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Review on Odour Assessment and Odour Abatement Techniques

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Abstract: Odour can be defined as a perception of smell or in scientific terms it can be defined as a sensation resulting from the reception of stimulus by the olfactory sensory system. Odours may cause pleasant or unpleasant sensation and is induced by inhaling volatile organic and inorganic odorants. The sources of odour may be air-borne or water-borne. Foul odour may cause ill health or respiratory symptoms, insomnia, asthama, nausea and discomfort and other environmental nuisance. Odours can be assessed either by sensory measurements or analytical measurements. There are various physical, chemical and biological treatments for odour abatement. The release of unpleasant odours from sewage carrier system as well as sewage treatment system has become a great public concern especially among densely populated countries. These odours cause environmental nuisance and severe damage to locals. Odour is an important physical characteristic of both water and wastewater. Thus, it requires significant attention in terms of measurement as well as abatement. This study reviews the various odour measurement and abatement techniques.
Keywords- Odour, assessment, abatement, measurement, nuisance.

I. INTRODUCTION

Odour is an important physical characteristic of both water and wastewater. Odour is the property attributed to the presence of mixture of substances and gases that are capable of stimulating the olfaction sense sufficiently to perceive an odour. These odours can be very offensive and unpleasant. Undesirable odour contributes to the air quality concerns and affect human lifestyle. Odours are nowadays the major cause of population's complaints to the local authorities.

With the growing population, urbanization and industrialization, the odour problem has reached objectionable proportion. Urbanization without proper sanitation facilities and insufficient solid waste management facilities is the major cause of odour problem. Rapidly growing urbanization has further aggravated the problem by means of various odourous industrial operations. However, in the developing urban and rural areas of India, the major source of odour pollution is open carriage system of sewage (Nallah) and the improperly located sewage treatment plants. Moreover, the irregular and inefficient working of STPs and hence the undesirable quality of treated effluent aggravates the problem. Wastewater treatment processes produce odours which cause nuisance to adjacent population and also contribute significantly to atmospheric pollution. Odours in wastewater treatment mainly arise from biodegradation of sewage, especially anaerobic degradation. Studies show that odour is the main public concern with respect to sewage treatment works and in recent years the odour complaints have been increasing. Though the STP has no special unit for the purpose of odour removal still, it can considerably reduce the odour. But the nuisance created by the open sewers is still unattended. Till date, not much attention has been paid towards odour problems in India. Hence, attempts need to be taken to throw light on the causes and processes of odour formation as also sampling, measurement and control technologies.

By reviewing all the papers, it can be concluded that yes odour is a potential pollutant, that poses harm to the environment and human beings. There is progress in research with respect to sources, measurement, biological and economic effects and abatement technologies. But a deeper study is needed on effective and economic odour abatement technology.

II. LITERATURE REVIEW

A. *Odour: Introduction, Sources and Effects*

1) *Introduction to odour*

Odour can be defined as the perception of smell resulting from the reception of stimulus by the olfactory sensory system. Air contains a mixture of light and small molecules and chemicals which upon inhalation get trapped into the olfactory epithelium, a small region of both nasal cavities. These odorants will stimulate an electrical response of olfactory nerves, the olfactory signal is thus transmitted to the brain and upon a series of neural computations a final odour is perceived [6].

Depending upon the composition of inhaled air, the odours may be pleasant or unpleasant

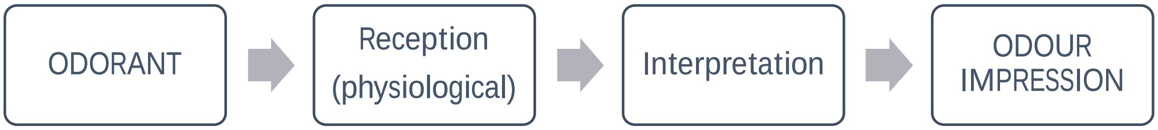

Fig 1: Perception of odour

With the growing population, urbanization and industrialization, the odour problem is becoming more objectionable. Rapidly growing industrialization without proper implementation of emission control policies is a major cause of odour nuisance. Urbanization without proper sanitation and solid waste management facilities further aggravate the condition. These factors greatly affect the air quality [9,10,22].

