TCE-DEGRADATION USING COMPOST TECHNIQUE CADMIUM AS CO-CONTAMINANT

INTRODUCTION

1. Background

Industrial activity associated with the production and discharge of chlorinated organic compounds has become a major environmental concern due to the persistency of many of these compounds. Trichloroethylene (TCE) and Vinylchloride (VC) are the two chlorinated volatile organic compounds (VOCs). TCE is commonly used as a degreaser, dry cleaning solvent and as anaesthetic chemical which was first synthesized in 1864. TCE and VC have been used as an ingredient in plastic industries. In addition, VC is an intermediate product in reductive dechlorination of TCE. They are suspected to be a carcinogen and mutagen (US EPA, 1997). They are distributed in air and accumulated in soil. Bioregradation of TCE has been a major focus of investigation for the past decade. Aerobic biological process such as aerobic composting are very effective in removing volatile organic compounds from soil. In the past studies, Cd is known as the heavy metals pollution (Chizhikov, 1966). Cd made microorganism in soil unable to work (Friberg *et al.*, 1996).

2. Objectives

This study focus on the effect of aerobic composting process to degrade TCE, with and without Cd as the co-contaminant.

Using aerobic composting process as a tool to clean up soil polluted with TCE. The specific aims are to study:

2.1 The potential of microorganisms in enhancing the removal of TCE contaminated in soil.

2.2 The enhancing of indegenous microoganisms in degradation of TCE in composted soil.

2.3 Effect of Cd as a co-contaminant in removal of TCE contaminated in soil.

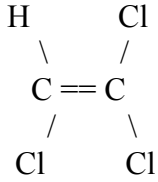
LITERATURE REVIEW

1. Trichloroethylene (TCE)

1.1 General information of TCE

1.1.1 Common name: Trichloroethylene is an aliphatic substance of the organic halogen and halogen-derivation families.

1.1.2 Chemical structure:



1.1.3 Molecular formula: C_2HCl_3

1.1.4 IUPAC and CAS name: Trichloroethene

1.1.5 Common synonyms: acetylene trichloride, ethinyl trichloride, TRI, ethylene trichloride, TCE, 1-chloro-2,2-dichloroethylene, 1,1-dichloro-2-chloethylene, 1,1,2-trichloroethylene

1.1.6 CAS registry number: 79-01-6

1.1.7 Molecular weight: 131.40

1.2 Physical and chemical properties

In its pure state, TCE is a colourless liquid with a characteristic, slightly sweet odor.

1.2.1 Chemical reactivity

TCE oxidizes to yield acids, including hydrochloric acid (US EPA, 1995). Its reactivity increases with rise in temperature and with exposure to ultraviolet radiation (UVR). Under pressure, at 150 ºC, it reacts with alkalis to produce glycolic acid. With sulfuric acid, it reacts to produce monochloroacetic acid (Kirk and Othmer, 1964). In the presence of alkali, dehydrochlorination may occur in solution as well as in the vapour phase, with the formation of dichloroacetylene, which is highly neurotoxic and carcinogenic for animals and probably for man (US EPA, 1995).

1.2.2 Chemical degradation

The chemical degradation of TCE in water is very slow. In contact with red-hot metals or a direct flame, liquid or vapour-phase trichloroethylene decomposes to form phosgene and hydrogen chloride (Waters *et al.*, 1977).

1.2.3 Photochemical degradation

Photochemical reactions initiate the degradation of TCE in the environment. When exposed to UVR and humidity, the compound decomposes to form acids that have mean half-lives ranging from 6 to 12 weeks (Correia *et al.,* 1977). With an OH^- concentration of the order of 10^6 molecules/cm^3 (accepted mean value), a calculated half-life of TCE is around 5 days. TCE exposure to xenon are lamp radiation with a wavelength greater than 290 nm, at constant temperature, produces carbon monoxide, carbon dioxide, water, hydrogen chloride, dichloroacetyl chlorides, and phosgene; the phosgene hydrolyses to produce carbon dioxide and hydrogen chloride. Dichloroacetyl chlorides enter the hydrosphere as dichloroacetate anions (McConnell *et al.,* 1975). Some physical and chemical properties of TCE are listed in table 1

Table 1 Physical and chemical properties of TCE.

Properties	Information
Freezing point (°C)	-84.8
Boiling point (°C) at atm	86.7
Specific gravity (at 25 °C)	1.46
Vapour pressure (mmHg) at 25°C	69
Refraction index (n_D) at 20 °C	1.4782
Viscosity (cP) at 20 °C	0.58
Dielectric constant at 16 °C	3.42
Surface tension (dyn/cm) at 20 °C	26.4
Critical temperature (°C)	271.0
Critical pressure (atm)	49.7
Dipole moment (debye)	0.90
Heat of combustion (kcal/g)	1.751
Oxidizing properties	none
Solubility in water (g/l) at 20 °C	1.07
n-octanol/water partition coefficient(log)	Log K^o/w 2.42
Organic carbon partition coefficient, K_{oc}	K^o/w x 0.6
Bioconcentration factor, K_B	K^o/w x 0.048

Source: WHO (1985)

1.3 Sources in the environment and uses

TCE does not occur naturally. It was first synthesized by Fisher in 1864 and become commercially available for the first time in 1908 in Austria and the United Kingdom (Kirk and Othmer, 1964).

1.3.1 Production

TCE is produced by three processes. The dehydrochlorination of sym-tetrachloroethane, the high-temperature oxychlorination of chlorinated products with one or two carbon atoms, or the chlorination of ethylene.

In Western Europe, production was approximately 250,000 tonnes in 1978. The major producing countries are the Federal Republic of Germany, France, whose individual production capacity is of the order of 100,000 tonnes, Italy and the United Kingdom. Sweden and Spain are smaller producers. In the USA the production of TCE in 1979 was 130,000 tonnes (Bellar *et al.,* 1979). In Japan, the annual production was approximately 74,500 tonnes in 1981 and 67,500 tonnes in 1982 (Japanese Yearbook of Chemical Industries Statistics, 1983).

1.3.2 Uses

TCE is an industrial solvent mainly (85-90%) used for the vapour degreasing and cold cleaning of fabricated metal parts. TCE has also been used as a carrier solvent for the active ingredients of insecticides and fungicides; as a solvent for waxes, fats, resins, and oils; as an anaesthetic for medical and dental use; and as an extractant for spice oleoresins and for caffeine from coffee. TCE has been used in printing inks, varnishes, adhesives, paints, lacquers, spot removers, rug cleaners, disinfectants, and cosmetic cleansing fluids. It may also be used as a chain terminator in polyvinyl chloride production and as an intermediate in the production of pentachloroethane (Defalque, 1961; Kirk and Othmer, 1963 ; US CFR, 1976; Waters *et al.,* 1977; IARC, 1979).

1.4 Transformation in the environment

Recent studies on the degradation of TCE in various environmental compartments are discussed below.

1.4.1 Air

The main removal reaction appears to be that of attack by the tropospheric hydroxyl radical (Penkett, 1982), the steady-state concentrations of which are around $4 \times 10^5/cm^3$ (Graedel, 1978). The decay of TCE is a function of the rate of its (bimolecular) reaction with the hydroxyl radical (Graedel, 1978), which is about $2.4/10^{12}$ cm^3 per molecule per second at 25 ºC (Howard, 1976). This leads to a calculated reaction rate of approximately $4/10^3$ per hrs., with the calculated lifetime of TCE in the atmosphere of around 11 days (Graedel, 1978). A half-life of the order of 5 days has been calculated by (De More *et al.,* 1983). Silngh *et al.* (1977) reported a half-life of less than 2 days in a smog chamber. Pearson and McConnell (1975), using unrealistically high concentrations of TCE in quartz flasks, estimated its half-life to be 11 weeks.

1.4.2 Soils and sediments

When methanogenic bacterial batch cultures were exposed to low concentrations of TCE (simulating conditions in an organic-rich sediment or in a sewage treatment system), at 35 ºC, for 8 weeks, TCE concentrations were reduced by about 40% (Bouwer and McCarty, 1983). If it is assumed that the reaction rate is halved with every 10 ºC drop in temperature, this corresponds to an exponential decay rate (first order with respect to TCE) of about $2/10^4$ per hrs. at 15 ºC. In a study on a laboratory fresh water-sediment system, it was concluded that TCE, formed by

biotransformation from tetrachloroethylene, was itself biotransformed to chloroethane, cis- and trans-1,2-dichloroethene, and dichloromethane (Parsons *et al,*1984).

1.4.3 Water

Wakeham *et al.* (1982) measured a TCE exponential decay rate in a sea-water mesocosm of approximately $2.5/10^2$ per day at 8-16 ºC, which is equivalent to a rate of about $1/10^3$ per hrs. This is similar to the rate described by Bouwer and McCarty (1983) for microbial degradation. Pearson and McConnell (1975) measured a chemical degradation rate, in sealed bottles, which led to a half-life estimate of 2.5 years.

1.4.4 Biota

The only data available refer to the degradation of TCE in a soil-plant system (Klozskowski *et al.,* 1981) in which the rate of trichloroethylene loss was 10% per week. This was accounted for mainly by conversion to carbon dioxide, but with some evaporation of organic compounds. This corresponds to an exponential decay rate of about $6/10^3$ per hrs., which is about 10 times the microbial decay rates.

1.5 Standard and reglulation

1.5.1 Concentration in landfill and emission site

Landfill gas at seven U.K. waste disposal sites contained TCE at <0.1 to 152 mg/m^3 (Allen *et al.,*1997). Gas sample from 3 old and 1 active municipal landfill in Southern Finland contained TCE at average concentration of 0.1 to 5.25 mg/m^3 and a maximum concentration of 13 mg/m^3. Average concentration of TCE 710 and 2,079 ppb. were measured in samples of landfill gas (Brosseau and Heitz,1994). Emissions of TCE from hazardous waste incinerators in the US were estimated as 81.8 µg/l. Primary sludge from seven U.S. publicly owned treatment works contained TCE at 35-284 µg/l. Stationary source emissions of 2640 tons/yr., TCE were reported for the Netherlands in 1980 (TOXNET, 1985).

1.5.2 Drinking water standards

According to the National Primary Drinking Water regulations of U.S. Environmental Protection Agency the drinking water standard of TCE is 0.005 mg/l (US EPA, 1997).

1.6 Kinetic and metabolism

1.6.1 Absorption

TCE absorption in mammals can take place by the respiratory, oral, and/or dermal routes. Intraperitoneal uptake has been demonstrated experimentally. Uptake via the oral route is high because of the ease with which TCE penetrates the gastrointestinal barrier. In man, oral intake is a frequent cause of acute poisoning (Waters *et al.,* 1977).

1.6.2 Metabolic transformation

TCE is metabolized primarily in the liver and to a much lesser extent in other tissues. Metabolism is by the mixed function oxidase system and is dependent on cytochrome P450. The major mammalian metabolites are free and conjugated trichloroethanol and trichloroacetic acid. Other metabolites include 2-hydroxyacetylethanolamine and oxalic acid (Dekant and Henschler, 1982; Dekant *et al.,* 1984). Metabolism is showed in Figure 1 Metabolically activated TCE binds convalently to the hepatic microsomal proteins and DNA in vitro. This finding supports the formation of an epoxide intermediate (Banerjee and Van Duuren, 1978).

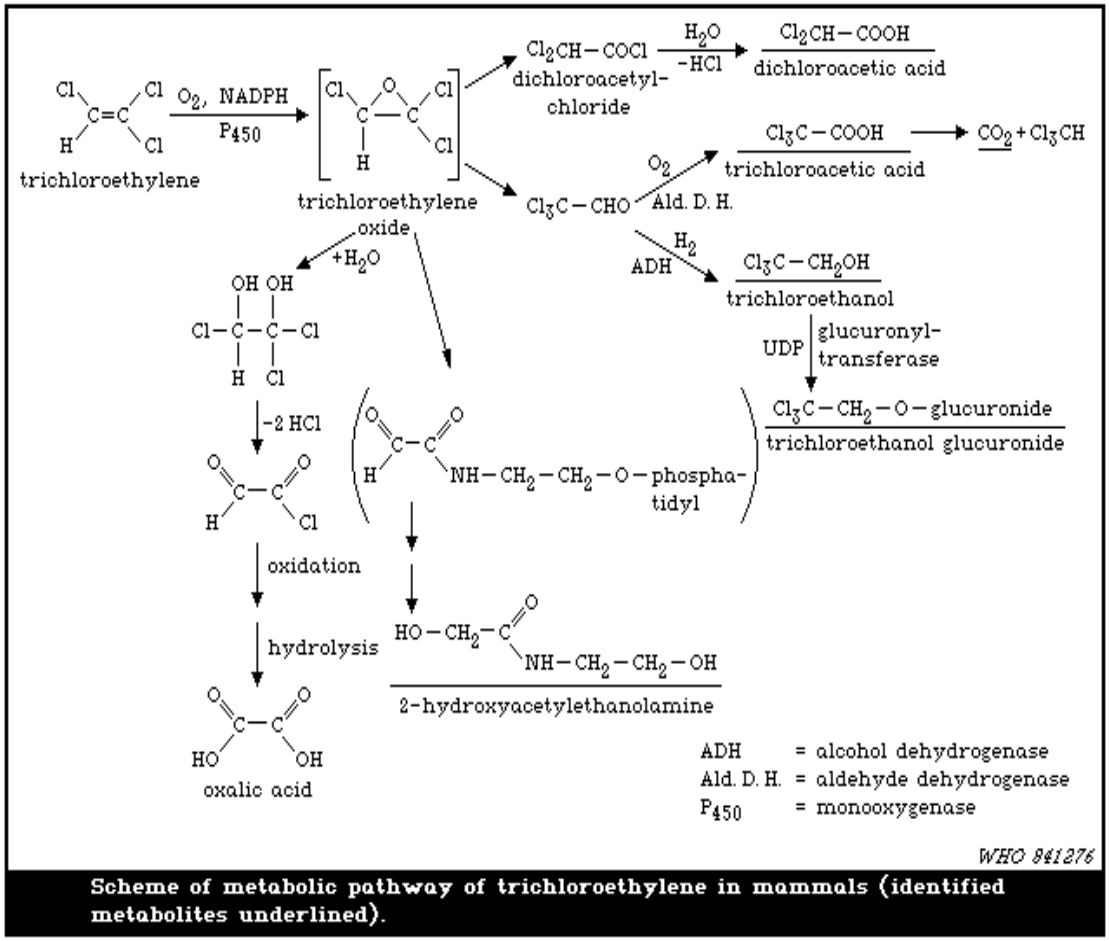


Figure 1 Metabolic pathway of TCE in mammals
Source: WHO (1985)

1.6.3 Elimination

TCE is eliminated unchanged through the lungs and is eliminated in the urine in the form of metabolites. Elimination by other routes (e.g. faeces, sweat and saliva) accounts for less than 10 % of the total (Bartonicek, 1962).

1.7 Effect on environment

1.7.1 Aquatic Organisms

There is little information on the toxicity of TCE for fish. The US Registry of Toxic Effects of Chemical Substances (Christensen and Lugenbyhl, 1975) reports, for an unidentified species, that exposure to a concentration range of 100-1000 mg/l produced toxic effects in 96 hrs. Toxicity tests carried out on salt-water flatfish, Limanda limanda (sole), 15-20 cm long, in a continuous water flow, established a 96-h LC_{50} of 16 mg/l (Pearson and McConnell, 1975). A 96-h LC_{50} of approximately 40 mg/l (static) or 67 mg/l (continuous flow) has been reported for the minnow Pimephales promelas (Alexander *et al.,* 1978).

Verschueren (1977) established an LC_{100} of 600 mg/l for Daphnia magna. The LC_{50} for the balanide salt-water crustacean nauplius (larva) (Elminius modestus) was 20 mg/l after 46 hrs. (Pearson and McConnell, 1975), and the LC_{50} for the protozoon Entosiphon sulcatum was established as 1200 mg/l (Bringmann and Kuhn, 1980). Various LC_{50} values have been established for algae including 63 mg/litre for Microcystis aeruginosa, (Verschueren, 1977); a concentration of 1,000 mg/litre did not have any observable effect on Scenedesmus quadricauda (Bringmann and Kuhn, 1980). A short-term photosynthesis efficiency test gave an LC_{50} of 8 mg/litre (Pearson and McConnell, 1975) and, finally, in tests carried out on Thalassiosira pseudonana and Dunaliella tertiolecta, there were observable effects at 50 and 100 µg/l, in a mixed culture (Biggs *et al.,* 1979).

1.7.2 Uptake, Distribution, Storage, Metabolism, and Elimination in Plant and Animal Organisms

Bioaccumulation of TCE in a marine environment has been studied by Pearson and McConnell (1975); concentration levels were determined for a wide variety of marine organisms, mostly in the Bay of Liverpool. The greatest increase in TCE concentrations in the tissues of animals that are relatively high up in the food chain (bird's eggs, fish liver, and seal fat) was nearly 100 times the level in water (from $0.5/10^9$ µg/l in water to $50/10^9$ µg/kg in tissues).

These data agree with the laboratory findings of Barrows *et al.* (1980) who, in a 14-day test, noted that TCE accumulation in the sunfish species, Lepomis macrochirus was 17 times that of the aquatic medium with a halving time of less than one day. A low bioconcentration factor (concentration in organism divided by concentration in environment) (Eurocop-cost, 1976) has been derived using water solubility and the equation proposed by Kenaga (1980).

1.7.3 Effects on the Stratospheric Ozone Layer

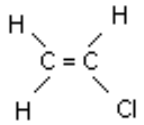
Consideration has been given to the possibility that TCE, together with other halocarbons in the atmosphere, may contribute to the depletion of the stratospheric ozone layer, which would lead to atmospheric heating and increased exposure of terrestrial biota to ultraviolet radiation (Molina and Rowland, 1974). Atmospheric TCE concentrations seem to be about one-fifth to one-tenth of those of

other chlorocarbons such as CH_3CCl_3, CH_2Cl_2, CCl_4, C_2Cl_4 or the major chlorofluoro-carbons (Cronn *et al.,* 1977; Penkett, 1982). The reason for this is that while TCE emissions into the atmosphere are of the same order as those of other halocarbons (Jesson, 1980), TCE is efficiently scavenged by hydroxyl radicals in the troposphere, and the reaction rate for this process is appreciably faster for TCE than for other halocarbons (Penkett, 1982). Thus, the predicted atmospheric lifetime for TCE is short (about 10-11 days) (Derwent and Eggleton, 1978; Graedel, 1978) compared with those for the chlorofluorocarbons, which may be 10 years or more (Jesson, 1980). It is not clear whether TCE is even present in the stratosphere (Cronn *et al.,* 1977). However, the data suggest that TCE is unlikely to be involved in the possible depletion of the ozone layer.

2. Vinyl chloride

2.1 General information of VC

2.1.1 Common name: Vinyl chloride.
2.1.2 Chemical structure:



2.1.3 Molecular formula: C_2H_3Cl
2.1.4 Molecular weight: 62.50
2.1.5 Common sysnonyms: Chloroethene, Chloroethylene, VC, Ethylene monochloride, Monochloroethene, Monochloroethylene, Vinyl chloride monomer (VCM)
2.1.6 CAS registry number: 75-01-4

2.2 Physical and chemical properties

Vinyl chloride monomer is a sweet smelling, colouless gas at room temperature. Some physical and chemical properties of vinyl chloride are listed in table 2

Table 2 Physical and chemical properties of vinyl chloride

Properties	Information
Melting point (°C)	-153.8
Boiling point (°C) at atm	64.25
Flash point (°C)	-78
Autoignition temperature (°C)	472
Critical temperature (°C)	156
Critical pressure (kPa)	5600
Density (g/cm^3) at 20 °C	0.910
Vapour pressure (kPa) at20 °C	333
Henry's Law Constant (Hc) ($kPa.m^3/mol$) at 25 °C	2.0-2.8
log n-octanol/water partition coefficient (log K_{ow}) at 22 °C	1.58

Source: WHO (1987)

2.3 Production

Vinyl chloride monomer (VCM) is a gas that is currently in the United States. VC also known as polyvinyl chloride (PVC) is produced in several steps. In the first step, ethylene dichloride (EDC) is produced by the chlorination of ethylene through either direct chlorination or oxychlorination. Direct chlorination reacts ethylene with chlorine. Oxychlorination is done by reacting ethylene with dry hydrogen chloride (HCl) and oxygen at temperatures generally less than 325 ºC. The resulting EDC is then subjected to pressures between 20-30 atmospheres and temperatures between 550-650 ºC. This process is known as pyrolysis, or thermal cracking. Equal parts of VC and HCl are created during this stage. The VC is then isolated and finally, PVC is made by the polymerization of the VC. Polymerization is a chemical reaction linking the molecules of a simple substance (monomer) together to form large molecules whose molecular weight is a multiple of that of the monomer. There are two general types of polymerization. PVC is made by addition polymerization, which occurs when VC reactive monomers unite without forming any other products. Its resulting molecular structure is similar to that of polyethylene (Paul, 2001).

2.4 Sources of vinyl chloride

The principal emission sources, in order of importance, are VC production plants, PVC polymerization facilities, and plants where PVC products are fabricated. PVC is used in many consumer and industrial products including pipes, wire and cable coatings, furniture upholstery, wrapping film, hoses, flooring, windows, videodiscs, credit cards, and many others. Minor sources include storage and handling facilities for VC and PVC and plants producing ethylene diamine or ethylene dichloride. In the United States, VC emissions have been reported from municipal landfills, but the exact source of emission is unclear and systematic survey data are unavailable. Approximately 5 million tonnes of VC were produced in the

whole of Europe in 1981. The levels of emission from VC and PVC production facilities depend upon the processes and control technology employed. The use of the best available technology can reduce emissions to less than 1% of production volume, but emissions from facilities in some countries exceed this value (Criteriadocument over vinylchloride, 1984).

