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Comparative Analysis of Biofiltration and Other Traditional Air Pollution Control Techniques

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ABSTRACT
This study evaluated the performance of biofiltration, against the traditional air pollution control technologies using a multi-criteria decision analysis technique, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). In the TOPSIS analysis, factors considered included: ease of deployment, waste generation, environmental impact, cost, efficiency, conversion rate and energy requirement. The technologies analyzed against these factors included: absorption, adsorption, membrane, incineration, condensation, oxidation and biofiltration. The researcher also scored the technologies against the criteria based on the outcomes of literature review conducted., which provided the strengths, the limitations and drawbacks of each of the options considered in the study. From the TOPSIS analysis, the best air pollution control technology considering the several criteria adopted in this study, was Biofiltration which scored 0.6989. The second-best air pollution control technology was Condensation, with a score of 0.5983, followed by Membrane with a TOPSIS score of 0.4842. The least efficient air pollution control technology based on the outcome of the TOPSIS analysis was Absorption with a TOPSIS score of 0.2193. Thus, Biofiltration technology, despite being a more recent technology is the best (technically and economically) air pollution control technology. Based on this finding, it is recommended that a more practical and experimental study be conducted, which will involve biofiltration and a couple of the conventional air pollution control technologies Nigeria.

Keywords: Biofiltration, Air-Pollution-Controls, TOPSIS

I. INTRODUCTION

The concept of using microorganisms for the removal of environmentally undesirable compounds by biodegradation has been well established in the area of wastewater treatment for several decades [2]. In fact, few environmental professionals in this country appear to be aware that "biofiltration," i.e., the biological removal of air contaminants from off-gas streams in a solid phase reactor, is now a well-established air pollution control (APC) technology in several western countries, most notably the Netherlands and Germany. In these countries, biofiltration has been used successfully to control odors, and both organic and inorganic air pollutants that are toxic to humans (air toxics), as well as volatile organic compounds (VOC) from a variety of industrial and public sector sources. The development of biofiltration in Europe, most of which took place in the late 1970s and the 1980s, was brought about by a combination of increasingly stringent regulatory requirements and financial support from federal and state governments. In fact, few environmental professionals in this country appear to be aware that "biofiltration," i.e., the biological removal of air contaminants from off-gas streams in a solid phase reactor, is now a well-established air pollution control (APC) technology in several western countries, most notably the Netherlands and Germany. The experiences in Europe have demonstrated that biofiltration may have economic and other advantages over existing APC technologies, particularly if applied to off-gas streams that contain only low concentrations (typically less than 1000 ppm as methane) of air pollutants that are easily biodegraded [4]. However, what these advantages are and by how much are not well established now. One of the reasons why biofiltration is not presently well recognized in Nigeria., and has been applied in only a few cases, could be a lack of regulatory programs, little governmental support for research and development, and lack of descriptions written in the English language. Many of the more complex technical and engineering issues related to the development and use of biofiltration would also be discussed in great depth in the course of the study. In addition to biofiltration, other biological traditional air pollution control (APC) systems include "bio scrubbers", trickling filters [5]; [6]; [3]. This study aims to evaluate biofiltration, a

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viable alternative to traditional air pollution control technologies with the other traditional technologies using a multi-criteria decision analysis technique – TOPSIS.

II. LITERATURE REVIEW

Biofiltration for use as a VOC-reducing air pollution control technology is not a new concept. Its effective use at sewage treatment plants for odor control has been studied and documented United states as early as the 1950s [7]. The concept of biofiltration is simple; contaminated air is forced through media populated by microorganisms which biologically degrade the undesired contaminant (see Figure 1). Contaminant degradation occurs when the microorganisms metabolize the carbon-based contaminant (VOC) molecules to their primary components, usually carbon dioxide, water, and other harmless substances [7].