2) Sources of odour

Odour pollution is often linked to activities such as waste treatment (wastewater treatment plant, compost facilities, landfills), intensive animal farming, food processing, pulp and paper production and so on. (Estrado)They are generally emitted from anthropogenic activities**.** Odour sources can be broadly classified as:

- Point sources: point sources refer to the confined emissions from stacks, vents and exhausts.
- Area sources: these are the unconfined sources like sewage treatment plant, wastewater treatment plant, solid waste landfill, composting, settling lagoon, etc.
- Building sources: building sources include pig sheds, chicken confinements, slaughterhouses, food processing factories, etc.
- Fugitive sources: in this source of odour, emissions are of fugitive nature i.e. they disappear quickly like emissions from soil bed or bio-filter surface [9,10,].

3) Effects of odour

Odour affects human beings in a number of ways. Most of the odours emanating from various sources are not physically dangerous rather they have proved to be psychologically dangerous. If strong, unpleasant or offensive smells are more persistent or frequent then it can cause disturbance in person's enjoyment of life. Toxic stimulants of odour may cause ill health and respiratory problems. Secondary effects may include nausea, discomfort, insomnia, loss of appetite, nasal irritation, psychological stress, etc.

Odour greatly affects the air quality and hence can be considered as an air pollutant. Nowadays, it is more often regarded as an environmental concern. Due to the general discomfort caused by odorous areas, the property values in such areas decrease causing economic losses [9, 5].

B. Odour Nuisance of Wastewater

Wastewater collection, transmission and treatment are all associated with nauseous odours. Normal fresh sewage has a musty odour which is not generally offensive but it begins to give offensive odour as it gets stale. Within 3 to 4 hours, the entire dissolved oxygen present in it gets exhausted and the organic matter undergoes anaerobic decomposition giving off offensive odours of hydrogen sulphide, ammonia and other gases. Odourous compounds in sewage mainly originate from two processes: anaerobic decomposition of biodegradable material and direct emission of specific chemicals with wastewater discharge [23, 24].

If the WW is conveyed through closed conduits, then the odourous gases released to the sewer atmosphere as a result of biological conversion under anaerobic condition can be released through air release valves, cleanouts, manholes, house vents. In case of WW conveyance through open drains, the disposal of garbage into it and clogging could be the main cause for development of anerobic conditions. Considering the wastewater treatment facilities, headworks and preliminary treatment operations have the highest potential for release of odour. Return flows from filter backwashing and from sludge processing facilities are also a major source of odour. Sludge and biosolids handling facilities like sludge thickening, sludge digestion and sludge load-out facilities are typically the most significant source of odour [11].

In recent years, the release of unpleasant odour from wastewater has become a major public concern especially in densely populated and developing countries. Moreover, people have the tendency to throw garbage in nallahs which not just clog the sewers but also depletes the DO content, worsening the condition. Sewage treatment works which are primarily concerned with treatment of liquid wastes produce solid and gaseous waste in course of treatment.

This leads to secondary pollution if not effectively managed. Gaseous waste in the form of odours lead to air pollution, thus, affecting the population surrounding the treatment works. Effluents from various industries also discharges odourous chemicals and gases and affect the locals in its vicinity [15].

1) Odorous compounds in wastewater

The common odorous compounds resulting from the anaerobic decomposition of sewage mainly includes compounds of sulphur and nitrogen. H_2S is considered as the most commonly encountered odorant. It is a toxic, flammable, colourless, corrosive gas with a very unpleasant smell of rotten egg. It can be smelled even at a very low concentration of about 0.5 ppb. Another odorous substance that is majorly encountered in wastewater is ammonia, which is caused by the bacterial decomposition of urea produced in sewage networks. The major categories of odorous compounds are as follows:

Table 1: Major categories of odorous compounds [23].

