactometer used to mix two volumes of carbon-filtered air with specific volumes of odorous ambient air.

D/T = Volume of carbon filtered air / volume of odorous air

Common D/T ratios used for ambient air were 2, 4, and 7, apart from having higher D/T ratios such as 15, 30, 60 and higher ratios. This is a cost-effective method to quantify odor strength.

The measures of odor are taken in the morning when the fishing port can be considered as the main source of odor in the area. The odor concentrations released at the emission sources are measured and then it’s evaluated at the receptors to establish a link between emissions and impacts.

European Way of Odor Management

The odor problem in Europe was more due to increasing population in cities, which was dealt with by variety of regulations. Earlier the judgment of an environmental health officer was the source of odor information. However, the recent trend is to rely on quantitative measurement of emission and dispersion modeling odor, pioneered in Netherland, to give accurate information on exposure and safe levels based on dose effect studies. The European standard EN13725:2003, which give a reliable method for measurement of odor was followed. This standard defines the EROM, or a mass that is just detectable when evaporated into 1 m3 of neutral gas, as equivalent to 123 µg n-butanol. Odor detection thresholds are given in Table 4.

Table IV: Odor Detection Thresholds (in ppm)

Compound	**Odor Quality**	**NL**	**Japan**	**Factor Japan/NL**
Acetone	Sweet / Fruity	28.0		
Benzene	Aromatic / Sweet	1.7		
n-Butylacetate	Sweet / Banana	0.076		
n-Butanol	Sweet / Alcohol	0.040	0.038	0.95
Ethyl Alcohol	Sweet / Alcohol	0.370		
Hydrogen sulphide	Rotten eggs	0.0005	0.000495	0.99
Isobutyl Alcohol	Sweet / Musty		0.012	
Methyl Ethyl Ketone	Sweet / Sharp	3.1		
Methyl Mercaptan	Rotten cabbage		0.000102	
Styrene	Sharp / sweet	0.025	0.033	1.32
Toluene	Sour / Burnt	1.6	0.9	0.58

NL: Netherland

Comparison of Monitoring Methods for Impact Assessment

Odor impact of fishing port was assessed [16] by three methods such as dynamic olfactometry, dispersion modeling and mobile electronic nose (e-nose). The use of these three methods in a complementary manner to assess odor impacts around a fishing port allowed both the quantification of the emissions using dynamic olfactometry and the evaluation of their impact on the study area with model dispersion. The results enabled also to identify the most affected areas of the city by odor emissions and to recognize the meteorological parameters maximizing odor impact. The other goal of this work is to compare the results of the odor dispersion modeling and e-nose measurements for one year in terms of frequency of overtaking the set alert thresholds over the same period. Comparison highlights the strengths and weaknesses of both approaches. Modeling can be used predicatively but it does not take into account fugitive emissions reliably in the absence of data on these emissions, modeling based on the hourly average misjudges the odor peaks, while e-nose made it possible to obtain validated data and provides accurate, affordable and real-time odor measurement capability tacking in to account the role of human perception without being able to characterize the extent of the odor nuisance caused by each source. It was concluded that these three valuation methods provide complementary information about odor nuisance and reasonable estimates of odors.

Reactions to odors can result in a large variety of effects, generally the impact of an odor results from a combination of interacting factors, collectively known as FIDOL; namely, frequency (F), intensity (I), duration (D), offensiveness (O), and location (L) [17]. These characteristics of an odor are taken in to account when assessing its offensiveness.

It's noted that the "Community Survey" is the low cost methodology compared to others methods to assess odor impacts from facilities in urban areas taking into account past experiences, seasonal effects and the role of human perception through social participation, but it is difficult to insure impartial judgment in order to avoid errors in the responses [18].

