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Design and Development of Liquid Spray Gas Scrubber for Odour Control

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Abstract—**One of the major factors affecting the productivity of workers in industry is quality of air in the working ambience. The quality of air can be characterized by means of microbial contaminants, chemicals, gases, allergen, odour or any mass or energy stressor that can induce health issues. This study is concerned with the presence of excessive detergent odour in industrial laundries. Odours are basically chemicals dissolved in air which we may be perceived by the sense of olfaction and always referred to as unpleasant smell. As for the case of industrial laundries, the effect of detergent odour becomes significant as cleaning processes simultaneously discharge high detergent concentration to the surrounding air which may lead to serious health issues apart from reducing workers' performance. Therefore, a design of liquid spray gas scrubber had been proposed in this work as a means to overcome the problem. A prototype has been designed and developed to prove the working principle of the scrubber. By taking that the scrubbing efficiency is independent of the chemical specie, a solution of ammonium hydroxide (NH_4OH) was used as a source of odour as alternative to detergent. This is due to the unavailibity of tools to measure detergent odour while concentration of NH_4OH in the scrubbing liquid, i.e. water can be easily determined. From the tests conducted, scrubbing efficiency up to 36% is obtained in a single stage, which is encouraging considering that the scrubber head was a simple shower nozzle. With improved designs of the spray, the scrubber unit may be used to improve indoor working environments.**

Keywords: air quality, gas scrubber, odour, ammonium hydroxide

I. INTRODUCTION

One of the major factors affecting the productivity of workers in industry is the quality of air in the working ambience. The quality of air (or usually termed Indoor Air Quality) can be characterized by means of measuring the microbial contaminants (mould, bacteria, etc.), chemicals (toxicants, radon, etc.), gaseous (carbon monoxide, sulphur dioxide, etc.), allergen, odour or any mass or energy stressor that can introduce health concerns. This study is related to the presence of excess detergent odour in industrial laundries as reported by [1] and [2] in their respective case studies conducted on several "*Dr Clean*" laundry outlets around Johore. Their findings conclude two significant factors affecting workers productivity, namely heat stress and excessive detergent odour. Therefore, the present work proposes a liquid spray gas scrubber design to overcome the excessive detergent odour inside the laundry stores.

Odours are chemicals dissolved in air which we may perceive by the sense of olfaction. Odours always refer to unpleasant smell, and generally regarded as a nuisance. In the case of industrial laundries, the effect of odour becomes even more significant. The cleaning processes which release a significant amount of detergent concentration to the surroundings may lead to serious health issues apart from reducing workers performance, human discomfortand furthermore, may harm workers' health.

By treating the above statements as problems requiring solution, an odour control mechanism is necessary in such environments. The existing odour control technology actually works on the principle of removing odours-causing-chemical compounds from the foul air stream by physical or chemical means. Wet water scrubber is one of the methods of odour control. Wet water scrubber is a system with high reliability and high efficiency that are relatively low in cost.

A design of a liquid spray gas scrubber had been proposed in this work. To prove the working principle and concept of the designed scrubber, a prototype has been developed. A few tests conducted had shown good scrubbing efficiency apart from the potential to be commercialized in working ambience which needs control.

II. LITERATURE REVIEW

Detergents belong to the group of consumer products, which are necessary for cleanliness, health and hygiene. Detergents are mixtures of several ingredients such as surfactants, builder, filler, anti-redeposition agent, perfume, dye and fluorescent - whitening agent. Increase of detergent use for both industrial and domestic purposes has resulted in rapid deterioration in air quality and water quality. The environmental risk of detergent effluents associated with manufacture, use and disposal of chemicals had always been one of the biggest environment issues around the globe.

In industry, the pollution of these effluents is mainly due to the residual products in the reactor, which have to be washed away in order to use the same facility for the manufacture of other products. As for domestic use, the detergent is commonly called as laundry detergent which is used for cleaning of clothes and fabrics. Detergents commercialized for hand use are normally neutral or slightly acid in order to protect human skin. However, a lot of household and industrial cleaning formulations have a high

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pH, being highly corrosive for skin and for laboratory instrumental [3].