Sr. No.	Compounds	Typical formula	Odour quality
1.	Amines	CH_3NH_2, $(CH_3)_3N$	Fishy
2.	Ammonia	NH_3	Ammoniacal
3.	Diamines	$NH_2(CH_2)_4NH_2$, $NH_2(CH_2)_5NH_2$	Decayed flesh
4.	Hydrogen sulphide	H_2S	Rotten egg
5.	Mercaptans	CH_3SH, $CH_3(CH_2)_3SH$	Skunk
6.	Organic sulphides	$(CH_3)_2S$, CH_3SSCH_3	Rotten cabbage
7.	Skatole	$C_8H_5NHCH_3$	Faecal

C. Measurement of Odours in Wastewater

Odour measurement is the very first step towards its monitoring and abatement. The odours in wastewater can be measured directly in liquid phase or it may require the separation of odorants from liquid to gas phase. While considering odour measurement, it is important to understand the difference between odorant and odour. An odour is a compound responsible for imparting odour whereas odour is the perceived effect of odorant as detected and interpreted by human olfactory system. As a result of this, two broad classes of odour measurement exist:

- analytical measurements – associated with odorants
- sensory measurements – employing human senses relating to odour

1) Dimensions of an odour:

Dimensions of an odour refer to the characteristics of odour that can be measured. The general dimensions of an odour are:

- Odour detectability or threshold or concentration
- Odour intensity
- Odour character
- Hedonic tone

Odour detectability or threshold or concentration: It is a sensory property referring to the minimum concentration that produce an olfactory response. It can be measured both analytically aas well as by sensory means. Analytical measurements give the physical concentration of specific odorants while sensory measurements determine the number of dilutions required to reduce an odour to its threshold detectability.

Odour intensity: It is a subjective dimension and it refers to the strength of perceived odour. It is represented using a subjective category scale as:

1 – Barely perceptible, 2 – Slight, 3 – Moderate, 4 – Strong, 5 – Very strong

Odour intensity is related to odorant concentration. Generally, it increases with odorant concentration. The relationship between odorant concentration and odour intensity is established by Steven's law or power law. It can be expressed as:

$$I = k\,(C)^n$$

$$\text{Or } Log\,I = Log\,K + n\,Log\,(C)$$

Where, I - Intensity expressed in parts per million of butanol,

C - Concentration,

k - Constant

n - Exponent (value ranges from 0.2 to 0.8, depending on odorant)

Hedonic Tone: It is also a subjective parameter and is a measure of degree of pleasantness or unpleasantness of an odour.

Odour character: It is the property to identify an odour and differentiate it from others. [9,10].

2) Analytical measurements:

Analytical measurements are concerned with the physical or chemical properties of the odorous compounds. They are generally preferable due to their advantages of objectivity, repeatability and accuracy and the ability to be integrated with odour formation, emission and dispersion models. However, analytical measurements have the following disadvantages:

- It is difficult to relate the analytical measurement to the actual odour intensity as perceived by humans.
- Since odour is a complex mixture of various molecules, it is not possible to determine the composition and concentration of each and every component.
- Some odorants may be present in very small concentration which is beyond the limit of analytical threshold detection.
- Analytical measurements of odour from wastewater may fall into two categories- quantitative measurement of single odorant, qualitative-quantitative measurement of range of odorants. Complete analysis in either case is not possible since it is difficult to separate every constituent odorant. At the same time, it is impossible to quantify each odorant as some may be present at very low concentration. Gas chromatography-mass spectrometry (GC-MS) is widely used to characterize odour samples. Gas-chromatography is ideally suited for the rapid separation of the complex volatile components that contributes to odour formation and is followed by mass spectrometry that allows for the identification and quantification of these components [26].

3) Sensory Measurements

Sensory measurements measure the effect of odour as perceived by humans and hence are best suited. They employ human nose for the purpose of odour detection. They measure the total effect of overall odour overriding the problems of complex mixtures, interactions between components and detectability below the threshold of smell.

Unfortunately, sensory measurements are highly subjective and difficult to interpretate. They have expensive test procedures and are not suited to field use since they are prone to be affected by surroundings. There are many factors that influence the perception of odour. Major amongst them is the variability in the sense of smell among various observers. To overcome this, a panel of several sensory trained evaluators is formed and the results are expressed by some measure of central tendency of individual results. Great care regarding the surrounding environment should be taken while presenting the samples to evaluators.