2.5 Transformation in environment

2.5.1 Microbial degradation

With few exceptions, VC is not easily degraded by unadapted microbial consortia under environmental conditions. Maximum unacclimated biodegradation half-lifes of VC were estimated to be in the order of several months or years. However, special enrichment or pure (e.g., Mycobacterium sp.) cultures are capable of degrading VC under optimal culture conditions. The main degradation products were glycolic acid or carbon dioxide after aerobic conversion and ethane, ethene, methane or chloromethane after anaerobic transformation. Frequently, the degradation reaction of VC proceeded faster with aerobes than with anaerobes (Freedman and Gossett, 1989; Semprini *et al.,* 1995).

2.5.2 Photodegradation

Reaction with photochemically produced OH radicals is the dominant atmospheric transformation process, resulting in calculated tropospheric half-lifes of 1 to 4 days. Several critical compounds, such as chloroacetaldehyde, formaldehyde and formyl chloride, are generated during experimental photolysis reactions (Tuazon *et al.,* 1988; Pitts, 1993).

2.5.3 Hydrolysis

Photolytic reactions as well as chemical hydrolysis are thought to be of minor importance in aqueous media. However, the presence of photosensitizers may enhance the transformation of VC (Jeffers and Wolfe, 1996).

2.6 Standards and regulating

2.6.1 In drinking water

US EPA determine safe levels of chemicals in drinking water that do or may cause health problems. These non-enforceable levels, based solely on possible health risks and exposure are called Maximum Contaminant Level Goals (MCLG). US EPA set the MCLG for VC at zero because it believes that only this level of protection prevent the potential health problems associated with VC (US EPA, 1995b).

2.6.2 Public water suppliers

US EPA has set an enforceable standard called a Maximum Contaminant Level (MCL) of public water suppliers to detect and remove contaminants using suitable treatment technologies. US EPA set the MCL at two part per billion (2 ppb) (US EPA, 1995b).

2.6.3 Occupational safety

The Occupational Safety and Health Administration (OSHA) has set the maximum allowable level of VC in workroom air during an eight hour workday in forty hour work week at one part VC per million parts of air (1 ppm) (OSHA, 1998).

2.7 Kinetic and Metabolism

2.7.1 Absorption and distribution

VC is rapidly and well absorbed after inhalation or oral exposure. The primary route of exposure to VC is inhalation. In animal and human studies, under steady-state conditions, approximately 40% of inspired VC is absorbed after exposure by inhalation. Animal studies showed an absorption of more than 95% after oral exposure. Dermal absorption of VC in the gaseous state is not significant.

Data from oral and inhalation studies on rats indicate rapid and widespread distribution of VC. Rapid metabolism and excretion limits accumulation of VC in the body. Placental transfer of VC occurs rapidly in rats. No studies on distribution after dermal exposure have been reported (WHO, 1999).

2.7.2 Metabolic transformation and excretion

The main route of metabolism of VC after inhalation or oral uptake involves oxidation by cytochrome P-450 (CYP2E1) to form chloroethylene oxide (CEO), a highly reactive, short-lived epoxide which rapidly rearranges to form chloroacetaldehyde (CAA). The primary detoxification reaction of these two reactive metabolites as well as chloroacetic acid, the dehydrogenation products of CAA, are conjugation with glutathione catalysed by glutathione S-transferase. The conjugation products are further modified to substituted cysteine derivatives (S-(2-hydroxyethyl)-cysteine, N-acetyl-S-(2-hydroxyethyl)cysteine, S-carboxymethyl cysteine and thiodiglycolic acid) and are excreted via urine. The metabolite carbon dioxide is exhaled in air. CYP2E1 and glutathione S-transferase isoenzymes are known to have large inter-species and inter-individual variation in activity show in Figure 2

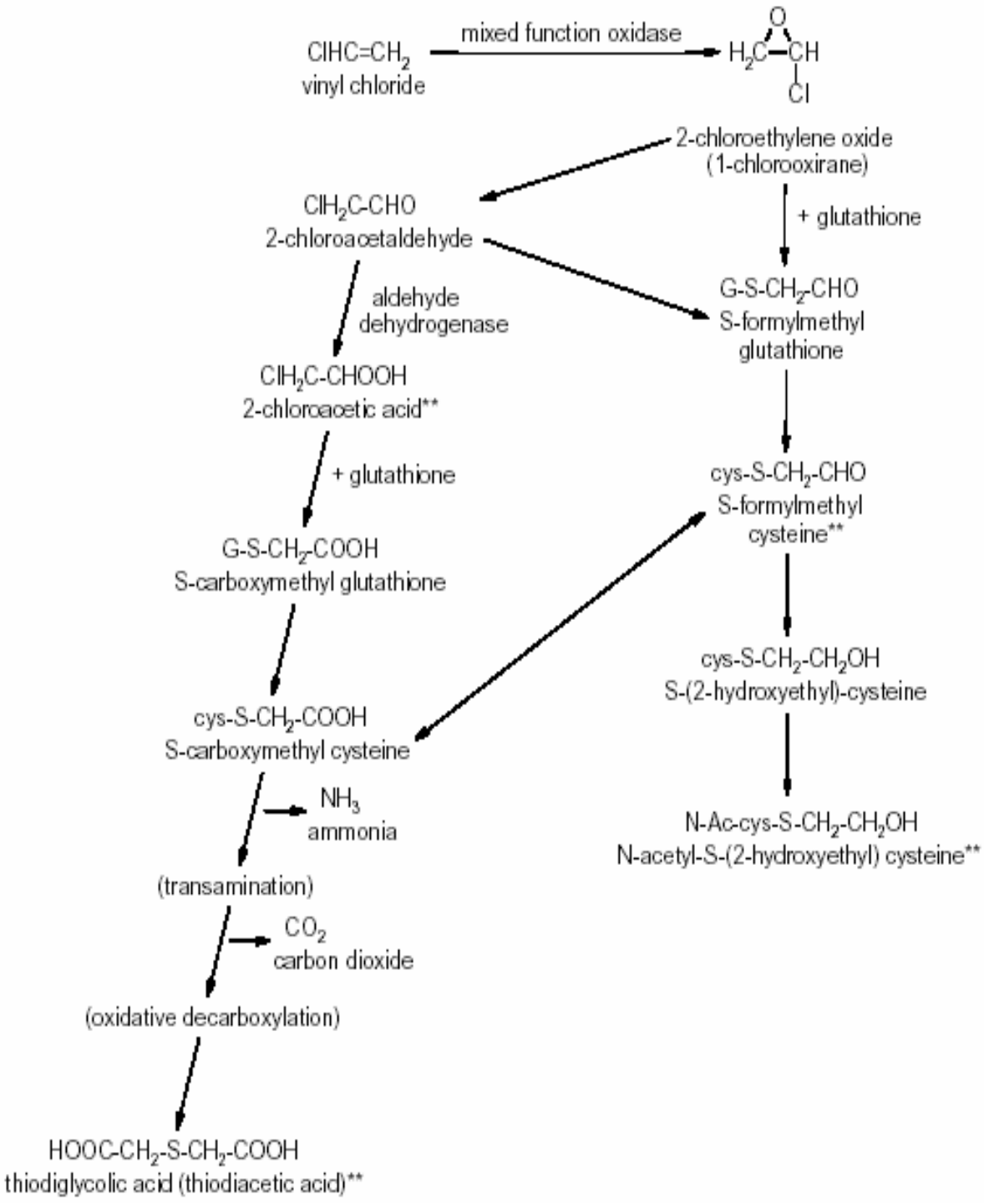


Figure 2 Proposed metabolic pathways for vinyl chloride
Source: ATSDR (1997)

2.8 Effects on environment

There is very limited information on the environmental effects of VC. Laboratory tests indicate that it has low toxicity for aquatic organisms. If released to soil or surface water, volatilization is likely to take place. Biodegradation is possible but very slow in anaerobic environments. VC is not expected to hydrolyse, adsorb to organic fractions of soils or sediments, or to biomagnify. VC has been found to leach into groundwater and has been found there as a degradation product of trichloroethylene and related solvents, where it may remain under certain conditions.

3. Cadmium

Cadmium is a heavy metal discovered as an element only in 1817, and industrial use was minor until about 50 years ago. But now it is very important metal with many applications. Because of its noncorrosive properties, its main use is in the electroplating or galvanizing. It is also used as a color pigment for paints and plastics and as a cathode material for nickel-cadmium batteries. Cadmium is a by-product of zinc and lead mining and smelting, which are important sources of environmental pollution (Robert *et al.,* 2001).

3.1 Physical and chemical properties

Cadmium is a silver-white, blue-tinged, odorless, lustrous distorted hexagonal close packed structured metal. Some of its physical and chemical properties are listed in table 3

Table 3 Physical and chemical properties of cadmium

Properties	Information
Molecular formula	Cd
Molecular weight	112.41
Boiling point	765°C
Melting point	321°C
Heat of vaporization	99.87kJ/mole at 767°C
Corrosivity	Highly corrosion resistant
Density	8.65g/cm^3 at 25°C
Solubilities	Insoluble in water
Vapor pressure	1 Pa at 257°C
Stable isotopes in nature	Eight: (106) Cd: 1.21%; (108) Cd: 0.88%; (110) Cd: 12.39%; (111) Cd: 12.75%; (112) Cd: 24.07%, (113) Cd: 12.26%; (114) Cd: 28.86%; (116) Cd: 7.58%.

Source: TOXNET (1985)

3.2 General information

3.2.1 Production

Cadmium is a by-product of zinc production. As a result, the level of cadmium output has closely followed the pattern of zinc production, little being produced prior to the early 1920s. The subsequent rapid increase corresponded to the commercial development of cadmium electroplating (Wilson, 1988).

3.2.2 Uses

Cadmium has a limited number of applications but within this range the metal is used in a large variety of consumer and industrial materials. The principal applications of cadmium fall into five categories: protective plating on steel; stabilizers for poly-vinyl chloride (PVC); pigments in plastics and glasses; electrode material in nickel-cadmium batteries; and as a component of various alloys (WHO, 1992).

3.2.3 Natural occurrence and cycling

Cadmium is widely distributed in the earth's crust at an average concentration of about 0.1 mg/kg. However, higher levels may accumulate in sedimentary rocks, and marine phosphates often contain about 15 mg cadmium/kg. Weathering also results in the riverine transport of large quantities of cadmium to the world's oceans and this represents a major flux of the global cadmium cycle; volcanic activity is a major natural source of cadmium release to the atmosphere (GESAMP, 1987).

3.3 Sources of human and environmental exposure

Cadmium is released to the air, land, and water by human activities. In general, the two major sources of contamination are the production and consumption of cadmium and other non-ferrous metals and the disposal of wastes containing cadmium. Areas in the vicinity of non-ferrous mines and smelters often show pronounced cadmium contamination.

Increases in soil cadmium content result in an increase in the uptake of cadmium by plants; the pathway of human exposure from agricultural crops is thus susceptible to increases in soil cadmium. The uptake by plants from soil is greater at low soil pH. Processes that acidify soil (e.g., acid rain) may therefore increase the average cadmium concentrations in foodstuffs. The application of phosphate fertilizers and atmospheric deposition are significant sources of cadmium input to arable soils in some parts of the world; sewage sludge can also be an important source at the local level. Edible free-living food organisms such as shellfish, crustaceans, and fungi are natural accumulators of cadmium (WHO, 1992).

Cadmium is quite mobile element in agricultural soils. More often it could compete with several micronutrients especially the metal ones such as zinc and iron for plant uptake. This process will lead to possible increase the Cd concentration

in relevant food crops, in particular, rice, wheat and soybean. However Cd is more toxic to man but less so to the plants (Parkpian *et al.,* 2004).

3.4 Standards

3.4.1 Drinking water standards

Federal drinking water standard is 5µg/l (TOXNET, 1985)

3.4.2 Effluent Standards

Japan: 0.1 mg/l (JEQ, 1997). Thailand: 0.03 mg/l (DEQP, 1992)

3.5 Kinetics, metabolism and mechanism of toxicity

3.5.1 Kinetics and metabolism

Data from experimental animals and humans have shown that pulmonary absorption is higher than gastrointestinal absorption. Depending on chemical speciation, particle size, and solubility in biological fluids, up to 50% of the inhaled cadmium compound may be absorbed. Excretion is normally slow, and the biological half-time is very long (decades) in the muscles, kidneys, liver, and whole body of humans. The cadmium concentrations in most tissues increase with age. Highest concentrations are generally found in the renal cortex, but excessive exposures may lead to higher concentrations in the liver. Metallothionein is an important transport and storage protein for cadmium and other metals. Cadmium can induce metallothionein synthesis in many organs including the liver and kidney. The binding of intracellular cadmium to metallothionein in tissues protects against the toxicity of cadmium. Cadmium not bound to metallothionein may therefore play a role in the pathogenesis of cadmium-related tissue injury (WHO, 1992).

3.5.2 Mechanism of Toxicity

Cadmium is transported in blood by binding to red blood cells and high-molecular-weight proteins in plasma, particularly albumin. It is distributed primarily to the liver and kidney. In the liver cadmium induces the synthesis of metallothionein and is then either stored in the liver as Cd-MT complex or transported via blood to the kidney, where it may accumulate in lysosomes. Cd-MT complex in lysosomes is slowly catabolized to non-metallothionein-bound cadmium but may again be complexed with metallothionein or may induce renal toxicity (Robert *et al.,* 2001).

Acute cadmium poisoning may produce degenerative changes in renal tubular cells. Cadmium inhibits many enzymes, competes with calcium metabolism and alters phosphorylation patterns.

Veselov *et al.,* (2003) reported that cadmium causes the breakdown of plant hormone, reduces the cytokinin content, and inhibits the growth rate, transpiration and ion uptake.

3.6 Toxicity

3.6.1 Acute toxicity

LD_{50} of cadmium in different laboratory animals shown in table 4.

Table 4 LD_{50} of cadmium

Species	**LD_{50} (Oral, mg/kg BW)**
Rat	225
Mouse	890

Source: TOXNET (1985)

Acute toxicity may result from the ingestion of relatively high concentrations of cadmium, as may occur from contaminated beverages or food. Nausea, vomiting and abdominal pain occurred from consumption of drinks containing approximately 16mg/l cadmium. Inhalation of cadmium fumes may produce an acute chemical pneumonitits and pulmonary edema (Robert et al., 2001).

3.6.2 Chronic toxicity

The principal long term effects of low-level exposure to cadmium are chronic obstructive pulmonary disease and emphysema and chronic renal tubular disease. There may also be effects on the cardiovascular and skeletal systems (Robert *et al.,* 2001).

3.6.3 Carcinogenicity

Epidemiological studies have shown a relationship between occupational (respiratory) exposure to cadmium and lung cancer and possibly prostate cancer. There are few studies that examine a relationship between oral intake of cadmium and cancer in humans. Oral cadmium exposure is associated with tumor of the prostate, testes and hematopoietic system in rats (Robert *et al.,* 2001). Cadmium has recently been accepted by the International Agency for Research on Cancer as a category 1 (human) carcinogen, based primarily on its relationship to pulmonary tumors.

4. Composting

There are two major phases in composting process. In the first stage, microorganisms decompose the composting feedstock into simpler compounds, producing heat as a result of their metabolic activities. The size of the composting pile is reduced during this stage. In the second stage, the compost product is "cured" or finished. Microorganisms deplete the supply of readily available nutrients in the compost, which, in turn, slows their activity. As a result, heat generation gradually diminishes and the compost becomes dry and crumbly in texture. When the curing stage is complete, the compost is considered "stabilized" or "mature". Any further microbial decomposition will occur very slowly.

4.1 The Role of Microorganisms

Composting is a succession of microbial activities whereby the environment created by one group of microorganisms invites the activity of successor groups. Different types of microorganisms are therefore active at different times in the composting pile. Bacteria have the most significant effect on the decomposition process, and are the first to take hold in the composting pile, processing readily decomposable nutrients (primarily proteins, carbohydrates, and sugars) faster than any other type of microorganism. Fungi, which compete with bacteria for food, play an important role later in the process as the pile dries, since fungi can tolerate low-moisture environments better than bacteria. Some types of fungi also have lower nitrogen requirements than bacteria and are therefore able to decompose cellulose materials, which bacteria cannot. Because fungi are active in composting piles, concern has arisen over the growth of opportunistic species, particularly those belonging to the genus Aspergillus.

Besides microorganisms, other animals also play a role in the composting process. Rotifers, nematodes, mites, springtails, sowbugs, beetles, and earthworms reduce the size of the composting feedstock by for aging, moving in the compost pile, or chewing the composting materials. These actions physically break down the materials, creating greater surface area and sites for microbial action to occur.

The microorganisms necessary for composting are useturally present in most organic materials, including leaves, grass clippings, other yard trimmings, and other organic materials. Products are available that claim to speed the composting process through the introduction of selected strains of bacteria, but tests have shown that inoculating compost piles in this manner is not necessary for effective composting of typical yard trimmings or MSW feedstock (Rynk *et al.,*1992; Haug, 1980; Gray *et al.,* 1971a).

The bacteria and fungi are important in decomposing the feedstock material where can be classified as mesophilic or thermophilic. Mesophilic microorganisms or mesophiles (those that grow best at temperatures between 25 and 45ºC) are dominant throughout the composting mass in the initial phases of the process when temperatures are relatively low. These organisms use available oxygen to transform carbon from the composting feedstock to obtain energy, and, in so doing, produce carbon dioxide (CO_2) and water. Heat is also generated as the microorganisms metabolize the composting feedstock. As long as the compost pile is of sufficient size to insulate internal layers from ambient temperatures and no artificial aeration or turning occurs, most of the heat generated by the microorganisms will be trapped inside the pile. In the insulated center layers, temperatures of the composting mass will eventually rise above the tolerance levels of the mesophilic organisms. Figure 3 shows a typical temperature pattern for natural composting processes. When the temperatures reach toward 45 ºC (113 ºF), mesophiles die or become dormant, waiting for conditions to reverse.

At this time, thermophilic microorganisms or thermophiles (those that prefer temperatures between 45 and 70 ºC) become active, consuming the materials readily available to them, multiplying rapidly, and replacing the mesophiles in most sections of the composting pile. Thermophiles generate even greater quantities of heat than mesophiles, and the temperatures reached during this time and weed seeds are hot enough to many composting kill most pathogens facilities maintain a temperature of 55 ºC (131 ºF) in the interior of the compost pile for 72 hours to ensure pathogen destruction and to render weeds inviable.

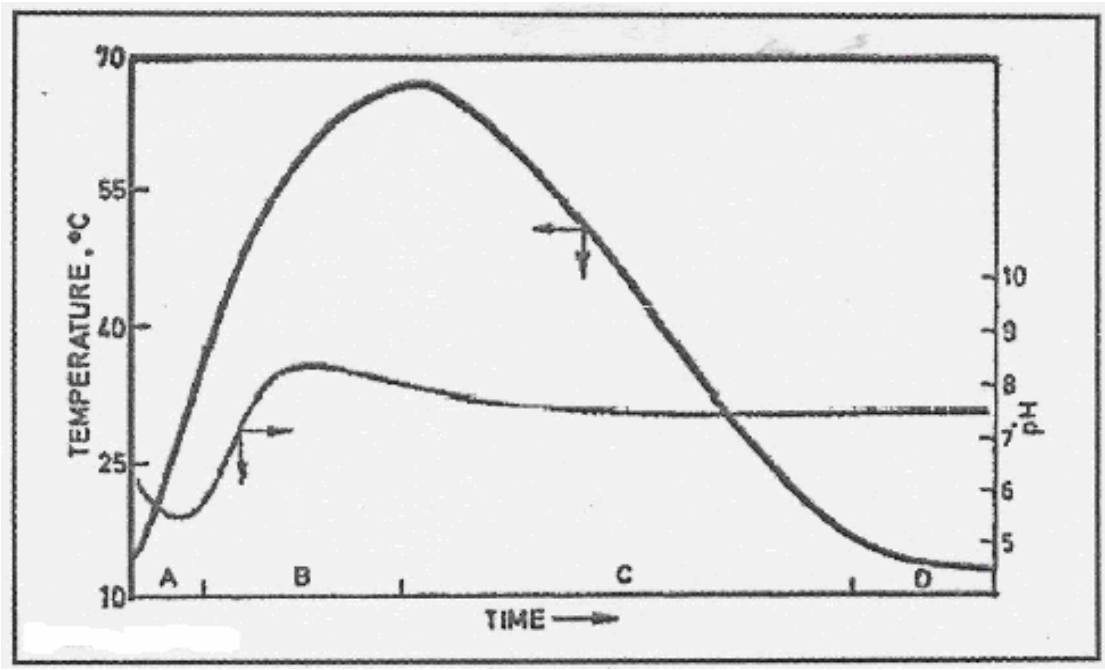


Figure 3 Temperature and pH variation with time phases of microbial activity.
A = mesophilic, B = thermophilic, C = cooling, D = maturing.
Source: Gray *et al.* (1971a)

The thermophiles continue decomposing the feedetock materials as long as nutrientand energy sources are plentiful. As these sources become depleted, however, thermophiles die and the temperature of the pile drops. Mesophiles then dominate the decomposition process once again until all readily available energy sources are utilized. Table 5 shows the density of microorganisms as a function of temperature during composting.

Table 5 Microbial populations during aerobic compacting.

Microbe	Number per wet Gram of Compost			
	Mesophilic Initial Temp (< 40°C)	**Thermophilic (40 – 70 °C)**	**Mesophilic (70 °C to Cooler)**	**Numbers of Species Identified**
Bacteria				
Mesophilic	10^4	10^6	10^{11}	6
Thermophilic	10^4	10^9	10^7	1
Actinomycetes				
Thermophilic	10^4	10^8	10^6	14
Funcgi				
Mesophilic	10^6	10^3	10^5	18
Thermophilic	10^3	10^7	10^6	16

Source: Haug (1980)

4.2 Factors Influence the Composting Process

Because microorganisms are essential to composting, environmental conditions that maximize microbial activity will maximize the rate of composting. Microbial activity is influenced by oxygen levels, particle sizes of the feedstock material, nutrient levels and balance (indicated by the C/N ratio), moisture content, temperature, and acidity/alkalinity (pH). Any changes in these factors are interdependent; a change in one parameter can often result in changes in others.

