KITCHEN WASTEWATER TREATMENT BY ADSORPTION PROCESS USING BANANA TRUNK FIBERS (*MUSA SAPIENTUM*) AND CHITOSAN

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ABSTRACT

The presence of pollutants in wastewater pose environmental disposal problems because of their non-biodegradable and persistence in the environment. Kitchen wastewater that were discharge to the environment, it's become one of the contributing factors to water pollution in developing countries. Adsorption of pollutants by banana trunk fiber and chitosan are one of the emerging methods of biological treatments. Therefore, this become environmental friendly for the removal and recovery of pollutants. This research is undertaken to develop an adsorbent in treating wastewater contaminated with a various type of pollutant in kitchen wastewater. This study has focused on the effectiveness of the kitchen wastewater treatment using low-cost natural fiber from banana trunk and chitosan as an adsorbent to treat kitchen wastewater collected from ARKED food court, UTHM. The result of a chemical composition of fiber were analyzed by using TAPPI method before adsorption shows the presence of cellulose (58.5%), hemicellulose (15.4%) and lignin (13.2%) for 1g which confirm the high efficiency in adsorbing pollutants. Meanwhile, the chemical composition of chitosan shows the presence of degree of deacetylation with 90-95%. Based on SEM-EDX analysis, banana trunk fiber has rough surface and chitosan showed the external surface a smooth surface with scars, highly likely due to the removal of inorganic particles. FTIR analysis on the banana trunk fiber and chitosan confirmed the involvement of the carbonyl group, nitro compound, and an amine group in absorbent which play an important role to reduce COD, NH_3-N, SS, turbidity, oil and grease. The optimum ratio of F:C is 2:6 with 75% of COD removal, 78% of NH_3-N, 76% of SS, 68% of turbidity and 71% of oil and grease removal. For optimization study of parameter affecting adsorption such as pH, adsorbent dosage, shaking speed and contact time under determined optimum condition based on the highest percentage follow the order of fiber with chitosan (FC) > fiber (F) > chitosan (C). The determined optimum condition in this study for F, C and FC is pH (6, 6, 7), dosage 2g, 6g, 5g at shaking speed 150 rpm, 125 rpm,

125 rpm and 2 hours contact time. Meanwhile, the adsorption isotherm study shows that the value of correlation, R^2 (0.873 – 0.999) that obtained, the Freundlich model are best fitting model for COD, NH_3-N, SS, turbidity, oil and grease adsorption compared to Langmuir models and the adsorption of COD, NH_3-N, SS, turbidity, oil and grease had followed the pseudo-second order kinetics rather than pseudo-first order kinetics. The regeneration study on FC adsorbent shows that after the regenerated, the removal percentage had decreased in range of 33% - 45% in COD, NH_3-N, SS, turbidity, oil and grease removal. Thus, it indirectly indicated that the FC is a reusable adsorbent. This study show that the removal follow the order of FC > F > C which is banana trunk fiber with chitosan adsorbent can be considered for efficient removal of organic and nutrient pollutants in kitchen wastewater.

ABSTRAK

Kehadiran bahan pencemar di dalam air sisa menimbulkan masalah pelupusan dalam alam sekitar disebabkan oleh sifatnya yang tidak terbiodegradasi dan kekal di dalam alam sekitar. Air sisa dapur yang dilepaskan ke alam sekitar adalah salah satu faktor yang menyumbang kepada pencemaran air di negara-negara membangun. Penjerapan bahan pencemar menggunakan serat batang pisang (*Musa Sapientum*) dan kitosan adalah salah satu rawatan biologikal sebagai kaedah baru bagi penyingkiran bahan pencemar daripada air sisa dapur yang lebih ekonomi dan mesra alam sekitar. Kajian ini dilaksanakan untuk membangunkan bahan penjerap yang mesra alam sekitar dalam merawat air sisa tercemar dengan pelbagai jenis bahan pencemar seperti air sisa dapur. Dalam kajian ini memberi tumpuan kepada keberkesanan rawatan air sisa dapur menggunakan serat semula jadi kos rendah dari batang pisang (*Musa Sapientum*) dan kitosan sebagai penjerap digunakan untuk merawat air sisa dapur di medan selera Arked, UTHM. Hasil analisis komposisi kimia serat batang pisang dengan menggunakan kaedah TAPPI sebelum penjerapan menunjukkan selulosa (58.5%), hemiselulosa (15.4%) dan lignin (13.2%) bagi 1g yang mengesahkan ia mempunyai potensi yang tinggi untuk menjerap bahan pencemar. Sementara itu, komposisi kimia kitosan menunjukkan kehadiran tahap deacetylation dengan 90 – 95%. Berdasarkan analisis SEM-EDX, serat batang pisang mempunyai permukaan kasar dan kitosan menunjukkan permukaan luar yang licin dengan parut, disebabkan oleh penyingkiran zarah bukan organik. Ciri-ciri serat batang pisang melalui analisis FTIR mengesahkan penglibatan kumpulan karbonil, sebatian nitro dan kumpulan amina dalam bahan penjerap yang memainkan peranan penting untuk mengurangkan Permintaan Oksigen Kimia, ammonia nitrogen, pepejal terampai, kekeruhan, minyak dan gris. Nisbah optimum F:C adalah 2:6 dengan 75% daripada penyingkiran COD, 78% daripada NH_3-N, 76% daripada SS, 68% daripada kekeruhan dan 71% daripada minyak dan gris. Untuk kajian pengoptimuman parameter yang mempengaruhi penjerapan seperti pH, penjerap dos, kelajuan goncangan dan masa menunjukkan keadaan optimum ditentukan berdasarkan peratusan tertinggi bahawa serat dengan kitosan (FC) > serat (F) > kitosan (C). Keadaan optimum dalam kajian ini adalah pH (6, 6, 7), dos 2g, 6g, 5g pada kelajuan goncangan 150 rpm, 125 rpm, 125 rpm dan pada masa 2 jam bagi F, C dan FC. Sementara itu, kajian menunjukkan penjerapan isoterma bahawa nilai pekali korelasi, R^2 (0.873-0.999) yang diperolehi, model Freundlich adalah model terbaik yang sesuai untuk penjerapan COD, NH_3-N, pepejal terampai, kekeruhan, minyak dan gris berbanding model Langmuir dan penjerapan COD, NH_3-N, pepejal terampai, kekeruhan, minyak dan gris telah mengikuti kinetik tertib pseudo-kedua bukannya kinetik tertib pseudo-pertama. Kajian semula ke atas FC menunjukkan penjerap serat batang pisang bersama kitosan bahawa selepas generasi, peratusan penyingkiran telah menurun kira-kira 33% - 45% dalam COD, NH_3-N, pepejal terampai, kekeruhan, minyak dan penyingkiran gris. Oleh itu, ia secara tidak langsung menunjukkan bahawa serat batang pisang bersama kitosan adalah penjerap boleh diguna semula. Kajian ini menunjukkan bahawa penyingkiran FC > F > C yang merupakan serat batang pisang bersama kitosan boleh dipertimbangkan untuk penyingkiran cekap bahan pencemar organik dan nutrien di dalam air sisa dapur.

