Pre-treatment Methods in the Abatement of Volatile Organic Compounds: A Discussion

Edison Muzenda

***Abstract*—**This paper presents a discussion, an analysis, and literature review on the available pre-treatment options for volatile organic compounds (VOCs) prior to abatement. The abatement can be achieved through process and equipment modification, and aid on control techniques. Add on control techniques can be recovery or destructive based such as absorption, adsorption, condensation, membrane separation, and catalytic and thermal oxidation respectively. The pre-treatment methods considered in this paper are dilution, preheating, cooling, particulate removal, dehumidification and liquid knock – out. Pre-treatment is the process of conditioning a volatile organic compound stream and this increase the total cost of the treatment technologies. This paper also highlights the factors governing the selection and application of control technologies.

***Keywords*—**Abatement, conditioning, destruction, recovery, pre-treatment

I. Introduction

THE release of volatile organic compounds (VOCs) into the atmosphere from various process plants possess environmental and health challenges. Many countries have introduced regulations to help reduce the emission of volatile organic compounds from chemical and other manufacturing industries. Various methods can be used to abate volatile organic compounds from process gaseous effluents. The first step in the selection of a treatment method is to prepare an emission inventory. This inventory include information and details on the entire industrial facility such pollutants emitted, VOCs in each vent stream, periodical emission averages including worst case emission scenarios, existence and status of pollution control equipment and as well as regulatory status [1]. The appropriate control device may be selected after a consideration of a number of factors for example a regulation mandating specific control equipment for a particular VOC emission problem [2]. However, most regulations set maximum level of emissions without enforcing the abatement technology to use. Using a prepared emission inventory, the appropriate abatement technique can be selected on the basis of factors such as cost, VOC inlet concentration, effluent gas flow rate and the required control level [2]. Volatile organic compounds abatement techniques can be broadly categorized into process and equipment modification, and add on control techniques [1], [3].

Edison Muzenda is with the Department of Chemical Engineering, Faculty of Engineering and the Built Environment, University of Johannesburg, Doornfontein, Johannesburg 2028; phone: 0027-11-5596817; Fax: 0027-11-5596430; e-mail: emuzenda@uj.ac.za).

II. Abatement Techniques

A. Process and Equipment Modification

Process and equipment modification refers to any strategy that seeks to reduce VOCs emissions by modifying the operational practices of the plant or making internal equipment changes [3]. The modifications may be small changes in operational procedures such as changing the temperature, pressure or composition of the raw materials. This may also involve major changes such as introducing new equipment or processes. Improved production techniques maybe realized by modifying the current equipment or installing more efficient equipment. This may lead to VOCs emission reduction as a result of more efficient use of process raw material [4]. The impact of process modifications must be considered when considering any changes. The following factors are important: (i) A process is a series of operations and a change in one operation might be small relative to the whole process. A combination of small changes will however cause significant changes i.e. reduction in cost, utilities use, or volume of VOC emission. (ii) A change in a single operation may be made and evaluated to assess its impact on the product, the efficiency of the process, cost, labour, raw materials and VOCs emission. (iii) Generally process modification is plant or process specific and therefore cannot be universally industry applied. (iv) To successfully change or modify a process it requires comprehensive knowledge of the process and alternative processes as well as the material. Cooperative effort from material and equipment suppliers as well as in-house engineering staff is required to successfully implement process modifications or changes.

There is a variety of process or equipment modification techniques that can be implemented. For paint, ink, and other coating manufacturing industries the following modification techniques maybe used to reduce VOCs emissions: (i) Tank lids – the most common type of alteration made to equipment to regulate volatile organic compounds emission. Open top tanks can be closed by making use of lids thus reducing the amount of volatile organic compounds emitted during mixing operations and reduction efficiencies are in the range from 40 to 96 %. (ii) Modified milling equipment - volatile organic compounds emissions may be reduced by modifying older milling equipment to more efficient closed systems such as horizontal media mills. Volatile organic compounds emission during operation of the horizontal media mill is controlled as the filtering screen is enclosed by a metal cover sheet. (iii) Equipment cleaning devices – A variety of devises such as rubber wipers, high-pressure spray, line tanks with Teflon, plastic or foam pigs and automatic tank washers can be used to reduce amounts of solvents used during vessel cleaning and hence lessen VOCs emission. The amount of VOCs released during cleaning depends on the frequency of use of the cleaning devices. Some devises like high-pressure sprays can reduce the use of cleaning solvents by 80 to 90 % [5]. Advantages of process and equipment modification include reduced VOC vapour volume, medium-term solution and reduced production costs while disadvantages include the requirement of research and development effort, and usually do not have industry wide impact.