Odor Index (OI) of Odourants

The odour index is defined as the dimensionless ratio of the vapour pressure and the 100% odour recognition threshold (the concentration at which 100% of the odour panel detect / recognize the odor as being representative of the odorant being studied). The odor index (OI) provides information on the potential of a particular compound to cause odor problems under evaporative conditions. The odor indices of the common odorous compounds are given in Table 5 [4]. Chloroform has lowest OI and hydrogen sulphide has highest OI.

Table V: Odor Indices of the Common Odourous Compounds [4]

Compound	Odour Index (OI)
Chloroform	70
Benzene	300
Toluene	720
Ethane	25,300
Ammonia	167,300
Formaldehyde	5,000,000
Hydrogen sulphide	17,000,000

Odour Impact Criteria (OIC)

The basic unit of odor with regard to sense of smell is considered as the concentration of the odorous substances in a volume of air (ppm or µg/m3). Odor impact criteria (OIC) are adopted in many countries to determine distances between odor sources and residential areas to reduce the odor nuisance to the residents. However, different OIC are used by different countries which depend upon odor concentration threshold (between 0.12 o.u.E/m3 and 10 o.u.E/m3), the averaging period (hourly or instantaneous) and by the tolerated exceedance probability of the adopted threshold (between 0.1% and about 35% of the time). The calculation of the separation distance is carried out using a dispersion model, which predicts the ambient odor concentration on an hourly basis. This time-series of concentration values allows a calculation of the percentage (%) of time in the year during which the threshold odor (OIC) would be exceeded. This can be compared to the tolerated exceedance probability [19].

Climate Dependence of Odor Problems

It is observed that winter intensifies smell from industries and affect residents. Residents who live near industrial areas are concerned with the foul smell emanating from the industries in their areas which lasts for a few minutes to even hours, and will become more intense in winter (Deccan Chronicle, June 29, 2017). In case of anaerobic biological degradation of organic matter, higher temperature stimulates the activity producing high intense odor.

Impact Assessment of Odour

Evaluation of Methods for Odor Impact

In the United States, the standard followed for olfactometry is ASTM Standard of Practice E679-91, “Determination of Odor and Taste Threshold by a Forced Choice Ascending Concentration Series Method of Limits.” To allow an impact assessment, the following guideline values are used as context of discussion about exposure to odors:

- 1 o.u.E·m−3 point of detection (the level at which an odor is detectable by 50% of screened panelists).
- 3 to 5 o.u.E·m−3 the odor recognition threshold, at this concentration, odor is liable to cause offence.
- 5 o.u.E·m−3 faint odor, at this concentration, people become consciously aware of the presence of an odor.
- 5 to 10 ouE·m−3 odors are strong enough to evoke registered complaints.
- 10 o.u.E·m−3 distinct odor.

Some authors reported a proposed odor annoyance criterion of 5 or 10 odor units as a 98thpercentile, which mean that the level of 5 or 10 o.u.E/m3 can be exceeded for no more than 2% of the time [19].

A shade on the last threshold should be introduced, because the complaints also depend on odor intensity, their aggressiveness, their appreciation and finally frequency. It is important to note that the first three parameters are essentially subjective (individual having its own assessment of odor). Thus, some individuals are particularly sensitive and hampered by low concentrations of odors (see below the theoretical threshold of 1 o.u.E·m−3), while others feel no discomfort at levels above 10 o.u.E·m−3. The odor concentration is representative of the average population.

As a guide, it is important to mention that in most countries where there is legislation on odors, the threshold usually used as the acceptable upper limit of ambient air odor concentration is 5 o.u.E·m−3.