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LIST OF SYMBOLS AND ABBREVIATIONS

SEM-EDX	-	Scanning Electron Microscopy-Energy Dispersive X-ray
FTIR	-	Fourier Transform Infrared Spectroscopy
UTHM	-	Universiti Tun Hussein Onn Malaysia
COD	-	Chemical Oxygen Demand
BOD	-	Biochemical Oxygen Demand
NH_3-N	-	Amoniacal Nitrogen
SS	-	Suspended Solid
O&G	-	Oil and Grease
FOG	-	fats, oil and grease
AC	-	activated carbon
mg/L	-	milligram per litre
mg/g	-	milligram per gram
°C	-	Degree Celcius
%	-	Percent
g	-	gram
ml	-	milliliter
sd	-	Standard deviation
pH	-	Potential of hydrogen
R^2	-	correlation coefficient
C_o	-	Initial concentration
C_f	-	Final concentration
q	-	Adsorption capacity
V	-	Volume of solution
m	-	Mass of adsorbent
F	-	fiber
C	-	chitosan
FC	-	fiber with chitosan

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Malaysia has been progressing from an agricultural exporter to a major exporter of food and beverages, petroleum, textiles, clothing, palm oil, wood products and many other industrial commodities (Zain *et al.*, 2004). Wastewater generated from food operations has distinct characteristics that make it different from common municipal wastewater managed by public or private wastewater treatment plants, as it is biodegradable and nontoxic, but it is well known for its high concentration of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and Suspended Solid (SS). The constituent of food containing wastewater are often complex to predict due to the differences in BOD and pH in effluents from vegetable, fruit, milk and meat products and due to the seasonal nature of food processing and post-harvesting (Onet, 2010 and Silambarasan, 2012).

Kitchen wastewater that is discharged to the environment is one of the contributing factors to water pollution in developing countries. Such condition is a result of many kitchens which are continuously emerging to cater the need of the public due to the expanding population. The wastewater that is directly discharged to the drainage system without any sort of pre-treatment is mainly composed of contaminants such as fats, oil and grease (FOG) as well as a surfactant (dishwashing detergent). These contaminants could cause many detrimental environmental impacts, including fouling and clogging in the drainage and sewer system which generate unpleasant odour and introduce extra burden to the municipal wastewater collection and treatment works which eventually leads to decreased efficiency (Chen *et al.*, 2000).

Treatment of effluents from petroleum, metals, food processing, textile, cooling and heating industries as well as municipal wastewaters is considered a global environmental issue. Effluent derived from these activities can provoke serious environmental impact on the neighboring receptor water bodies because of the presence of oil in water not only induces detrimental effects to aquatic life, but also causes serious problems in wastewater treatment plant due to its high stability and can only be separated with the help of chemical clarification (Ibrahim *et al*., 2010).

The treatment of this waste has been addressed by several techniques such as coagulation, biosorption, adsorption, filtration, screening and much more. Among the various techniques, adsorption process is one of the effective methods for removing organic and inorganic pollutants in waterway system (Kumar *et al*., 2000). Traditionally, activated carbon (AC) was used as an adsorbent for adsorption process. Due to low efficiency and the high cost production of activated carbon for oily wastewater treatment (Moazed & Viraraghavan, 2005) the possibility of using inexpensive materials as alternatives was explored by many researchers in the past years. Any cheap material, with a high cellulose content and low inorganics, can be used as a raw material (Okieimen *et al*., 2007). Agricultural by products are available in large quantities and are one of the most abundant renewable resources in the world. These waste materials have little or no economic value and often present a disposal problem. Therefore, there is a need to valorize these low cost by products. Thus, conversion of waste materials would add considerable economic value, help reduce the cost of waste disposal and most importantly provide a potentially inexpensive alternative to the existing commercial. These waste materials have proved to be promising raw materials a high adsorption capacity, considerable mechanical strength, and low ash content (Savova *et al*., 2001).

Adsorption methods employing solid sorbents are widely used to remove certain classes of chemical pollutants from wastewater. However, among all the sorbent materials proposed, natural fiber is the most popular material for the removal of pollutants from wastewater. The factors which favor the selection of agricultural adsorbents are its low cost, widespread presence and organic composition. Because of their low cost, after being expended, these materials can be disposed of without expensive regeneration. A wide variety of adsorbents have been been used for the removal of pollutants from agricultural by products such as oil palm's empty fruit bunch (Vinod, 2012), date-palm (Riahi, 2008), barley straw (Ibrahim *et al*., 2010) and walnut shell (Srinivasan & Viraraghavan, 2008), corn straw and wheat straw (Lanzetta *et al*., 1998), rice straw (Ahmedna *et al*., 2000), sawdust (Prakash *et al*., 2005; Malik, 2003), corn cob and bagasse (Juang *et al*., 2002; Valix *et al.*, 2004), cotton stalk (Putun *et al*., 2005), nut shells (Yang *et al*., 2003), coconut husk and oil palm shell (Tan *et al*., 2008), and oil palm fiber (Tan *et al.*, 2007).

Therefore, this study focused on the effectiveness of the kitchen wastewater treatment using a natural fiber from banana trunk (*Musa Sapientum*) as an adsorbent to remove Chemical Oxygen Demand (COD), Suspended Solids (SS), turbidity, NH_3-N and oil and grease. The treatment system is expected to effectively remove pollutants that are present in wastewater and thus suitable for reuse for agricultural activities. In this study, the use a natural fiber banana trunk is selected based on several such as it is the usage of the section is not being explored yet, biodegradable in nature, inexpensive, naturally abundant, high oil sorption capacity, and easy disposal with the least environmental hazard.