4.2.1 Oxygen

Composting can occur under aerobic (requires free oxygen) or anaerobic (without free oxygen) conditions, but aerobic composting is much faster (10 to 20 times faster) than anaerobic composting. Anaerobic composting also tends to generate more odors because gases such as hydrogensulfide and amines are produced. Methane also is produced in the absence of oxygen.

Microorganisms important to the composting process require oxygen to break down the organic compounds in the composting feedstock. Without sufficient oxygen, these mloroorganisms will diminish, and anaerobic microorganisms will take their place. This occurs when the oxygen concentration in the air within the pile falls below 5 to 15 percent (ambient air contains 21 percent oxygen). To support aerobic microbial activity, void spaces must be present in the composting material. These voids need to be filled with air. Oxygen can be provided by mixing or turning the pile, or by using forced aeration systems.

The amount of oxygen that needs to be supplied during composting depends on:

1) The stage of the process-oxygen generally needs to be supplied in the initial stages of composting; it usually does not need to be provided during curing.

2) The type of feedstock-dense, nitrogen-rich materials (e.g., grass clippings) will require more oxygen.

4.2.2 Particle Size

The particle size of the feedstock affects the composting process. The size of feedstock materials entering the composting process can vary significantly. In general, the smaller the shreds of composting feedstock, the higher the composting rate. Smaller feedstock materials have greater surface areas in comparison to their volumes. This means that more of the particle surface is exposed to direct microbial action and decomposition in the initial stages of composting. Smaller particles within the composting pile also result in a more homogeneous mixture and improve insulation (Gray *et al.,* 1971b). Increased insulation capacity helps maintain optimum temperatures in the composting pile. At the same time, however, the particles should not be so small as to compact too much, thus excluding oxygen from the void spaces, as discussed above.

4.2.3 Nutrient Levels and Balance

For composting to proceed efficiently, microorganisms require specific nutrients in an available form, adequate concentration, and proper ratio. The essential macronutrients needed by microorganisms in relatively large amounts include carbon (C), nitrogen (N), phosphorus (P) and potassium (K). Microorganisms require C as an energy source. They also need C and N to synthesize proteins, build cells, and reproduce. P and K are also essential for cell reproduction and metabolism. In a composting system, either C or N is usually the limiting factor for efficient decomposition (Richard, 1992a).

Composting organisms also need micronutrients, or trace elements, in minute amounts to foster the proper assimilation of all nutrients. The primary micronutrients needed include boron, calcium, chloride, cobalt, copper, iron, magnesium, manganese, molybdenum, selenium, sodium, and zinc (Boyd, 1984). While these nutrients are essential to life, micronutrients present in greater than minute amounts can be toxic to composting microorganisms.

Even if these nutrients are present in sufficient amounts, their chemical form might make them unavailable to some or all microorganisms. The abilty to use the available organic compounds present depends on the microorganisn's "enzymatic machinery" (Boyd, 1984). Some microorganisms cannot use certain forms of nutrients because they are unable to process them. Large molecules, especially those with different types of bonds, cannot be easily broken down by most microorganisms, and this slows the decomposition process significantly. As a result, some types of feedstock break down more slowly than others, regardless of composting conditions (Gray *et al.,*1971a). For example, lignin (found in wood) or chitin (present in shellfish exoskeletons) are very large, complex molecules and are not readily available to microorganisms as food. These materials therefore decompose slowly.

The C:N ratio is a common indicator of the availability of compounds for microbial use. The measure is related to the proportion of carbon and nitrogen in the microorganisms themselves.

High C:N ratios (high C and Low N levels) inhibit the growth of microorganisms that degrade compost feedstock. Low C:N ratios (Low C and high N levels) initially accelerate microbial growth and decomposition. With this acceleration, however, available oxygen is rapidly depleted and anaerobic, foul-smelling conditions result if the pile is not aerated properly. The excess N is released as ammonia gas. Extremeamounts of N in a composting mass can form enough ammoniato be toxic to the microbial population, futher inhibiting the composting process (Gray *et al.,* 1971b; Haug, 1980). Excess N can also be lost in leachate, in either nitrate, ammonia, or organic forms (Richard, 1992b).

4.2.4 Moisture

The moisture content of a composting pile is interconnected with many other composting parameters, including moisture content of the feedstock microbial activity within the pile, oxygen levels, and temperature. Microorganisms require moisture to assimilate nutrients, metabolize new cells, and reproduce. They also produce water as part of the decomposition process. If water is accumulated faster than it is eliminated via either aeration or evaporation (driven by high temperatures), then oxygen flow is impeded and anaerobic conditions result (Gray *et al.,* 1971b). This usually occurs at a moisture level of about 65 percent (Rynket, 1992).

Water is the key ingredient that transports substances within the composting mass and makes the nutrients physically and chemically accessible to the microbes. If the moisture level drops below about 40 to 45 percent, the nutrients are no longer in an aqueous medium and easily available to the microorganisms. Their microbial activity decreases and the composting process slows. Below 20 percent moisture, very little microbial activity occurs (Haug, 1980).

4.2.5 Temperature

Temperature is a critical factor in determining the rate of decomposition that takes place in a composting pile composting temperatures largely depend on how the heat generated by the microorganisms is offset by the heat lost through controlled aeration, surface cooling, and moisture losses (Richard, 1992a). The most effective composting temperatures are between 45 and 59ºC (113 and 138 ºF) (Richard, 1992a). If temperatures are less than 20 ºC (68 ºF), the microbes do not proliferate and decomposition slow. If temperatures are greater than 59ºC (138 ºF), some microorganisms are inhibited or killed, and the reduced diversity of organisms resuits in lower rates of decomposition (Finstein *et al.,* 1986).

Microorganisms tend to decompose materials most efficiently at the higher ends of their tolerated temperature ranges. The rate of microbial decomposition therefore increases as temperatures rise until an absolute upper limit is reached. As a result, the most effective compost managing plan is to maintain

temperatures at the highest level possible without inhibiting the rate of microbial decomposition (Richard, 1992a; Rynket, 1992).

4.2.6 pH

The pH of a substance is a measure of its acidity or alkalinity (a function of the hydrogen ion concentration), described by a number ranging from 1 to 14. A pH of 7 indicates a neutral substance, whereas a substance with pH level below 7 is considered to be acidic, and a substance with a pH higher than 7 is alkaline. Bacteria prefer a pH between 6 and 7.5. Fungi thrive in a wider range of pH levels than bacteria, in general preferringa pH between 5.5 and 8 (Boyd, 1984). If the pH drops below 6, microorganisms, especially bacteria, die off and decomposition slows (Wiley, 1956). If the pH reaches 9, nitrogen is converted to ammonia and becomes unavailable to organisms (Rynket, 1992). This too slows the decomposition process.

Similar to temperature, pH levels tend to follow a successional pattern through the composting process. Figure 3, shows the progression of pH over time in a composting pile. As is illustrated, most decomposition takes place between pH 5.5 and 9 (Rynket, 1992; Gray *et al.,* 1970). During the start of the composting process, organic acids typically are formed and the composting materials usually become acidic with a pH of about 5. At this point, the acid-tolerating fungi play a significant role in decomposition. Microorganisms soon breakdown the acids, however, and the pH levels gradually rise to a more neutral range, or even as high as 8.5. The role of bacteria in composting increases in predominance again as pH levels rise. If the pH does not rise, this could be an indication that the compost product is not fully matured or cured.

METERIALS AND METHODS

Meterials

1. Equipments

1.1 pH Meter
1.2 Hammermill Shredder
1.3 Soil Thermometer
1.4 Dessiccator
1.5 Gas Chromatograph
1.6 Atom Analyzer
1.7 Analytical Balance
1.8 Shaker
1.9 Digestion Apparatus
1.10 Kjeldahl Distillation Apparatus
1.11 Digestion Tube 250 ml
1.12 Oven
1.13 Beaker 10, 25, 100, 250, 600 and 1,000 ml
1.14 Elenmayer Flask 250 ml
1.15 Buret 50 ml
1.16 Pipet 10, 25 ml
1.17 Cylinder 10, 50 and 100 ml

2. Chemicals

2.1 Sulfuric acid (H_2SO_4)
2.2 Nitric acid (HNO_3)
2.3 Hydrochloric acid (HCl)
2.4 Ascorbic acid
2.5 Boric acid (H_2BO_3)
2.6 Copper Sulfate ($CuSO_4$)
2.7 Potassium Sulfate (K_2SO_4)
2.8 Potassium Nitrate (KNO_3)
2.9 Potassium dichromate ($K_2Cr_2O_7$)
2.10 Potassium dihydrogenphosphate (KH_2PO_4)
2.11 Potassiumantimonyltatrate[$K(SbO)C_4H_4O_6.2H_2O$]
2.12 Sodium hydroxide (NaOH)
2.13 Sodiumhydrogen carbonate ($NaHCO_3$)
2.14 Ferrous Ammonium Sulfate [$Fe(NH_4)_2(SO_4)_2$]
2.15 Ferrous Sulfate Heptahydrate ($FeSO_4.7H_2O$)
2.16 Ammoniummolibdate [$(NH_4)_6Mo_7O_{24}.4H_2O$]
2.17 O-phenanthroline
2.18 Phenopthaline Indicator

3. Materials

3.1 TCE Contaminated Soil
3.2 Chicken manure

Methods

1. Experiment setup for soil–compost treatment

The experiment was setup into 10 groups. Soil samples were taken from AIT Campus, and chicken manure was taken from Department of Animal Science at Kasetsart University TCE and Cd were added to soil samples in the ratios 0:0 (ER1), 50:0 (ER2), 1000:0 (ER3), 0:3 (ER4), 0:30 (ER5), 50:3 (ER6), 50:30 (ER7), 1000:3 (ER8), 1000:30 (ER9). Soil sample in ER10 experiment was a soil from mesocosm unit experiment which was contaminated with TCE. The composting experiment has been studied for 10 weeks.

Table 6 Experiment setup for soil–compost treatment

Experiment	Components	TCE (ppm)	Cd (ppm)
ER1	Soil and Chicken manure	0	0
ER2	Soil and Chicken manure	50	0
ER3	Soil and Chicken manure	1000	0
ER4	Soil and Chicken manure	0	3
ER5	Soil and Chicken manure	0	30
ER6	Soil and Chicken manure	50	3
ER7	Soil and Chicken manure	50	30
ER8	Soil and Chicken manure	1000	3
ER9	Soil and Chicken manure	1000	30
ER10	soil from mesocosm unit experiment	11.18	0

2. Soil sampling and analysis

Twenty compost sample was collected from each experiments in every 7 days for a period of 10 weeks. Samples collected for TCE and VC analysis were analyzed immediately after collected. Samples collected for cadmium analysis were kept in poly bag and refrigerated at 4°C until analysis.

3. Compost sample analysis for TCE and VC

Ten grams of sample was put in 50 ml glass vial. Ten ml of methanol and 30 ml of de-ionized water were added to the sample and closed immediately with Teflon lined rubber and aluminium cap. The vial was shaked manually of about one minute for thorough mixing and kept at room temperature for 24 hours. Then, shaken in incubator shaker (Yamato, IK41) at 60 rpm, 25°C for 4 hours. Head space gas was analyzed by GC-ECD (HP 5890 Series II) through manual injection by micro syringe

of 0.1ml/injection. Concentration was calculated from the peak area and compared with the standard curve made for TCE and VC. The unit was expressed as ppb.

4. Compost sample analysis for cadmium

Samples were air dried, grinded with mortar-pestle and then weighed 5 grams dried grinded soil was added to 50 ml of concentrated HNO_3 (69% BDH AnalaR) at the rate of 10 ml HNO_3 for 1 grams of soil and left for twenty hours. The solution was heated on hot plate (Thermolyne, Type 2200) at 125°C until the appearance of brown transparent color. The solution was filtered through whatman filter paper (GF/C 47 mm, Cat No: 1822047) and volume was adjusted up to 50 ml in volumetric flask. The filtrate was analyzed by Atomic Absorption Spectrophotometer (Polarized Zeeman AAS, Hitachi Z-8230). The unit was expressed as ppm.

5. Mass balance

A simple mass balance was introduced for evaluation of the removal of TCE and Cd from the contaminated compost.

Mass balance equation:

$$\text{Input} = \text{Removal} + \text{Output}$$

6. Data analysis

Microsoft excel with statistical package and computer software was employed for analyzing all the measured data.

RESULTS AND DISCUSSION

1. Characteristics of composting components.

The ingredients of compost mixing were soil from agricultural farm at AIT campus and chicken manure from Department of Animal Science at Kasetsart University. In this experiment, 10 kg soil and 2 kg chicken manure were mixed to get the initial C/N ratio of 26.1/1. The characteristics of soil and chicken manure before mixed were shown in Table 7.

Table 7 Characteristics of composting components.

Characteristics / Components	% MC	% C	% N	C/N	Dry Weight (kg)	Wet Weight (kg)	C/N ratio
Soil	62.20	16.06	0.04	401.50	6.22	10.00	26.1/1
Chicken manure	87.06	37.95	3.51	10.81	1.74	2.00	

Note MC = Moisture Content
C = Carbon
N = Nitrogen

Initial characteristics of mixing components were in Table 8.

Table 8 Initial characteristics of mixing components.

Characteristics	Experiments									
	ER1	ER2	ER3	ER4	ER5	ER6	ER7	ER8	ER9	ER10
C/N ratio	26.1/1	26.1/1	26.1/1	26.1/1	26.1/1	26.1/1	26.1/1	26.1/1	26.1/1	26.1/1
Temperature (^{O}C)	30.00	30.60	30.70	30.80	30.50	30.30	30.10	30.00	29.80	29.40
pH	5.50	5.70	5.40	5.50	5.10	4.90	4.90	5.10	5.20	5.30
Moisture (%)	41.23	43.72	43.04	41.63	45.39	44.24	44.7	46.53	44.71	48.41
Carbon (%)	23.89	26.88	23.79	24.89	24.78	24.15	24.63	24.09	24.84	23.98
Nitrate (%)	0.108	0.107	0.090	0.062	0.137	0.100	0.092	0.092	0.084	0.162
Phosphate (%)	0.027	0.019	0.014	0.015	0.017	0.023	0.020	0.015	0.021	0.006

Means, n=4

Characteristics of composting material after 10 weeks of composting process were in Table 9.

Table 9 Characteristics of mixing components after composting.

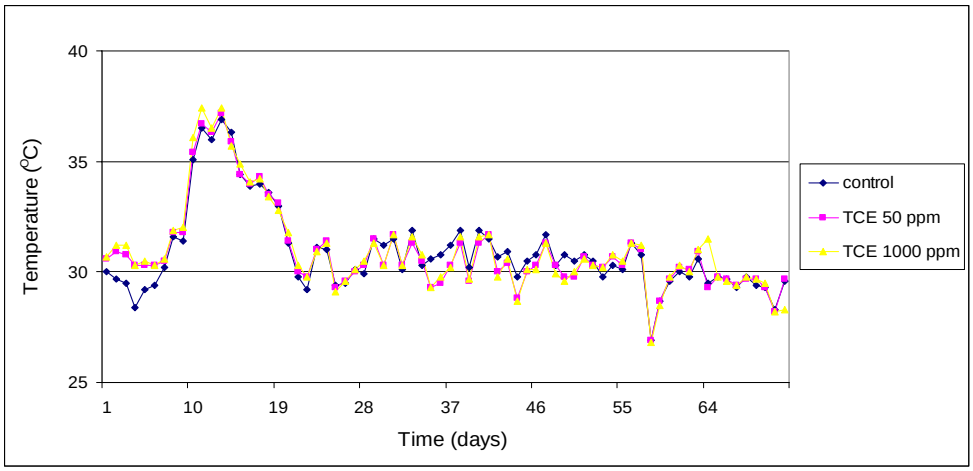
Characteristics	Experiments									
	ER1	**ER2**	**ER3**	**ER4**	**ER5**	**ER6**	**ER7**	**ER8**	**ER9**	**ER10**
C/N ratio	18.9/1	20.1/1	21.9/1	18.8/1	19.4/1	21.9/1	20.8/1	23.3/1	25.2/1	16.0/1
Temperature (^{O}C)	29.60	29.70	28.30	29.90	29.80	29.80	29.70	29.70	29.60	29.70
pH	6.30	6.30	6.30	6.40	6.30	6.40	6.30	6.40	6.30	6.40
Moisture (%)	48.45	46.57	48.69	49.17	43.09	43.85	48.02	40.25	42.22	43.20
Carbon (%)	16.28	16.61	18.94	16.81	16.48	20.01	18.03	20.4	20.54	12.27
Nitrate (%)	0.245	0.272	0.248	0.246	0.278	0.292	0.306	0.303	0.304	0.346
Phosphate (%)	0.031	0.027	0.028	0.028	0.035	0.038	0.038	0.036	0.038	0.010

Means, n=4

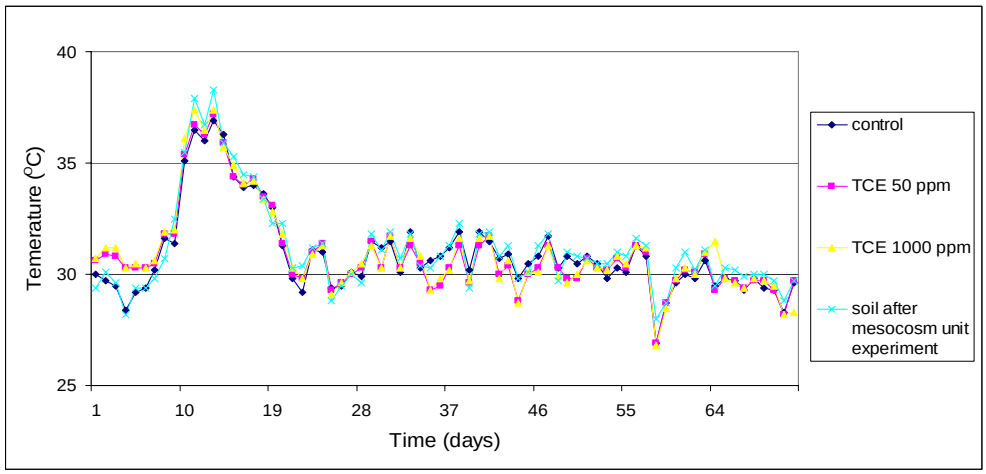
After composting process C/N ratio of every experiments were decreased due to the activity of the microorganism consumed carbon as energy source and nitrogen to produce new cell. The compost temperature before and after composting process was nearly to the room temperature, initial pH was low due to the organic acid from the biodegradation and at the end of experiment pH was increasing due to some other types of microorganism used organic acid in methane producing stage. At the end of experiment, pH was rather steady at 6.3. During the experiment, moisture content usually fluctuate as well as the ambient temperature. Water was added to compost to control moisture content. The properly moisture content was between 40-70%. At the end of experiment, nitrate and phosphate content were higher than the initial ones. They were produced from biodegradation of organic compound.

2. Compost characteristics during the composting process.

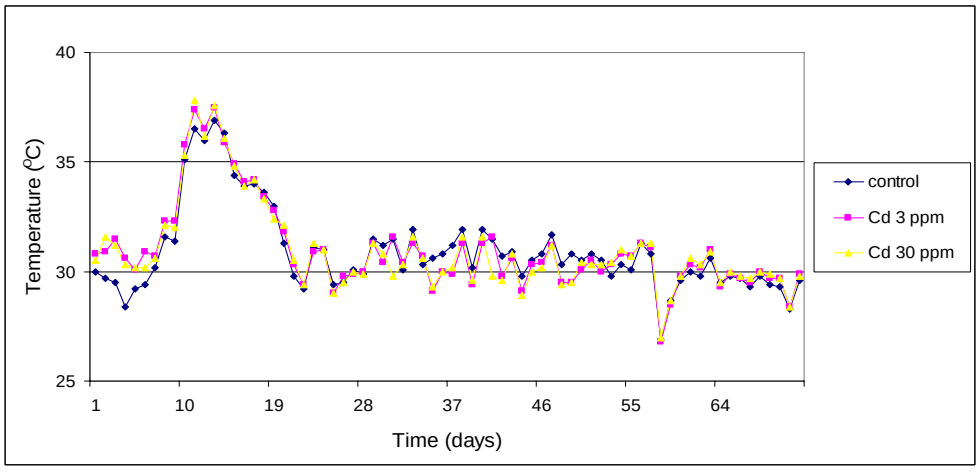
2.1 Temperature



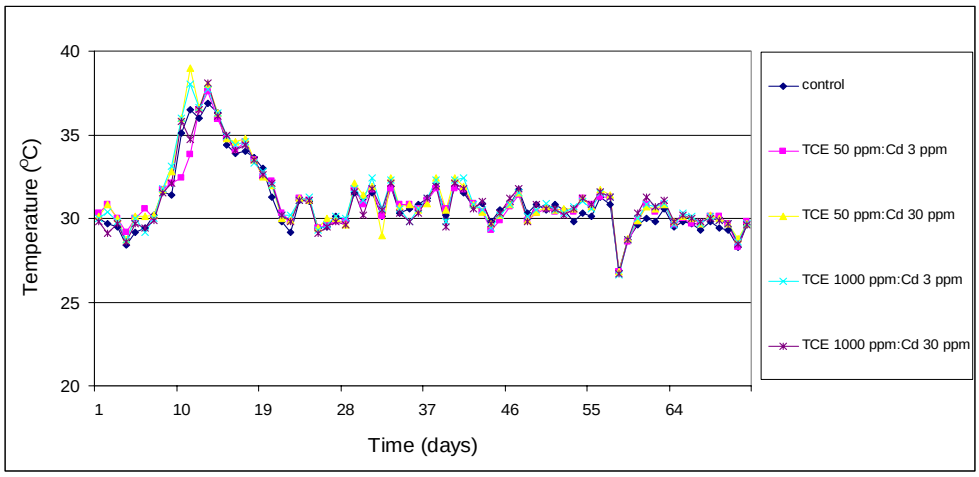
(a)



(b)



(c)



(d)

Initial average temperature of 10 experiments was about 30 ºC and continueously increasing for 12 days. The highest temperature of each experiment was on the 11th day of composting. The highest temperature was about 39 ºC and slowly decrease to 29-30 ºC. The compost temperature was fluctuated according to the weather outside which was not steady. However, there was no different of temperature change in each experiments (Figure 4).