Sensory measurements can be broadly categorized as:

- Subjective measurements
- Objective measurements

Subjective sensory measurements employ human nose for odour detection without the help of any other equipment. Hence, the results can be quickly obtained at relatively low cost. But the measurements being highly subjective, the results are difficult to interpretate. Parameters that can be measured subjectively include odour character, hedonic tone and odour intensity.

Objective sensory measurements employ human nose in conjunction with an instrument called olfactometer that dilutes the odorous sample with odour-free air or water. The most commonly adopted dilution-based measurement technique is the threshold olfactometry. It involves dilution of sample until it is reduced to its threshold concentration. The threshold is expressed as the dilution at which the odour is just detected. Mathematically, it is expressed as

$$C = \frac{Vo + Vf}{Vo}$$

Where C is the odour concentration, Vo is the volume of odorous sample and Vf is the volume of odour-free sample required to reduce odour to threshold value.

Another important parameter to be considered while using the dilution-based technique is the order in which the sample is presented to the observers. Since a weak odour (higher dilution) is more difficult to detect after exposure to a strong odour (lower dilution), it is preferable to present the samples in ascending order of odour concentration. Descending order may provoke adaptations in panellists due to the effects of adsorption and desorption.

Dilution may be static or dynamic. Static dilution involves the mixing of fixed volumes (V) of odourous and odour-free samples whereas dynamic dilution involves mixing of known flows (Q) of odourous and odour-free samples.

Static dilution is adopted for measurement of odour directly from wastewater. But if the odour is to be measured after the separation of odourous compounds and gases from wastewater then dynamic olfactometry is preferred [6,15].

4) Sensor Array Technology:

Due to the complexity and subjectivity of human olfactory system, a need for a more analytical approach towards quantitative measurement of odour was felt. This led to the development of sensor array systems also called as "electronic noses". The electronic nose is a device developed to reproduce the human olfactory system that can characterize an odour without reference to its chemical composition. It basically consists of following parts:

- Sampling system of odours to be analyzed
- An array of non-specific sensors to characterize an odour where each sensor responds differently to a given odorant
- Data analysis and signal processing unit for feature extraction and significant information [6, 15].

D. Odour Abatement Techniques for Wastewater

The potential release of odours form wastewater is a major concern of public acceptance. It causes nuisance to adjacent population and contribute significantly to atmospheric pollution. The odorous gases hover over the point of generation and can be measured at great distance from point of generation. In the early morning or evening hours, a cloud of odour develops over the treatment units and then transport (even upto 25 kms). This is known as puff movement and the concept was developed by Wilson (1975). In order to reduce these effects, there is an increased need to adopt various odour abatement techniques at various sources [11].

The minimization of odour impact involves first the assessment of key odour sources and the composition of odourous emissions, and second, a correct design, operation and maintenance of wastewater carriage system and wastewater treatment facilities and, if necessary, the systems provided for odour abatement. Most of the odour control strategies adopted nowadays work on any of the following measures:

1) Prevention of odour formation at source: This involves measures like devising the process design and operation so as to maintain aerobic conditions during conveyance and treatment of wastewater (since anaerobic processes are the major source of odorous emissions such as hydrogen sulphide, ammonia, etc.)
2) Control of dipersion of odourous emissions: This will ensure an exposure of nearby populations to minimum levels of odour nuisance. Dispersion of odorous emissions can be controlled by means of implementation of buffer zones (acts as separation between odour source and potentially affected population), turbulence-inducing structures such as trees, high barrier fences, etc. that could reduce the odour concentration.
3) Minimization of the effects: The effects of odour pollution can be minimized by means of spraying masking or inhibitory agents or neutralizers in cases of intermittent emissions. Spraying them inhibits, masks or neutralizes the unpleasant hedonic tone of odour. This is the best suitable method at places where open drains are used for WW conveyance.
4) Implementation of treatment technologies: At times when it is difficult to prevent and control dispersion, odour abatement technologies need to be implemented to avoid odour nuisance [14].

a) Odour abatement technologies in WWTPs:

The odour abatement technologies adopted in WWTPs can be broadly classified into physical, chemical and biological methods. Important physical methods include aeration, activated carbon adsorption, absorption (clean water scrubber); chemical methods include chemical scrubbing, thermal oxidation and catalytic oxidation whereas biofiltration, bioscrubbing and activated sludge diffusion are the important biological methods [7, 24].. The selection of a particular technology depends upon factors such as site characteristics including operation and maintenance capabilities, treatment objectives, characteristics and strength of odourous emissions.