An odour is a chemical dissolved in air, generally at a very low concentration, which we perceive by the sense of olfaction. Odours also called smells, which can refer to both pleasant and unpleasant. Stench is specifically used to describe an unpleasant odour. On the other hand, the terms fragrance, scent, or aroma are used primarily by the food and cosmetic industry to describe a pleasant odour, and are sometimes used to refer to perfumes [4]. Odours always refer to unpleasant smell, and generally regarded as a nuisance and commonly perceived to be those 'foul smelling substances' found as fugitive emissions from a variety food, chemical or wastewater treatment operations. But, when a fragrance is synthetic, such as perfume, scented shampoo, scented deodorant, or other common products, a person can actually be allergic to the oil derivatives. The reaction can be anywhere from a slight headache to anaphylactic shock, which can result in death. When allergy occurs, the person may have a slight intolerance, environmental illness or some other similar negative effect.

Odour intensity is the strength of the perceived odour sensation and is related to the odorant concentration, which is an entirely different category of measurement [5]. The intensity of an odour is perceived directly without any knowledge of the odorant concentration or of the degree of air dilution of the odorous sample needed to eliminate the odour. The following equation defines the relationship between the odour intensity (I) and concentration (C) where k is a constant and *n* is the exponent.

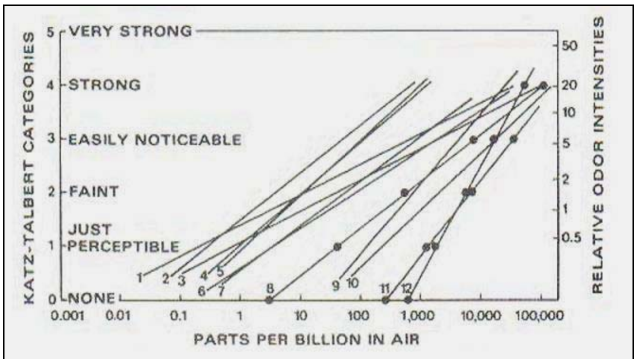
$$I\ (\text{perceived}) = k\,(C)^n$$

or

$$\log I = \log K + n \log (C) \qquad (1)$$

This is known as Stevens' Law or the power law [5]. As for odours, *n* ranges from about 0.2 to 0.8, depending on the odorant. This is an important concept that is related to the basic problem of reducing the odour intensity of a substance by air dilution or other means. Figure 1 shows the data [6] for different chemicals as a log to log plot, where the concentration, in parts per billion, as the abscissa varies with the right-side ordinate show as relative odour intensity. The spacing of the numbers on the relative-odour-intensity scale is based on data available for methyl sulphide and the four italicized odorants (IIT Research Institute data). The slope of the straight line is equal to *n*, which is the evident that the effect of dilution on the odour intensity of methyl sulphide is much lesser than that for hydrogen sulphide.

Odour control is part of air pollution control, which can be generally described as a "*separation*" technology [7]. The pollutants, whether gaseous, aerosol, or solid particulate, are separated from a carrier gas, which is usually referred to as air [8]. Usually the term "*gas scrubber*" is used to describe the technology. To overcome air-pollutant based problems, odour control methods should be applied, and by separating these pollutant substances from air, human health issues will be overcome. There are several available methods to control odours, with a variety of advantages, disadvantages and degree of cost-effectiveness. Some of these methods are thermal oxidizers, biological systems, wet scrubbing systems and activated carbon.



Odor intensity vs. concentration plots for several odorants. Individual points are shown for 8, 11, and 12 to illustrate the linerity. Legend : 1. Thiophenol ; 2. Ethyl selenomercaptan ; 3. Ethyl sulphide ; 4. Phenly isocyanide ; 5. Ethyl selenide ; 6. Methyl sulphide ; 7. Courmarin ; 8. Methylmercaptan ; 9. Hydrogen sulphide ; 10. Pyridine ; 11. Ally alcohol ; 12. Nitrobenzene.