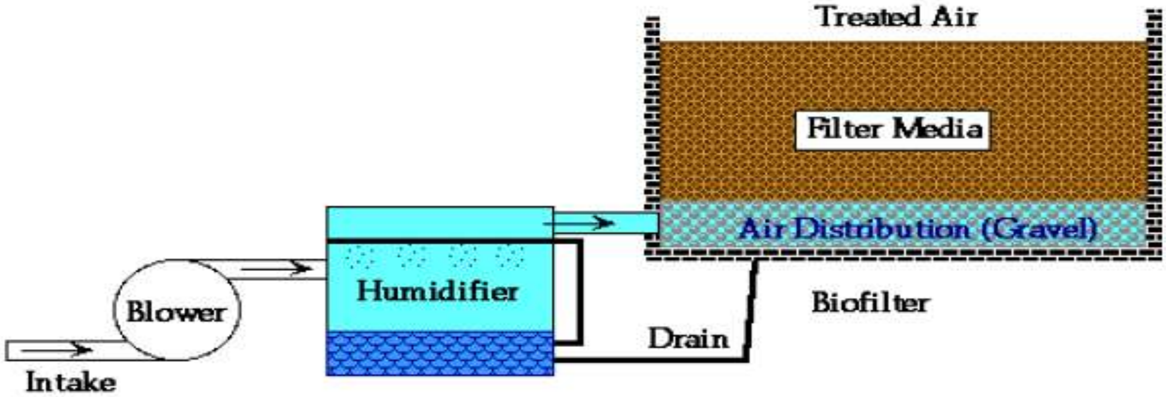

Figure 1: Biofilter Schematic ((http://compost.css.cornell.edu/science.html).

Biofiltration can be traced to its earliest roots for odor control at sewage treatment plants. A German scientist named Bach alluded to the use of biological processes to treat the emission of odorous hydrogen sulfides at sewage treatment plants in Germany in 1923 [8]. The first patent for a soil bed designed to treat odorous gases was issued by the United States in 1957 to Richard Pomeroy, the creator of the Long Beach soil bed [8]. The simplest technology to be considered within the science of biological air purification is the biofilter. A biofilter consists of a stationary filter bed containing porous media or packing material serving as a host to a microbial population. Bio trickling filters are closely related to biofilters in that they operate similarly. Contaminants from a waste-gas stream are absorbed into a liquid phase. The liquid phase is then trickled over an inert, inorganic packing material such as plastic rings, open pore foam, or lava rock. From the bio trickling technology evolved the next generation of biological treatment systems known as bio-scrubbing. To date, the majority of bio-scrubbers in operation exist to eliminate odors from waste-gas streams. There are two types of bio-scrubbers, fixed-film bio-scrubbers and suspended-growth bio-scrubbers. A late addition to the family of biofilters is the rotating drum biofilter (RDB). Due to its relatively recent development, not many studies exist investigating this technology. Perhaps the most comprehensive document concerning the development and design of the RDB is the doctoral dissertation presented by Dr. Chunping Yang at the University of Cincinnati in 2004. Also used for biological treatment of contaminated air, though less common than the above-mentioned technologies, is membrane biofiltration. A membrane bioreactor contains a series of membranes through which the contaminated air stream passes, surrounded by circulating nutrient media. A biomass growth surrounds the membranes, which are fabricated of some type of diffusive material. Biofiltration has been shown to be a cost-effective method of treating contaminated waste-air streams. Conventional treatment methods (such as thermal oxidization, adsorption, or condensation) for VOC control vary, however, these systems often have higher energy requirements to operate effectively, processes that require additional chemicals and fuels, intricate and frequent maintenance requirements, and residual products requiring disposal or further treatment prior to environmental release [7]. Choosing the right design and size biofilter is an important step in the process of controlling VOC emissions. The parameter of residence time is a function of the filter volume and the contaminated air flow rate into the filter. Control of VOC emissions into the atmosphere was of minimal popular concern until the 1970s and 1980s. It wasn't until the passage of