1.2 Problem Statement

The main problems kitchen wastewater containing a high concentration of FOG will clog the inlet pipe, even before the wastewater flows into the drain field. Food courts and restaurats produce a lot of wastewater rich in oil and grease content which is present in drain lines. It often congeals within drain and sewer lines and cause blockages. Grease traps may also fail to rettain dissolved and emulsified the oil and grease efficiently. If oil and grease is not properly treated by wastewater treatment process, it may enter rivers and oceans causing potentially detrimental environment impacts (Peng, 2010).

Moreover, the dishwashing detergent that discharges may also be detrimental to the environment because detergent it can be relatively toxic to aquatic life. Most of the dishwashing detergent composes of a high level of phosphate concentration which is a water-softening mineral additive that is able to enhance the performance of detergent as a cleaning agent. However, when they enter waterways, phosphate can stimulate excessive growth of algae which leads to a reduction of the oxygen in water and as a result depletes other living organisms in the water. This environment impact is well known as Eutrophication (Turunawarasu *et al*., 2013).

IPPC, (2007) reported that, the treatment of this waste has been addressed by several techniques such as biological treatment, coagulation and flocculation, adsorption, air stripping, oxidation processes, membrane processes and ion exchange. Biological treatment has shown a very effective in removing organic and inorganic pollutants in kitchen wastewater (Kumar *et al*., 2000). Thus, other treatment method that considered is physico-chemical processes make a rational process due to cost effectiveness (Li *et al*., 2010).

In particular agricultural materials containing cellulose show a potential sorption capacity for various pollutants. If these wastes could be used as low-cost adsorbents, it will provide a two-fold advantage to environmental pollution. Firstly, the volume of waste materials could be partly reduced and secondly the low-cost adsorbent, if developed, can reduce the treatment of wastewaters at a reasonable cost (Lofrano, 2012). Figure 1.1 shows one of the drainage systems in UTHM from our naked eye observation, they have installed the oil and grease trap as regulated from the university but it can't cope with high loadings. This situation gives some impact on the environment, especially the aquatic life, it’s discharged to the river nearby and caused unpleasant odor from the kitchen wastewater disturb the pedestrian cross over the drainage.

Figure 1.1: Drainage system of Arked food court, UTHM

1.3 Objective of Study

The main objective of this study is to develop an environmental friendly adsorbent in treating wastewater contaminated with a various type of pollutant. Banana trunk fiber and chitosan will be used as a component of adsorbent in this study. The four primary objectives by which they could be achieved were:

a) to identify characteristics and chemical composition of banana trunk fiber (*Musa Sapientum*) and characterize the kitchen wastewater that were collected from the Arked food court, UTHM.

b) to investigate the effect of pH, contact time, adsorbent dosage and shaking speed using banana trunk fiber (F), chitosan (C) and banana trunk fiber with chitosan (FC) in the removal of COD, NH_3-N suspended solid, turbidity, oil and grease in the kitchen wastewater.

c) to analyze the kinetics and isotherms adsorption of F, C and FC for adsorption of COD, NH_3-N suspended solid, turbidity, oil and grease in the kitchen wastewater.

d) to determine the effectiveness of regeneration of F, C and FC for wastewater treatment.

1.4 Scope of Study

This study consists of field activities, laboratory work and application of mathematical models. The field activities were carried out at Arked's food court, UTHM. Laboratory work consists of five stages which were preliminary study, preparation and characterization of natural fibers from the banana (*Musa Sapientum*) adsorbent, optimization study, batch adsorption and regeneration studies. The result obtained from laboratory work was used to formulate a mathematical modeling that describes the adsorption behaviour onto the adsorbent.

This study is to determine the effectiveness of banana trunk fiber (*Musa Sapientum*) before and after in treatment of kitchen wastewater treatment and also focused on the optimum condition of environmental parameters such as pH, contact time, adsorbent dosage and shaking speed. The studies conducted under room temperature. The water quality parameters that would be tested in this study were the COD, NH_3-N, suspended solid, turbidity and oil and grease.

1.5 Significance of Study

This study significantly contributes to the environment cleanliness, to minimize water pollution and to solve the problem lacking in the fields. This data is needed to be accessible to local parties, kitchen wastewater management and future researchers so that they can develop this strategy to overcome the kitchen wastewater problem. In addition, the natural fibers used are among domestic plants which can be easily found in Malaysia. The application of these fibers can help to provide a cost reduction of the product. The natural adsorbent is readily available, hence there will no side effect to our earth. In spite of the scarcity of consistent cost information, the widespread uses of low-cost adsorbents in industries for wastewater treatment applications today are strongly recommended due to their local availability, technical flexibility, engineering applicability, and cost effectiveness. In addition, the natural fibers are recyclable and biodegradable.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Wastewater from the kitchen, restaurants and other commercial food service facilities differs significantly from residential wastewater. In addition to higher surge volumes during busy periods, and generally higher temperatures, kitchen wastewater is typically higher in strength than residential wastewater. This is due to higher levels of oil, grease and foods which cause a higher biochemical oxygen demand (BOD). Oil and grease frequently cause problems for both on-site sewage disposal systems and public sewer systems. According to Barnstable County Department of Health and Environment (2011), the problem occurs when oil and grease liquefy at higher water temperatures used to wash dishes and later solidify in sewer lines or sensitive soil interfaces in the leaching facilities of on-site systems. The problem is exacerbated when highly efficient detergents are used to emulsify the oil and grease, keeping them in suspension until they enter the leaching field. Although conventional grease traps are supposed to prevent grease from entering the septic tank or sewer line, high grease loads emulsified grease, and surge wastewater loadings often cause grease to bypass the grease trap and enter the leach field.