Figure 1. Odour intensity versus concentration

The present work focuses on wet scrubbing systems. Usually a wet scrubbing system is used under situations where the contaminant cannot be removed easily in dry form, soluble gases are present or soluble wet particulates are present. The contaminant might undergo some subsequent wet process such as recovery, wet separation or settling or neutralization. The pollution control system must be compact, and the contaminants are mostly safely handled wet rather than dry [9]. There are several types of available wet scrubbing system, and can be roughly be grouped into seven major categories: venturi scrubbers, mechanically-aided scrubbers, pump-aided scrubbers, wetted-filter-type scrubbers, tray-type or sieve type scrubbers, spray towers, and hybrid scrubbers.

A wet scrubber uses capture techniques. It removes the particles from the gas by capturing the particles in liquid (usually water) droplets and separating the droplets from the gas stream. The droplets act as conveyors of the particulates out of the gas stream. There are three mechanisms that wet scrubbers use to capture the particulates [7, 9]: "*impaction"* of the particles directly into a target droplet, "i*nterception"* of the particles by a target droplet as the particle comes near the droplet and *"diffusion"* of the particle through the gas surrounding to the *"target droplet"* until the particle is close enough to be captured. The three mechanisms are shown in Figures 2, 3 and 4 respectively.

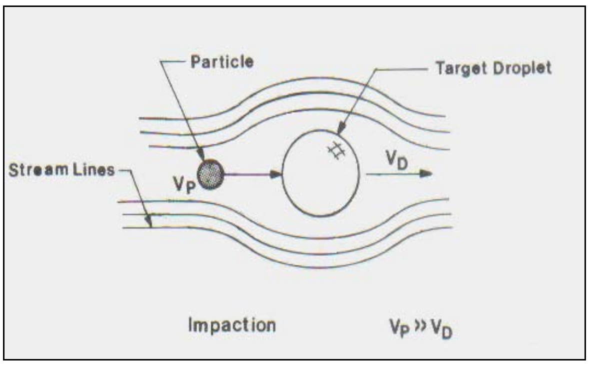


Figure 2. Direct impaction into a droplet [9]

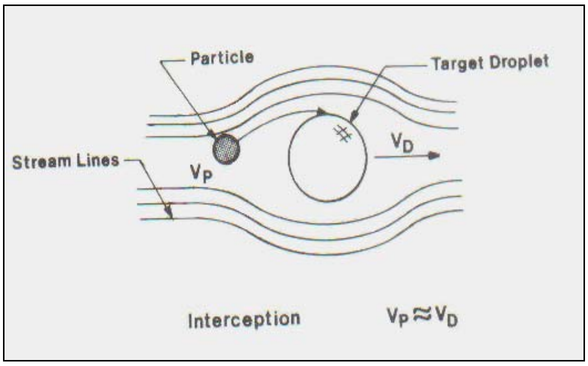


Figure 3. Interception [9]

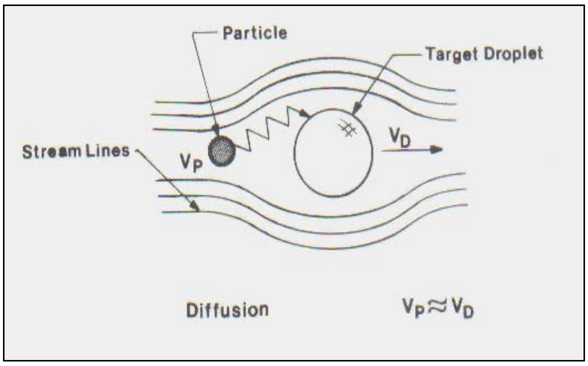


Figure 4. Diffusion [9]

"Target droplet" is the key word in wet scrubbing systems. A successful scrubber creates and controls the droplet dispersion effectively. Almost all high-efficiency wet scrubbers are proficient at creating target droplets, by accelerating gases to high velocity, injecting liquid, then pneumatically shearing the liquid into a fine spray, or use mechanical energy such as spinning disk or high-pressure sprays to create the target droplet diffusion. The goal is to cause the tiny pollutant particle to be lodged inside the collecting droplet and then to remove the larger droplet from the gas stream. There are two general ideas in creating a wet scrubbing system:

i. The smaller the target droplet, the smaller the size of particulate that can be captured.
ii. The more densely the droplets are packed, the greater is the probability of capture.