The temperature increasing during 0-12 days was due to heat released from biodegradation activities of aerobic bacteria.

$$\text{(CHONS)} + \text{aerobic bacteria} \longrightarrow CO_2 + NH_3 + CH_4 + \text{other end products} + \text{energy (heat)}$$

Small increasing of temperature in some periods after day 24th to the end of experiment which might be the heat releasing from the reaction that changed methane (CH_4) to methanol (CH_3OH).

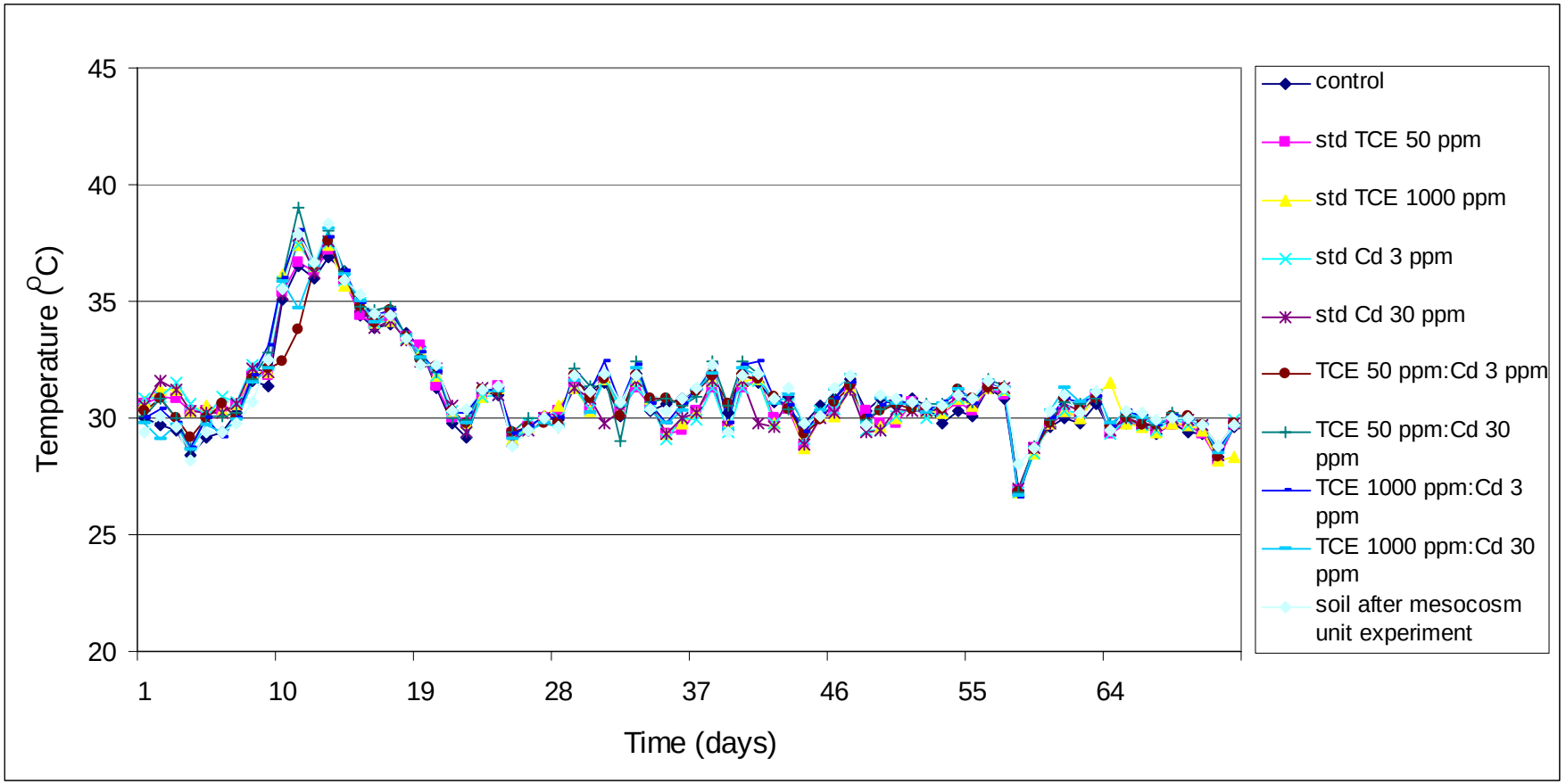
$$CH_4 + H_2O \longrightarrow CO + 3H_2$$

$$CO + 2H_2 \longrightarrow CH_3OH + \text{heat}$$

(Tchobanoglous, 1993)

This reaction released the heat energy that causing the temperature increase.

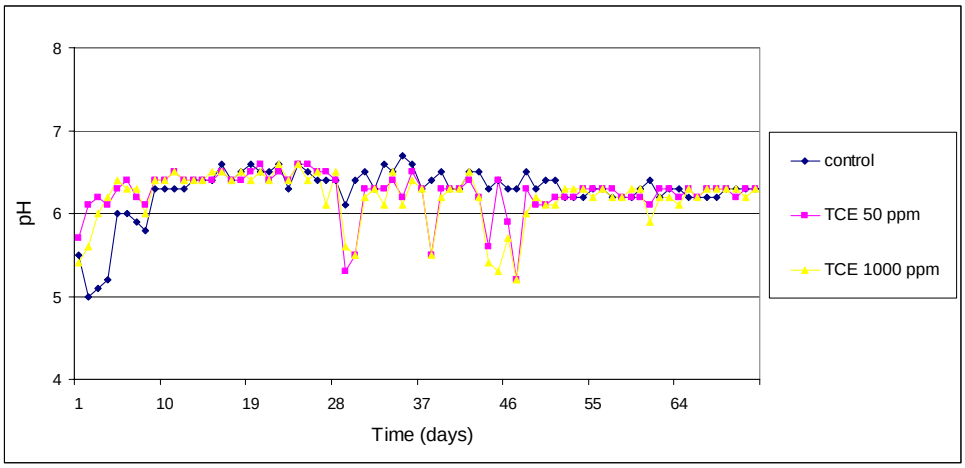
The temperature in day 54th was decreased because the heavy rain causing the temperature decreased.



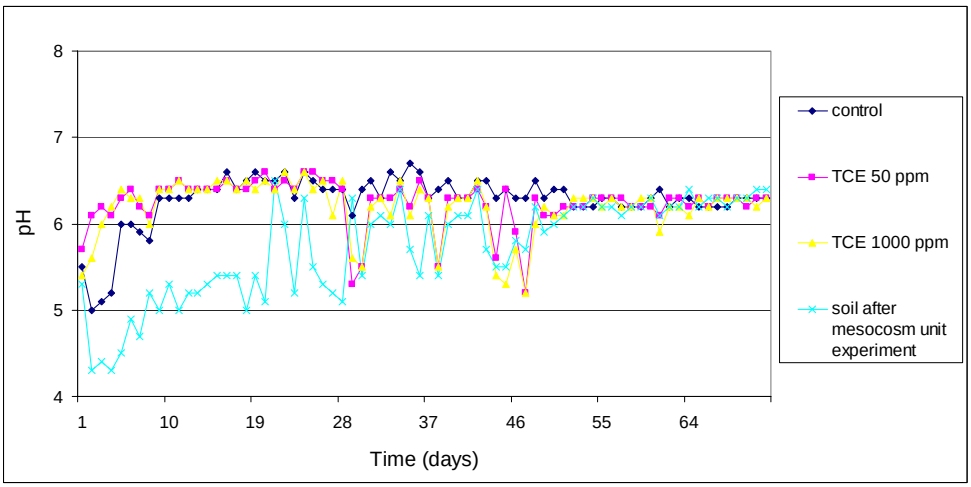
(e)

Figure 4 Average daily temperature (a): Control TCE; (b): Control TCE and soil after mesocosm unit experiment; (c): Control Cd; (d): Experiment which add TCE and Cd in differents concentration; (e): Average daily temperature of every experiments.

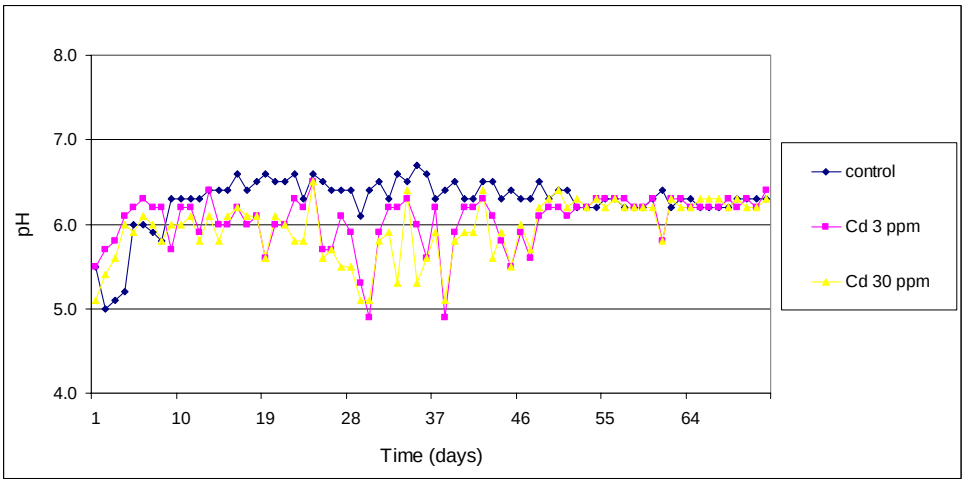
2.2 pH


8
7
6
5
4
pH
1
10
19
28
37
46
55
64
Time (days)
control
TCE 50 ppm
TCE 1000 ppm

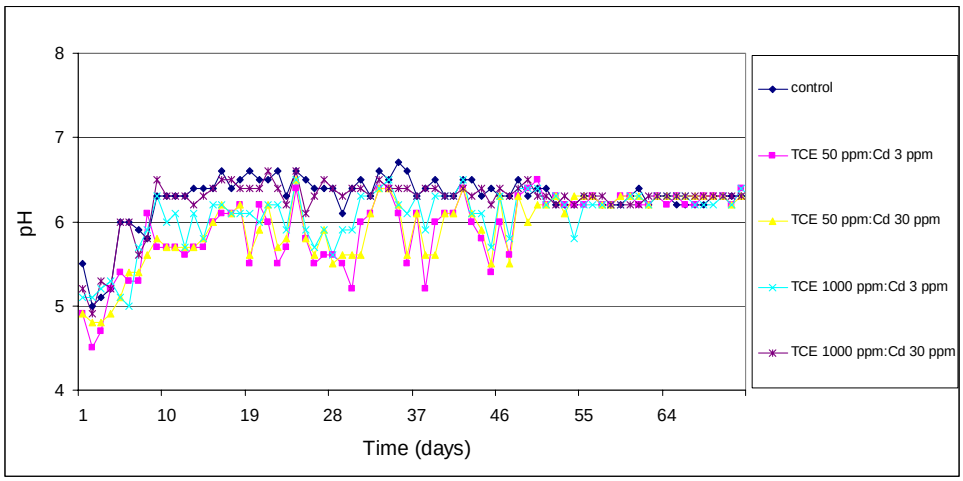
(a)


8
7
6
5
4
pH
1
10
19
28
37
46
55
64
Time (days)
control
TCE 50 ppm
TCE 1000 ppm
soil after mesocosm unit experiment

(b)


8.0
7.0
6.0
5.0
4.0
pH
1
10
19
28
37
46
55
64
Time (days)
control
Cd 3 ppm
Cd 30 ppm

(c)



(d)

Initial pH of 10 experiments were about 5.3 and increased to nearly steady at 6.3. There was no different of pH in every experiments (Figure 5).

In the begining period of experiments pH was low due to the organic acid released from the biodegradation process. Initial pH was about 5.

$$\text{(CHONS)} + \text{aerobic bacteria} \longrightarrow CO_2 + NH_3 + CH_4 + \text{other end products} + \text{energy (heat)}$$

As from the equation above, CO_2 combined with water forming carbonic acid (H_2CO_3) causing compost pH decrease. pH and temperature were revealed in the some pattern. This was shown that biodegradation activity of aerobic bacteria was high with organic acids and decreased pH. Consequently, the other types of aerobic bacteria used bacteria as a raw material to produce their own energy yeilding methane (CH_4) as the product.

$$4HCOOH \longrightarrow CH_4 + 3CO_2 + H_2O$$

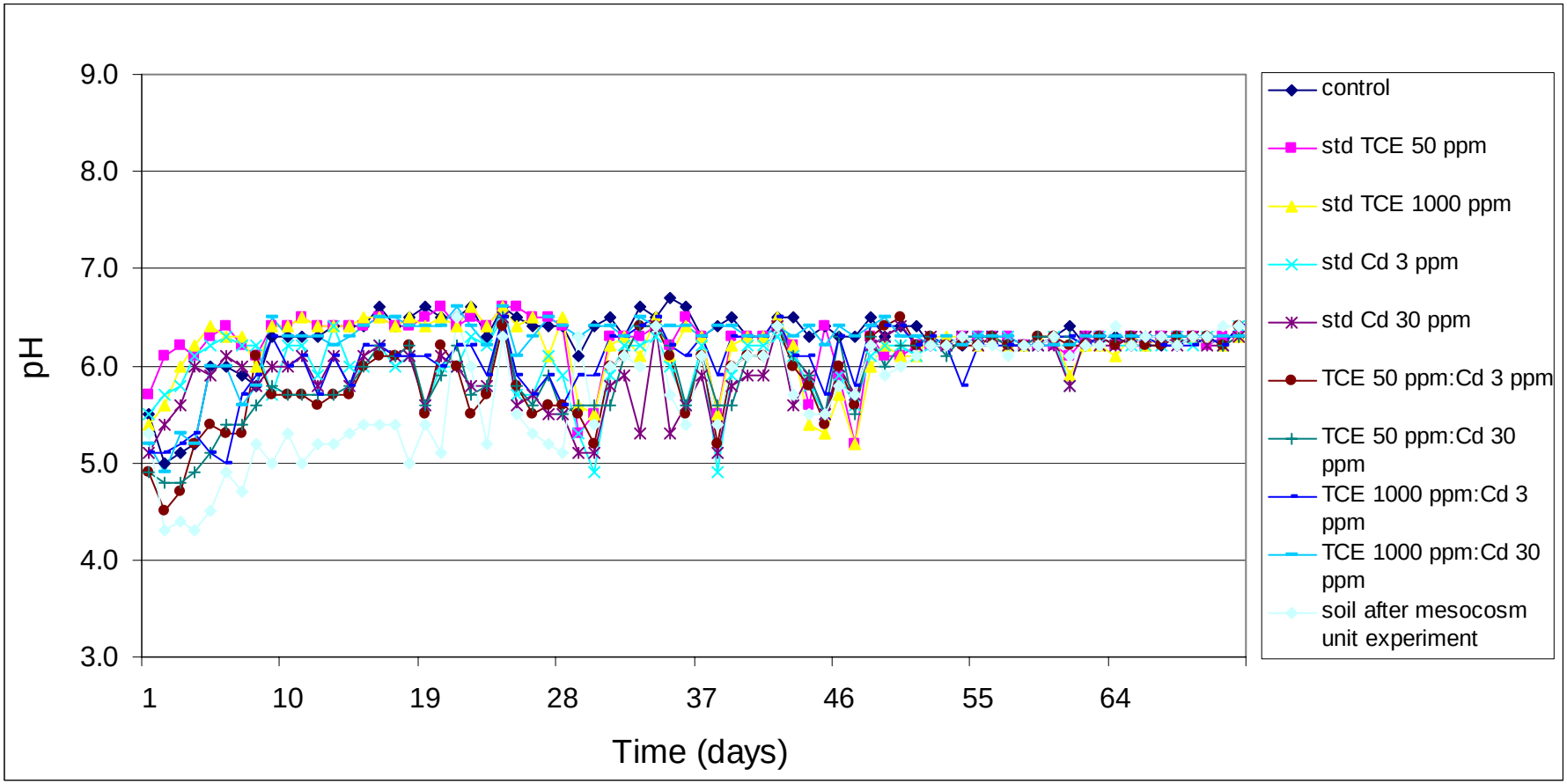
$$4CH_3OH \longrightarrow 3CH_4 + CO_2 + 2H_2O$$

When organic acid was used in methane producing stage, pH was increasing from 5.8 to 6.5 (Tchobanoglous et al., 1993), however, pH was decreased in some periods because of methanol produced.

$$CH_4 + H_2O \longrightarrow CO + 3H_2$$

$$CO + 2H_2 \longrightarrow CH_3OH$$

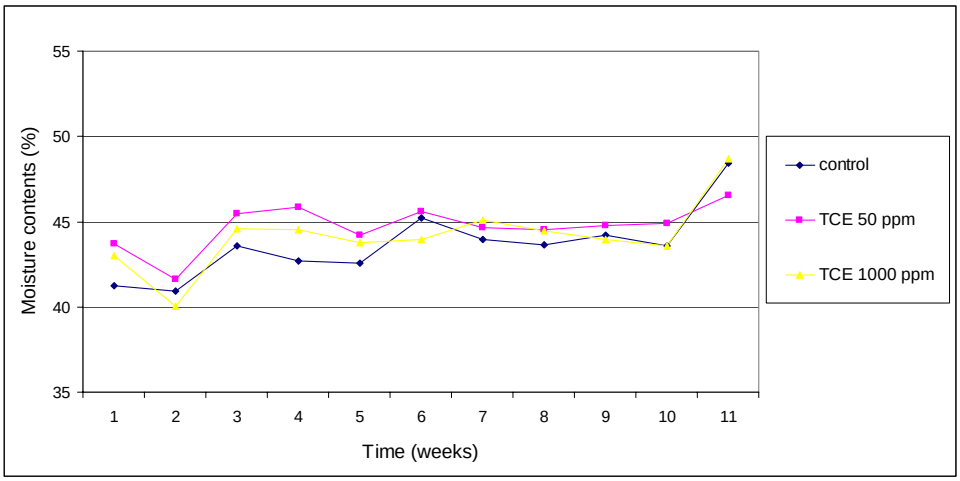
At the end of experiment, pH was rather steady at 6.3.



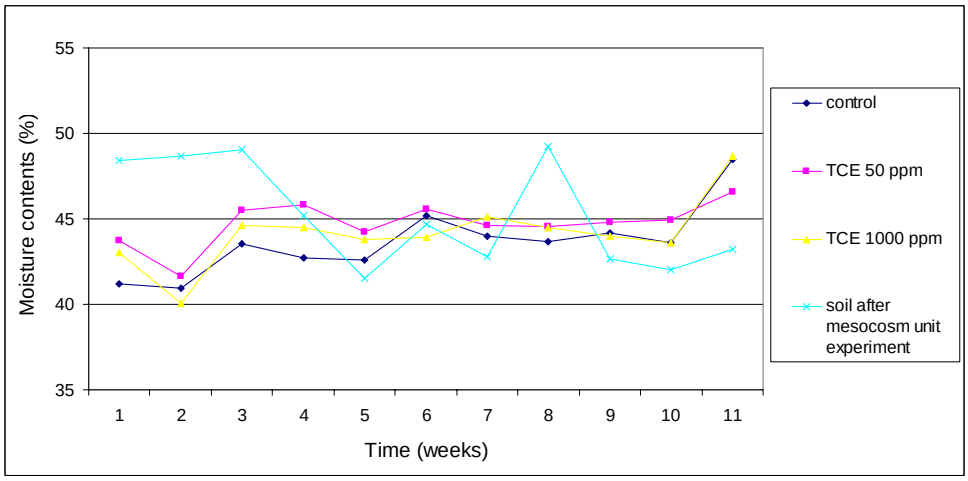
(e)

Figure 5 Average daily pH. (a): Control TCE; (b): Control TCE and soil after mesocosm unit experiment; (c): Control Cd; (d): Experiment which add TCE and Cd in differents concentration; (e): Average daily pH of every experiments.