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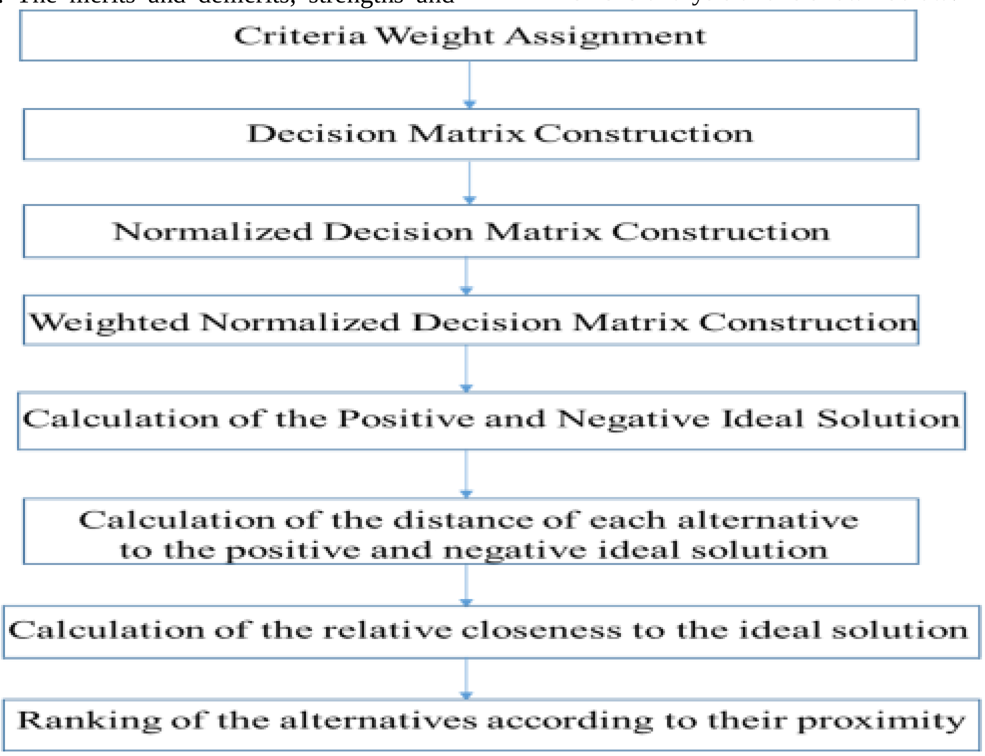
the 1990 Clean Air Act (CAA) amendments that VOC emissions became regulated, stirring further public interest and research into their control.

III. METHODOLOGY

This studyis a comparative analysis between biofiltration technology and other air pollution control technologies was done with a multi-criteria decision analysis tool - the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).The data collected were secondary data and were gathered from existing literature. The merits and demerits, strengths and limitations of the different air pollution control techniques were obtained from the literature. TOPSIS Multi-Criteria Decision-Making Analysis tool was used to develop an effective decision matrix in this study. TOPSIS method is based on the concept that the chosen alternative should have the shortest distance to Positive Ideal Solution (PIS) (the solution which minimizes the cost criteria and maximizes the benefit criteria) and the farthest distance to Negative Ideal Solution (NIS).

TOPSIS Algorithm

The algorithm depicts the steps undertaken in TOPSIS analysis and is shown below:



IV. RESULT AND ANALYSIS

Comparative analysis of the air pollution control technologies

Technology	Principle and characteristics	Performances and limitations	Costs/($m^3 \cdot h{-}1$) air
Adsorption	• Transfer of VOC to a porous solid phase, fixed or fluidized • Materials: activated carbons, zeolites and polymers • Ex.: Activated carbon adsorbs 10–30% VOC on a weight basis • Doubled installations: adsorption–desorption	• Conversion: 90–99% • Possible recovery of VOC (desorption) • Can accept variations of flowrates and shutdown periods But . . .	• Investment: US $15–120 • Operation: US $10–35

	cycles • Operating temperature: <50–60◦ C: ignition risks may be present	• Treatments for adsorbent regeneration are required • Moisture level of effluents: <50% • Pressure drop • Bed poisoning problems with certain VOC	
Incineration	• Thermal oxidation of VOC • 760 < Temperature < 1200◦C • 0.3 < Residence time < 2 s • VOC concentration < 25% of explosion limit • Required O_2 level ~10%	• Conversion: 98–99.5% • Possible energy recovery • Elimination of halogenated or sulphurated VOC with adequate and addition requirement But . . . • High investment and operating costs • Toxic by-products: CO, NOX, dioxins, furans • Efficiency for low VOC concentrations	• Investment: US $10–450 • Operation: US $20–150 (depends on the quantity of recovered energy)
Catalytic oxidation	• Thermal, catalytic oxidation of VOC • 300 < Temperature < 650◦C • 0.07 < Residence time < 1s • Catalysts: noble metals (Pt, Pd, Rh) on supports (alumina, other ceramics), or metal oxides (Cu, Ti, Ni, Mn, etc.) • Catalyst lifetime: 2–5 years • Usable VOC concentration: far lower than the explosion limit	• Conversion: 90–99% • Less energy required than incineration and less toxic by-products But . . . • Catalyst deactivation problems (clogging, poisoning, overheating) • Disposal of used catalyst • Combustion by-products	• Fixed catalyst Investment: US $20–250 Operation: US $10–75 • Fluidized catalyst Investment: US $35–220 Operation: US $15–90

