STUDY THE EFFECT OF OPERATION PARAMETER FOR MONOETHANOLAMINE (MEA) WASTEWATER TREATMENT USING ACTIVATED CARBON, CHITOSAN AND RICE HUSK

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ABSTRACT

Absorption of carbon dioxide (CO_2) technology by Monoethanolamine (MEA) is widely used in oil and gas industry. Upon usage, the MEA is contaminated with hydrocarbon and suspended solids. Heavily contaminated MEA solution reduces its effectiveness in stripping the CO_2 gas and also causes foaming phenomenon in the CO_2 removal unit which further reduces the overall performance of the unit. Due to that, MEA is discharge from the industry as wastewater. This research is conducted to evaluate the feasible methods to recycle and reuse the monoethanolamine (MEA) wastewater while maintaining the amine concentration level via adsorption process. Adsorption method is used for the treatment with three different types of adsorbent which are activated carbon, chitosan and rice husk. Two different variables, namely adsorbent dosage and circulation time are varied to examine the effects on the parameters which are percentage of residue oil and amine concentration. Activated carbon showed the best performance among these three adsorbent. Application of activated carbon resulted in 95 % reduction in residue oil at 6.5 hours of contact time. Chitosan reduced the residue oil up to 90 % and rice husk 71 %. These three adsorbents were able to maintain the MEA concentration by percentage loss below than 9 %.

Keywords: Monoethanolamine, Adsorption, Activated carbon, Chitosan, Rice husk, Residue oil, MEA concentration

ABSTRAK

Penyerapan karbon dioksida (CO_2) teknologi oleh ‘Monoethanolamine’ (MEA) digunakan secara meluas dalam industri minyak dan gas. Namun, MEA telah tercemar dengan hidrokarbon dan pepejal terampai. Ini telah menyebabkan pengurangan keberkesanannya dalam membuang gas CO_2 dan juga menyebabkan ‘foaming’ fenomena dalam unit penyingkiran CO2 yang selanjutnya mengurangkan prestasi keseluruhan sistem. Oleh kerana itu, MEA telah dibuang dari industri sebagai air sisa. Kajian ini dijalankan untuk mengkaji kaedah terbaik yang boleh dilaksanakan untuk mengitar semula MEA di samping mengekalkan tahap kepekatan amina melalui proses penjerapan. Kaedah penjerapan digunakan untuk rawatan dengan tiga jenis bahan penjerap iaitu ‘activated’ karbon, kitosan dan sekam padi. Dua pembolehubah yang berbeza iaitu dos dan masa telah diubah untuk mengkaji kesan kadar pengurangan peratusan minyak sisa dan kepekatan amina. Karbon teraktif menunjukkan prestasi terbaik di kalangan ketiga-tiga bahan penjerap. Penggunaan ‘activated’ carbon menyebabkan pengurangan minyak sebanyak 95 % dalam masa 6.5 jam. Chitosan mengurangkan minyak baki sehingga 90 % dan sekam padi 71%. Ketiga-tiga adsorben dapat mengekalkan kepekatan MEA dengan kehilangan peratusan bawah daripada 9%.

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LIST OF ABBREVIATIONS

%	Percent
˚C	Degree celcius
BWD	Back washed and drained
CCS	Capture and storage
CO	Carbon oxide
CO_2	Carbon dioxide
G	Gram
GAC	Granular activated carbon
GHG	Greenhouse gases
H	Hour
H_2	Hydrogen
H_2S	Hydrogen sulfide
L	Litres
M^2	Area
MEA	Monoethanolamine
Mg/ L	Concentration
mL	Milliliter
Wt%	Weight percentage
µm	Micrometer