- *Physical methods*

These methods employ the physical phenomenon like absorption adsorption, dissolution to achieve the desired treatment.

- Aeration: Aeration is a process of increasing the area of contact between air and water either by natural methods or by mechanical means. It is a method of increasing the DO concentration in water. It will remove all the odours and tastes that are imparted due to dissolved gases and volatile compounds that could escape rapidly at water-air interface [1, 20].

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- Activated carbon adsorption: Adsorption by activated carbon is an efficient, reliable and a well-established technique for treating malodours in WWTPs. This technology is based on the physical adsorption of odorants on an activated carbon bed by means of intermolecular interactions. (Estrada). If the adsorbed materials are poorly reactive, they will remain trapped in adsorbent but if the odorants are reactive then they may chemically react with other adsorbed compounds. The important feature of this method is that the exhausted adsorptive capacity of AC can be regenerated. In the framework of sustainable economy, an oxidative thermal regeneration of GAC from odour control system of WWTP has been developed for its reuse.
  Nowadays, the expensiveness of adsorption/catalysis technologies has prompted a growing research interest into production of sludge-based adsorbent in odour removal application [4]. However, it is suitable for lower concentration of pollutant and the regeneration of carbon bed may regenerate the pollutants.
- Absorption: It involves the transfer of odourous compounds from gas phase into the bulk liquid. Water-soluble compounds such as H_2S can be readily adsorbed into the liquid [7].

b) Chemical methods

The chemical methods involve the use of certain chemical so as to change the chemical composition of odourous emissions and make it less offensive. The physical/chemical technologies are majorly implemented due to its rapid installation, low empty bed residence time (EBRT) and extensive experience in its design and operation [28].However, their main drawbacks, if adopted conventionally are high operating costs and environmental impacts. But researches are being carried out so as to make them more sustainable [14].

- *Chemical scrubbing:* The design objective of chemical scrubbers is to provide sufficient contact between air, water and chemicals in a packed tower so as to enable oxidation and entrainment of odorous compounds. Commonly used scrubbing liquids are sodium hypochlorite, potassium permanganate and hydrogen peroxide solutions [3].Since the chemical scrubbers are based on odorant transfer to an aqueous solution of oxidant, they present serious limitations in the elimination of hydrophobic VOCs. Also, the hazardous nature of chemicals employed and solid waste generated may pose serious challenges.

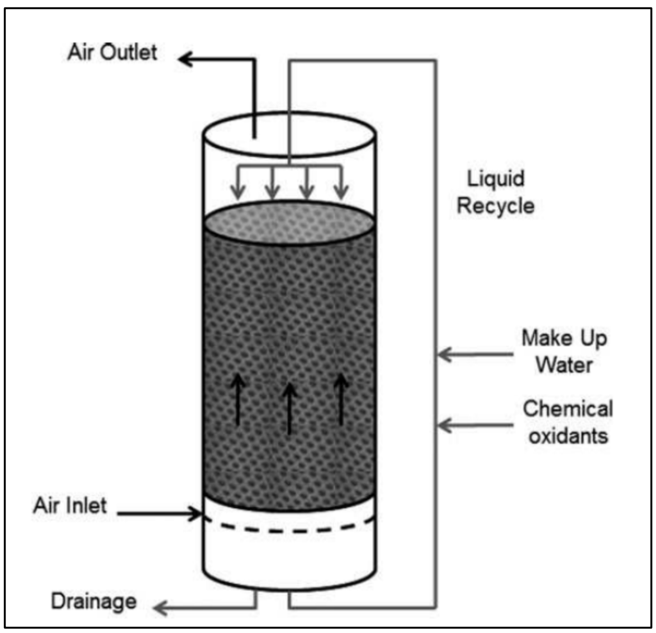

Fig 2: Schematic diagram of chemical scrubber [14].