Currently, there are many promising technologies available to separate fat, oil and grease (FOG) from wastewater before being discharged to the drainage and sewer line. For instance, grease interceptors are used to trap grease from kitchen wastewater and generally installed under kitchen sinks in restaurants. However, there are several drawbacks that make this technology is not the best option to be deployed in the restaurants. It is costly; required through maintenance and a large space to be installed and often neglected as it cause an odor nuisance (Wakelin *et al*., 1998). Other than that, a biological treatment facility utilized to reduce BOD as well as works to decompose grease also another alternative to treat oily wastewater. Nevertheless, it is ruled out due to high cost, the requirement of large space and depends on a skilled technician to maintain such facility (Turunawarasu *et al*., 2013). To date, numerous meaningful research works have been conducted to separate oil from water through oil adsorption by using adsorbents. The interesting properties and characteristics of oil adsorbents have led to the development of applying environmentally benign approaches for the treatment of oily wastewater. The advantages of utilizing oil adsorbents include high oil absorption capacity, inexpensive, abundant, and can be operated easily. It is preferable to use natural adsorbents in comparison to organic synthetic adsorbent due to its biodegradable nature. The limitations of the current restaurant wastewater treatment facilities have led to the recent interest in developing an alternative treatment which is compact and cost efficient due to it is a cheap process and required low maintenance.

2.2 Water Issues in Malaysia

Malaysia is rich in water resources; its development has been the basis for the socio-economic development of the country over the past decades. Lately, the water supply situation in the country has changed from one of relative abundance to one of scarcity. Population growth, urbanization, and industrialization and the expansion of irrigated agriculture are imposing rapidly increasing demands and pressure on water resources, besides contributing to the rising water pollution. The way forward to prosperous and sustainable future is to keep development to a level that is within the carrying capacity of the river basin while protecting and restoring the environment.

Even though Malaysia has been blessed with an abundant supply of water resources, the authorities, industries and the society should not take for granted that there will always be sufficient supply to meet the demand. A study conducted by Mohd Kassim *et al*., (2009) found the problem of water pollution is now becoming more serious with reports indicating a downward trend of about 1% per annum in river water quality. Sewage or wastewater pollution accounts for about 79% of the pollution source, while industrial and agricultural pollution accounts for 8% and 13% respectively.

Malaysia has more than 150 river systems that contribute 98% of the total national water use, whilst the remaining is contributed by groundwater. To secure yield from surface water sources, 55 single purpose and 17 multipurpose dams were constructed, with a total storage of 30 billion m^3. Water supply systems that are too dependent on surface water sources are at the mercy of the weather (Randall, 2008).

Paradigm shift for sustainable waste management is necessary to ensure optimum utilization of resources. Corcoran *et al*., (2010), reported that this is none reuse or recycling of household systems. This alternative is really beneficial for future recycling scenarios in Malaysia.

2.3 Greywater

Greywater is all wastewater that is discharged from a house, excluding black water (toilet water). This includes water from showers, bathtubs, sinks, kitchen, dishwashers, laundry tubs, and washing machines. It commonly contains soap, shampoo, toothpaste, food scraps, cooking oils, detergents and hair. Greywater makes up the largest proportion of the total wastewater flow from households in terms of volume. Typically, 50-80% of the household wastewater is greywater. If a composting toilet is also used, then 100% of the household wastewater is greywater (Bullermann *et al*., 2001).

Greywater contribution to domestic wastewater is 60 - 75% of the water volume and includes the release of 9 - 14%, 20 - 32%, 18 - 22% and 29 - 62 % of nitrogen, phosphorus, potassium and organic matter respectively. Several issues emerge with greywater, namely, reusing with or without simple treatment (Al-Jayyousi, 2003). A study conducted by Khalaphallah (2012), the first issue is recycled for indoor use such as flushing toilets, washing clothes and/or bathing. The second issue is for outdoor use such as irrigating domestic gardens, lawns on college campuses, athletic fields, cemeteries, parks and golf courses, washing vehicles and windows, extinguishing fires, feeding boilers, developing and preserving wetlands and recharging ground water. The third issue is (standards) mainly related to health and social aspects in order to improve the control of the recycling process. The fourth issue is obtaining affordable treatment technologies to cope with the quantity and quality variation of greywater sources.

However, specific pathogens and significant numbers of indicator bacteria have been reported (Rose *et al*., 1991; Birks *et al*., 2004; Jefferson *et al*., 2004), indicating that the disinfection of greywater prior to reuse is essential to reduce the risk to public health. The following subsection, examines various greywater treatment methods with the aim of coming up with an efficient, simple and affordable treatment method with safe effluent for use. A treatment method is considered efficient if it produces the required effluent quality, is simple in operation with minimum maintenance, and affordable due to its low energy usage.

2.3.1 Biological Greywater Treatment

Several greywater treatment systems used aerobic biological process. This system can often be scaled up or down, depending on the quantity of greywater influent. Table 2.1, list several of the major manufacturers and treatment details. Nubian, 2010 pointed out that a company based in Australia has developed a modular greywater treatment system that can treat from 1,000 to 50,000 liters of gray water per day (the average per capita water use is around 200 liters per day in Australia), aeration to increase dissolved oxygen and activate bacteria present in the greywater to consume the oxygen and digest the organic contaminants. Some aerobic treatment systems include corrugated plastic sheets or other media for bacteria to attach to and grow on.

Biological greywater treatment also includes membrane bioreactors (MBR), which have become common in wastewater treatment. The breakthrough for the MBR came in the early 1990s, when the separation membrane was directly immersed into the bioreactor. MBRs required a great deal of pressure (and therefore energy) to maintain filtration. The submerged membrane relies on bubble aeration to mix the effluent and limit clogging of the membrane pores. The energy demand of the submerged system can be up to 2 orders of magnitude lower than previous bioreactors (Judd, 2006). Aeration is considered as one of the major parameters on process performances both hydraulic and biological.

Lowest operating cost obtained with the submerged membrane along with the steady decrease in the membrane cost encouraged an exponential increase in MBR in wastewater plants. There is now a range of MBR systems commercially available, most of which use submerged membranes, although some external modules are available. Membranes typically consist of hollow fibers and flat sheets (Le-Clech *et* *al*., 2006). For instance, the Copa MBR Technology is an aerobic biological treatment process that incorporates Kubota flat sheet membranes. The membrane panels have a pore size of 0.1 to 0.4 microns, thus filtering out particulates, spores like giardia and cryptosporidium, bacteria, and even viruses.