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Environmental issues due to emissions of pollutant from combustion of fossil fuels have become global problems, including air toxics and greenhouse gases (GHG). Increasing GHG level in atmosphere is believed to cause global warming. Among these GHG, carbon dioxide (CO_2) is the largest contributor in regard of its amount present in the atmosphere contributing to 55% of global warming effects (Mondal et al, 2012). The petrochemical plants have generated the largest amount of CO_2 emission for about 33-40% of the total. CO_2 emission from combustion flue gases needs to be captured and removed as this CO_2 is posing as interference in the processing activities and would thwart the product quality. Therefore, the stability, safety and environment acceptability of CO_2 capture and storage (CCS) technologies have been paid worldwide attention. These technologies include the chemical absorption and adsorption methods (Xia et al, 1999), membrane separation (Mohamed et al, 2011) and chemical looping combustion (Matissson et al, 2001). Removing CO_2 from combustion flue gases by chemical method usually uses amine, ammonia and alkaline solution as absorbents. In recent years, some domestic and foreign researches have deeply researched amine solution, ammonia and alkaline solution as absorbents to absorb CO_2 from aspects of the mechanism, mass transfer coefficient and absorption efficiency. The leading option for CO_2 capture is an absorption process in which the solvent can be a chemical such as monoethanolamine (MEA) absorption process. This technique has been widely used in chemical process industry for over 60 years (Yang et al., 2008). This chemical method has been used due to its advantages of high absorption efficiency, it can produce a relatively pure CO_2 stream, low energy consumption and can be used for dilute systems and low CO_2 concentration (Razali et al., 2011). Currently, aqueous MEA is widely for removing CO_2 and hydrogen sulfide, (H_2S) from flue gas streams (Harol et al, 1998). MEA has the advantages of absorbing low concentration CO_2 from combustion flue gases for its small molecular weight and large ability to absorb acid gases such as CO_2 and absorbent can be recycled (Kuntz et al, 2009). The absorption efficiency of amine is between 61%-90% (Peng et al, 2011).

Figure 1 shows the basic flow scheme for the MEA process of which principal reactions of MEA with CO_2 are represented as follows:

$2HOCH_2CH_2NH_2 + H_2O + CO_2 \longrightarrow CHOCH_2(H_2NH_3^+)_2CO_3^{2-}$ ……………..[1]

$(HOCH_2CH_2NH_3^+)_2CO_3^{2-} \longrightarrow 2HOCH_2CH_2NH_2 + H_2O + CO_2$ …………...…..[2]

There are two major units in this process, namely absorber and stripper. Absorber is the place where CO_2 absorption process takes place. Flue gas stream containing CO_2 is introduced at the bottom of the absorber. Absorbent is introduced from the top of the column that leads counter current contact between flue gas and solvent and a selective absorption of CO_2 take place. The reaction in the absorber as shown in equation [1] is occurred at 38-49˚C (Ohtaguchi et al, 2007). Then, CO_2 rich stream is fed to the regenerator/ stripper, where desorption of CO_2 occurs and regenerated solvent is recycled for further use, desorbed CO_2 is compressed and sent to storage. The chemical solvent is regenerated in the stripper at elevated temperature of 93-127˚C [equation 2]. Heat is supplied to the reboiler using low pressure steam to maintain regeneration conditions. This leads to a thermal energy penalty because the solvent has to be heated to provide the required desorption heat for the removal of the chemically bound CO_2 and for the production of steam, which acts as a stripping gas (Razali et al., 2011). Steam is recovered in the condenser and feed back to the stripper, after which the produced CO_2 gas leaves the condenser. The lean MEA is then recycled back to the absorber. Process illustration of CO_2 capture by alkaline amine based solution is shown in figure 1.