Odour Dispersion Modeling

The emission normally has an outgoing or upward gas flow from the source like garbage. Improper handling of public amenities like toilets of cinema halls, bus stations, railway stations, hospitals, shopping complexes etc. generate pungent odor, which affects the users as well as neighbourhood residents. Odor dispersion modeling has been used as a reliable and cost-effective approach for predicting off-site odor impacts from odor sources. The atmospheric dispersion model, AERMOD (American Meteorology Society and the U.S. EPA) is used for regulatory purposes, which is formally proposed by EPA in April 2000 as a replacement for the ISCST3 model. AERMOD is a steady-state advanced plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources and both simple and complex terrain. It assumes the concentration distribution to be Gaussian in both the vertical and horizontal. In the convective boundary layer, the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function used to calculate the concentrations of gaseous compounds, odors or particulates resulting emission point sources, surface or volume in urban or rural [20]. AERMOD uses hourly weather data as files that contain information about air temperature, wind direction and speed, thermal inversion heights, sunshine (or cloud) and type (urban or rural). Surface parameters required modeling domain (albedo, Bowen ratio, roughness) are also included in the model. Modeling system consists of two pre-processors, namely the meteorological preprocessor (AERMET) and the mapping program (AERMAP) and the dispersion model itself [20]. AERMOD simulates five different plume types depending on the atmospheric stability and on the location in and above the boundary layer: direct, indirect, penetrated, injected, and stable. During stable conditions, plume is modeled with the familiar horizontal and vertical Gaussian formulations. During convective conditions, the horizontal distribution is still Gaussian, the vertical concentration distribution results from a combination of three plume types; the direct plume material, the indirect plume material and the penetrates plume material.

Control and Elimination of Odor

Table 6 presents odour control technologies adopted in India.

Table VI: Odour Control Technologies Adopted in India [6, 9]

Pollutants	Control System
HCl (Hydrochloric acid)	Water/Caustic scrubber
Cl2 (Chlorine)	Water/Caustic Scrubber
CH3Cl (methyl chloride)	Incinerator
H2S (Hydrogen sulphide)	Scrubber with NaOH media; Deodourization with sodium metabysulfide.
NH3 (ammonia)	Incinerator; Deodourization with an organic acid radical
CH3OH (methyl alcohol)	Adsorption Bed (Charcoal or molecular Sieve)
HBr	Caustic Scrubber
Mercaptan	Incinerator; Deodourization with Neutrapol.

Caustic scrubber technology is used for the removal of H2S and other acid species from gases in different industries for many years. Caustic scrubbing of gases containing high CO2 levels (refinery) is particularly problematic because the CO2 can also react with caustic, causing unwanted consumption and possibility of sodium carbonate solids precipitation. Apart from this, following general methods [9] are used to prevent odour:

- **Masking agents:** Terpenic compounds and some oxygenated molecules like coumarin masks the odourous emission nuisance and blocks some specific malodour receptors.
- **Surfactants:** Amphiphathic molecules such as alcohols, glycerol and esters compounds increase the apparent solubility of odourous compound in aqueous media, thus reducing the odour emission.
- **Neutralizers:** Aliphatic and aromatic aldehyde reacts with odourous compounds including ammonia, and TRS and decreases the odourous annoyance. Further, fibre degrading enzyme and plant extract have also been used as a neutralizer.
- **Adsorption processes:** The common adsorbents for odour are activated carbon, rapheme, carbon-neon hybrid materials etc.
- **Dry Scrubbers:** In this process, dry replaceable media are used to absorb odourous gases until the media becomes saturated and needs to be replaced.
- **Chemical Scrubbers:** Odorous gases are passed through chemical scrubber solution that react with odour molecules and remove them.

- **Incarnation:** In industries or in case of landfill gases, high concentrations of high temperature VOCs are removed by self sustainable and self maintained incarnation system, in which in presence of methane, the sulphurous odourants and other VOCs gets converted to SOx, NOx and CO2.which are treated in a suitable scrubber.
- **Bio-filters:** using bacterial slime
- **Bio-trickling filter:** It consists of microorganisms immobilized inert packing material.
- **Bio-Scrubbers**: Consists of aeration tank with suitable bio mass, capable of degrading odours.
- **Chemical treatment**: Chemicals such as chlorine or hydrogen peroxide are injected into process-gas stream to control odour.
- **Irradiation with UV radiation or use of Neutrapol** which is harmless and non-toxic.
- **Hybrid processes:** it is a combination of chemical and biological processes or bio-filter along with bio trickling filter in sequence.
- **Vegetation cover** around the odour emitting areas such as landfill area or industry to reduce odour by sorbing and forming sinks for odourous gases.