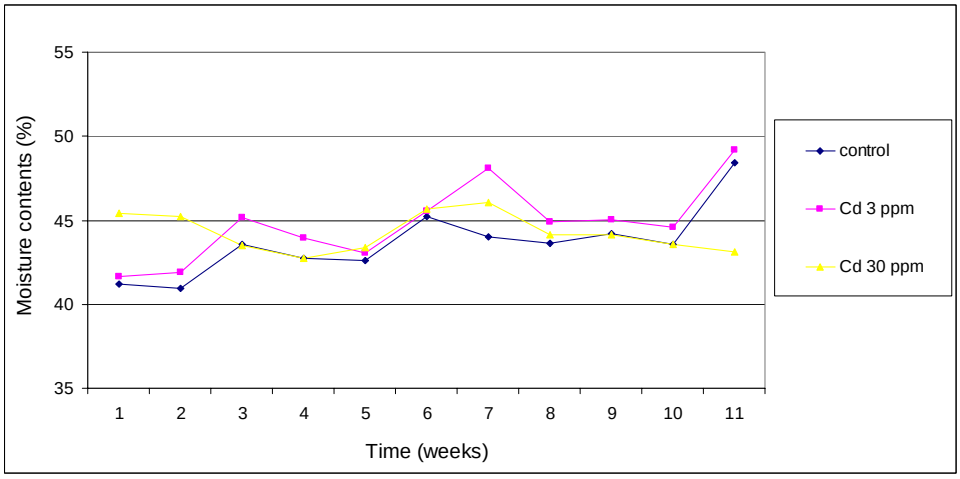
2.3 moisture content



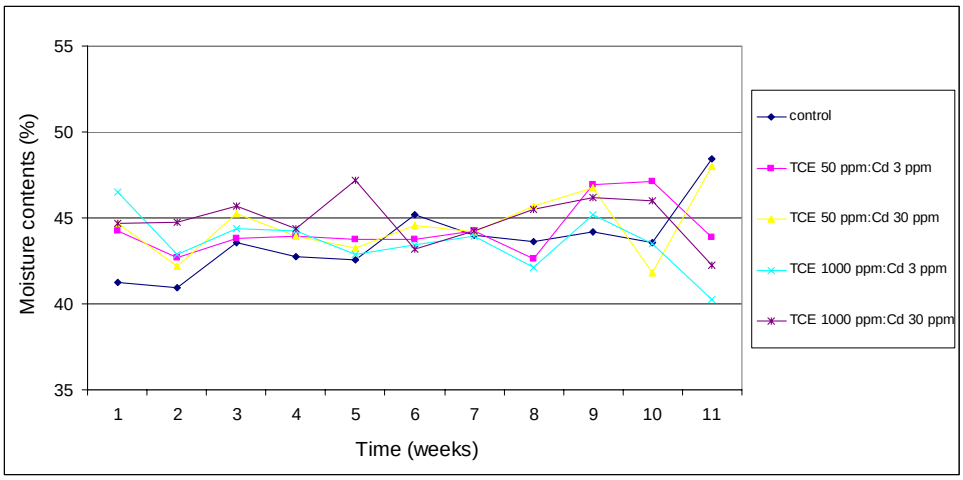
(a)



(b)



(c)



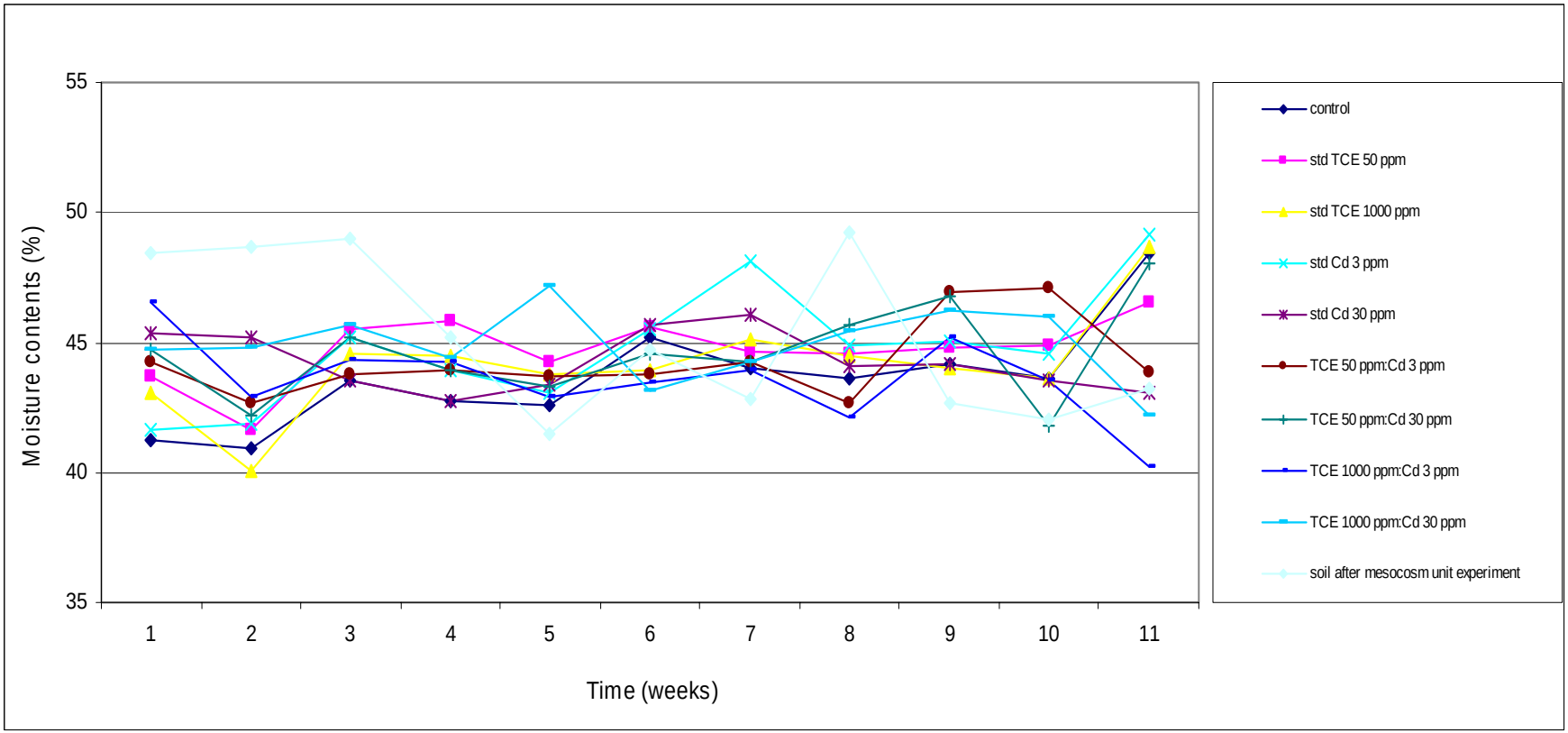
(d)

The initial moisture content of 10 experiments was about 44.5%. Moisture content was one important factor of the reaction in composting process. In Figure 6, the weekly moisture content of composting process was usually changed as well as the ambient temperature. Water was added to compost to control moisture content about 40-70%. At week 10^{th} the moisture of the compost was quite high due to some leachate was unintended mixed with compos.

The compost moisture was decreased. Some parts of water has been used in hydrolysis reaction.

$$4(CH_3)_3N + 6H_2O \longrightarrow 9CH_4 + 3CO_2 + 4NH_3$$

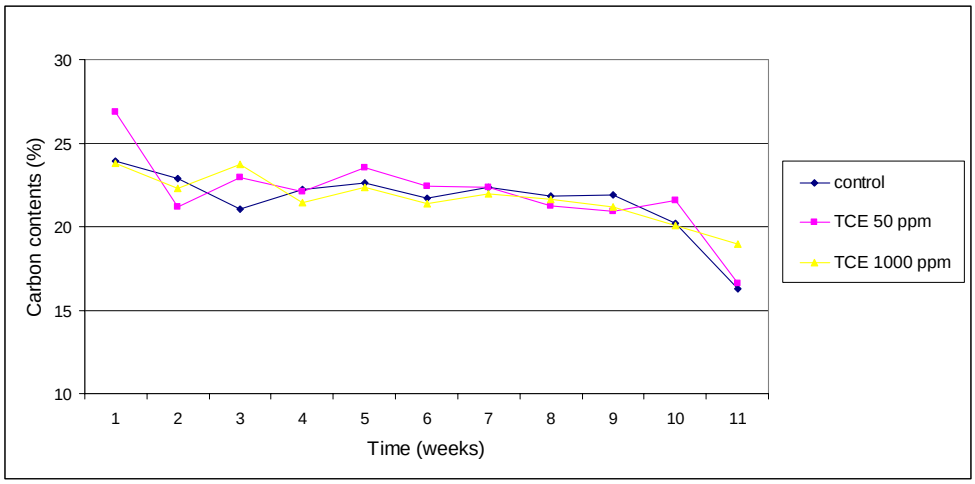
During the composting process, an aerobic bacteria had various activities to released heat energy from reaction which caused the compost temperature to be increased.



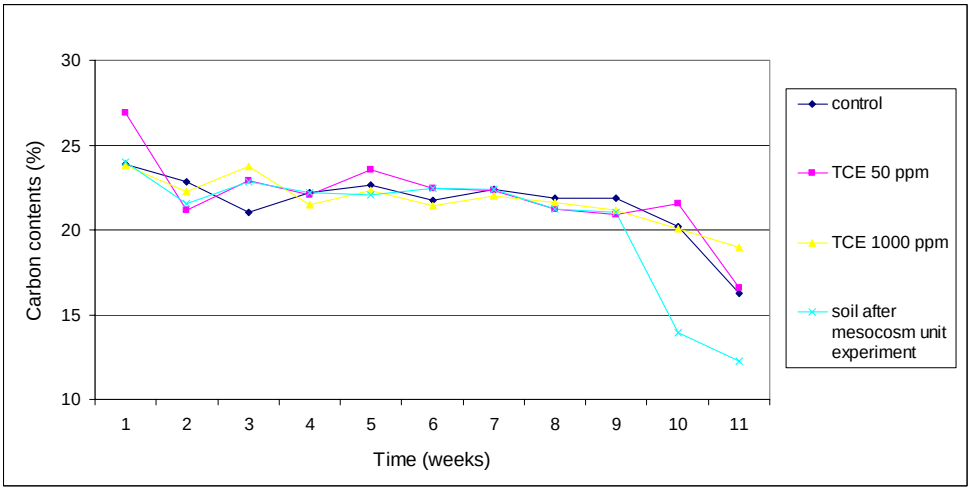
(e)

Figure 6 Average weekly moisture content. (a): Control TCE; (b): Control TCE and soil after mesocosm unit experiment; (c): Control Cd; (d): Experiment which add TCE and Cd in differents concentration; (e): Average daily temperature of every experiments.

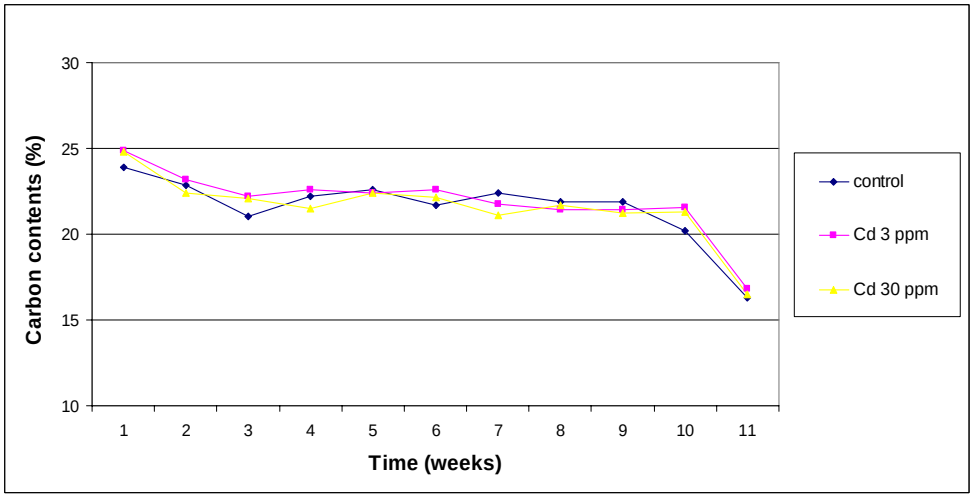
2.4 Carbon content



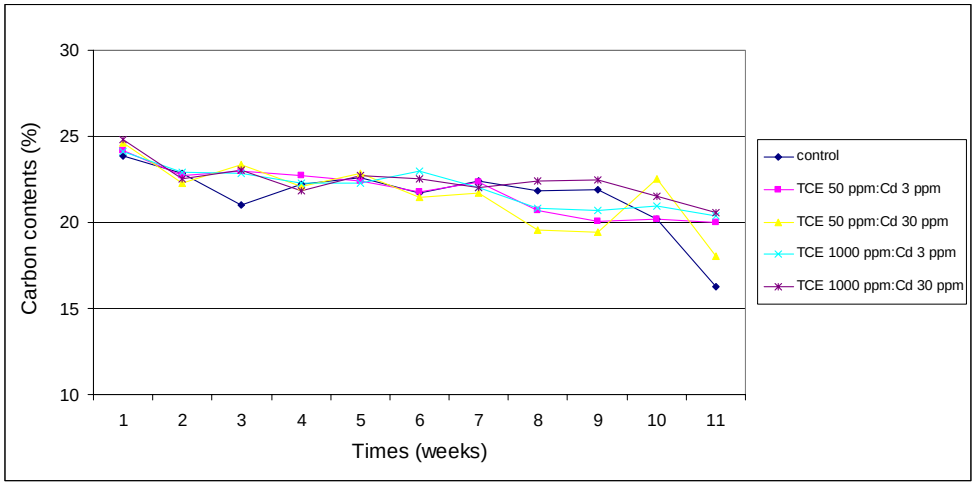
(a)



(b)



(c)

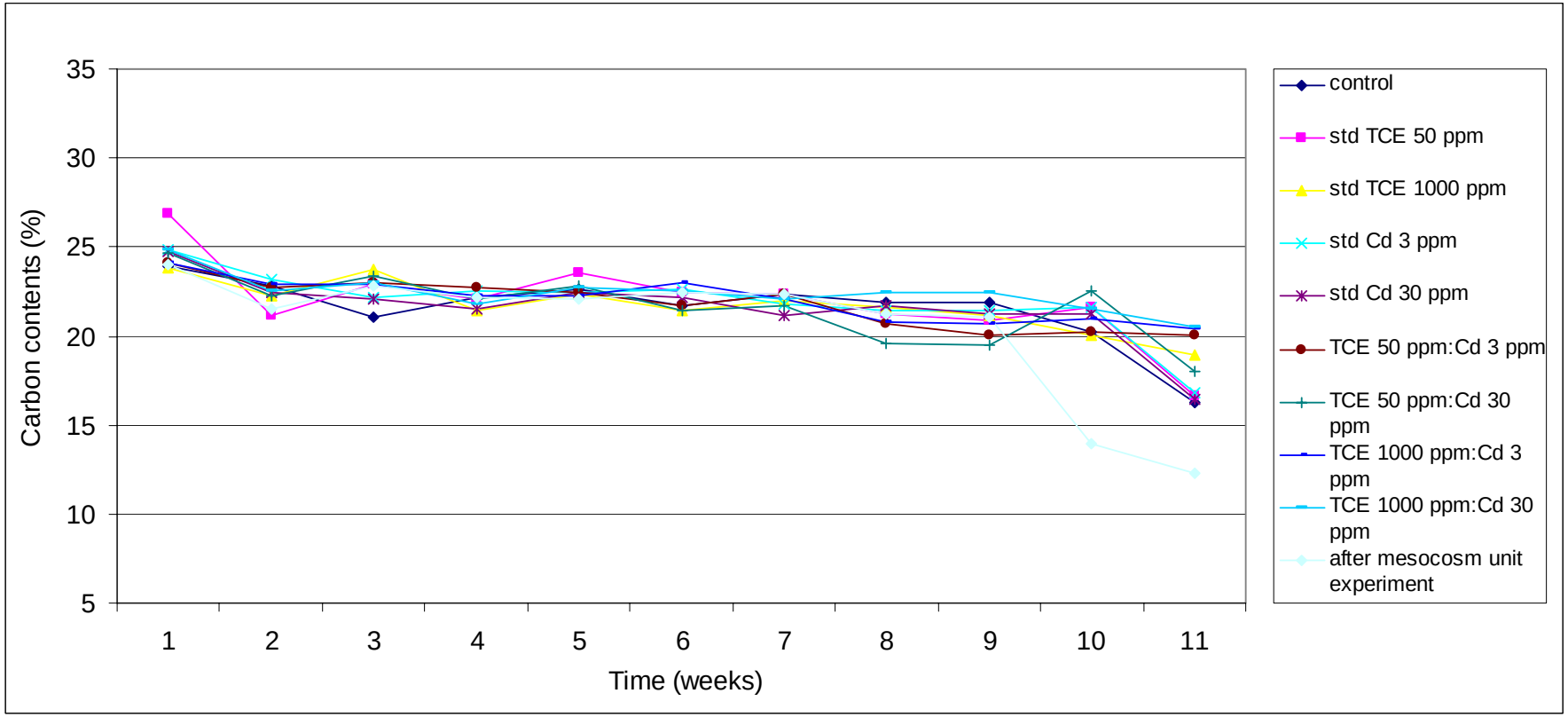


(d)

The initial average of carbon in 10 experiments was 24.5%. After completed composting process carbon was decreased. During the composting period aerobic bacteria consumed carbon as energy source.

$$\text{(CHONS)} + \text{aerobic bacteria} \longrightarrow CO_2 + NH_3 + CH_4 + \text{other end products} + \text{energy (heat)}$$

With the ANOVA statistic calculation at significance 0.05 and 0.01, it was found that the changed of carbon content in composting of each experiment had no different in significance. Carbon content after composting period was 16-20% (Figure 7).



(e)

Figure 7 Average weekly carbon content. (a): Control TCE; (b): Control TCE and soil after mesocosm unit experiment; (c): Control Cd; (d): Experiment which add TCE and Cd in differents concentration; (e): Average weekly carbon content of every experiments.

2.5 Nitrate content

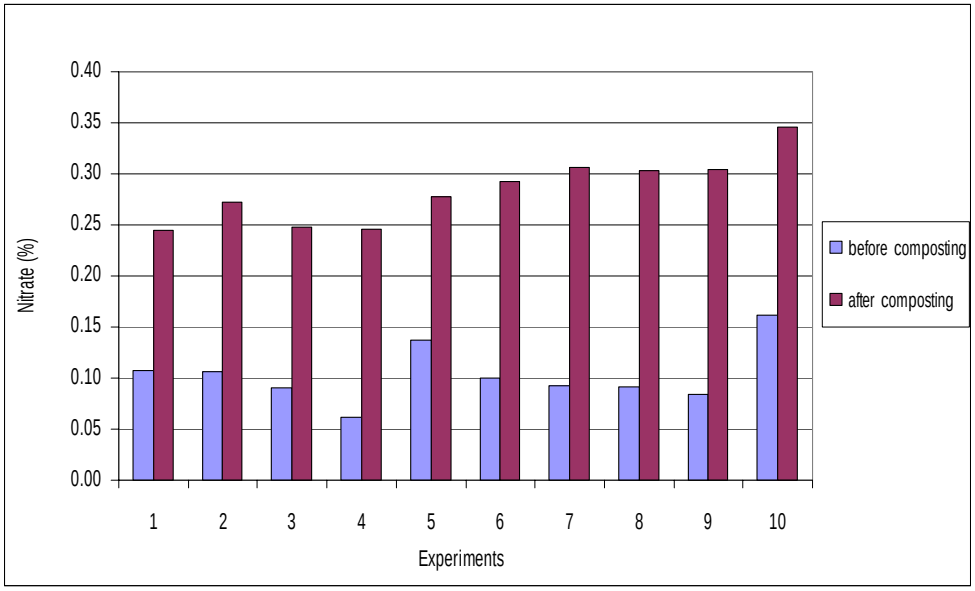


Figure 8 Average nitrate content.

The initial average nitrate content of 10 experiments was 0.06-0.16%. At the end of experiments, nitrate content was increased in all experiments (Figure 8).

The increased of nitrate content in composting was from the activities of aerobic bacteria in nitrification reaction that converted ammonia to nitrate form.

$$3NH_3 + 3O_2 \longrightarrow 2HNO_2 + 2H_2O$$

$$HNO_2 + 1/2O_2 \longrightarrow HNO_3$$

The ammonia was come from the reaction of nitrogen biodegradation of aerobic bacteria and ammonia–oxidizing bacteria that converted ammonia to nitrate form. The nitrate content was increased during the period of experiment. The oxygen that aerobic bacteria used in reaction was come from the biodegradation of the composting raw materials, such as carbohydratre. Ammonia–oxidizing bacteria used oxygen to change ammonia to nitrate. The nitrate content was not increased in a big volume because it was lost in the reaction converted nitrate to ammonia as the following equation:

$$HNO_3 + 4H_2 \longrightarrow NH_3 + 3H_2O$$

2.6 Phosphate content

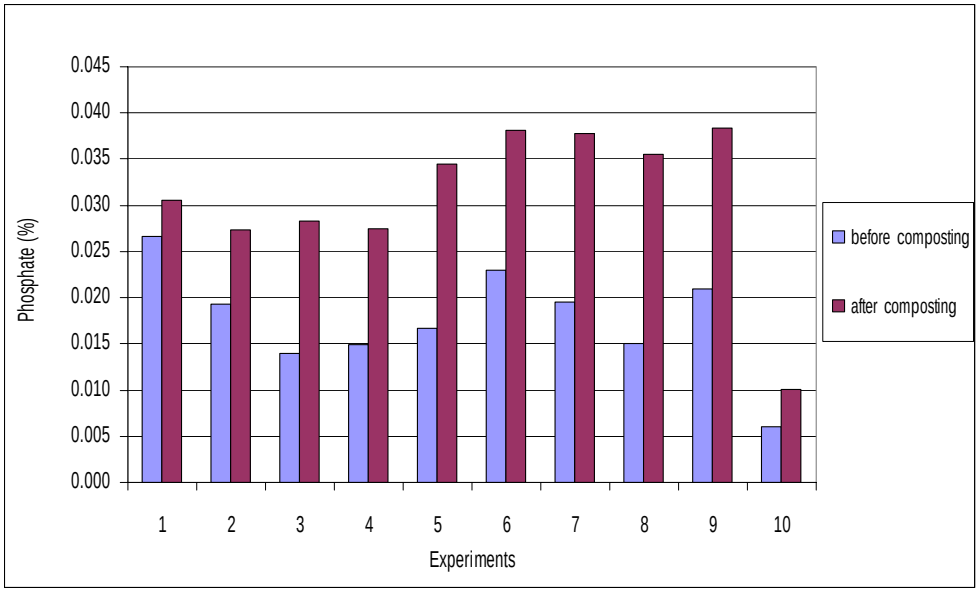


Figure 9 Average phosphate content.

The phosphate content in 10 experiment was 0.006-0.027%. At the end of experiments, the phosphate content was increased in all experiments (Figure 9). It was because the activities of aerobic bacteria in composting and fragmentation of the nutrients to the form that plants can utilize. The activities of bacteria in this period could be identified from the increasing of temperature that was the factor to point out the activities of bacteria in composting. During the biodegradation process, the bacteria released the heat energy.