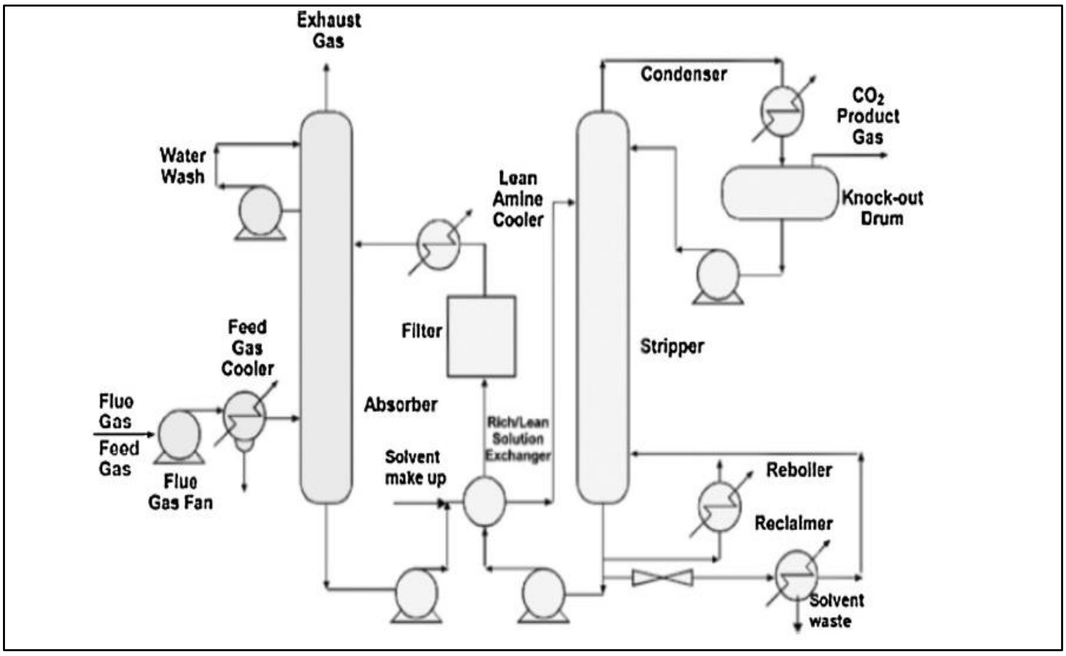

Figure 1.1: Typical process diagram of CO_2 capture using solvent absorption in industry

1.2 PROBLEM STATEMENT

Over the past decades, there is an increasing in wastewater research in many parts of the world. The improvement of the industrial waste must receive a better attention where industry generates an amount of waste almost everyday as a result of advance in processes and product. The rapid growth of different industrial sector such as chemicals, petrochemicals, iron and steel, cement, paper and pulp and other minerals and metal production has been attributed to the availability of the fuel gas production. This flue gas which contains CO_2 needs to be treated to remove the CO_2 prior to further processing activities. Currently, industry used MEA in order to absorb CO_2 from the flue gas in the refineries.

MEA is the baseline solvent for CO_2 capture from flue gas by absorption stripping. MEA is an attractive solvent because it is relatively cheap, has a fast reaction rate with CO_2 and has a high heat of absorption. MEA acts as a weak base, colourless, toxic, flammable, corrosive and viscous liquid with an odor similar to ammonia. Besides that, MEA have a low volatility at room temperature. MEA is obtained from the reaction between ammonia and ethylene oxide. It can be used to treat natural gas and petroleum residual gas in the absorption of CO_2 due to the formation of covalent bond when MEA is reacting with CO_2. The reaction will release CO_2 as gaseous state. Primary and secondary amines react rapidly with CO_2 to form carbamate. By the addition of amine to a purely physical solvent such as water, the CO_2 absorption capacity and the rate is enhanced manifola (Mandal, 2006). As the MEA left in aqueous solution, any treatment methods imply would be ease due to ions mobilization in the solution (Razali et al., 2011).

From the literature point of view, it is found that there is heavy hydrocarbon component could be carried over to the absorber with the feed gas which caused sudden foaming in the absorber. Foaming is a severe operational problem in acid gas absorption process using aqueous alkanolamine solutions (Thitakamol et al., 2009). It occurs during plant start-up and operation in both absorber and regenerator (Abdi et al, 2001), (Stewart et al, 1994), (Thitakamol et al., 2009) is caused by high gas velocity, sludge deposits on gas contactors and process contaminants entering the process with feed gas and make up water, or generated within the process through reaction of alkanolamine degradation (MEA + CO_2). The reaction between CO_2 and MEA also contributed to the foaming problems because the reaction will produce some salt and increased the amount of suspended solids in absorber. This phenomenon will lead to a number of different problems. Foaming impacts integrity of plant operation, causing excessive loss of absorption solvents, premature flooding, reduction in plant throughput, off-specification of products, decreased absorption efficiency, increased amine losses, reduced quality of product gas and MEA somehow is not appropriate to feed back into the stripper due to properties deterioration and thus give difficulties in optimizing the absorption processes and it has been removed as a wastewater (Thitakamol et al., 2009). These problems have lead to the removing of wastewater from the plant.