Table 2.1: Matrix of greywater system characteristics adapted (Nova Tec Consultants Inc., 2004)

Manufacturer	Filtration	Secondary Treatment	Disinfection
Greywater Saver	X	-	-
Aquacarius	X	-	-
Nature Loo	X	-	-
Biolytix	X	X(biological)	-
Equarius	-	X(biological)	-
CopaMBR	X	X(biological)	X(ultraviolet)
Wasser	X	X(biological)	X(ultraviolet)
WaterSaver Technologies (AQUS)	X	-	X(chlorine)
ReWater	X	-	-
Pontos AquaCycle	X	X(biological)	X(ultraviolet)

(X = Greywater treatment done)

2.3.2 Physical and Chemical Greywater Treatment Systems

Physical and chemical greywater treatment systems primarily utilize disinfection and filtration to remove contaminants while biological treatment uses aeration and membrane bioreactors (Lucy, 2010). Table 2.2 provides a list of common greywater treatment technologies and some of their respective advantages and disadvantages.

Physical and chemical treatment systems usually involve holding tanks, filters, and pumps. For example, the major components of the ReWater greywater treatment system are a surge tank, sand media filtration tank, and piping to an outdoor irrigation system.

Table 2.2: Common greywater treatment technologies (Nova Tec Consultants Inc., 2004)

Treatment technique	Description	Pros	Cons
Disinfection	Chlorine, ozone, or ultraviolet light can all be used to disinfect greywater.	Highly effective in killing bacteria if property designed and operated, low operator skill requirement.	Chlorine and ozone can create toxic by-products, ozone and ultraviolet can be adversely affected by variations in the organic content of greywater.
Activated carbon filter	Activated carbon has been treated with oxygen to open up millions of tiny pores between the carbon atoms. This results in highly porous surfaces with areas of 300-2000 square meters per gram. These filters, thus are widely used to adsorb odorous or colored substances from gases or liquids.	Simple operation activated carbon is particularly good at trapping organic chemicals, as well as inorganic compounds like chlorine.	High capital cost, many other chemicals is not attracted to carbon at all e.g., sodium, nitrates, etc. this means that an activated carbon filter will only remove certain impurities. It also means that, once all of the bonding sites are filled, an activated carbon filter stops working.
Sand filter	Beds of sand or in some cases, coarse bark or mulch which trap and adsorb contaminants as gray water flows through.	Simple operation, low maintenance, low operating costs.	High capital cost, reduces pathogens but does not eliminate them, subject to clogging and flooding if overloaded.
Aerobic biological treatment	Air is bubbled to transfer oxygen from the air into the greywater. Bacteria present consumes the dissolved oxygen and digest the organic contaminants, reducing the concentration of contaminants.	High degree of operations flexibility to accommodate greywater of varying qualities and quantities, allows treated water to be stored indefinitely.	High capital cost, high operating cost, complex operational requirements, does not remove all pathogens.
Membrane bioreactor	Uses aerobic biological treatment and filtration together to encourage consumption of organic contaminants and filtration of all pathogens	Highly effective if designed and operated properly, high degree of operations flexibility to accommodate greywater of varying qualities and quantities, allows treated water to be stored indefinitely.	High capital cost, high operating cost, complex operational requirements.

2.3.3 Odor and Color Removal

Sewage and wastewater odors are most often associated with hydrogen sulfide and ammonia. These odors can be effectively treated in the vapour phase with thermal, biological and chemical treatment methods. The selection of which method works best depends on the concentration of the odor causing compounds, the air flow rate, available land area for the system, capital budget and discharge limitations for wastewater from the system. Chemical scrubbing using ozone as the oxidant is an effective choice for high-intensity odors and high air volumes where the amount of space for the treatment system is limited (Riva *et al*., 2005).

There is a possibility of odour generation in greywater treatment system due to the following; first, a slime layer will develop on the submerged walls of filters, collection sump and possibly in sedimentation tank and as velocity of the greywater through the system sometimes is too low to scour the sides. Second treatment, if aeration is not sufficient dissolved oxygen will reduce substantially and only anaerobic bacteria will attach to the slime layer and the anaerobic condition will lead to release of odorous compounds from the system and build-up of hydrogen sulphide may result in a situation hazardous to human health (Al-Jayyousi, 2003).

2.3.4 Oil and Grease Removal

Greywater may contain significant amounts of fat such as oil and grease originating mainly from kitchen sinks and dishwashers (e.g. cooking grease, vegetable oil, food grease, etc.) important O&G concentrations ranging between 37 and 78 mg/l and 8-35 mg/l, respectively (Christova *et al*., 1996).

The oil and grease content of kitchen greywater strongly depends on the cooking and disposal habits of the household. No data was found in oil and grease concentrations specific to kitchen greywater, but values as high as 230 mg/l was observed in Jordan for mixed greywater (Al-Jayyousi, 2003). Oil and grease concentrations ranging between 1,000 and 2,000 mg/l in restaurant wastewater. As soon as greywater cools down, grease and fat congeal and can cause matting on the surfaces of settling tanks, in the interior of pipes and other surfaces. This may cause a shutdown of treatment and disposal units such as infiltration trenches or irrigation fields. Therefore, important that oil and grease concentrations are maintained at acceptable levels (<30mg/l), to avoid problems with downstream treatment and disposal system (Crites & Tchobanoglous, 1998).

2.4 Kitchen Wastewater

A study conducted by Turunawarasu *et al.*, (2013) reported that kitchen wastewater that is discharged to the environment is one of the contributing factors to water pollution in developing countries. The wastewater that direct discharges to the drainage system without any sort of pre-treatment is mainly composed of contaminants such as fats, oil and grease (FOG) as well as a surfactant (dishwashing detergent). These contaminants may can affect to water quality such as nutrients, sediments, organ chlorines, heavy metals, oil and hydrocarbons, chemical constituents and pathogens (EPA, 2012).

2.4.1 Characteristics of Kitchen Wastewater

Wastewater generated from food operations has distinctive characteristics that differentiate from common municipal wastewater managed by public or private wastewater treatment plants throughout the world. Food wastewater is biodegradable and nontoxic but has high concentrations of biochemical oxygen demand (BOD) and suspended solids (SS). It is complex to predict the constituents of food and wastewater due to the differences in BOD and pH in effluents from vegetables, fruit, milk and meat products and due to the seasonal nature of food processing and post harvesting (Onet, 2010).