3. Concentration of TCE and VC in composted soil.

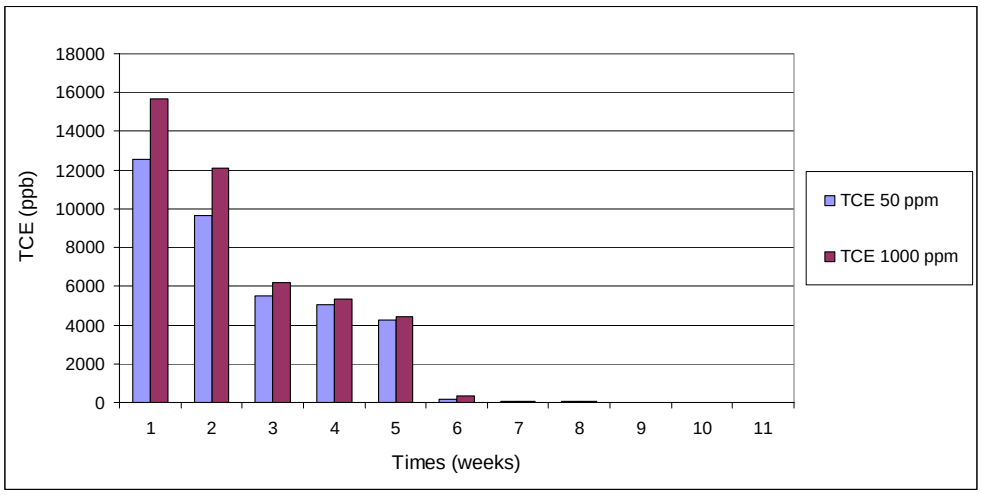
Table 10 Concentration of TCE in composted soil (ppb).

Weeks	Experiment						
	ER2	**ER3**	**ER6**	**ER7**	**ER8**	**ER9**	**ER10**
0	12541.6	15650.5	12430.9	12515.4	15748.3	15181.0	11045.4
1	9642.6	12110.2	9414.5	9340.9	11954.4	11771.8	10025.1
2	5481.8	6191.1	5880.7	6073.2	6977.3	7689.5	6628.3
3	5025.3	5321.5	4960.6	4929.9	6056.8	6660.2	4855.5
4	4261.2	4448.0	2933.4	2514.3	3599.2	3364.5	3067.4
5	186.8	346.3	122.3	621.7	374.4	334.9	594.7
6	50.8	80.4	76.4	67.8	218.0	258.3	251.2
7	30.9	46.6	31.3	25.7	83.0	94.0	85.8
8	11.7	13.6	12.1	11.9	45.1	54.1	48.9
9	9.9	10.8	10.0	9.9	33.3	36.5	34.0
10	5.7	6.4	6.1	5.6	20.7	22.6	23.8

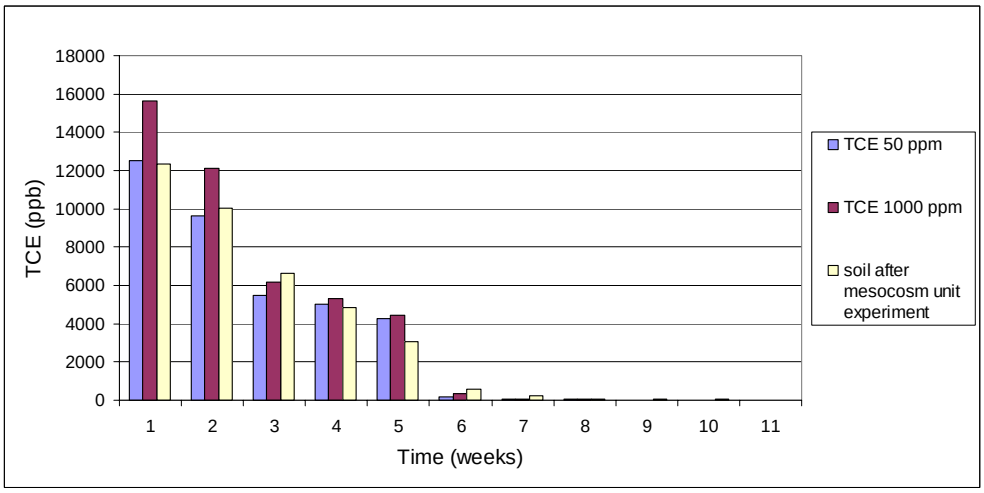
Means, n=4

The concentration of TCE in compost-soil was slowly decreased from week 0 to 10th. The decreasing of TCE in the experiments which was added with TCE in every concentration and the experiment with and without Cd had the similar trend of the ratio of decresing TCE nearly the same (Table 10 and Figure 10). The decreasing of TCE in composting process; ER2, ER3, ER6, ER7, ER8, ER9 and ER10 were 99.87%, 99.99%, 99.88%, 99.89%, 99.99%, 99.99% and 99.79%, respectively.

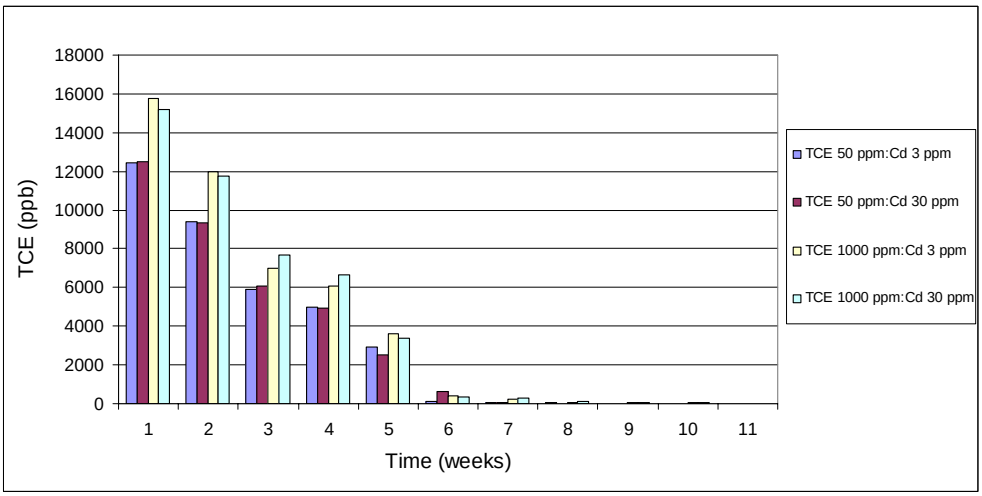
The average temperature in the compost process was 30ºC and highest one was 39 ºC, which played an important role in the overall evaporation of TCE from soil surface. This agrees with the findings of Win (1998). Volatilization as well as microorganism in compost played significant role in the degradation of TCE in soil. The results relates with the study of Sukeson and Watwood (1998). They studied the capacity of finished compost in microbial degradation of TCE within batch reactor. They found that 99% of the head-space TCE removed via biodegradation.


18000
16000
14000
12000
10000
8000
6000
4000
2000
0
TCE (ppb)
1
2
3
4
5
6
7
8
9
10
11
Times (weeks)
TCE 50 ppm
TCE 1000 ppm

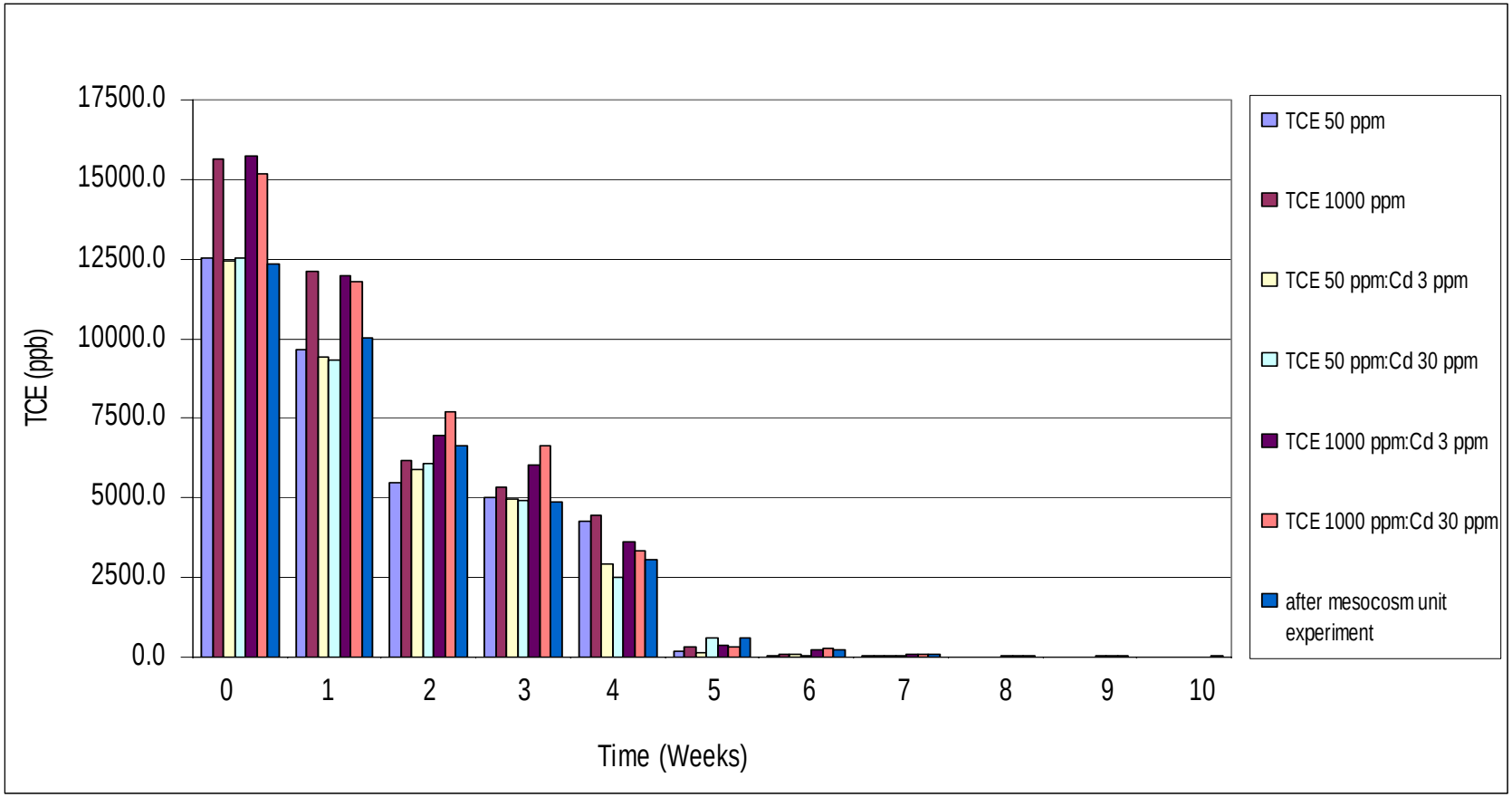
(a)


18000
16000
14000
12000
10000
8000
6000
4000
2000
0
TCE (ppb)
1
2
3
4
5
6
7
8
9
10
11
Time (weeks)
TCE 50 ppm
TCE 1000 ppm
soil after mesocosm unit experiment

(b)


18000
16000
14000
12000
10000
8000
6000
4000
2000
0
TCE (ppb)
1
2
3
4
5
6
7
8
9
10
11
Time (weeks)
TCE 50 ppm:Cd 3 ppm
TCE 50 ppm:Cd 30 ppm
TCE 1000 ppm:Cd 3 ppm
TCE 1000 ppm:Cd 30 ppm

(c)



(d)

Figure 10 Concentration of TCE in compost soil (ppb). (a): Control TCE; (b): Control TCE and soil after mesocosm unit experiment; (c): Experiment which add TCE and Cd in differents concentration; (d): Concentration of TCE in composted soil.

Comparision between the decreasing of TCE in the experiments with and without Cd by ANOVA at significance 0.05 and 0.01, it was found that the decreasing of TCE in each composting experiment had no different in significant.

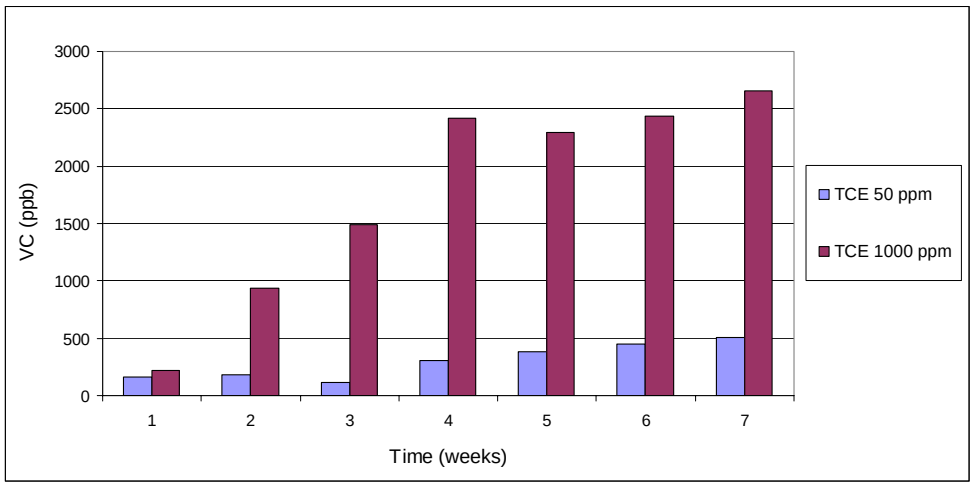
Table 11 Concentration of VC in compost soil (ppb).

Week	Experiment						
	ER2	**ER3**	**ER6**	**ER7**	**ER8**	**ER9**	**ER10**
4	163.4	222.4	263.0	218.8	282.0	506.6	595.8
5	183.0	935.3	330.7	542.7	440.8	1125.8	1408.1
6	200.3	1495.0	378.6	1038.2	968.4	1711.5	1945.7
7	303.3	2416.6	550.8	1704.6	1483.2	2616.7	2699.9
8	380.1	2289.6	1021.3	2814.0	2491.7	4707.4	5462.7
9	448.1	2436.9	1121.3	3625.8	2886.3	5136.6	5763.3
10	510.1	2657.0	2069.7	4151.6	3539.9	5921.8	6146.4

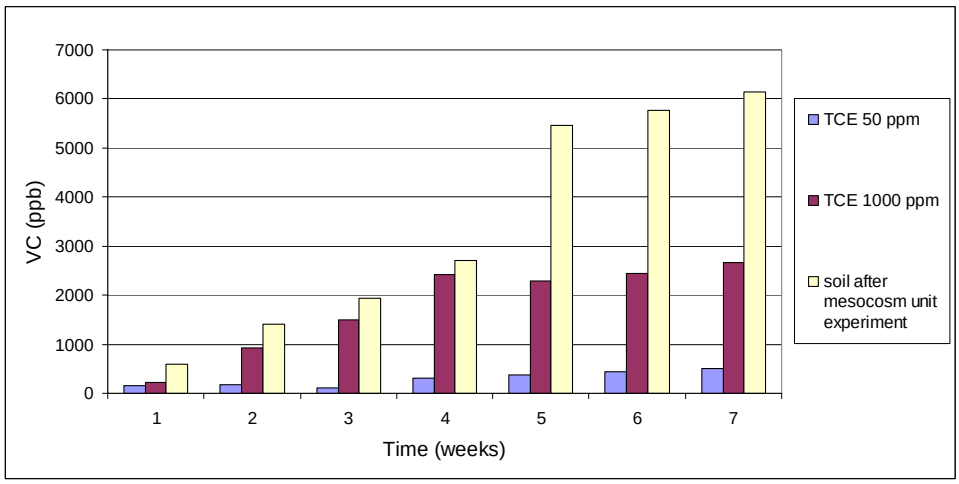
Means, n=4

During week 4^{th} to 10^{th}, the concentration of VC was slowly increasing. When compared with the experiments with TCE in the different concentration (ER2 , ER3) by using the ANOVA, the ratio of increasing of VC had the significance different at significance 0.05 and 0.01. In the experiments with 1000 ppm TCE had higher increasing ratio of VC than the experiment with 50 ppm TCE.

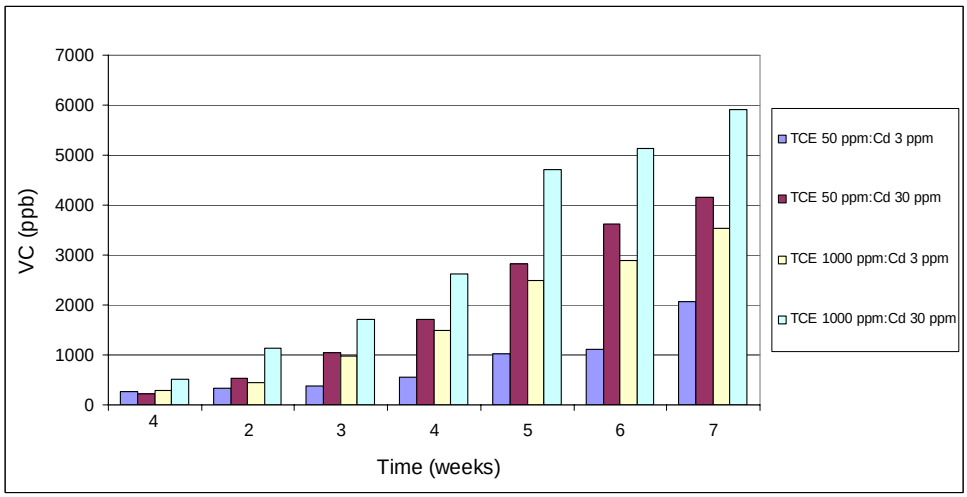
VC in all experiments with Cd in different concentration (ER6, ER7, ER8, ER9) were increased. In the experiment with 30 ppm Cd had higher ratio than the experiment with 3 ppm Cd. The concentration of VC had the significance different at significance 0.05 and 0.01. The increasing of VC show in Table 11 and Figure 11.


3000
2500
2000
1500
1000
500
0
VC (ppb)
1
2
3
4
5
6
7
Time (weeks)
TCE 50 ppm
TCE 1000 ppm

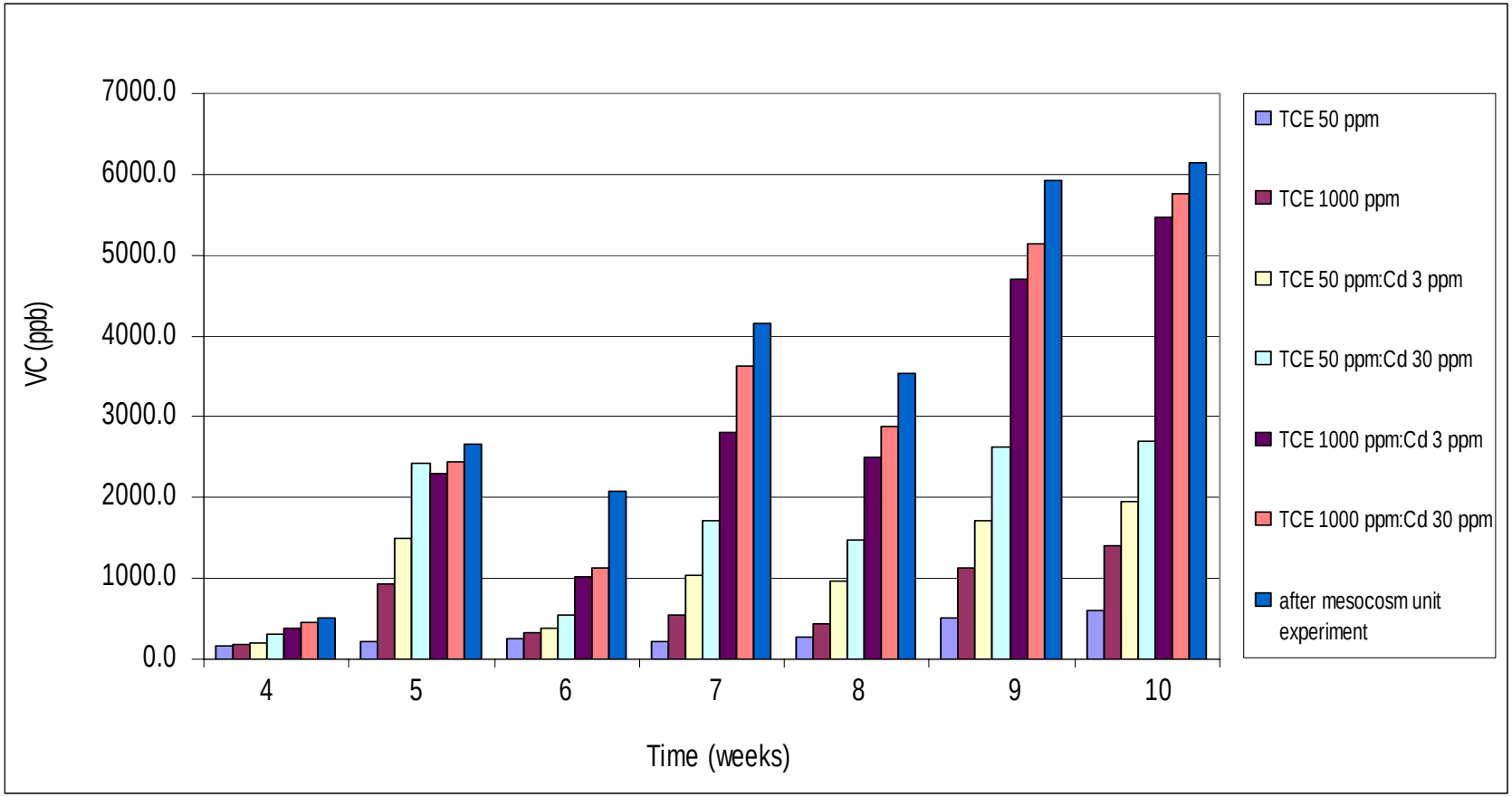
(a)


7000
6000
5000
4000
3000
2000
1000
0
VC (ppb)
1
2
3
4
5
6
7
Time (weeks)
TCE 50 ppm
TCE 1000 ppm
soil after mesocosm unit experiment

(b)


7000
6000
5000
4000
3000
2000
1000
0
VC (ppb)
4
2
3
4
5
6
7
Time (weeks)
TCE 50 ppm:Cd 3 ppm
TCE 50 ppm:Cd 30 ppm
TCE 1000 ppm:Cd 3 ppm
TCE 1000 ppm:Cd 30 ppm

(c)



(d)

Figure 11 Concentration of VC in compost soil (ppb). (a): Control TCE; (b): Control TCE and soil after mesocosm unit experiment; (c): Experiment which add TCE and Cd in differents concentration; (d): Concentration of VC in composted soil (ppb).