Preventive Measures in Plant / Industry

- A solution to an odor nuisance problem in a plant is always a combination of dedicated measures within the boundary limits of a plant, based on the particular location of the plant.
- The batch reactors and feed systems may be kept covered with control operating temperatures. Nitrogen blankets may be installed on pumps, storage tanks and during formulation processes and install condensers after process equipment to condense the vapour and to recover solvents. Close and air tight area is used for cleaning of reactors, washing of drums and other equipment.
- There is need to consider eco-friendly use of non-halogenated and nonaromatic solvents (viz. ethyl acetate, alcohols and acetone), instead of more toxic solvents (viz. benzene, chloroform and trichloroethylene).
- VOC vapors generated from solvent handling activities and processes should be controlled by connecting it to air control devices.
- In wet scrubbers or gas scrubbers, with application of water, caustic and acidic scrubber systems mixing of Hypochlorite solutions was recommended to reduce odor nuisance.
- Activated carbon adsorption was suggested to achieve VOC removal efficiency up to 95-98% even thermal oxidation/ incineration system can be suggested for 99.99 % removal of VOCs.
- In the case of biodegradable VOCs, biofiltration treatment can be used,
- Nozzles, sprayers and atomizers that spray ultra-fine particles of water or chemicals along the boundary lines and area sources were suggested to suppress odor.
- More stress may be emphasized on Green Belt Development. Green belts are used to form a surface capable of absorbing and forming sinks for odorous gases [22]. Plants which counteract odor are bushes with mild but active fragrance. *Acacia farnesiana* (Mexican plant). It is a type of bush with yellow colored fragrant flowers. It does not have rich canopy but very effective for counteracting smell. Its limitation is seasonality and thorny nature.
- Other plants suggested are: (1) *Melaleuca* species: It has sweet fragrance and thin canopy. (2) Pine, cedar, junipers for their excellent canopy and protection. (3) Eucalyptus is as very good belt and good odor source. (4) Hedges, herbs (tulsi, turmeric etc.) for counteracting odor (5) aromatic plants like Lemon grass, Vanilla, Sandal wood, Kewada, Meetha neem, Sadabahar, Rajnigandha, Tulsi, Jasmin, Champa, Magnolia etc. *Vetiver* plant is a king of perfumes for inactivating other odors. It affects the nervous system and relieves fatigue. It is used as key species in aromatherapy & was suggested near office and work areas [22, 23 to 30].

Stakeholders

The stakeholders for standardized odor measurement are regulators, researchers, industry, manufactures, consultants and citizens, which can benefit from scientific methods of odor monitoring.

Conclusions

Considerable work has been done on monitoring and impact assessment of odor from different sources and different environmental conditions. Objective, quantitative standard methods are available for measuring and quantifying odor such as OIRS method, and calibrated field olfactometer, which work on dilution of odorous air with carbon filtered air in distinct D/T ratios. All the point, area and volume emission sources can be studied for odor concentration, intensity, persistence, and descriptors. These methods are useful to study and control community nuisance odours and problematic odorous emissions.

Unpleasant odor situations can be mitigated by installing air odor control system based on masking the disagreeable smell with a stronger more pleasant scent, though this is a temporary solution. Alternatively, odour can be eliminated by neutralizing them by absorbing them with specially configured powders, sprays and filters. Odor control systems can be installed at all places with unpleasant odors affecting quality of life and product. Odor control systems may be in form of application of sprays, filters or granules with different chemical compounds to attack and dissipate odorous Volatile Organic Compounds (VOCs). Granules made of porous materials such as activated carbon to dissolve odor are useful. The more permanent solution is to have very thick and leafy plantation in and around odour sources and residential areas.

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