III. Methodology

A theoretical framework for the idea of developing a wet water scrubber system had been undertaken based on literature review of the current wet water scrubber system. The idea in developing this system is to spray scrubbing liquid (e.g. water) onto the surface which has large area per unit volume (such as fill material in cooling towers) whereby the odorous gas is being forced to flow over the surface as well. The simultaneous contact between the odorous gas and the scrubbing liquid will result in capturing of odorous substance at certain concentration. These process will reduce the amount of odour concentration in the gas, thus enable us to determine the scrubbing efficiency of the whole system.

The proposed system consists of 3 main sub-assemblies, namely the odour generator, scrubbing unit and scrubbing liquid collector. The odour generator operates atmospheric air is blown through sparger, in which air is bubbled through detergent solution with certain concentration thus creating detergent odour gas. This odourous gas then flows directly into the scrubbing unit where gas and scrubbing liquid which is sprayed by an array of nozzles comes into contact simultaneously. Contact between these two fluids creates scrubbing action in which the droplets of scrubbing liquid capture the odour generating particles from the gas. Augmentation of scrubbing action is achieved by enlarging the total surface area of contact between the odourous gas and scrubbing liquid, by means of using a large surface area to volume material, similar to fill materials used in cooling towers. Finally, the scrubbing liquid is collected and filtered before the same liquid is pumped inside the scrubbing unit [10]. The process is illustrated in Figure 5.

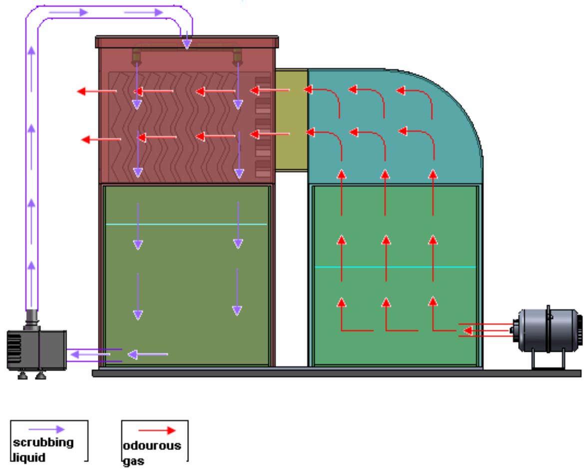


Figure 5. Principle of operation [10]

However, in this work, the composition of chemicals which creates odour in commercial detergents could not be identified. This is due to the inability to extract information from the manufacturer as they are kept as industrial secrets. As a result, the corresponding target droplet inside the scrubbing liquid could not be established. However, a criterion to determine the scrubbing efficiency is required to evaluate the performance of the proposed liquid scrubber. Therefore, the principle of dependence of scrubbing efficiency to chemical specie is applied [10]. By this principle, the scrubbing efficiency is taken to be independent of any particles or contaminants. As such, ammonium solution in water or ammonium hydroxide (NH_4OH) which features pungent odour is used to generate odour in this work. NH_4OH is diluted in distilled water with a concentration of 1:50, which is then bubbled with air to generate vapour and forced to flow inside the scrubber. The efficiency of the scrubber is basically a ratio of pH of NH_4OH captured to pH of NH_4OH injected**;**

$$\eta_{scrubber} = \frac{pH_{captured}}{pH_{injected}} \qquad (2)$$

$$pH_{injected\ (t=i)} = pH_{solution\ (t=i-1)} - pH_{solution\ (t=i)} \quad i = 1, 2, \ldots, 15$$
$$pH_{captured\ (t=i)} = pH_{water\ (t=i)} - pH_{water\ (t=i-1)} \quad i = 1, 2, \ldots, 15$$

where t are in minutes.

IV. Results and Discussion

The wet water scrubber system consists of two main chambers with other parts such as nozzles, fill material, pump and blower. It can be divided into three sub-assemblies; Sub-assembly A is where the scrubbing process takes part, Sub-assembly B is where the detergent odour being carries out from the detergent contaminated water, and Sub-assembly C works as a connector path, allowing detergent odour to flow from Sub-assembly B to Sub-assembly A. These sub assemblies and the scrubber's individual parts are shown in Figure 6.