- *Thermal oxidation:* When the odourous emissions contains VOCs at a high concentration and the process of combustion could be self-sustained, the technique of incineration is generally adopted [14].Thermal oxidation involves preheating of the odourous gases prior to its movement into the combustion chamber so that complete oxidation can be achieved [3].
- *Catalytic oxidation:* It is a flameless oxidation process that occurs in the presence of catalysts such as palladium, platinum, rubidium, etc. Since the process takes place at lower temperature, the energy requirement reduces considerably. The gases to be oxidized should not contain particulate matter or constituents that will result in residue and foul the catalyst [3].

c) Biological methods

Biological methods are increasingly used for odour treatment due to their ability to treat malodorous emissions at lower operating costs. They have the advantage of producing less secondary waste and having low demand of resources such as chemicals or adsorbent materials over its physical/chemical counterparts. However, the biological processes often require larger EBRTs (2-120 s vs. 1-5 s) and has more associated environmental footprints as compared to physical/chemical technologies with same odour removal efficiency [28].

- *Biofiltration:* It is the most commonly employed biotechnology for odour treatment. It involves passing the humified odorant through a packed bed of compost, peat, bark or a mixture of these on which the micro-organisms are attached as biofilm. While passing through the bed, the pollutants are absorbed by the filter material and degraded by the biofilm. However, control of the key parameters such as pH and moisture content within the bed and prevention of accumulation of inhibitory by-products are the major limitation of this method. Other limitations include large land requirement as high EBRT is needed for efficient odour removal, and high associated footprint [24]

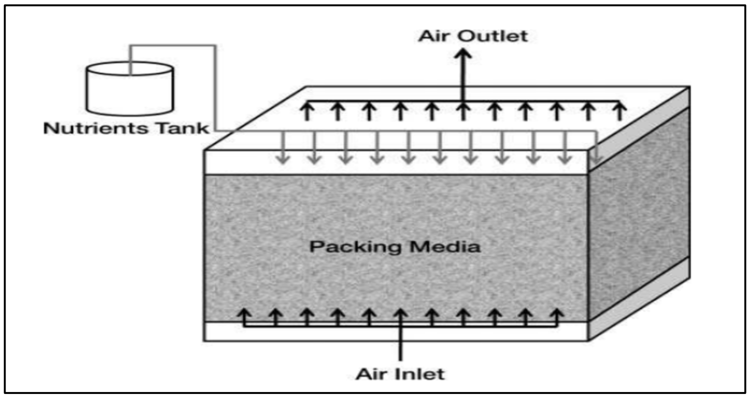

Fig 3: Schematic diagram of biofilter [14].

- *Biotrickling:* A biotrickling filter consists of a packed bed filled with chemically inert carrier material (usually plastic rings, resins, ceramic material, rocks, etc.) which is colonized by micro-organisms. A nutrient solution is continuously circulated over the packed bed. When the odourous stream is forced through it, the odorants are first taken up by the biofilm on carrier material and then degraded. This method is a good option to be adopted when the gas stream contains high concentration of H_2S and other reduced sulphur compounds. It has footprints comparable to that of physical-chemical technologies. However, there are certain drawbacks such as limited mass transfer of oxygen into biofilm, problem of biofilm development on carrier surface which gradually reduces the empty volume of filter and leads to its clogging [13, 14].

