

**STUDY OF THE COMBINED EFFECTS OF OXIDATION AND
ADSORPTION PROCESS IN REMOVING MTBE FROM WASTEWATER**

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ABSTRACT

Treatment of Methyl Tert-Butyl Ether (MTBE) from wastewater supplies presents specific challenges due to the physicochemical properties of MTBE which depend strongly on its hydrophilic nature, and translate into a high solubility in water. MTBE has very low Henry's constant and very low affinity for common adsorbents. An investigation was carried out for the treatability of methyl tert-butyl ether (MTBE) in synthetic wastewater. In this research, experimental rig and bench-scale studies using granular activated carbon (GAC) and hydrogen peroxide (H_2O_2) were conducted to observe the treatability of MTBE in synthetic wastewater. An experimental rig was built up that consist of three conjugated system. Subsequently, MTBE was amended to the H_2O_2 and air flow, followed by adsorption treatment with GAC. Generally, the major finding suggests that the longer cycle pulsation time (3 minutes open valve + 5 seconds closed valve) with air flow rate at 6 L/min over the synthetic wastewater caused a greater removal of MTBE. The result of this study can help to provide specific guidance into process parameter selection for treating MTBE in wastewaters. The optimum operating conditions are very important for treating the wastewater effectively in a larger scale.

ABSTRACK

Perawatan Methyl Tert-Butil Eter (MTBE) dari bekalan air sisa menyajikan cabaran-cabaran khusus kerana sifat fisikokimia MTBE yang sangat bergantung pada sifat hidrofilik, dan menterjemahkan ke dalam kelarutan tinggi dalam air. MTBE memiliki afiniti Henry konstan dan adsorben yang sangat rendah. Penyelidikan dilakukan untuk merawat Methyl tert-butyl metil (MTBE) di dalam air sisa sintetik. Dalam kajian ini, rig eksperimen dan kajian skala bangku menggunakan karbon aktif granular (GAC) dan hidrogen peroksida (H_2O_2) dilakukan untuk mengetahui rawatan kepada MTBE dalam air sisa sintetik. Sebuah rig eksperimen dibina yang terdiri daripada tiga sistem konjugasi. Selanjutnya, MTBE dirawat dengan H_2O_2 dan aliran udara, diikuti dengan rawatan jerapan dengan GAC. Secara umum, penemuan utama menunjukkan bahawa kitaran masa denyut (3 minit injap terbuka + 5 saat injap tertutup) dengan kelajuan aliran udara pada 6 L/min pada air sisa sintetik menyebabkan penghapusan MTBE yang lebih besar. Keputusan kajian ini dapat membantu memberikan bimbingan khusus dalam proses pemilihan parameter untuk mengubati MTBE dalam air sisa. Keadaan kerja yang optimum sangat penting untuk memproses sisa cair secara berkesan dalam skala yang lebih besar.

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LIST OF ABBREVIATIONS

MTBE	-	Methyl Tertiary Butyl Ether
EPA	-	Environmental Protection Agency
CAA	-	Clean Air Act
NAAQS	-	National Ambient Air Quality Standard
RFG	-	Reformulated Gasoline
AOPs	-	Advanced Oxidation Processes
FR	-	Fenton Reagent
COD	-	Chemical Oxygen Demand
BOD	-	Biochemical Oxygen Demand
DOC	-	Dissolved Organic Carbon
NOM	-	Natural Organic Matter
DBP	-	Disinfection by-Products
VOCs	-	Volatile Organic Compounds
GAC	-	Granular Activated Carbon
H ₂ O ₂	-	Hydrogen Peroxide
UV Light	-	Ultraviolet Light
EBCT	-	Empty Bed Contact Time

CHAPTER 1

INTRODUCTION

1.1 Background of Study

1.1.1 Adsorption Process

Adsorption is a process which uses a solid to remove particles from a liquid or gas that passes across it. The particles stick to its surface. This process creates a film of the adsorbate (the molecules or atoms being accumulated) on the surface of the adsorbent. It differs from absorption, in which a fluid permeates or is dissolved by a liquid or solid. The term sorption encompasses both processes, while desorption is the reverse of adsorption.

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. The exact nature of the bonding depends on the details of the species involved, but the adsorption process is generally classified as :

i) Physisorption (by Van Der Waals and electrostatic forces)

This is the most common form of adsorption. The molecules are attracted by van der Waals forces, and attach themselves to the surface of the solid. The molecules remain intact, and can be freed easily (the forces are small, and short-range).

ii) Chemisorption (by chemical bonding)

The molecules undergo a chemical bonding with the molecules of the solid, and this attraction may be stronger than the forces holding the solid together. If the molecules are removed, they may form different compounds.