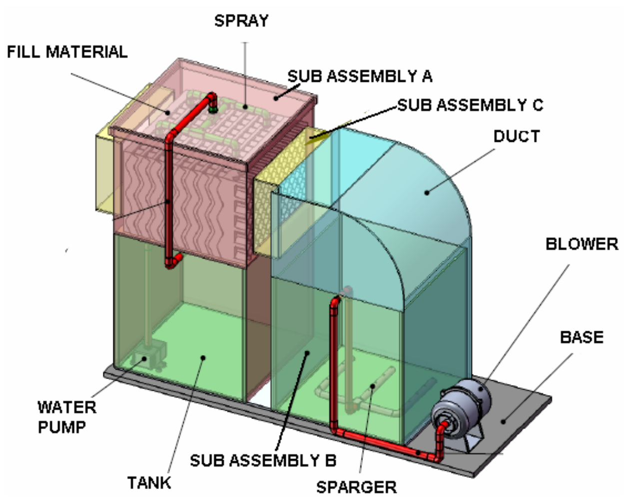


Figure 6. Wet water scrubber system [10]

Ammonium solution (NH_4OH) which is used in this work is a corrosive liquid and upon vaporization, it becomes toxic by inhalation and is hazardous. Therefore it is important to determine a safe operating condition during experiments. This is achieved by diluting the ammonium hydroxide with distilled water in a ratio of 1:50. This enables a minimum volume of ammonium hydroxide used but sufficient to provide necessary odour. From this ratio, 10 litres of water is used with 0.2 litres of NH_4OH. The chamber and connections are perfectly sealed to avoid any gas leakage. The experiment is run for 15 minutes where both initial values of pH injected and captured are recorded simultaneously. The results are shown in Table 1.

Table 1. Results

Time (minutes)	pH in Chamber B	pH in Chamber A	pH of Scrubbing Liquid	Efficiency (%)
t = 0	9.24	8.82	6.43	14.95
t = 5	9.18	8.73	6.82	19.07
t = 10	9.11	8.68	7.17	22.16
t = 15	9.07	8.89	7.68	12.95
t = 20	8.99	8.64	7.79	29.17
t = 25	9.04	8.67	8.01	35.92
t = 30	8.92	8.81	8.11	13.58

During experiments, observations shown that the flowrate of NH_4OH vapor are smaller than expected. The main reason is due to the small amount of air supplied by the blower. The large cross sectional area of ducts reduces the velocity, and the level of water combined with fill material imposes large pressure drop. Therefore, amount of NH_4OH vapor flowing through the scrubbing unit becomes low. As a result, amount of NH_4OH removed from the vapor also becomes relatively small affecting the total scrubbing efficiency. However, the pressure drop by water is unrealistic for a real application of scrubber as this is only necessary for lab experiments.

V. Conclusion

From the results, a maximum scrubbing efficiency of 35.92% was obtained. Although this efficiency is actually far from typical liquid scrubber's efficiency which ranges more than 90%, several conclusions can be drawn. First, determination of a scrubber's efficiency can be generalized by taking the efficiency to be independent of chemical specie. Second, the fill material may increase the total surface of scrubbing area but costs pressure drop significantly. Therefore, appropriate type of custom made fill material can be considered in the scrubbing unit if the blower size is a constraint. Third, the array and height of nozzle which sprays the scrubbing liquid also plays important role to ensure equal distribution of scrubbing liquid with maximum wetted area. Hollow-cone type of spray must be avoided.

Several improvements can also be considered in the current design of scrubber. Swirling flow of gas entering the scrubber unit can improve scrubbing efficiency significantly as gas and scrubbing liquid became better in contact. The swirling motion can be obtained through devices such as custom made gas swirler; similarly as being used in internal combustion engines for fuel saving and creating homogenous air-fuel mixture for better combustion. One can also consider counter-flow type of scrubbing unit to increase the reaction time and area of contact between gas and scrubbing liquid as both fluid now flows in opposing directions.

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