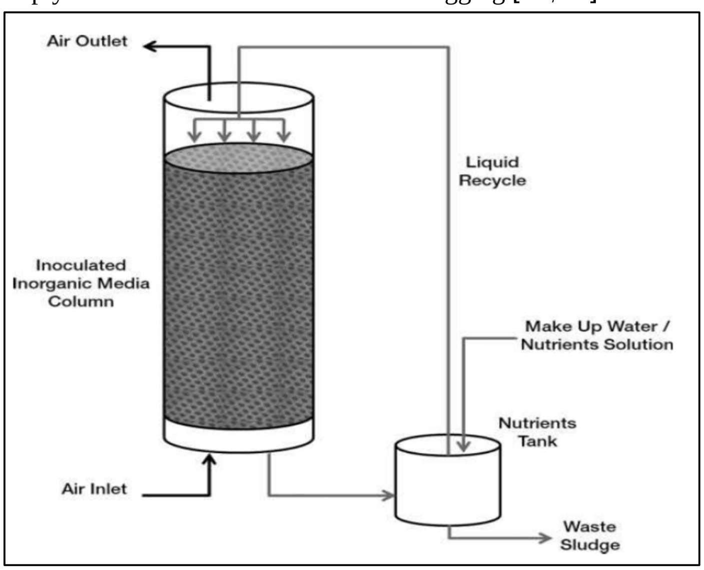

Fig 4: Schematic representation of biofilter [14].

- *Bioscrubbing:* Bioscrubbing mainly combines absorption and biodegradation. The scrubbing water contains a population of micro-organisms in suspension which are capable of oxidizing odorous compounds. In bioscrubbers, the pollutants are first adsorbed in an aqueous phase in absorption tower and then converted into CO_2, H_2O and biomass by micro-organisms in a separate activated sludge unit. The effluent is recirculated into the absorption tower to maximise the efficiency and stability. Parameters such as pH, temperature, nutrient balance and removal of metabolic by-products can be more easily altered in water of the reactor and hence can be easily controlled. However, it removes only highly soluble contaminants efficiently due to its good gas dissolution property. Also, the biomass growth needs to be controlled in order to reduce solid waste generation [7, 8].
- *Activated sludge diffusion:* Activated sludge diffusion offers a low-cost liquid-based odour abatement technique. It involves conversion of odourous emissions from gaseous to liquid phase by collecting and diverting the emissions into an activated sludge aeration basin. Complete mixing in the aeration basin ensures adequate food supply for the microbial cells and sufficient oxygen supply to optimize mass transfer and disperse the products of metabolism from inside the flocs. It has proved to be a robust and efficient technology with over 95% removal efficiency for synthetic odour. Its biggest advantage is that available equipments can be utilized which ensures lower costs and easy operations [16, 24].

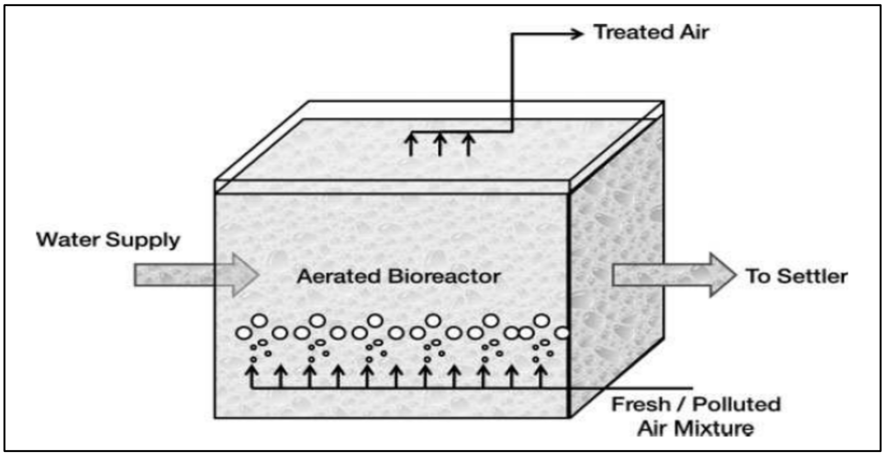

Fig 5: Schematic representation of activated sludge diffusion [14].

III. CONCLUSIONS

Odour pollution is emerging as an important aspect of air pollution. It is an important consideration for protecting the environment and our community well-being. The lack of comprehensive theory of olfaction, a lesser understanding of linkage between analytical and sensory measurement and limitations of electronic and other devices for odour measurement has made it difficult to quantify the problem. Thus, it is difficult to develop meaningful regulatory threshold limits for odour. However, based on international experience on odour control, our country needs to adopt effective odour control policies.