As the awareness and responsibility towards the environment, the industry has come out with an idea to treat and reuse the water consumption, water discharge and other emission (Vissen, 2012). A few methods have been suggested to treat MEA wastewater. There were chemical separation, filtration, membrane separation, electrochemical treatment, ion exchange and adsorption (Sampranpiboon et al, 2010).

All these methods with exception of adsorption are costly and have low output. Among these methods, adsorption has been shown to be a feasible alternate method to separate amine from wastewater. Adsorption is a process where a solid is used for removing a soluble substance from water (Mohamed et al, 2009). This process occurs when the attractive force at the carbon surface overcome the attractive forces of the liquid. The overall adsorption process consists of a series of steps in series. When the fluid is flowing past the particle in a fixed bed, the solute first diffuses from the bulk fluid to the gross exterior surface of the particle. Then the solute will diffuses inside the pore to the surface of the pore. Finally, the solute is adsorbed on the surface. Basically, adsorption is a surface phenomenon that needs the usage of an adsorbent for the removal and recovery amines.

Many adsorbents have been developed for a wide range of separations such as activated carbon, silica gel, chitosan, molecular sieve zeolite and rice husk. All of these adsorbents have been characterized by very large pore surface area of 100 to over 2000 m^2/g. In chemical processes, the adsorbent is usually in the form of small particles small pellets, beads or granules ranging from about 0.1 mm to 12 mm in size, with the larger particles being used in packed beds (Geankoplis, 2003). A particle of adsorbent has a very porous structure with many fine pore and pore volumes up to 50 % of total particle volume. Physical adsorption, or Van der Waals adsorption, usually occurs between the adsorbed molecules and the solid internal pore surface and is readily reversible. Activated carbon, rice husk and chitosan have the potential to be an adsorbent for the treatment of MEA wastewater. It has been proven by several researchers that these adsorbents have the capability to adsorb metals ions, oil and grease and improve wastewater quality (Mojiri, 2011).

Chitosan is a cationic biodegradable biopolymer produced by the extensive deacytylation of chitin obtained from shrimp shell waste. Chitosan has been investigated as biosorbent for the capture of some pollutant such as oil and grease, heavy metals, dissolved dyes and other toxic substances from waste water (Lahading, 2011). Rice husk is an agricultural waste material generated in rice producing countries, especially in Asia. During milling of paddy about 78% of weight is received as rice, broken rice and bran. Rest, 22% of the paddy is received as husk. Rice husk has a good properties in adsorption and has a potential in removal of methylene blue up to 88% to 94% at the dose 20/L (Gidde et al, 2009). Activated carbon in a microcrystalline material made by thermal decomposition of wood, vegetable shells, coal and so on. Besides that, activated carbon is a broad-spectrum agent effectively removes toxic and bio-refractive substances such as insecticides, chlorinated hydrocarbons and heavy metal, typically present in many water supplies.

From the literature point of view, the treatment of MEA wastewater is insufficiently conducted especially for recycle purpose in the industry. Due to that, these three adsorbents were selected, employed and explored in this study in order to examine its characteristic and feasibility in reducing oil concentration in the MEA wastewater and at the same time maintaining the level of amine concentration at acceptable limit. This parameters evaluation was very crucial in determining the treated MEA could be recycled or else. Since MEA wastewater is producing everyday from different processing plants, the research to find the alternative methods with the best adsorbent for treating MEA wastewater which is cheap, simple and environmental friendly is needed.

1.3 OBJECTIVE

The following are the objectives of this research:

- To study the effect of operation parameter for monoetahnalamine (MEA) wastewater treatment using activated carbon, chitosan and rice husk.

1.4 SCOPES OF THIS RESEARCH

The following are the scope of this research:

i) To characterize the amine contaminated wastewater containing MEA.

ii) To study the performance of activated carbon, chitosan and rice husk in continuous process.

iii) To study the influence of adsorbent dosage and circulation time in treating MEA wastewater.

1.5 MAIN CONTRIBUTION OF THIS WORK

The main contribution of this research is the best adsorbent at optimal conditions in treating MEA wastewater can be identified and apply in the real industries. Besides that, amine used can be recycled back in the absorber as amine concentration is maintained when treatment is done.