B. Add-on Control Techniques

Add-on control techniques involve the treatment of emissions from processes by means of specialized technologies which either destroy or recover the volatile organic compounds. These methods have many advantages as well as limitations [1]. Fig. 1 shows the classification of volatile organic compounds abatement techniques.

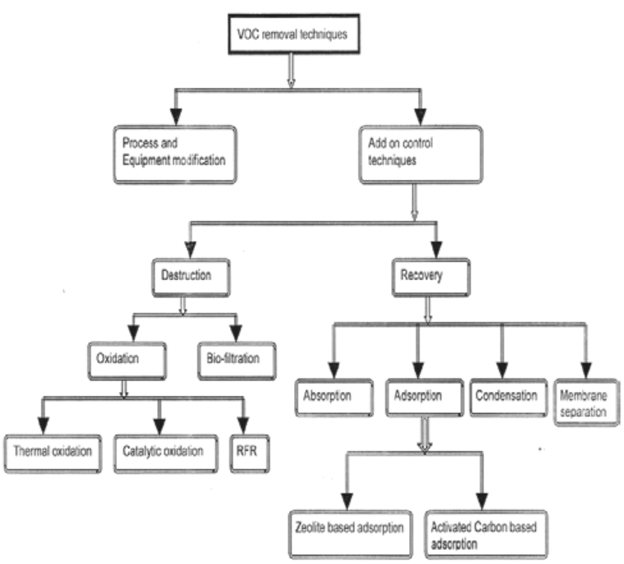

Fig. 1 Classification of volatile organic compounds control techniques [1]

The choice of an add-on control technology depends on a number of factors such as pollutant type and concentration, exhaust gas flow rate, regulatory set emission limits and as well as the recovered VOC(s). Recovery techniques are more desirable and favoured when the cost of procuring VOCs is more than the recovery cost. When there is no substantial value in recovering the VOC, then destruction techniques are more appropriate [7]. Some control devices require pre-treatment of the emitted VOCs and this increase the total cost of these technologies. Pre-treatment refers to the methods and practices used to condition a VOC stream [8].

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III. Pre-treatment Methods

The purpose of this paper is to illustrate various pre-treatment options for particular abatement techniques and these are shown in Table 1.

TABLE 1
TYPICAL PRE-TREATMENT CONSIDERATIONS [7]

VOC abatement technique	Typical Pre-treatment Consideration
Thermal oxidation	Dilution, preheating
Catalytic oxidation	Dilution, particulate removal, pre-heating
Adsorption	Cooling, dehumidification, dilution, particulate removal
Absorption	Cooling, particulate removal
Condensation	Dehumidification
Flaring	Liquid knock-out
Biofiltration	Humidification, cooling, particulate removal
Membrane separation	Particulate removal

A. Dehumidification

This is the removal of water vapour from the VOCs contaminated effluent air stream and aid in reducing its moisture content. It is an important pre-treatment option for adsorption and condensation systems as water vapour competes with VOCs for adsorption sites. Reducing the water vapour in the adsorption inlet stream will subsequently increase the adsorption capacity for VOCs. Water vapour may condense in the condenser tubes and this reduces the heat transfer capacity of the system [8]. Fig. 2 shows a dehumidification pre-treatment of a VOC laden air stream.

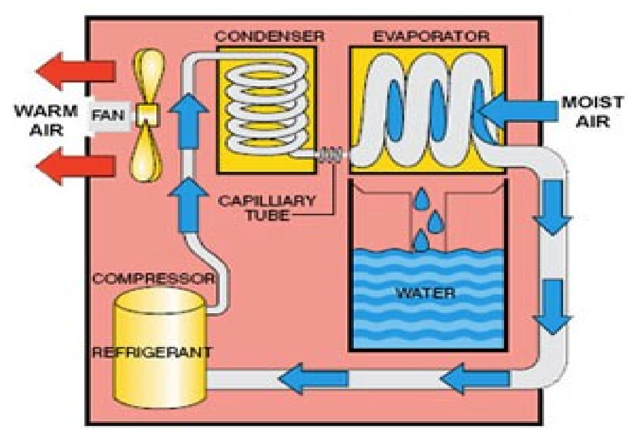

Fig. 2 An example of a humidifier pre-treatment unit [9]

The humidification operation sequence is as follows: (i) VOC laden air enter stream (ii) Air passes over cold surface and loses heat (iii) Moisture condenses as air is cooled (iv)

Moisture falls into container (v)Air is re-heated by a heat recovery system (condenser) (vi) Air flows out of the dehumidifier warmer and dryer.

B. Humidification

Water is added to the air stream to increase its humidity. Humidification is an important pre-treatment consideration for bio filtration systems as these require moisture to prevent the filter bed from drying and cracking and hence prevent the escape of unreacted VOC into the atmosphere. Also enough moisture is required to support the growth of microorganism. Fig. 2 shows a humidification pre-treatment phase for a VOC laden air stream.