4. Degradation of TCE related to the increasing of VC.

Table 12 Concentration of TCE and VC in compost soil.

Weeks	Experiment													
	ER2		ER3		ER6		ER7		ER8		ER9		ER10	
	TCE	VC	TCE	VC	TCE	VC	TCE	VC	TCE	VC	TCE	VC	TCE	VC
0	12541.6	ND	15650.5	ND	12430.9	ND	12515.4	ND	15748.3	ND	15181.0	ND	11045.4	ND
1	9642.6	ND	12110.2	ND	9414.5	ND	9340.9	ND	11954.4	ND	11771.8	ND	10025.1	ND
2	5481.8	ND	6191.1	ND	5880.7	ND	6073.2	ND	6977.3	ND	7689.5	ND	6628.3	ND
3	5025.3	ND	5321.5	ND	4960.6	ND	4929.9	ND	6056.8	ND	6660.2	ND	4855.5	ND
4	4261.2	163.4	4448.0	222.4	2933.4	263.0	2514.3	218.8	3599.2	282.0	3364.5	506.6	3067.4	595.8
5	186.8	183.0	346.3	935.3	122.3	330.7	621.7	542.7	374.4	440.8	334.9	1125.8	594.7	1408.1
6	50.8	111.3	80.4	1495.0	76.4	378.6	67.8	1038.2	218.0	968.4	258.3	1711.5	251.2	1945.7
7	30.9	303.3	46.6	2416.6	31.3	550.8	25.7	1704.6	83.0	1483.2	94.0	2616.7	85.8	2699.9
8	11.7	380.1	13.6	2289.6	12.1	1021.3	11.9	2814.0	45.1	2491.7	54.1	4707.4	48.9	5462.7
9	9.9	448.1	10.8	2436.9	10.0	1121.3	9.9	3625.8	33.3	2886.3	36.5	5136.6	34.0	5763.3
10	5.7	510.1	6.4	2657.0	6.1	2069.7	5.6	4151.6	20.7	3539.9	22.6	5921.8	23.8	6146.4

Note ER2 : TCE 50 ppm, Cd 0 ppm; ER3 : TCE 1000 ppm, Cd 0 ppm; ER6 : TCE 50 ppm, Cd 3 ppm; ER7 : TCE 50 ppm, Cd 30 ppm; ER8 : TCE 1000 ppm, Cd 3 ppm; ER9 : TCE 1000 ppm, Cd 30 ppm and ER10 : TCE 11.18 ppm, Cd 0 ppm.
Means, n=4
ND = not detecable

TCE is a volatile organic compound, it was also absorbed by the experimental units. Gordon et al. (1998) reported that major problem in the mass balance study of TCE is its volatility and absorption by commonly used materials, such as rubber, tygon and various sealant. Therefore, in this study we used buckets with made from plastic, so there was possibility that TCE be absorbed by them.

It was obvious that when TCE concentrations was decrease VC concentrations was still high. This may be conclude that VC with determined in the experiment was byproducts from TCE–degradation. This agree with the finding of Kao and Prosser (1999). They was found that the bioremidation process is occurring, which caused the decrease in TCE concentrations and increase in TCE degradation by products (e.g., DCEs, VC) concentrations. In addition, VC, an intermediate product in the reductive dechlorination of TCE were found from the studied Creech and Johnson (1974).

In this study, it might be concluded that aerobic degradation process has been occured by the VC product. Volatilization and other pathway were indirect measured from composted soil and calculated from equation. Mass balance of TCE in composting process was shown in Table 13.

5. Mass balance of TCE in composting process.

Table 13 Mass balance of the concentration of TCE in composted soil.

Experiments	Mass	Initial TCE (ppm)	Leachate		Removal			Total
			TCE (ppm)	VC (ppm)	TCE absorb in soil (ppm)	Aerobic-anaerobic microorganism degradation (ppm)	Other from calculations (Turbulance,Volatilization, Evapotranspiration, Absorption,Adsorption)(ppm)	
ER2	Amount	50	0.0766	0.2278	0.0057	0.5101	49.1798	50
	%	100	0.1532	0.4556	0.0114	1.0202	98.3596	100
ER3	Amount	1,000	0.0834	0.2800	0.0064	2.6570	996.9732	1,000
	%	100	0.0083	0.0280	0.0006	0.2657	99.6978	100
ER6	Amount	50	0.0718	0.2787	0.0061	2.0697	47.5737	50
	%	100	0.1436	0.5574	0.0122	4.1394	95.1474	100
ER7	Amount	50	0.0922	0.2716	0.0056	4.1516	45.4790	50
	%	100	0.1844	0.5432	0.0112	8.3032	90.9580	100
ER8	Amount	1,000	0.1087	0.2799	0.0207	3.5399	996.0508	1,000
	%	100	0.0109	0.0280	0.0021	0.3540	99.6051	100
ER9	Amount	1,000	0.1206	0.2892	0.0226	5.9218	993.6458	1,000
	%	100	0.0121	0.0289	0.0023	0.5922	99.3646	100
ER10	Amount	11.18	0.1626	0.2919	0.0238	6.1464	4.5553	11.18
	%	100	1.4544	2.6109	0.2129	54.9767	40.7451	100

Means, n=4

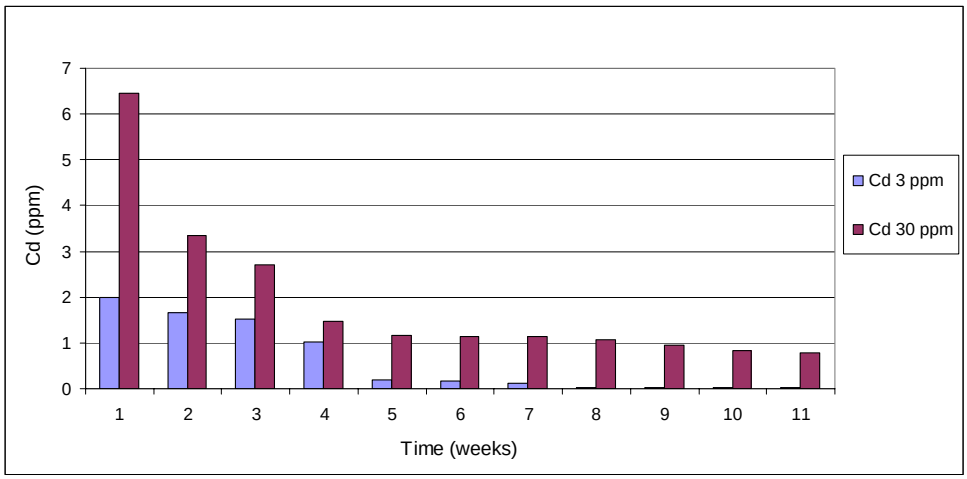
6. Concentration of cadmium (Cd) in composted soil.

Table 14 Concentration of cadmium (Cd) in composted soil.

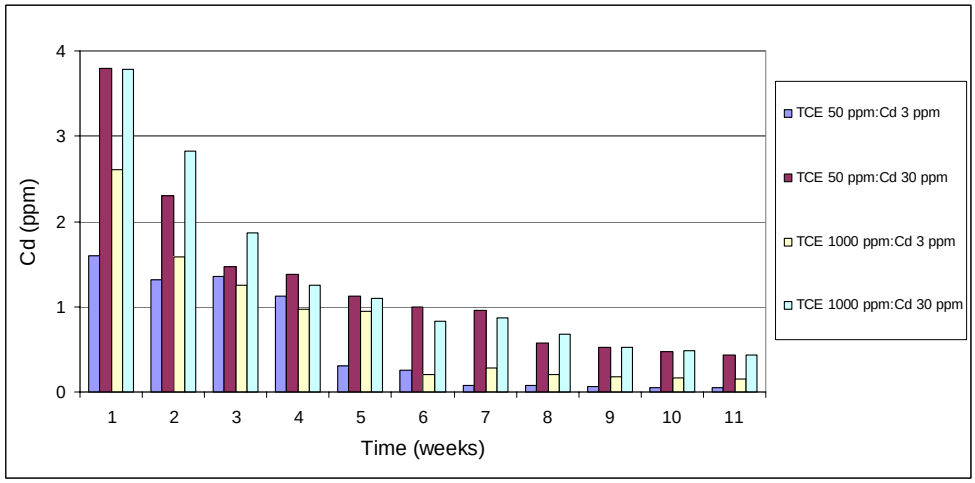
Weeks	Experiments					
	ER4	**ER5**	**ER6**	**ER7**	**ER8**	**ER9**
0	1.99	6.45	1.60	3.79	2.61	3.78
1	1.67	3.35	1.32	2.30	1.59	2.83
2	1.52	2.70	1.35	1.47	1.25	1.86
3	1.47	2.57	1.13	1.38	0.97	1.25
4	1.36	2.76	0.31	1.12	0.94	1.10
5	1.37	2.55	0.26	1.00	0.21	0.83
6	1.42	2.63	0.08	0.96	0.28	0.87
7	1.45	2.34	0.08	0.58	0.21	0.68
8	1.38	2.43	0.07	0.52	0.18	0.53
9	1.42	2.47	0.05	0.47	0.16	0.48
10	1.32	2.42	0.05	0.43	0.15	0.44

Note ER4 : TCE 0 ppm, Cd 3 ppm; ER5 : TCE 0 ppm, Cd 30 ppm; ER6 : TCE 50 ppm, Cd 3 ppm; ER7 : TCE 50 ppm, Cd 30 ppm; ER8 : TCE 1000 ppm, Cd 3 ppm; and ER9 : TCE 1000 ppm, Cd 30 ppm.
Means, n=4

The concentration of Cd in the experiment without TCE was decreased during week 1st and 2nd. The concentration of Cd in the experiment with the same TCE concentration was slowly decreased during week 0 to 10th (Table 14 and Figure 12). Each experiment had been decreasing as following; ER6, ER7, ER8 and ER9 98.33%, 85.67%, 99.50% and 98.53%, respectively.

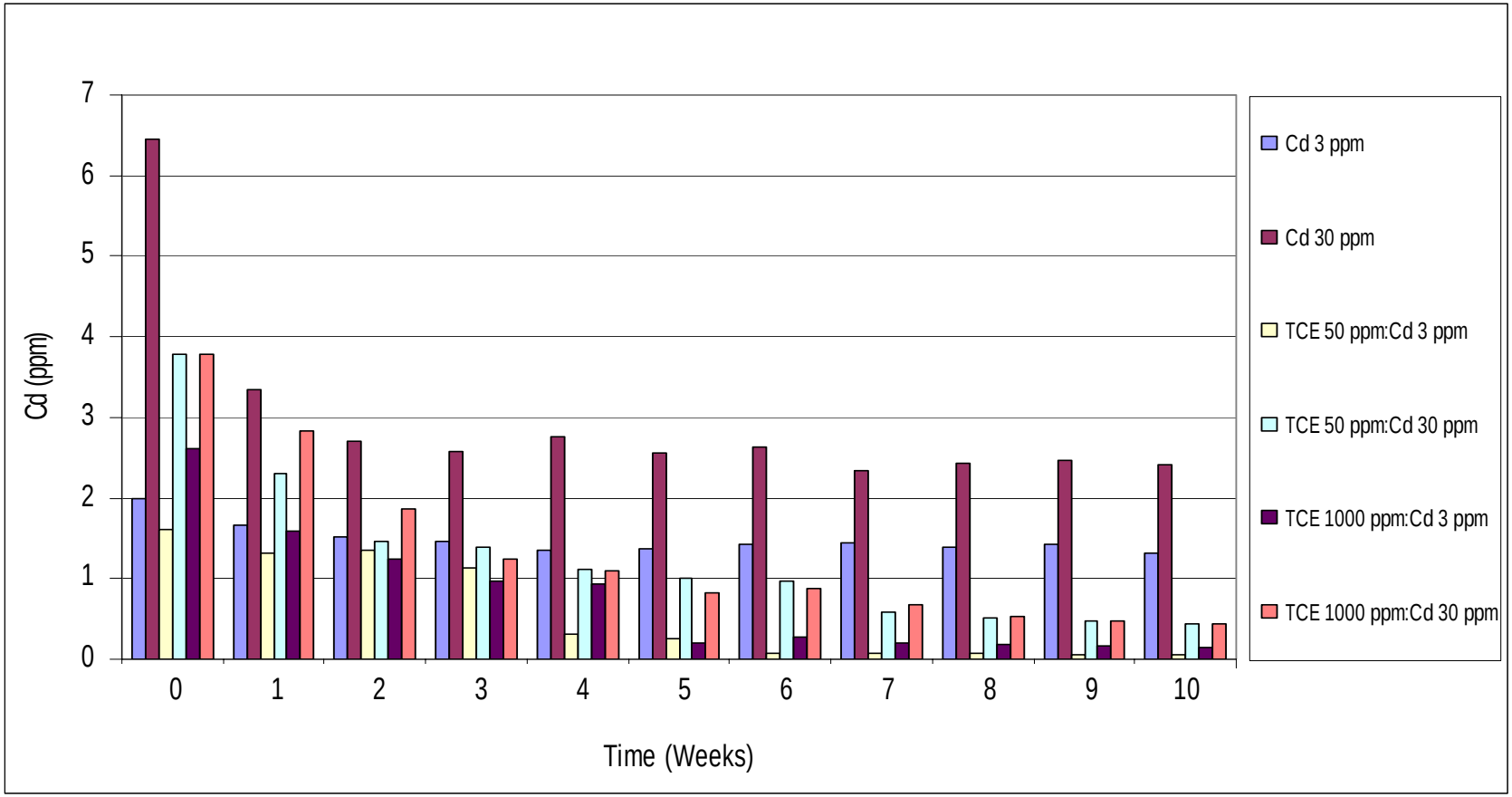


(a)



(b)

In Figure 12, among the experiments with added with the same concentration of TCE (ER6 and ER7, ER8 and ER9), the experiments with 3 ppm Cd added had more decreasing amount than the experiments with 30 ppm Cd added.



(c)

Figure 12 Concentration of cadmium (Cd) in compost soil. (a): Control Cd; (b): Experiment which add TCE and Cd in differents concentration; (c): Concentration of cadmium (Cd) in compost soil.

7. Mass balance of Cadmium (Cd) in composting process.

Table 15 Mass balance of the concentration of Cd in composted soil.

Experiments	Mass	Initial Cd (ppm)	Leachate	Absorb in soil (ppm)	Other pathway	Total
ER4	Amount	3	0.146	1.32	1.534	3
	%	100	4.87	44	51.13	100
ER5	Amount	30	0.149	2.42	27.431	30
	%	100	0.50	8.07	91.44	100
ER6	Amount	3	0.144	0.05	2.806	3
	%	100	4.80	1.67	93.53	100
ER7	Amount	3	0.178	0.43	2.392	3
	%	100	5.93	14.33	79.73	100
ER8	Amount	30	0.175	0.15	29.675	30
	%	100	0.58	0.50	98.92	100
ER9	Amount	30	0.146	0.44	29.414	30
	%	100	0.49	1.47	98.05	100

Means, n=4

Cadmium was observed over the period of 10 weeks. Since heavy metals are not biodegradable, however TCE is easily volatilized, consequently there was possibility that small amount of Cd might be co-volatilized with TCE. This agreed with the finding of Moshin (2004).

CONCLUSION

TCE and Cd were spiked to soil composted with chicken manure to study the degradation of TCE by aerobic composting with Cd as co-contaminant. The results were as follow.

1. The experimental was conducted for 10 weeks to complete the composting process. The complete process indicated by the temperature of the unit was decreased down to the room temperature. At the end of experiment, pH was neutral to 6.0-7.5, moisture was not higher than 30-40%, some insects or their eggs were not appeared and nutrients such as nitrate and phosphate were higher than an initial level.

2. Decreasing of TCE in the experiment with the different level 50 ppm(ER2) and 1000 ppm(ER3) had no different in significance at 0.05 and 0.01. The decreasing of TCE in the experiments with different level added of Cd (ER6, ER7, ER8, ER9) and the experiments without Cd added (ER2, ER3) had no different in significance at 0.05 and 0.01.

3. The VC in the experiments with 1000 ppm TCE added (ER3) had higher increasing amount than the experiments with 50 ppm TCE added (ER2) and they were different in significance at 0.05 and 0.01. The experiments with 30 ppm Cd added had higher level of VC than the experiments which added only 3 ppm Cd. There was the different in significant at 0.05 and 0.01.

4. The mass balance of TCE of composting process shown that aerobic microorganism degradation was assumed from VC concentration in composted soil. From TCE removal had the highest amount compared to the others calculation.

5. The result of soil from mesocosm unit experiment was similar to the other experiments. There was decreasing of TCE with slowly increasing of VC.

6. In the experiments with Cd added at the different level of 3 and 30 ppm, the experiments with different concentration of TCE as ER6 and ER7, ER8 and ER9, the experiments with 3 ppm Cd added (ER6 and ER7) had higher decreasing of Cd than the experiments with 30 ppm Cd added.

7. Cd as co-contaminate in soil contaminated with TCE in different concentration 3 and 30 ppm Cd had no effect in the degradation of TCE by using compost technique.

RECOMMENDATIONS

1. Degradation of TCE in co-contamination with other heavy metal.

2. Degradation of TCE in soil by different ratio of compost or change compost component.

3. Vary different concentration of Cd for study effect of Cd as an co-contamination in removal of TCE contaminated.

4. Degradation of TCE with anaerobic composting.

5. Plan the experiment to treat VC that occur in TCE-Degradation by composting process.

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APPENDIX

APPENDIX A

Figure of TCE-Degradation study using compost technique


Appendix Figture A1 Drill the bucket and coat glue


Appendix Figture A2 The pipe after coat glue

Appendix Figture A3 Put the sieve in the bucket

Appendix Figture A4 Bucket for the composting

Appendix Figture A5 Chicken manure

Appendix Figture A6 Soil

Appendix Figture A7 Weigh chicken manure and soil

Appendix Figture A8 Mix the composition

Appendix Figture A9
Fill the soil composition in the bucket

Appendix Figture A10 Soil composition

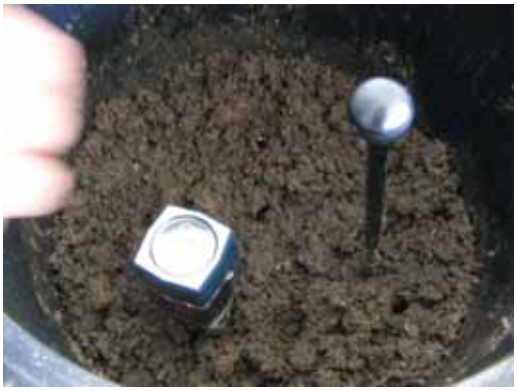
Appendix Figture A11 Soil with TCE

Appendix Figture A12 Soil from mrsocosm unit experiment

Appendix Figture A13 Set up experiment on platform

Appendix Figture A14 pH meter

Appendix Figture A15 Soil temperature



Appendix Figture A16 Measure pH and temperature

Appendix Figture A17 Soil composting after 1 week

Appendix Figture A18 Soil composting the last week

APPENDIX B

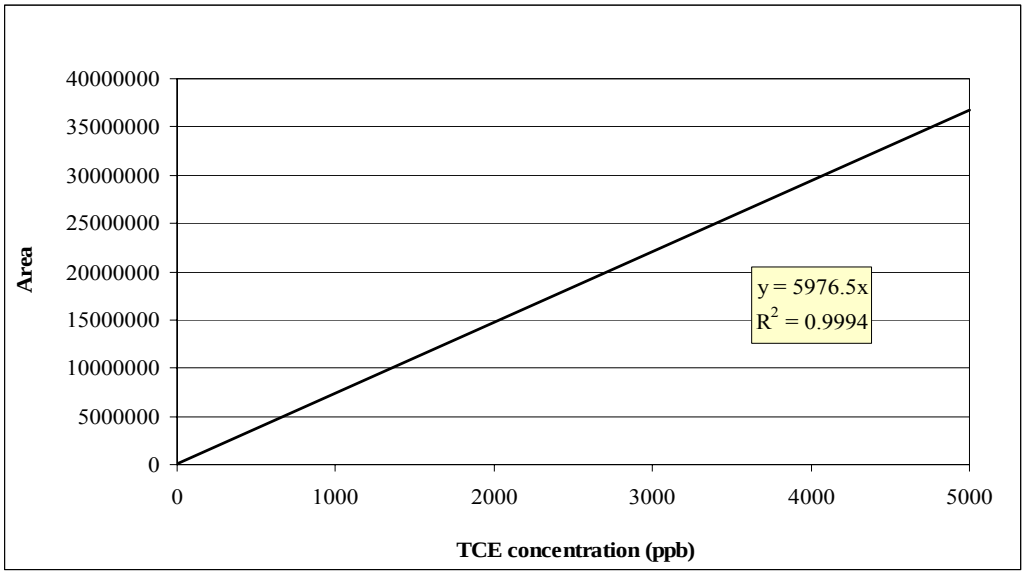
GC Standard curve for TCE and VC

1. Preparation of TCE standard curve

Stock solutions for TCE were prepared from a concentration of 99.8% conc. TCE into 200 mg/l TCE in 100 ml methanol in 50 ml glass vial. All stock solution were capped with Teflon lined and aluminium cap.

Standard solutions were prepared using a series of dilutions. The stock solution were dissolved into 40 ml DI water in 50 ml vial and then tightly sealed with Teflon lined rubber and aluminium cap. The standard solutions (10, 50, 100, 500, 1000, 5000 ppb) were put into an incubator shaker and shaked at 60 rpm. at 25 ºC for 1 hours. Head space gas 0.1 ml was taken by syring and analyzed by GC-ECD (HP 5890 Series II). Standard curve was developed from the measurement of the peak area of GC against the known concentrations of 10, 50, 100, 500, 1000 and 5000 ppb of TCE. Operating condition of instrument (GC-ECD) is presented the box below.