1.6 ORGANISATION OF THIS THESIS

The structure of the reminder of the thesis is outlined as follow:

Chapter 2 provides a description of the problems, background, and applications of amine scrubbing process for CO_2 removal in natural gas processing. Besides that, general description on the characteristics of the technique, as well as the theories that are related for wastewater treatment. This chapter also provides a brief discussion on types of separation process for CO_2 removal from natural gas processing plant and which one among those processes most suitable for removing CO_2. Referring to the objective, this chapter also present the discussion on types of separation process in treating MEA wastewater. Besides that, types of adsorbents used in this experiment were also discussed in this chapter.

Chapter 3 presented a detailed explanation of the research methodology according to which conducted this research. It utilized the chemicals, materials and instruments available in the lab in order to make this research successful.

Chapter 4 is about the results that have been obtained from the experiment done. This chapter will revisit the action research methodology, analysing it, and discussing its appropriateness for this type of research.

Chapter 5 is about the conclusion regarding the experiments. Besides that, in this chapter also provides suggestions to improve this research.

CHAPTER 2

LITERATURE REVIEW

Literature reviews provide a handy guide and a solid background to a particular topic. This chapter explores the subtopic of introduction of wastewater treatment, monoethanolamine (MEA) wastewater, adsorption theory and types of adsorbents. This discussion concerns the works of the previous researches that related to this research.

2.1 INTRODUCTION TO WASTEWATER

Wastewater is any water that has been adversely affected in quality by any anthropogenic influence. In other words, wastewater is water that has been used and must be treated before it can reuse for any applications due to the unsafe level of impurities that contain in it. Wastewater or also called sewage, is mostly contain water by mass with 99.9% (Templeton, 2011). The contaminants in waste water include suspended solids, biodegradable dissolved organic compounds, inorganic solids, nutrients, and pathogenic microorganisms (Butler, 2011). It therefore includes liquid waste discharged from domestic house, industrial, agricultural and commercial processes. It does not include rain-water uncontaminated by human activities (Razali et al., 2011). Normally, industry will discharge large volumes of oily waste water (Naidi et al, 2008). The presence of high strength oil and grease in industrial wastewater poses serious challenges for water treatment, often necessitating costly modifications by inclusion of physio-chemical processes such as membrane, adsorption, absorption and flocculation (Nakhla et.al, 2003).

A number of technologies are available with varying degree of success to control water pollution. Some of them are coagulation and flocculation, membrane, ion exchange, adsorption and filtration.

2.1.1 Coagulation and flocculation

Coagulation and flocculation are the terms used to describe the charge neutralization and aggregation of the colloidal particles present in the water. Coagulation is used to reduce turbidity, colour, organic substances, phosphorous, and trace metal precipitates such as iron, manganese and chromium. Coagulation and flocculation are basic steps in the treatment of both potable and wastewater. Potable water treatment in clarification of water using coagulating agents has been practiced from ancient times (Miller, 2013). In potable water treatment coagulation produces clear water with reduced taste and odor issues. This further allows the essential disinfection process to work efficiently resulting in a reliable and safe drinking water supply. In wastewater treatment coagulation is used after natural microbial processes have broken down the contaminants. Coagulation reduces phosphorous levels, very important in eliminating algae blooms in the creeks and rivers. Coagulation also allows greater water recycling by making the wastewater clear and suitable for re-use (Wang et al., 2007).

2.1.2 Membrane separation

Membrane filtration is a process used to separate dissolved substances and fine particles from solutions. Membrane acts as a semipermeable and selective barrier that separates particles based on molecular or physical size (Ozturk et al., 2012). Solutes smaller of solution than the membrane pore size are able to pass through the membrane as permeate flux while particles and molecules larger than the membrane pore size are retained. The two fluxes at outlet of membrane are important because this process has a high efficiency in the separation. (Claudia et al, 2012).