During adsorption, the molecules from gas or liquid phase will be attached in a physical way to a surface, in this case the surface is from the active carbon. The adsorption process takes place in three steps:

- i. Macro transport: The movement of organic material through the macro-pore system of the active carbon (macro-pore $>50\text{nm}$)
- ii. Micro transport: The movement of organic material through the meso-pore and micro-pore system of the active carbon (micro-pore $<2\text{nm}$; meso-pore 2-50nm)
- iii. Sorption: The physical attachment of organic material on the surface of active carbon in the meso-pores and micro-pores of the active carbon.

The activity level of adsorption is based on the concentration of substance in the water, the temperature and the polarity of the substance. A polar substance (a substance which is good soluble in water) cannot or is badly removed by active carbon, a non-polar substance can be removed totally by active carbon. Every kind of

carbon has its own adsorption isotherm and in the water treatment business this isotherm is definite by the function of Freundlich.

Another feature of a good adsorbent is a large surface area. The bigger its surface area, the more molecules it can trap on its surface. Generally this means that a good adsorbent will be very porous, full of many tiny little holes on its surface that effectively increase its surface area by many times. Adsorption, ion exchange, and chromatography are sorption 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. It can adsorb the following soluble substances:

- Adsorption of organic, non-polar substances such as:
 - Mineral oil
 - BTEX
 - Poly aromatic hydrocarbons (PACs)
 - (Chloride) phenol
- Adsorption of halogenated substance: I, Br, Cl, H and F
- Odor
- Taste
- Yeasts
- Various fermentation products
- Non-polar substances (Substances which are non soluble in water)

1.1.2 Advanced Oxidation Processes (AOPs)

Oxidation is defined as the transfer of one or more electrons from an electron donor (reductant) to an electron acceptor (oxidant), which has a higher affinity for electrons. These electron transfers result in the chemical transformation of both the oxidant and the reductant, in some cases producing chemical species with an odd number of valence electrons. These species, known as radicals, tend to be highly unstable and, therefore, highly reactive because one of their electrons is unpaired. Oxidation reactions that produce radicals tend to be followed by additional oxidation reactions between the radical oxidants and other reactants (both organic and inorganic) until thermodynamically stable oxidation products are formed. The ability of an oxidant to initiate chemical reactions is measured in terms of its oxidation potential. The most powerful oxidants are fluorine, hydroxyl radicals ($\bullet\text{OH}$), ozone, and chlorine with oxidation potentials of 2.85, 2.70, 2.07 and 1.49 electron volts, respectively (Dorfman and Adams, 1973). The end products of complete oxidation (i.e., mineralization) of organic compounds such as MTBE or benzene are carbon dioxide (CO_2) and water (H_2O).

Advanced oxidation processes (AOPs) involve the two stages of oxidation: 1) the formation of strong oxidants (e.g., hydroxyl radicals) and 2) the reaction of these oxidants with organic contaminants in water. However, the term advanced oxidation processes refer specifically to processes in which oxidation of organic contaminants occurs primarily through reactions with hydroxyl radicals (Glaze et al., 1987). Advanced chemical oxidation processes make use of (chemical) oxidants to reduce COD/BOD levels, and to remove both organic and oxidisable inorganic components. In water treatment applications, AOPs usually refer to a specific subset of processes that involve O_3 , H_2O_2 , and/or UV light. This process can produce hydroxyl radicals, which can react with and destroy a wide range of organic contaminants, including MTBE.

Advanced Oxidation Processes are particularly appropriate for effluents containing refractory, toxic or non-biodegradable materials. The processes offer several advantages over biological or physical processes, including:

- Process operability(No biological process)
- Unattended operation with very small foot print.
- The absence of secondary wastes (sludge).
- The ability to handle fluctuating flow rates and compositions.

1.1.3 Background of Methyl Tertiary Butyl Ether (MTBE)

Methyl tertiary butyl ether (methyl tert-butyl ether, methyl t-butyl ether, or MTBE) is a chemical compound used as a fuel additive in gasoline. It is an oxygenate, meaning it increases the oxygen content of the gasoline, and is also a source of octane in gasoline. It is widely used in those parts of the country where oxygenated gasoline is required, either by federal or state law. Refiners primarily have added MTBE to gasoline to meet the Clean Air Act (CAA) requirement that areas with severe problems in attaining the National Ambient Air Quality Standard (NAAQS) for ozone use Reformulated Gasoline (RFG) containing 2% oxygen by weight. Many states have voluntarily chosen to use RFG as a means of addressing marginal, moderate, or serious ozone nonattainment, and some refiners use MTBE to boost the octane of gasoline.