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	• Required O2 level ~2%		
Absorption	• Transfer of the VOC to a liquid phase • Plate tower, bubble column, packed tower, atomizer • Solvents: water (with adjusted pH), high boiling-point hydrocarbons, amines, etc. • Counter-current operation (the VOC transfer rate)	• Conversion: 90–98% • Possible recovery and valorization of the dissolved VOC with downstream treatments But . . . • Inadequate for VOC of low solubility • Production of wastewater	• Investment: US $15–70 • Operation: US $25–120
Condensation	• Liquefaction of high boiling-point VOC (>38◦C) via cooling and/or compression • Cooling/cryogenic systems: water (5◦C), brine (→−35◦C), liquid nitrogen (→−185◦C)	• Conversion: 50–99% • A recovery and valorization way But . . . • Well adapted to saturated VOC only • Disposal of condensates • Problems of frost deposits	• Investment: US $10–80 • Operation: US $20–120
Membranes	• Separation of gas mixtures through semi-permeable membranes • Materials: polymers (hollow fibers, silicones), porous ceramics • Gas flow compressed before membrane separation	• Conversion: 50–98% • VOC are concentrated 5–100 times, and valorization (recycle) possible • Selective membranes, resistant to halogenated VOC But . . . • Pressure drop • High operating pressures • Membrane cleaning required	Not available
Biofiltration	• Biocatalytic oxidation of VOC	• Conversion: 80–95%	• Investment: US $10–70

• 3 configurations: biofilters (most frequent), biotrickling filters and bioscrubbers	• Moderate installation and operating costs • Low maintenance But . . .	• Operation: US $3–10
• Biocatalysts: microorganisms (bacteria, fungi)	• Strict control of biological parameters (pH temperature, moisture level, nutrients, etc.)	
• 30 s < Residence time < several min	• Large spaces required for biofilters	
• Operating temperature: 20–40◦C • Filter-bed lifetime: 3–5 years	• Pressure drop problems	

From the TOPSIS analysis, the second-best air pollution control technology is Condensation, with a value of 0.5983, followed by Membrane with a TOPSIS score of 0.4842. The least efficient air pollution control technology based on the outcome of the TOPSIS analysis is Absorption with a TOPSIS score of 0.2193. Hence, the implication of this finding with respect to the aim of this study is that Biofiltration technology, despite being a novel and unconventional technology in Nigeria, is the best (technically and economically) air pollution control technology.It is worthy of note that in the analysis, more weight / significance was placed on criteria/factors like environmental impact, cost, efficiency, and conversion rate. These are the factors that gave biofiltration an edge over the traditional/conventional air pollution control technologies.

V. CONCLUSIONS

TOPSIS analysis was applied in this study over 7 alternatives and 7 broad attributes/criteria, in the evaluation of the performance of biofiltration against the conventional air pollution control technologies. The set of benefit attributes utilized in the study included: ease of use/deployment, low waste generation, low negative environmental impact, low cost, high efficiency, high conversion rate and low energy requirement. The researcher scored the technologies against the criteria based on the outcomes of literature review conducted in the study, which clearly provided the strengths, the limitations and drawbacks of each of the options considered in the study. From the TOPSIS analysis, the best air pollution control technology considering the several criteria adopted in this study, was Biofiltration which scored 0.6989. The second-best air pollution control technology was Condensation, with a score of 0.5983, followed by Membrane with a TOPSIS score of 0.4842. The least efficient air pollution control technology based on the outcome of the TOPSIS analysis was Absorption with a TOPSIS score of 0.2193. Thus, the implication of this finding is that Biofiltration technology, despite being a more recent technology is the optimum (technically and economically) air pollution control technology.

VI. RECOMMENDATIONS

This study adopted detailed desktop review and literature review of materials, past research works and articles for data collection. Having evaluated the theoretical performance of Biofiltration, it is recommended that a more practical study be conducted in the future, which will involve biofiltration and a couple of the conventional air pollution control technologies Nigeria.

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