2.1.3 Ion exchange

Ion exchange is an adsorption process in which charged molecules, called ions, in a solution are exchanged for other ions on the surface of an adsorbent or resin (Alchin, 2007). Ion exchange only removes compounds that ionize. It is also a concentration process. The phenomenon of ion exchange occurs in special synthetic resins and in many natural solids (Wang, 2006). A synthetic resin can be visualized as a skeleton-like structure having many exchange sites. This skeleton is insoluble in water, but is electrically charged holding ions of opposite charge at the exchange sites. Exchangers with negatively charged groups are called cationic and attract positive ions (dissolved metals such as nickel). Anion exchangers are positively charged and attract negative ions (anions such as chlorides, sulfates and chromates). Most ion exchange resins currently in use are made from a styrene divinyl benzene copolymer, appropriately treated to graft the functional groups. The copolymer is then treated by a process called sulfonation which produces the cation resins. Ion exchange resins are classified as strongly or weakly acidic cation exchange resins and strongly or weakly basic anion exchange resins (Alchin, 2007).

2.1.4 Adsorption

Adsorption is a fundamental process in the physicochemical treatment of municipal wastewaters, a treatment which can economically meet today's higher effluent standards and water reuse requirements. Activated carbon is the most effective adsorbent for this application (Walter et al., 1973). Expanded-bed contact systems permit most efficient use of granular carbon for waste treatment. The adsorption process is enhanced by in-situ partial regeneration effected by biological growth on the surfaces of the carbon. Physicochemical systems using adsorption with activated carbon consistently produce high levels of treatment and have a high degree of stability and reliability. Advantages over biological treatment systems include lower land area requirements, lower sensitivity to diurnal flow and concentration variations and to toxic substances, potential for significant heavy metal removal, greater flexibility in design and operation, and superior removal of organic wastes (Kandasamy et al., 2005).

2.2 MONOETHANOLAMINE (MEA)

Monoethanolamine is a clear, colourless, viscous liquid. It is one of a class of organic compounds called ethanolamines. MEA is use as a chemical intermediate in the manufacture of cosmetics, surface-active agents, emulsifiers, pharmaceuticals and plasticizing. Besides that, MEA is use for the absorption and removal of CO_2 and H_2S from refinery and natural gas streams. Its react quickly with CO_2 for its primary amine characteristics (Dang, 2001). MEA undergoes moderate biodegradation and is not expected to be persistent in the environment. MEA is water soluble and biodegrades rapidly. It should not bio accumulate or persist in the environment. However, large releases to wastewater treatment facilities can result in poor treatment and toxic shock to biologically active species (Maceiraset et.al, 2008).

2.2. 1 Production of Monoetahanolamine(MEA)

Monoethanolamine is produced by the reaction of ethylene oxide with aqueous ammonia. The reaction will produce diethanoalmine and triethanolamine as shown in figure below.

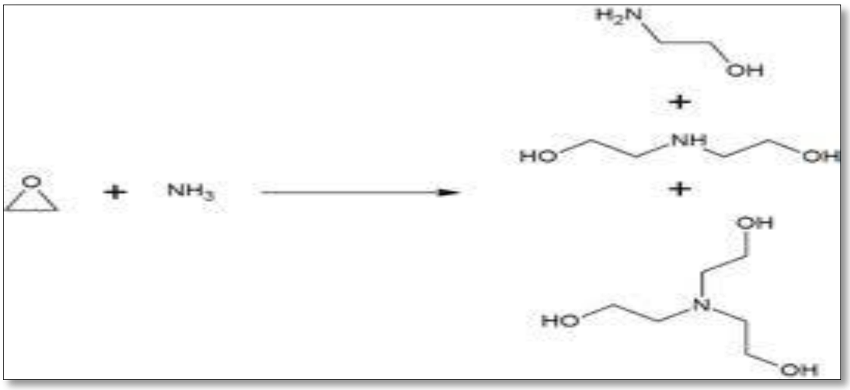

Figure 2.1: reaction between Ethylene Oxide and Ammonia

2.2.2 Application of Monoetahanolamine(MEA)

Usually MEA in a form of aqueous solution is used in industry for scrubbing an acidic gases and is also used pharmaceuticals, corrosion inhibitors, emulsifiers and polishes.