MTBE is a persistent molecule in the environment for several reasons: (1) the ether bond is stable and requires acidic conditions to cleave it; (2) the bulky tert-butyl group does not allow easy access to the ether linkage; and (3) it has only been

in the environment for a relatively short time, so indigenous microbes have not had time to develop enzymatic systems to transform MTBE. It is mobile and persistent in the environment due to its high water solubility (43,000–54,300 mg/L) (Mackay et al., 1993), low Henry's law constant (0.023–0.12; dimensionless) (Mackay et al., 1993), and relative bio recalcitrance under common conditions (Squillace et al., 1998). MTBE also is used sometimes to meet the requirements of the CAA Wintertime Oxygenated Fuel (Wintertime Oxyfuel) program, which specifies that gasoline must contain 2.7% oxygen by weight during the wintertime in areas not in attainment for the NAAQS for carbon monoxide. Purely as a fuel additive, MTBE performs successfully, but environmental problems with the compound led the EPA in March 2000 to provide an advance notice of its intent to initiate a rulemaking pursuant to section 6 of the Toxic Substances Control Act (TSCA) to eliminate or limit the use of MTBE as a fuel additive.

While the use of MTBE as a fuel additive in gasoline has helped to reduce harmful air emissions, it also has caused widespread and serious contamination of the nation's drinking water supplies. Current data on MTBE levels in ground and surface waters indicate widespread and numerous detections at low levels of MTBE, with a more limited number of detections at higher levels. Given MTBE's widespread use as a gasoline additive and the large volumes of gasoline that are stored, transported, and used in all areas of the country, releases of MTBE to the nation's ground and surface waters occur in a number of ways. Leakage from the gasoline storage and distribution system is a major source of contamination, but the contamination also comes from spills, emissions from marine engines into lakes and reservoirs, and to some extent from air deposition. It can end up in drinking water supplies even when there are no indications of other gasoline components. MTBE is detected in water much more often and at higher concentrations in areas of the country where RFG is sold.

The presence of MTBE in drinking water sources presents two major problems. The first concern is that MTBE contamination may render water supplies unuseable as drinking water. MTBE has an offensive taste and odor which can be

detected in water even at low levels. Because of the taste and odor problem, MTBE contamination has resulted in the loss of certain drinking water sources.

The second major concern involves uncertainty regarding the level of risk to public health from the chronic exposure of large numbers of people to low levels of MTBE in drinking water. While inhalation of MTBE in high concentrations has been shown to cause cancer in laboratory animals, the Agency concluded in 1997 that there is little likelihood that MTBE in drinking water would cause adverse health effects at levels that cause taste and odor problems. There is still much uncertainty about the extent of the health risks associated with chronic, low-level exposures to MTBE in drinking water. The Agency is continuing to review and update its analysis of the potential health risks posed by MTBE (Deeb et al., 2003).

Once MTBE contaminates a drinking water source, its chemical nature makes it difficult, expensive, and time-consuming to remediate. For example, it is much harder and more expensive to remove MTBE from drinking water than it is to remove other organic components of gasoline. Furthermore, MTBE does not biodegrade as readily as other components of gasoline.

1.1.4 Properties of Methyl Tertiary Butyl Ether (MTBE)

Methyl tertiary butyl ether (MTBE) are characterized by their cas no, density, specific gravity, melting point, boiling point, flash point, vapor pressure and water solubility. The most important parameters affecting the process are the flow rate of air and the contacting time between the granular activated carbon and the MTBE.

Table 1.1 : Properties of Methyl tertiary butyl ether (MTBE)

Constituent of concern	Methyl tertiary butyl ether (MTBE)
Aliases	MTBE, Methyl tert-butyl ether, 2-Methoxy-2-Methyl Propane, Methyl 1,1-Dimethylethyl Ether
Chemical formula	$C_5H_{12}O$ or $(CH_3)_3COCH_3$
Cas No.	1634-04-4
Molar mass	88.15 g/mol
Density	0.7404 g/cm ³
Specific gravity	0.74
Melting point	-109 °C, 164 K, -164 °F
Boiling point	55.2 °C, 328 K, 131 °F
Vapor pressure	249 mm Hg at 25 °C
Water solubility	51,000 mg/L
Flash point	10 °C
Henry's constant	0.022

Reference : Howard (1993), Merck (1996), and CRC (1998).