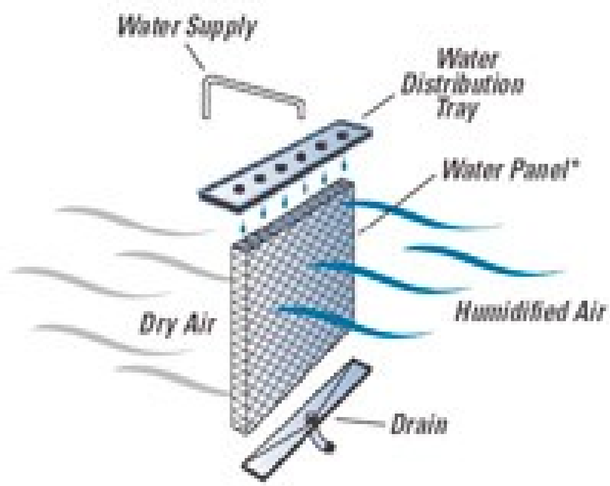

Fig. 2 An example of a humidification pre-treatment unit [10]

C. Pre-heating

The objective of pre-heating is to increase the thermal efficiency of the abatement processes such as thermal and catalytic oxidation systems. The exhaust gas stream from an oxidation system is utilized as pre-heating heat source. A large portion of the thermal energy in the flue gases is transferred to the incoming air via a heat exchanger placed in the exhaust stack. This recycling of heat reduces the amount of fuel required for oxidation systems [10].

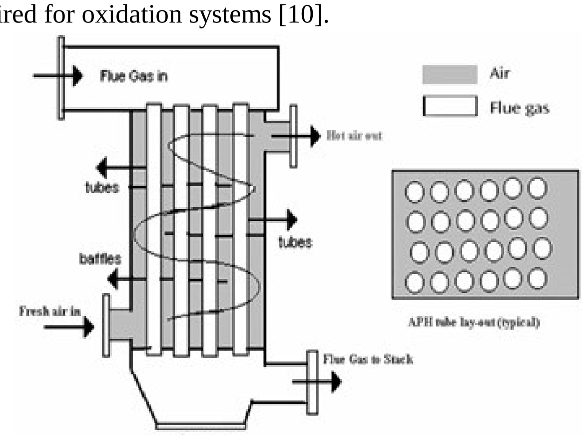

Fig. 4 A typical tubular air preheater layout [11]

D. Cooling

The VOC-laden air temperature is reduced before abatement and this is a process consideration for processes such as absorption, adsorption and bio-filtration systems. Both absorption and adsorption abatement techniques involve the physical transfer of mass or energy. At low temperatures VOC molecules in the air stream possess lower kinetic energy than at higher temperatures. Thus, when VOC molecules collide with the adsorbent / absorbent they will adhere and be withdrawn from the gas stream [12]. For bio filtration systems, cooling is necessary to maintain the temperature of microorganisms at a certain level to sustain life [13]. The driving force for heat exchange for the cooling unit in Fig. 4 is the temperature difference between the warmer VOC laden air and the colder cooling fluid. In practice the temperature difference should be as large as possible to maximize the rate of heat transfer between the two streams.

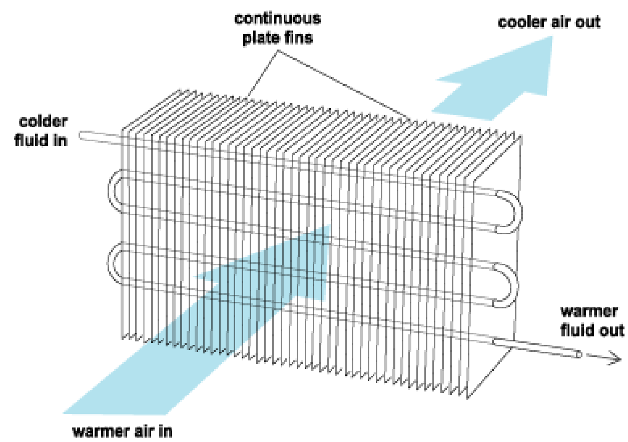

Fig. 5 A typical extended-surface air-cooling coil

E. Dilution

The concentration of volatile organic compounds in the exhaust stream is reduced. It is an important pre-treatment consideration for catalytic oxidation and adsorption systems. Dilute VOC streams are a requirement for catalytic oxidation systems as highly concentrated streams produce a lot of energy which may destroy or deactivate the catalyst [14]. The adsorbent adsorption capacity is influenced by its concentration and thus a dilution of VOC laden air stream increases adsorption capacity and reduces the amount of excess VOCs [15].