Focusing in a wastewater treatment, MEA is used as a medium to a remove CO_2 from the flue gas that release from the reaction in industry. MEA is act as a weak base solution that react with CO_2 which is acidic compound to form salt solution (Mansourizadeh and Ismail, 2011). The MEA neutralises acidic compounds dissolved in the solution to turn the molecules into anionic form, making them polar and considerably more soluble in a cold MEA solution and thus keeping such acidic gases dissolved in this gas-scubbing solution (Razali et al., 2011). Therefore, large surface area contact with such a cold scrubbing solution in a scrubber unit can selectively remove such acidic components as CO_2 from some mixed gas streams. The removal of CO_2 from the flue gas is very important process in order to reduce global warming phenomena. Besides that, MEA is often used for alkalinisation of water in steam cycles of power plants, including nuclear power plants with pressurized water reactors. This alkalinisation is performed to control corrosion of metal components. MEA is selected because it does not accumulate in steam generators (boilers) and crevices due to its volatility, but rather distributes relatively uniformly throughout the entire steam cycle. In such application, MEA is a key ingredient of so-called "all-volatile treatment" of water (AVT).

2.3 ADSORPTION

Adsorption is a process that occurs when a gas or liquid solute accumulates on the surface of a solid or a liquid (adsorbent), forming a molecular or atomic film (the adsorbate) (Geankoplis, 2003). In other word, adsorption process is one of the separation process consist of liquid-phase adsorption and gas-phase adsorption process. For liquid-phase, is used to separate or remove the liquid compound in the water or oil. While for gas phase, is commonlyy used to remove or separate liquid from the gas phase. But both types of adsorption still need adsorbent as an agent to adsorb the fluid or gas. It is different from absorption, in which a substance diffuses into a liquid or solid to form a solution (Pang et al., 2013). The term sorption encompasses both processes, while desorption is the reverse process. Adsorption is operative in most natural physical, biological and chemical systems, and is widely used in industrial application such as activated charcoal, synthesis resins and water purification (Xu, 2013).

The adsorption process has an advantage over the others due to the excellent adsorption efficiency. Adsorption process has been proven one of the best water treatment technologies around the world (AmitBhatnagar, 2010). Adsorption techniques are widely used to remove certain classes of pollutants from wastewaters, especially those that are not easily biodegradable (Crini, 2009).

Similar to surface tension, adsorption is consequence of surface energy. In a bulk material, all the bonding requirements (be they ionic, covalent or metallic) of the constituent atoms of the material are filled. But atoms on the (clean) surface experience a bond deficiency, because they are not wholly surrounded by other atoms. Thus it is energetically favourable for them to bond with whatever happens to be availble. The exact nature process of the bonding depends on the details of the species involved, but the adsorbed material is generally classified as exhiniting physisorption or chemisorption(Xiaoling et al, 2009).

2.3.1 Physisorption

Physisorption or physical adsorption is a type of adsorption in which the adsorbate adheres to the surface only through Van der Waals (weak intermolecular) interactions, which are also responsible for the non-ideal behaviour of real gases.

2.3.2 Chemisorption

Chemisorption is a type of adsorption whereby a molecule adheres to a surface through the formation of a chemical bond, as opposed to the Van der Waals forces which cause physisorption.

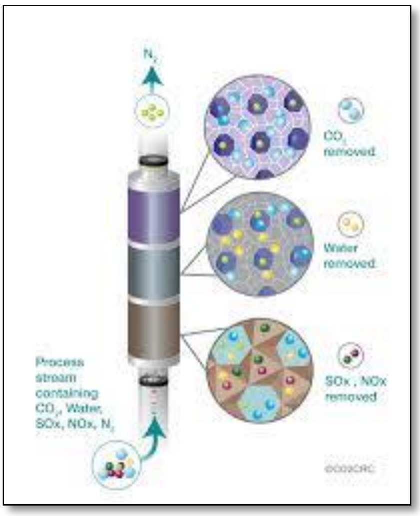

Figure 2.2: Adsorption process in a packed bed

2.3.3 Overview of adsorption process

In commercial process, the adsorbent is usually in the form of small particles in a fixed bed. The process of adsorption occurs when the fluid is passes through the bed and the solid particles will adsorb the components from the fluid. When the bed is almost reaching saturated state, the flow in this bed is being stopped and the bed is regenerated thermally or by other methods to make sure that desorption is occur. Desorption is the reverse of adsorption process. The adsorbed material or also known as adsorbate is thereby recovered and the solid adsorbent is ready for another cycle of adsorption process. Adsorption process is commonly used especially in gas phase adsorption (Kandasamy, 2005). For example, removal of water from hydrocarbon gases, sulfur compound from natural gas, solvents from air and other gases, and odors from air (Geankoplis, 2003).