1.1.5 Methyl Tertiary Butyl Ether (MTBE) Treatment Process

Table 1.2 : Overview on Methyl tertiary butyl ether (MTBE) treatment process

Process type	Examples	References
Fenton's reagent	Iron	Burbanoa, 2001
In situ air sparging	Air	Bruce, 1998
Adsorption	Granular activated carbon	Shih, 2003
Catalytic technologies	Pd-Cu-based catalytic	Centi, 2003
Degradation by ion-activated	Ferrous persulfate	Chen, 2009
Anaerobic bioremediation	Amended with Fe(III) oxide plus the electron-shuttling compound acid	Finneran, 2002
Aerobic bioremediation	Oxygen-rich biologically reactive treatment zone	Johnson, 2004
Ozone remediation	Ozone	Wheeler, 2001
UV-based advance oxidation	UV/TiO ₂ and UV/H ₂ O ₂	Mascolo, 2008
Polymer or carbon filter media	PetroLOK filter media (PLFM)	Advanced Water Systems, 1999
Phytoremediation	Hybrid poplar trees	Hong, 2001
Aerobic biodegradation	Biomass Concentrator Reactor (BCR)	Zein, 2004
Synthetic adsorbents	Ambersorb 572	Brendley, 2002

1.2 PROBLEM STATEMENT

Since the 1970's, methyl tertiary butyl ether (MTBE) has been widely used as a gasoline additive in the United States, initially as an octane-enhancing replacement for lead. MTBE frequently detected in the leaking underground storage tanks, spills

and urban runoff. Removal of MTBE from wastewater can be achieved through several water treatment processes such as air stripping with adsorption of collected material, advanced oxidation, membrane separation, and sorption (Shih et al., 1999).

MTBE is highly water soluble, air stripping may not be cost effective. Air stripping is difficult and requires a high air-to water ratio. Membrane separation is considered too expensive in general water treatment applications. Ozone and ozone/peroxide can be quite effective in removing MTBE from wastewater; however, hazardous bromate and biodegradable organic carbon are by-products of these processes and must be removed.

Adsorption using granular activated carbon (GAC) is the most commonly-used adsorbent in water treatment, and has been successfully used to remove MTBE from wastewater. However, GAC performance is reduced when synthetic organic compounds coexist with MTBE or in the presence of natural organic matter (NOM).

In this study, combined oxidation and adsorption system is used to remove MTBE from wastewater as a substitute for inefficient and high cost process.

1.3 OBJECTIVES

- i. To study the removal of pollutants (MTBE) from wastewater using adsorption and advance oxidation process.
- ii. To observe the efficiency of pollutants (MTBE) removal from wastewater using combine system of adsorption and oxidation processes at different operating condition.

1.4 SCOPE OF STUDY

In the present study, several important parameters have been investigated. These parameters are molar ratio of MTBE to hydrogen peroxide, air flow rate, and cycle pulsation time.

The detail of the scope is as below:

- i. Molar ratio of MTBE to hydrogen peroxide is 1: 10, 1:30, 1:50, 1:80, 1:100.
- ii. Air flow rate is 4 L/min and 6 L/min.
- iii. Cycle pulsation time is 30s, 40s, 50s, 60s, 120s and 180s.

1.5 SIGNIFICANCE OF THE RESEARCH

- i. To replace conventional method with the utilization of combine adsorption and oxidation for removing pollutants (MTBE) from wastewater.
- ii. Pollutants (MTBE) are released as a contaminant waste from the respective industries. We are trying to reduce large amount of waste in daily life.
- iii. Problems to be resolved such as operating condition and cost.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The Clean Air Act Amendments of 1990 mandated that fuel oxygenates be used in gasoline to reduce carbon monoxide emissions in non-attainment regions across the US (US Environmental Protection Agency., 1994). Methyl tert-butyl ether (MTBE) is the most commonly used fuel oxygenate currently in use with 70 percent of all gasoline in the US containing MTBE in 1997 (Eweis et al., 1998). Methyl tert-butyl ether (MTBE) has been frequently detected in groundwater (Baehr et al., 1999; Klinger et al., 2002; Schmidt et al., 2002; Schmidt et al., 2004; Squillace et al., 1996) and wastewater stream across the US with contamination occurring from both point- (e.g., leaking underground storage tanks, spills, and etc.) and non-point (e.g., urban runoff, water craft, etc.) sources. Due to its high water solubility, low Henry's law constant, and the commonly relatively low concentrations in the environment, it is not readily amenable to remove.