A study conducted by Lesikar *et al*., (2006) revealed that 28 restaurants wastewater located in Texas contains non-aqueous liquids includes fats (animal sources), oils (vegetable source) and grease (petroleum source) which are collectively known as fats, oils and grease (FOG). FOG occurs because of the installation grease interceptions on the restaurants. Oil and grease frequently cause a problem when oil and grease liquefy at higher water temperatures used to wash dishes and later solidity in a piping system. The problem is worsened when highly efficient detergents are used to emulsify the oil and grease which keeps them in suspension. Although conventional grease traps are supposed to prevent grease from entering the sewer line, high grease loads, emulsified grease, and surge wastewater loadings often cause grease to bypass the grease trap and enter the leach field.

Table 2.3 shows the characteristics of restaurant wastewater obtained from the study done by Chen *et al*., (2000) and Ji *et al*., (2013). According to the table, restaurant wastewater contains high-density organic, suspended solid substance, oil and grease.

Table 2.3: Characteristics of food stall wastewater
(Chen *et al*., 2000 and Ji *et al.*, 2013)

Parameters	Data of previous studied	References
pH	6.82-8.76	Chen *et al*., (2000)
Biochemical Oxygen Demand, BOD (mg/L)	545-1630	Chen *et al.*, (2000)
Chemical Oxygen Demand, COD (mg/L)	900-3250	Chen *et al.*, (2000)
Suspended Solid, SS (mg/L)	124-1320	Chen *et al*., (2000)
Oil and Grease	415–1970	Chen *et al*., (2000)
Ammonia Nitrogen, NH_3-N (mg/L)	1197	Ji *et al.*, (2013)
Cadmium,Cd (mg/L)	0.04-0.08	Ji *et al*., (2013)
Copper, Cu (mg/L)	0.5-0.8	Ji *et al.*, (2013)
Ferum, Fe (mg/L)	0.2-0.4	Ji *et al.*, (2013)
Zinc, Zn (mg/L)	0.02-0.04	Ji *et al*., (2013)

2.4.2 Kitchen Wastewater Treatment and Its Importance For Sustainable Water Management

Kitchen wastewater treatment and reuse is part of sustainable water management (SWM). The problem of sewage disposal and industrial waste management has become increasingly critical due to the increase of worldwide population. Catastrophic impacts on human health and on the environment could result if pollution of receiving waters is allowed to continue. Therefore, to preserve water quality for future generations, an effective means of solving this problem must be developed. Wastewater treatment technology has been improving, and currently, it is possible to treat wastewater to a highly usable level efficiently and cheaply (Nazim *et al*., 2013).

Greywater is also one of the major point pollution sources, which is discharged from residential and commercial areas into the rivers without any treatment (Idris *et al*., 2004). It is the wastewater from kitchen sinks and hands basins in household or cafeteria premises.

There are many ways several to treat kitchen wastewater so that it can be re-used. The treatment and reuse of wastewater are rapidly becoming a subject of great interest to researchers (Eriksson *et al*., 2002). The methods must be safe from a health point of view and not harmful to the environment. Decentralized wastewater management offers the most opportunities for maximizing recycling opportunities. Although treatment of wastewater and its legislation is well instituted in urban and rural areas in developed countries; proper sanitation, with efficient treatment, has not been practiced in many other places, especially in suburban areas in developed countries (Tan *et al*., 2008). Kitchen greywater may be re-used in a subsoil, irrigation area, providing it is screened and filtered to remove hair, lint and other suspended particles. Treatment systems for greywater exist in many forms, varying in their complexity, treatment method, and location within or outside the home, and should be designed in accordance with kitchen wastewater source, quality, site specifications, and reuse patterns. EPA (2002), reported that greywater treatment systems range in sophistication from simple branched-drain garden irrigation networks to full tertiary treatment systems that can filter water to nearly potable levels of quality.

Filtration is the most common physical treatment employed for the treatment of restaurant wastewater. Coarse filtration (sand filters) followed by sedimentation and/or disinfection is reported for the treatment. Membrane filters achieve excellent removal rates for dissolved and suspended solids, but the removal of organic matter is limited (Ramon *et al*., 2004). Coagulation with aluminum followed by sand filtration and electro-coagulation are chemical methods employed for the treatment of gray water. Biological treatment is required to remove biodegradable materials from wastewater. In the case of domestic wastewater the biological treatment aims to reduce the organic content and nutrients like nitrogen and phosphorous. Biological methods include attached growth or suspended growth process, aerobic or anaerobic process, etc. (Anjaly, 2011).

2.5 Adsorption

The Brownfields and Land Revitalization Technology Support Center (2009) reported that adsorption is the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface. This process creates a film of the adsorbate on the surface of the adsorbent. This process differs from absorption, in which a fluid (the absorbate) is dissolved by or permeates a liquid or solid (the absorbent), respectively. Adsorption is a surface-based process while absorption involves the whole volume of the material. The term adsorption encompasses both processes, while desorption is the reverse of it. Adsorption is a surface phenomenon.

Similar to surface tension, adsorption is a 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 by other atoms in the material. However, atoms on the surface of the adsorbent are not wholly surrounded by other adsorbent atoms and therefore can attract adsorbates. According to Ferrari *et al.*, (2010) revealed that the exact nature of the bonding depends on the details of the species involved, but the adsorption process is generally classified as physisorption (characteristic of weak van der Waals forces) or chemisorption (characteristic of covalent bonding). It may also occur due to electrostatic attraction.

A study conducted by Czelej *et al.*, (2016) reported that adsorption is present in many natural, physical, biological, and chemical systems, and is widely used in industrial applications such as heterogeneous catalysts activated charcoal, capturing and using waste heat to provide cold water for air conditioning and other process requirements (adsorption chillers), synthetic resins, increase storage capacity of carbide-derived carbons, and water purification. Adsorption, ion exchange, and chromatography are adsorption processes in which certain adsorbates are selectively transferred from the fluid phase to the surface of insoluble, rigid particles suspended in a vessel or packed in a column. Pharmaceutical industry applications, which use adsorption as a means to prolong neurological exposure to specific drugs or parts there of, are lesser known.

2.5.1 Mechanism of Adsorption

Adsorbents which are produced from agro-wastes may act as a significant material for contaminant adsorption. The term adsorption is said to have been first used by Kayser in 1881 in order to explain the condensation of gases on surfaces, in contrast to gas absorption in which gas molecules penetrate the bulk phase of the absorbing solid. The term ‘adsorption’ was proposed by McBain (1909) as a complete description of mass transport into a solid, encompassing surface adsorption, absorption by penetration into the solid and condensation within pores shown in Figure 2.1.