When a gas comes into contact with a solid surface, molecules of the gas will adsorb to the surface in quantities that are function of their partial pressure in the bulk. The measurement of the amount of gas adsorbed over a range of partial pressures at a single temperature results in a graph known as an adsorption isotherm (Walter et al., 2013). There are three types of adsorption isotherms that is commonly used; Langmuir, Freundlich and Linear isotherm. These isotherms can have different shapes depending on the type of adsorbent, the type of adsorbate, and the intermolecular interaction between the gas and the surface (Finding, 1998).

2.3.4 Factors affect the effectiveness of adsorption process

There are many factors that affecting the effectiveness of adsorption process. Below are the few factors (Yaala, 2012):

i. **Surface area of adsorbent**
   Larger sizes of adsorbent will imply a greater adsorption capacity.

ii. **Particle size of adsorbent**
   Smaller particle size reduce internal diffusional and mass transfer limitation to the penetration of the adsorbate inside the adsorbent (i.e., equilibrium is more easily achieved and nearly full adsorption capability can be attained). However, wastewater drop across columns packed with powdered material is too high for use of this material in packed beds. Addition of powdered adsorbent must followed by their removal.

iii. **Contact time or residence time**
   As the time increase, the adsorption process will become more complete.

iv. **Solubility of solute (adsorbate) in liquid (wastewater)**
   Substances slightly soluble in water will be more easily removed from water (i.e., adsorbed) than substances with highly solubility. Also, non-polar substances will be more easily removed than polar substances since the latter have a greater affinity for water.

v. **pH**

The degree of ionization of a species is affected by the pH (e.g., a weak acid or a weak basis). This, in turn, affects adsorption process.

2.3.5 The nature of adsorbents

Adsorbents are available as irregular granules, extruded pellets and formed spheres. The sizes reflects the need to pack as much surface area as possible into a given volume of bed and at the same time minimize pressure drop for flow through the bed. Sizes of up to about 6 mm are common.

To be attractive commercially, an adsorbent should embody a number of features (Suzuki, 1993):

I. It should have a large internal surface area.
II. The area should be accessible through pores big enough to admit the molecules to be adsorbed. It is a bonus if the pores are also small enough to exclude molecules which it is desired not to adsorb.
III. The adsorbent should be capable of being easily regenerated.
IV. The adsorbent should not age rapidly, that is losing its adsorptive capacity through continual recycling.
V. The adsorbent should be mechanically strong enough to withstand the bulk handling and vibration that is a feature of any industrial unit.

There are three types of adsorbents which are used in this research:

I. Activated carbon
II. Chitosan
III. Rice husk

2.4 ACTIVATED CARBON

2.4.1 Introduction of activated carbon

Activated carbon also called activated charcoal or activated coal is a general term that includes carbon material mostly derived from charcoal. For all three variations of the name ‘activated’ is sometimes substituted by ‘active’. By any name, it is a material with an exceptionally high surface area. Just one gram of activated carbon has a surface area of approximately 500 m^2 (for comparison, a tennis court is about 260 m^2)(Mohan et al., 1999). Activated carbon can also be considered as a material of phenomena surface area made up millions of pores-rather like a ‘molecular sponge’. It consists of highest volume of adsorbing porosity of any material known. This is why it is applicable for adsorption process. The three main physical carbon types are granular, powder and extruded (pellet). Granular activated carbons are versatile adsorbents with wide range of applications. They are most effective adsorbents in treating drinking water and industrial wastewater.

Figure 2.3: Activated Carbon

The adsorption process by using activated carbon as an adsorbent is being widely used by various researchers for wastewater treatment. Despite its extensive use in the water and wastewater treatment industries, activated carbon remains an expensive material (Khan et al, 2004). Activated carbon is the most common adsorbent due to its large surface area per unit mass(300 to 1500m^2g^{-1})(Razali, 2010). In comparing with others absorbents, the surface of activated carbon is non-polar as result of the surface oxide and inorganic impurities. This difference give a very useful advantage to wastewater treatment. Since activated carbon does not adsorb water very well, it does