MTBE treated by conventional techniques in water treatment. Recent developments suggest that synthetic resin sorbents may be economically competitive with other more established treatment technologies (air stripping, advanced oxidation processes, and granular activated carbon) for MTBE removal (Flores et al., 2000).

2.2 Granular Activated Carbon (GAC)

Carbon adsorption technology has been widely used in the past for removal of organic contaminants from drinking water. Sorption, in particular granular activated carbon (GAC) adsorption, is a proven technology for treating water contaminated with many taste- and odor-causing organics and synthetic organic chemicals (Keller et al., 1998). Simplicity and stable operations are the primary advantages of GAC relative to other water treatment technologies. Because of the simplicity of the equipment and materials, capital and installation costs are relatively low compared to more innovative technologies. There is no off gas treatment required for GAC systems and the creation of by-products is limited to spent carbon that can either be thermally regenerated or discarded. However, in spite of these advantages, GAC field-application knowledge specifically for MTBE removal from large-scale drinking water systems is currently limited.

The effectiveness of GAC for the treatment of MTBE has been limited by its poor physical and chemical adsorption characteristics. In particular, MTBE's high solubility causes the compound to preferentially remain in solution rather than be adsorbed onto a solid surface. In addition, natural organic matter (NOM) and other synthetic organic chemicals (SOCs) compete with MTBE for the adsorption sites of GAC (Speth, 1998). Since MTBE is only weakly adsorbed by GAC, other more preferentially adsorbed SOCs in the contaminated water can result in the sorption or the displacement of previously adsorbed MTBE from the GAC matrix.

Based on the MTBE isotherms currently available, coconut shell GAC appears to have better MTBE adsorption characteristics than coal-based GAC. The proper selection of cost-effective GAC and operational parameters are critical to the successful operation of full-scale GAC adsorbers. The time and cost requirements in conducting a pilot plant study are prohibitive, whereas the more rapid and inexpensive isotherm and rapid small-scale column test (RSSCT) studies have been shown to be useful predictors of GAC performance (Crittenden et al., 1989).

Suffet et al. (1999) traditional activated carbon used in point-of-use (POU) and point-of-entry (POE) water treatment applications are coconut shell-based and bituminous coal-based. Coconut shell-based GAC has a greater number of micropores. The quantity of micropores present in coconut shell-based GAC is about 50% higher than bituminous coal-based GAC. The greater amount of micropores in coconut shell-based GAC allows it to have a higher capacity to adsorb MTBE. In addition, coconut shell-based GAC has a higher retentivity. High retentivity ensures MTBE will not come off or desorb off the GAC when the influent MTBE concentration fluctuates. Coconut shell-based GAC is also purer, containing 97% to 98% carbon, whereas bituminous coal-based GAC contains about 88% to 94% carbon.

MTBE is difficult to remove by adsorption onto GAC (Dyksen et al., 1992). Isotherm data have been found for MTBE adsorption onto activated carbon (F400). Capacities of 4.8 mg/g and 2 mg/g have been calculated for solutions containing 628 µg/litre and 102 µg/litre, respectively, at equilibrium (Speth et al., 1990). Filtration of contaminated groundwater through F300 GAC (empty bed contact time 12 min) reduced concentrations from 25–35 µg/litre to non-detectable levels for approximately 2 months. The GAC had to be replaced after 4 months of operation because of taste and odour complaints (McKinnon et al., 1984). Small-scale column tests using two coconut-based GACs showed that the treatment capacity up to breakthrough (5 µg/litre) was 2.5 and 4.5 litre/g GAC for an influent concentration of 20 µg/litre (Shih et al., 2003).

California MTBE Research Partnership (2000) the carbon usage rates and unit treatment costs are highly dependent on influent MTBE concentrations, background water quality, and the concentration of other SOCs. The cost analysis suggests that GAC is most cost-effective for the removal of lower MTBE concentrations, which result in lower carbon usage rates and, consequently, lower operation and maintenance costs. GAC is also more likely to be cost-effective for waters that are relatively clean with respect to NOM (e.g., some groundwater). For example, computer modeling predicts that carbon fouling from NOM can cause

approximately 50 percent increases in carbon usage rates for the removal of 20 µg/L MTBE. Finally, GAC is more cost-effective for waters contaminated solely with MTBE since other SOCs will preferentially occupy adsorption sites and thereby increase carbon usage rates. Adsorption modeling and cost estimates show that moderate loads of total BTEX (800 µg/L) can cause greater than 50 percent increase in carbon usage rates for MTBE removal for systems treating influent with 20 µg/L MTBE.