Maximum odour complaints are associated with wastewater treatment and handling facilities. Thus, it should be given a due consideration while designing the sewerage and the treatment system. Though many physical, biological and chemical abatement techniques have been developed for odour control but their proper assessment, selection and implementation is still a matter of concern. The selection is dependent on various factors like characteristics of wastewater, land and cost considerations, operation and maintenance costs, etc. Sufficient care should be taken to ensure optimum working conditions of the adopted odour removal technique.

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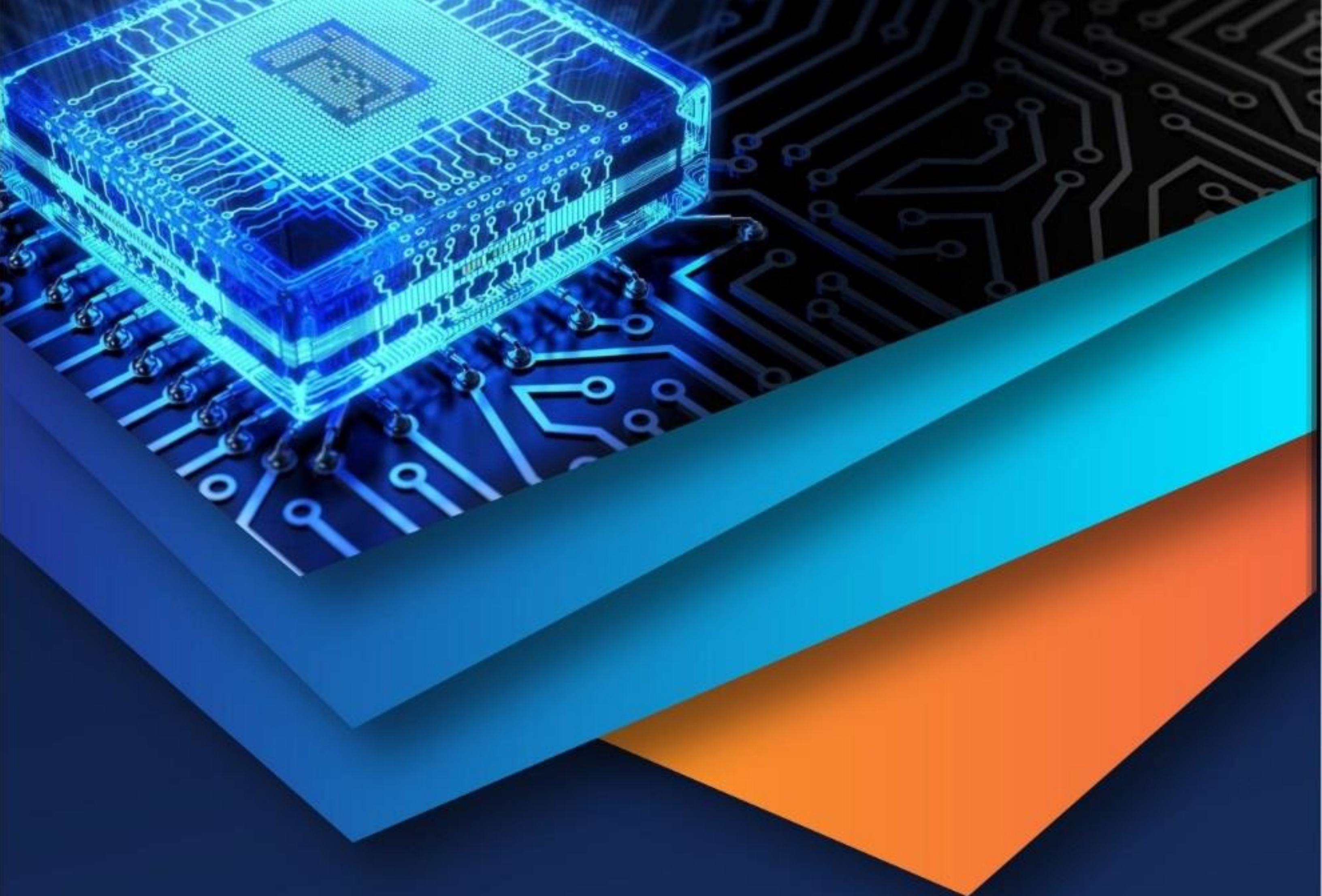

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