A study by Das *et al*., (2008) describe the process of adsorption involves a solid phase and liquid phase containing dissolved species to be sorbed (sorbate metal ions). Solid phase refers to sorbent or adsorbent and biological material while liquid phase is solvent, normally water. The later is attracted and separate by different mechanisms due to higher adsorbent-adsorbate affinity. Then, the process continues until equilibrium is reached between the amount of solid-bound sorbate species and its portion remaining in the solution. The distribution between the solid and liquid phases is determined by the degree of sorbent affinity for the sorbate. Several factors which influence the mechanism of pollutants adsorption are the status of biomass (living or non-living), types of materials, properties of metal solution chemistry, ambient or environmental conditions such as pH (Das *et al*., 2008).

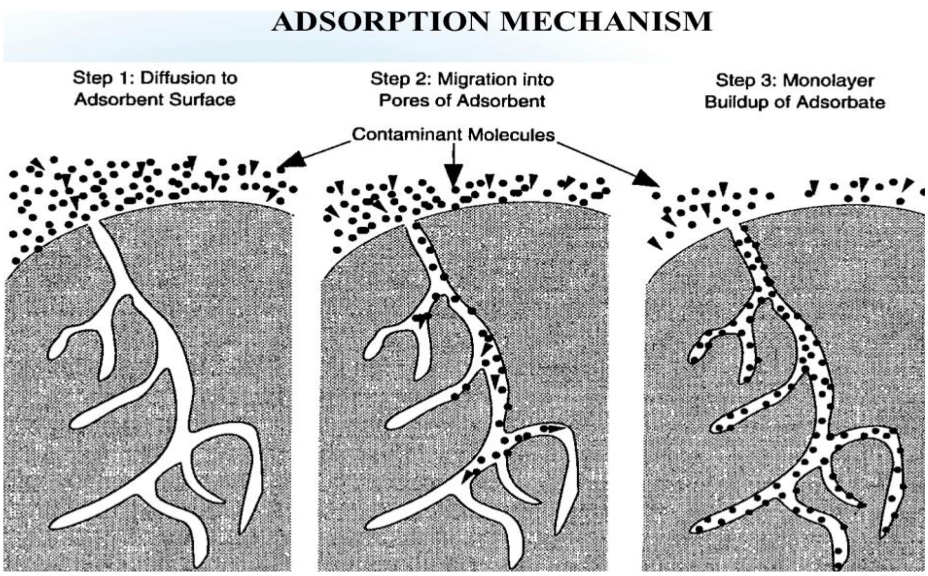

Figure 2.1 : Adsorption mechanism

(Vivek, 2012)

In order to understand how metals bind to the biomass, it is essential to identify the functional groups responsible for metal binding (Demirbas, 2008). Information on the active sites involved in the binding of pollutants can be obtained through the use of several analytical tools, such as infrared absorption spectroscopy or Fourier transformed infrared spectroscopy (IR or FTIR), scanning electron microscopy-energy dispersive X-ray (SEM-EDX), transmission electron microscopy (TEM), X-ray diffraction (XRD) analysis, etc. (Park *et al*., 2010).

Adsorption is divided into the two sub-categories of physical adsorption (physisorption) or van der Waals adsorption and chemical adsorption (chemisorption) and the adsorption process can be determined whether chemical bonds are formed during the process. Physisorption is applicable to all adsorbate-adsorbent systems provided the conditions of pressure and temperature are suitable whereas chemisorption may only occur if the system is capable of making a chemical bond (Ahalya *et al.,* 2003; Demirbas, 2008; Park *et al*., 2010). Table 2.4 shows adsorption mechanisms that may involve in the adsorption process.

Table 2.4: Adsorption mechanisms
(Ahalya *et al.,* 2003; Demirbas, 2008; Park *et al.,* 2010)

Mechanism	Process
Physical adsorption	Van der Waal’s forces (electrostatic interaction) were observed to take place between metal ions in the solution and cell wall of the microbe.
Complexion	Metal ions removals from solution take place through complex formation on the cell surface after the interaction between metal ions and active groups.
Ion exchange	The replacement of protons, alkali, alkali earth or other cations present on the surface of biomass by the heavy metal ions in the solutions.
Precipitation	This mechanism may be dependent or independent on cellular metabolism. The metal removal from solution is often associated with an active defence system of microorganism. They react in the presence of a toxic metal, producing compounds which favour the precipitation process.

2.5.2 Adsorption Kinetics

The study of adsorption kinetics describes the solute uptake rate and evidently this rate controls the residence time of adsorbate uptake at solid–solution interface. The kinetics of parameter adsorption onto the composite media was analysed using the pseudo-first-order (Lagergren, 1898) and pseudo-second-order equations (Ho *et al.*, 2000).

Batch rate analysis can be used to recognize the practical application of adsorption and design of the batch reactor. Some kinetic models with varying degree of complexity are available to illustrate the kinetics of parameter adsorption in batch systems. The sorption kinetics are significant in the treatment of wastewater, as it provides valuable insights into the reaction pathways and mechanisms of sorption reactions. Since adsorption is a metabolism- independent process, it would be expected to be a very fast reaction (Gupta *et al*., 2001; Gupta *et al*., 2006; Gupta, Rastogi & Nayak, 2010). Pseudo-first order and pseudo-second order was used in this study to understand the controlling mechanism of parameter adsorption.

2.5.2.1 Pseudo-first-order

Lagergren (1898) presented a first-order rate equation to describe the kinetic process of liquid-solid phase adsorption of oxalic acid and malonic acid onto charcoal, which is believed to be the earliest model pertaining to the adsorption rate based on the adsorption capacity. To distinguish kinetic equations based on the adsorption capacity from solution concentration, Lagergren’s first order rate equation have been called pseudo-first-order (Ho & McKay, 1998a). In recent years, it has been widely used to describe the adsorption of pollutants from wastewater in different fields, such as the adsorption of methylene blue from aqueous solution by broad bean peels and the removal of malachite green from aqueous solutions using oil palm trunk fiber (Hameed & El-Khaiary, 2008a; 2008b; Tan *et al.*, 2008).