F. Particulate Removal

Particulates are removed from the VOCs contaminated air streams as a pre-treatment consideration for catalytic oxidation, adsorption, absorption, bio- filtration and membrane separation systems. In the case of catalytic oxidation, particulates can foul or poison the surface of the catalyst and hence reduce its effectiveness [15]. Particulate matter can reduce the efficiency of the adsorption system by occupying the active sites on the adsorbent that would have been taken up by the VOC molecules. For bacteria on the biofilm to be healthy and actively abate volatile organic compounds in the air stream, the humidity of air spaces inside an organic bio filter material should be as close to 100% as possible. A combination of particulate matter which is often in the form of dust and water vapour can clog the filter. This can cause irregular flow, preferential flow channeling, poor utilization of the organic bio filter media and this reduces the VOC removal efficiency [16]. The membrane separation system can also be clogged by the presence of particulate matter in particular those not small enough to pass through the membrane. This reduces the volumetric flow through the membrane reducing its separation efficiency. Particulate removal devices utilize physical mechanisms sedimentation, electrostatic precipitation, inertial deposition or Brownian diffusion [17]. Equipment such cyclones, gravity settlers, electrostatic precipitators and fabric filters may be used to remove particulate matter from VOC contaminated air streams.

-**Particulate Settling**

In a gravity settler, the horizontal gas velocity is slowed, allowing particles to settle out by gravity. These have advantages of having low initial cost and are relatively inexpensive to operate because no much can go wrong.

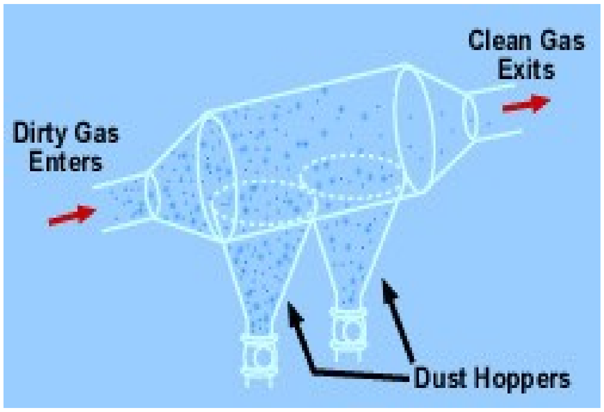

Fig. 6 An example of a particulate settling chamber [18]

-**Electrostatic Precipitation**

The operational process of an ESP is 3 staged (i) ionization of particles (ii) charging, migration and collection of particles on positively charged plates (iii) removal of particles from plates.

-**Inertial deposition**

When a gas stream changes direction as it flows around an object in its path, suspended particles tend to keep moving in their original direction due to their inertia. Particulate collection devices based on this principle include cyclones, scrubbers, and filters. A typical cyclone is shown in Fig. 7.

In a cyclone, particles are removed by causing the entire gas stream to move in a spiral pattern inside a tube. Cyclones are good at removing particles greater than 10µm in diameter. By centrifugal force, the larger particles move outward and collide with the wall of the tube. The particles slide down the wall and fall to the bottom of the cone and then removed. Clean gas flows out through the top of the cyclone. They are often used as pre-cleaners before efficient devices such as electrostatic precipitators and baghouse filters for example at petroleum refineries. Fabric filters can be used to remove particles from a VOC contaminated air stream. When the particulate laden air stream is forced through the fabric, particulates accumulate on the cloth allowing a particulate air stream to pass through. As particulates build up on the surfaces of the bags, the pressure drop increases. The bags are periodically cleaned by shaking or reversing the direction of air flow.

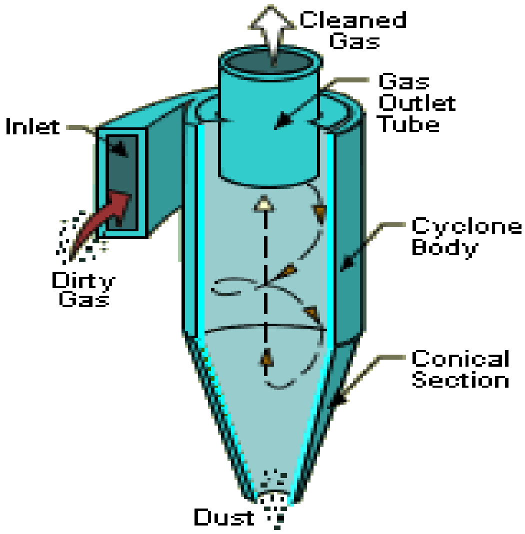

Fig. 7 A typical large-diameter cyclone [18].

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