2.3 Air Stripping

Air stripping is a technology in which volatile organic compounds (VOCs) are transferred from extracted water to air. Typically, air stripping takes place in a packed tower (known as an air stripper) or an aeration tank. The tendency for a compound to be removed from water by air stripping is characterized by its Henry's constant. MTBE's Henry's constant is several times lower than those of other organic compounds commonly treated through air stripping (e.g., trichloroethylene, TCE and benzene) and, thus, air stripping of MTBE is more difficult and more costly than for these other compounds. However, air stripping is a proven technology that has been used successfully to remove MTBE from drinking water. Packed tower air strippers are being used successfully for drinking water treatment.

The design of the contacting system between the contaminated water and the air used to strip out the organic compounds. In general, the goal is to maximize the extent of contact (maximum rate of mixing, highest specific surface area) while minimizing energy costs associated with the equipment design. This provides the highest rate of mass transfer from water to air at the lowest operating cost. The most common mass transfer design for air stripping systems is the use of randomly packed towers. Other options include spray towers, low profile units, bubble diffusers,

aspirators, and surface aerators. Selection of the appropriate technology is often site-specific.

In Rockaway Township, the groundwater was contaminated with several volatile organic compounds (VOCs), including MTBE. Initially, GAC was used, but costs were excessive (McKinnon and Dyksen, 1984). Subsequent modifications to the treatment system included using a packed tower air stripper prior to GAC polishing. The combined treatment process of air stripping followed by liquid phase GAC reduced initial MTBE concentrations at approximately 96 $\mu\text{g/L}$ to below detection limits (approximately 5 $\mu\text{g/L}$). The volumetric air/water ratio used in the air stripping system was 200.

Air stripping technologies are widely used for removing halogenated VOCs from drinking water supplies prior to distribution and use of the water for public consumption. Packed tower aeration is the most common air stripping technology for drinking water treatment. Packed tower aeration is a well-understood and proven technology (Roberts et al., 1985), and there are many equipment vendors and packing manufacturers who provide the external and internal components for packed tower systems (Lamarre and Shearhouse, 1996). Other air stripping technologies have been used, but primarily at low flow rates (<100 gpm) or in a remediation context. Other air stripping technologies include spray towers, bubble aerators, low profile aerators, surface aerators, and aspiration or centrifugal aeration devices.

Table 2.1 Air Stripping Technology (Roberts et. al. 1985)

Technology	Construction Requirements	Operational and Maintenance Requirements
Packed Tower	<ul style="list-style-type: none"> • Free standing or guy wired. • Requires concrete pad. • May be installed outdoors. 	<ul style="list-style-type: none"> • May require pretreatment to reduce fouling potential. • Cleaning of packing likely necessary for fouling. • Routine blower and pump maintenance required.
Bubble Aeration	<ul style="list-style-type: none"> • Typically requires process enclosure. • Needs self-supporting stack. 	<ul style="list-style-type: none"> • May require pretreatment to reduce fouling potential. • Cleaning of bubble diffusers and tank may be required if fouling occurs. • Routine blower and pump maintenance required. • Needs enclosed heating if ambient temperature below freezing.
Spray Tower	<ul style="list-style-type: none"> • Free standing or guy wired. • May require concrete pad. • May be installed outdoors 	<ul style="list-style-type: none"> • May require pretreatment to reduce fouling. • Cleaning of packing (for MTBE) and nozzles may be required if fouling occurs. • Routine blower and pump maintenance required.
Aspiration	<ul style="list-style-type: none"> • May be installed in an enclosure or outdoors • May require concrete pad. • Larger units need self-supporting stack. • Height of stack above ground level • Interference from other buildings 	<ul style="list-style-type: none"> • Routine pump maintenance required. • 3 phase, 230/460 volt, 60 hertz, power typically needed. • Emissions limit of organic compounds to the atmosphere (range: 1 to 10 lb/day). • MTBE treated as an organic. • Monitoring requirements: for new operation, daily monitoring; for operation up to two years, monthly monitoring.