The pseudo-first order kinetic model assumes “adsorbate adsorption process is first order in nature as it is only dependent on the number of adsorbate present at the specific time in the solution” (Lagergren, 1898). Pseudo-first order Lagergren can be presented as Eq. (2.1) :

$$\text{Log}\,(qe\text{-}qt) = \log qe - \frac{K_1 t}{2.303} \qquad (2.1)$$

Where K_1 (min^{-1}) is the rate constant of pseudo-first order adsorption model, *qe* and *qt* (mg/g) denote the amounts of adsorbed on F, C and FC at equilibrium and at any time *t* (min).

2.5.2.2 Pseudo-second-order

In 1995, Ho described a kinetic process of the adsorption of divalent metal ions onto peat (Ho & McKay, 1998b), in which the chemical bonding among divalent metal ions and polar functional groups on peat, such as aldehydes, ketones, acids, and phenolics are responsible for the cation-exchange capacity of the peat. The main assumptions for the above two equations were that the adsorption may be second-order, and the rate limiting step may be chemical adsorption involving valent forces through sharing or the exchange of electrons between the peat and divalent metal ions. In addition, the adsorption follows the Langmuir equation (Ho & McKay, 2000).

Pseudo-second order kinetic model assumes that “the adsorption process is dependent on the number of adsorbate present in the solutions as well as the free adsorption sites on the adsorbent surface” (Ho & Mckay, 2000). The pseudo-second order equation is expressed as Eq. (2.2) :

$$\frac{t}{qt} = \frac{1}{K_2 qe^2} + \frac{t}{qe} \qquad (2.2)$$

Where K_2 is the rate constant of pseudo-second order adsorption model (min^{-1}), q_t is the amount of adsorption time t (min), and q_e the amount of adsorption equilibrium (mg/g).

2.5.3 Adsorption Isotherm

According to Hussain *et al.,* (2006) revealed that adsorption process is usually studied through graphs known as adsorption isotherm. Adsorption is the amount of adsorbate on the adsorbent as a function if its pressure or concentration at constant temperature. The quantity adsorbed is nearly always normalized by the mass of the adsorbent to allow comparison of different materials. From the above, we can predict that after saturation pressure (Ps), adsorption does not occur anymore, that is there are limited numbers of vacancies on the surface of the adsorbent. At high pressure a stage is reached when all the sites are occupied and further increase in pressure does not cause any difference in adsorption process. At high pressure, adsorption is independent of pressure.

The analysis of adsorption data is important for developing an equation which accurately represents the results and which could be used for design purposes. The linear regression was used to determine the most fitted models among all written isotherms (Gupta *et al.*, 2010). Several isotherm equations have been widely used for the equilibrium modeling of adsorption systems, there are Langmuir and Freundlich equations.

2.5.3.1 Langmuir Adsorption Isotherm

In 1916, Irving Langmuir published a new model isotherm for gases adsorbed to solids, which retained his name. It is a semi-empirical isotherm derived from a proposed kinetic mechanism. The Langmuir isotherm model is based on the assumption that there is a finite number of active sites which are homogeneously distributed over the surface of the adsorbent. These active sites have the same affinity for adsorption of a mono molecular layer and there is no interaction between adsorbed molecules (Hussain *et al.*, 2006). Based on his theory, Langmuir derived an equation which explained the relationship between the number of active sites of the surface undergoing adsorption and pressure.

The Langmuir monolayer sorption isotherms are based on the following assumptions (Cruz *et al*., 2004):

(i) The solid surface presents a finite number of energetically uniform identical sites.

(ii) There is no interaction among adsorbed species, in the example the amount adsorbent has no influence on the rate of adsorption

(iii) A monolayer is formed when the solid surface reaches saturation.

The linearized Langmuir equation (Langmuir, 1918) is given as Eq. (2.3):

$$\frac{Ce}{qe} = \frac{1}{q_{\max}{}^{b}} + \frac{C_e}{q_{\max}} \qquad (2.3)$$

Where q_e (mg/g) is equilibrium adsorption capacity and Ce (mg L^{-1}) is equilibrium metal ion concentration, q_{max} (mg g^{-1}) is the maximum amount of pollutant per unit weight of adsorbent to form a complete monolayer on the surface, and b is a constant related to the affinity of binding sites with the pollutant (L mg^{-1}).

2.5.3.2 Freundlich Adsorption Isotherm

In 1909, Freundlich expressed an empirical equation for representing the isothermal variation of adsorption of a quantity of gas adsorbed by unit mass of solid adsorbent with pressure. The Freundlich isotherm (Choy *et al.*, 1999; Chiou & Li, 2002) applies to adsorption on heterogeneous surfaces with interaction between the adsorbed molecules, and is not restricted to the formation of a monolayer. This model assumes that as the adsorbate concentration increases, the concentration of adsorbate on the adsorbent surface also increases and, correspondingly, the sorption energy exponentially decreases on completion of the sorption centres of the adsorbent. Though Freundlich Isotherm correctly established the relationship of adsorption with pressure at lower values, it failed to predict values of adsorption at higher pressure. This relation is called as the Freundlich adsorption isotherm.

Freundlich (1906) created Freundlich equation and it is an empirical equation based on adsorption on heterogeneous surface and its linearized form can be given as Eq. (2.4):

$$\text{Log } q\text{e} = \log K_F = \frac{1}{n} \log C_e \tag{2.4}$$

Where K_F and $1/n$ are Freundlich constants related to adsorption capacity and intensity of adsorption, respectively.

2.5.4 Advantages of Adsorption

Adsorption treats wastewater contaminants with low pollutant concentration and has been an inexpensive, simple, and effective alternative to replace conventional methods. Furthermore, these materials can be reused for effluent decontamination. Since the concentration of a specific pollutant could be attained during the pollutant uptake, it is significant to note that these adsorbents appear to have an application as preconcentration agents. Some examples of waste products used in previous research were grape stalks wastes and peanut shell (Villaescusa *et al*., 2004; Witek-Krowiak *et al*., 2011).

Febrianto *et al*., (2009) stated that adsorption treatment has different advantages over conventional methods. The adsorption process is non-polluting, easy to operate, offers the high efficiency of treatment of wastewaters containing low pollutant concentrations and possibility of metal recovery.

A study by Vijayaraghavan & Yun (2008) pointed out three principle advantages of adsorption methods for the removal of pollutants. The first principle is this process can be carried out in situ at the contaminated site. Secondly, the process technologies are usually environmentally benign, which eliminate unnecessary secondary pollutant. Thirdly, they process are cost effective. Table 2.5 shows the advantages of adsorption process.

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