Detector	: Electron Capture Detector
Column	: Capillary (HP-5) (30 m x ID 0.32 mm x Filmthickness 0.25 µm)
Inlet temperature	: 210 ˚ºC
Detector temperature	: 210˚ºC
Oven temperature	: 90 ˚ºC
Total analysis time	: 10 minutes
Carrier gas flow	: 1.50 ml/min
Velocity	: 47.1 cm/sec



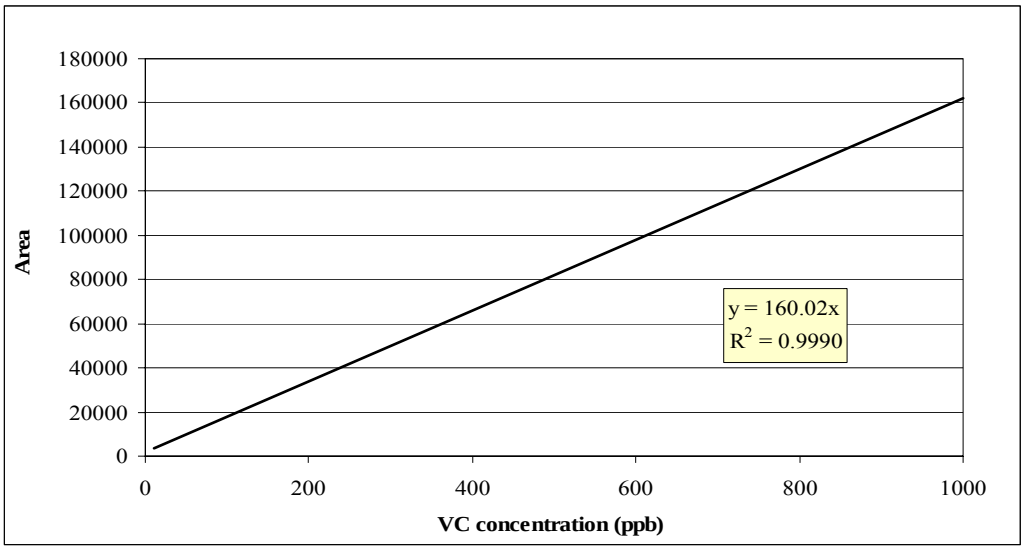
Appendix Figure B1 GC Standard curve for TCE

2. Preparation of VC standard curve

Stock solutions for VC were prepared from a 2000 µg/ml VC in methanol into 1000 µg/l VC in 100 ml methanol in 50 ml glass vial. All stock solution were capped with Teflon lined and aluminium cap. The stock solutions were stored at 4 ºC and were used in one month.

Standard solutions were prepared using a series of dilutions. The stock solution were dissolved into 40 ml DI water in 50 ml vial and then tightly sealed with Teflon lined rubber and aluminium cap. The standard solutions (10, 50, 100, 250, 500 and 1000 ppb) were put into an incubator shaker and shaked at 60 rpm. at 25˚ºC for 1 hours. Head space gas 0.1 ml was taken by syring and analyzed by GC-ECD (HP 5890 Series II). Standard curve was developed from the measurement of the peak area of GC against the known concentrations of 10, 50, 100, 250, 500 and 1000 ppb of VC. Operating condition of instrument (GC-ECD) is presented in the box below.

Detector	:	Electron Capture Detector
Column	:	Capillary (HP-5) (30 m x ID 0.32 mm x Filmthickness 0.25 µm)
Inlet temperature	:	250 ˚ºC
Detector temperature	:	250 ˚ºC
Oven temperature	:	40 ˚ºC
Total analysis time	:	30 minutes
Carrier gas flow	:	1.30 ml/min
Velocity	:	47.1 cm/sec



Appendix Figure B2 GC Standard curve for VC

APPENDIX C

Characteristics of composting components

Appendix Table C1 Average daily temperature record of compost for the experiment period.

NO.	Experiment									
	ER1	**ER2**	**ER3**	**ER4**	**ER5**	**ER6**	**ER7**	**ER8**	**ER9**	**ER10**
1	30.0	30.6	30.7	30.8	30.5	30.3	30.1	30.0	29.8	29.4
2	29.7	30.9	31.2	30.9	31.6	30.8	30.8	30.4	29.1	30.1
3	29.5	30.8	31.2	31.5	31.2	30.0	30.0	29.8	29.7	29.6
4	28.4	30.3	30.3	30.6	30.3	29.2	28.7	28.7	28.6	28.2
5	29.2	30.3	30.5	30.1	30.2	30.0	30.1	30.0	29.7	29.4
6	29.4	30.3	30.3	30.9	30.2	30.6	30.1	29.2	29.4	29.4
7	30.2	30.5	30.6	30.7	30.6	30.0	30.2	30.0	29.9	29.8
8	31.6	31.8	31.9	32.3	32.1	31.7	31.7	31.8	31.5	30.7
9	31.4	31.8	32.0	32.3	32.0	32.1	32.8	33.1	32.1	32.5
10	35.1	35.4	36.1	35.8	35.3	32.4	36.0	36.0	35.8	35.5
11	36.5	36.7	37.4	37.4	37.8	33.8	39.0	38.0	34.7	37.9
12	36.0	36.3	36.5	36.5	36.2	36.5	36.6	36.6	36.5	36.7
13	36.9	37.2	37.4	37.5	37.6	37.6	38.0	37.7	38.1	38.3
14	36.3	35.9	35.7	35.9	36.1	35.9	36.3	36.3	36.1	35.9
15	34.4	34.4	34.9	34.9	34.8	34.8	34.8	34.9	35.0	35.3
16	33.9	34.0	34.1	34.1	33.9	34.1	34.6	34.4	34.1	34.5
17	34.0	34.3	34.2	34.2	34.2	34.6	34.8	34.6	34.4	34.4
18	33.6	33.5	33.4	33.4	33.3	33.5	33.5	33.3	33.5	33.4
19	33.0	33.1	32.8	32.8	32.4	32.5	32.5	32.8	32.6	32.3
20	31.3	31.4	31.8	31.8	32.1	32.2	32.0	32.0	32.1	32.3

Appendix Table C1 (cont'd) Average daily temperature record of compost for the experiment period.

NO.	Experiment									
	ER1	**ER2**	**ER3**	**ER4**	**ER5**	**ER6**	**ER7**	**ER8**	**ER9**	**ER10**
21	29.8	30.0	30.3	30.3	30.5	30.3	30.0	30.2	30.2	30.3
22	31.1	31.0	30.9	30.9	31.3	31.2	31.2	31.1	31.1	31.2
23	29.2	29.8	29.8	29.4	29.4	29.8	29.9	30.2	29.8	30.4
24	31.0	31.4	31.3	31.0	31.0	31.1	31.1	31.3	31.1	31.4
25	29.4	29.3	29.1	29.0	29.0	29.4	29.4	29.3	29.1	28.8
26	29.5	29.6	29.6	29.8	29.5	29.6	30.0	29.6	29.5	29.5
27	30.1	30.0	30.1	29.9	30.0	29.8	30.0	30.1	29.8	30.0
28	29.9	30.3	30.5	30.0	29.9	29.8	29.6	30.0	29.6	29.6
29	31.5	31.5	31.3	31.3	31.3	31.8	32.1	31.8	31.6	31.8
30	31.2	30.3	30.3	30.4	30.8	30.8	31.4	31.1	30.2	31.1
31	31.5	31.7	31.7	31.6	29.8	31.7	31.9	32.4	31.8	31.9
32	30.1	30.3	30.3	30.4	30.3	30.1	29.0	30.6	30.5	30.7
33	31.9	31.3	31.6	31.3	31.6	31.8	32.4	32.3	32.1	31.8
34	30.3	30.5	30.8	30.7	30.6	30.8	30.7	30.6	30.3	30.4
35	30.6	29.3	29.3	29.1	29.3	30.8	30.8	29.8	29.8	30.3
36	30.8	29.5	29.8	30.0	30.0	30.6	30.5	30.6	30.3	30.8
37	31.2	30.3	30.2	29.9	30.2	31.1	30.9	31.2	31.2	31.3
38	31.9	31.3	31.6	31.3	31.6	31.8	32.4	32.3	31.9	32.3
39	30.2	29.6	29.7	29.4	29.6	30.6	30.5	29.8	29.5	29.4
40	31.9	31.3	31.6	31.3	31.6	31.8	32.4	32.3	32.1	31.8

Appendix Table C1 (cont'd) Average daily temperature record of compost for the experiment period.

NO.	Experiment									
	ER1	**ER2**	**ER3**	**ER4**	**ER5**	**ER6**	**ER7**	**ER8**	**ER9**	**ER10**
41	31.5	31.7	31.7	31.6	29.8	31.7	31.9	32.4	31.8	31.9
42	30.7	30.0	29.8	29.8	29.6	30.9	30.8	30.8	30.6	30.8
43	30.9	30.4	30.6	30.6	30.8	30.4	30.4	30.5	31.0	31.3
44	29.8	28.8	28.7	29.1	28.9	29.3	29.7	29.4	29.7	29.8
45	30.5	30.0	30.1	30.3	30.0	29.9	30.2	30.2	30.3	30.1
46	30.8	30.3	30.1	30.4	30.2	30.7	30.8	30.8	31.2	31.3
47	31.7	31.3	31.3	31.2	31.2	31.4	31.5	31.5	31.8	31.8
48	30.3	30.3	29.9	29.5	29.4	29.9	29.9	30.1	29.8	29.7
49	30.8	29.8	29.6	29.5	29.5	30.3	30.4	30.5	30.8	31.0
50	30.5	29.8	30.0	30.1	30.4	30.6	30.7	30.9	30.6	30.8
51	30.8	30.7	30.6	30.5	30.3	30.4	30.5	30.5	30.6	30.7
52	30.5	30.3	30.3	30.0	30.3	30.4	30.6	30.3	30.2	30.5
53	29.8	30.2	30.2	30.3	30.4	30.4	30.6	30.7	30.6	30.5
54	30.3	30.7	30.8	30.8	31.0	31.2	31.2	31.0	31.2	31.0
55	30.1	30.3	30.5	30.7	30.7	30.8	30.7	30.6	30.8	30.8
56	31.3	31.3	31.3	31.3	31.3	31.3	31.7	31.5	31.6	31.6
57	30.8	31.0	31.2	31.1	31.3	31.3	31.4	31.3	31.3	31.3
58	26.9	26.9	26.8	26.8	27.0	26.8	26.8	26.6	26.7	28.0
59	28.7	28.7	28.5	28.5	28.7	28.6	28.8	28.7	28.7	28.7
60	29.6	29.7	29.8	29.8	29.8	29.8	29.9	30.0	30.3	30.3

Appendix Table C1 (cont'd) Average daily temperature record of compost for the experiment period.

NO.	Experiment									
	ER1	**ER2**	**ER3**	**ER4**	**ER5**	**ER6**	**ER7**	**ER8**	**ER9**	**ER10**
61	30.0	30.2	30.3	30.3	30.6	30.8	30.7	30.8	31.3	31.0
62	29.8	30.1	30.0	30.2	30.3	30.4	30.6	30.7	30.7	30.2
63	30.6	30.9	31.0	31.0	30.9	30.8	30.8	30.9	31.1	31.1
64	29.5	29.3	31.5	29.3	29.5	29.6	29.8	29.6	29.8	29.5
65	29.8	29.8	29.8	29.9	30.0	30.0	30.1	30.3	30.2	30.3
66	29.7	29.7	29.6	29.7	29.8	29.7	30.0	30.1	30.0	30.2
67	29.3	29.4	29.4	29.5	29.7	29.7	29.7	29.7	29.8	29.9
68	29.8	29.7	29.8	30.0	30.0	30.1	30.2	30.1	30.0	30.0
69	29.4	29.7	29.7	29.7	29.9	30.1	30.0	29.9	29.9	30.0
70	29.3	29.3	29.5	29.7	29.7	29.7	29.7	29.7	29.7	29.7
71	28.3	28.2	28.2	28.4	28.4	28.3	28.8	28.6	28.5	28.8

Note ER1 : No TCE and Cd (control); ER2 : TCE 50 ppm, Cd 0 ppm; ER3 : TCE 1000 ppm, Cd 0 ppm; ER4 : TCE 0 ppm, Cd 3 ppm; ER5 : TCE 0 ppm, Cd 30 ppm; ER6 : TCE 50 ppm, Cd 3 ppm; ER7 : TCE 50 ppm, Cd 30 ppm; ER8 : TCE 1000 ppm, Cd 3 ppm; ER9 : TCE 1000 ppm, Cd 30 ppm and ER10 : TCE 11.18 ppm, Cd 0 ppm.

Appendix Table C2 Average daily pH record of compost for the experiment period.

NO.	Experiment									
	ER1	**ER2**	**ER3**	**ER4**	**ER5**	**ER6**	**ER7**	**ER8**	**ER9**	**ER10**
1	5.5	5.7	5.4	5.5	5.1	4.9	4.9	5.1	5.2	5.3
2	5.0	6.1	5.6	5.7	5.4	4.5	4.8	5.1	4.9	4.3
3	5.1	6.2	6.0	5.8	5.6	4.7	4.8	5.2	5.3	4.4
4	5.2	6.1	6.2	6.1	6.0	5.2	4.9	5.3	5.2	4.3
5	6.0	6.3	6.4	6.2	5.9	5.4	5.1	5.1	6.0	4.5
6	6.0	6.4	6.3	6.3	6.1	5.3	5.4	5.0	6.0	4.9
7	5.9	6.2	6.3	6.2	6.0	5.3	5.4	5.7	5.6	4.7
8	5.8	6.1	6.0	6.2	5.8	6.1	5.6	5.9	5.8	5.2
9	6.3	6.4	6.4	5.7	6.0	5.7	5.8	6.3	6.5	5.0
10	6.3	6.4	6.4	6.2	6.0	5.7	5.7	6.0	6.3	5.3
11	6.3	6.5	6.5	6.2	6.1	5.7	5.7	6.1	6.3	5.0
12	6.3	6.4	6.4	5.9	5.8	5.6	5.7	5.7	6.3	5.2
13	6.4	6.4	6.4	6.4	6.1	5.7	5.7	6.1	6.2	5.2
14	6.4	6.4	6.4	6.0	5.8	5.7	5.8	5.8	6.3	5.3
15	6.4	6.4	6.5	6.0	6.1	6.0	6.0	6.2	6.4	5.4
16	6.6	6.5	6.5	6.2	6.2	6.1	6.2	6.2	6.5	5.4
17	6.4	6.4	6.4	6.0	6.1	6.1	6.1	6.1	6.5	5.4
18	6.5	6.4	6.5	6.1	6.1	6.2	6.2	6.1	6.4	5.0
19	6.6	6.5	6.4	5.6	5.6	5.5	5.6	6.1	6.4	5.4
20	6.5	6.6	6.5	6.0	6.1	6.2	5.9	6.0	6.4	5.1

Appendix Table C2 (cont'd) Average daily pH record of compost for the experiment period.

NO.	Experiment									
	ER1	**ER2**	**ER3**	**ER4**	**ER5**	**ER6**	**ER7**	**ER8**	**ER9**	**ER10**
21	6.5	6.4	6.4	6.0	6.0	6.0	6.2	6.2	6.6	6.5
22	6.6	6.5	6.6	6.3	5.8	5.5	5.7	6.2	6.4	6.0
23	6.3	6.4	6.4	6.2	5.8	5.7	5.8	5.9	6.2	5.2
24	6.6	6.6	6.6	6.5	6.5	6.4	6.5	6.5	6.6	6.3
25	6.5	6.6	6.4	5.7	5.6	5.8	5.8	5.9	6.1	5.5
26	6.4	6.5	6.5	5.7	5.7	5.5	5.6	5.7	6.3	5.3
27	6.4	6.5	6.1	6.1	5.5	5.6	5.9	5.9	6.5	5.2
28	6.4	6.4	6.5	5.9	5.5	5.6	5.5	5.6	6.4	5.1
29	6.1	5.3	5.6	5.3	5.1	5.5	5.6	5.9	6.3	6.3
30	6.4	5.5	5.5	4.9	5.1	5.2	5.6	5.9	6.4	5.4
31	6.5	6.3	6.2	5.9	5.8	6.0	5.6	6.3	6.4	6.0
32	6.3	6.3	6.3	6.2	5.9	6.1	6.1	6.3	6.3	6.1
33	6.6	6.3	6.1	6.2	5.3	6.4	6.4	6.4	6.5	6.0
34	6.5	6.4	6.5	6.3	6.4	6.4	6.4	6.5	6.4	6.4
35	6.7	6.2	6.1	6.0	5.3	6.1	6.2	6.2	6.4	5.7
36	6.6	6.5	6.4	5.6	5.6	5.5	5.6	6.1	6.4	5.4
37	6.3	6.3	6.3	6.2	5.9	6.1	6.1	6.3	6.3	6.1
38	6.4	5.5	5.5	4.9	5.1	5.2	5.6	5.9	6.4	5.4
39	6.5	6.3	6.2	5.9	5.8	6.0	5.6	6.3	6.4	6.0
40	6.3	6.3	6.3	6.2	5.9	6.1	6.1	6.3	6.3	6.1

Appendix Table C2 (cont'd) Average daily pH record of compost for the experiment period.

NO.	Experiment									
	ER1	**ER2**	**ER3**	**ER4**	**ER5**	**ER6**	**ER7**	**ER8**	**ER9**	**ER10**
41	6.3	6.3	6.3	6.2	5.9	6.1	6.1	6.3	6.3	6.1
42	6.5	6.4	6.5	6.3	6.4	6.4	6.4	6.5	6.4	6.4
43	6.5	6.2	6.2	6.1	5.6	6.0	6.1	6.1	6.3	5.7
44	6.3	5.6	5.4	5.8	5.9	5.8	5.9	6.1	6.4	5.5
45	6.4	6.4	5.3	5.5	5.5	5.4	5.5	5.7	6.2	5.5
46	6.3	5.9	5.7	5.9	6.0	6.0	6.3	6.3	6.4	5.8
47	6.3	5.2	5.2	5.6	5.7	5.6	5.5	5.8	6.3	5.7
48	6.5	6.3	6.0	6.1	6.2	6.3	6.3	6.4	6.4	6.2
49	6.3	6.1	6.2	6.2	6.3	6.4	6.0	6.4	6.5	5.9
50	6.4	6.1	6.1	6.2	6.4	6.5	6.2	6.4	6.3	6.0
51	6.4	6.2	6.1	6.1	6.2	6.2	6.2	6.2	6.3	6.1
52	6.2	6.2	6.3	6.2	6.3	6.3	6.3	6.3	6.2	6.2
53	6.2	6.2	6.3	6.2	6.2	6.2	6.1	6.2	6.3	6.2
54	6.2	6.3	6.3	6.3	6.3	6.2	6.3	5.8	6.2	6.3
55	6.3	6.3	6.2	6.3	6.2	6.2	6.3	6.2	6.3	6.2
56	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.2	6.3	6.2
57	6.2	6.3	6.2	6.3	6.2	6.2	6.2	6.2	6.3	6.1
58	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
59	6.2	6.2	6.3	6.2	6.2	6.3	6.3	6.2	6.2	6.2
60	6.3	6.2	6.3	6.3	6.2	6.3	6.3	6.3	6.2	6.3

Appendix Table C2 (cont'd) Average daily pH record of compost for the experiment period.

NO.	Experiment									
	ER1	**ER2**	**ER3**	**ER4**	**ER5**	**ER6**	**ER7**	**ER8**	**ER9**	**ER10**
61	6.4	6.1	5.9	5.8	5.8	6.2	6.3	6.3	6.2	6.1
62	6.2	6.3	6.2	6.3	6.3	6.2	6.2	6.2	6.3	6.2
63	6.3	6.3	6.2	6.3	6.2	6.3	6.3	6.3	6.3	6.2
64	6.3	6.2	6.1	6.2	6.2	6.2	6.3	6.3	6.3	6.4
65	6.2	6.3	6.3	6.2	6.3	6.3	6.3	6.3	6.3	6.2
66	6.2	6.2	6.2	6.2	6.3	6.2	6.3	6.3	6.3	6.3
67	6.2	6.3	6.3	6.2	6.3	6.2	6.3	6.2	6.3	6.3
68	6.2	6.3	6.3	6.3	6.2	6.3	6.3	6.2	6.3	6.2
69	6.3	6.3	6.3	6.2	6.3	6.3	6.3	6.2	6.3	6.3
70	6.3	6.2	6.3	6.3	6.2	6.3	6.3	6.3	6.3	6.3
71	6.3	6.3	6.2	6.2	6.2	6.2	6.2	6.2	6.3	6.4

Note ER1 : No TCE and Cd (control); ER2 : TCE 50 ppm, Cd 0 ppm; ER3 : TCE 1000 ppm, Cd 0 ppm; ER4 : TCE 0 ppm, Cd 3 ppm; ER5 : TCE 0 ppm, Cd 30 ppm; ER6 : TCE 50 ppm, Cd 3 ppm; ER7 : TCE 50 ppm, Cd 30 ppm; ER8 : TCE 1000 ppm, Cd 3 ppm; ER9 : TCE 1000 ppm, Cd 30 ppm and ER10 : TCE 11.18 ppm, Cd 0 ppm.

Appendix Table C3 Average weekly Moisture content record of compost for the experiment period.

No.	Experiment									
	ER1	**ER2**	**ER3**	**ER4**	**ER5**	**ER6**	**ER7**	**ER8**	**ER9**	**ER10**
0	41.23	43.72	43.04	41.63	45.39	44.24	44.7	46.53	44.71	48.41
1	40.95	41.63	40.05	41.91	45.23	42.69	42.17	42.88	44.78	48.7
2	43.57	45.49	44.59	45.18	43.53	43.79	45.23	44.35	45.66	49.02
3	42.72	45.83	44.52	43.92	42.74	43.91	43.94	44.28	44.37	45.21
4	42.59	44.23	43.79	43.06	43.37	43.72	43.28	42.87	47.17	41.51
5	45.21	45.59	43.94	45.55	45.65	43.78	44.54	43.44	43.18	44.69
6	43.99	44.64	45.11	48.13	46.05	44.26	44.21	43.96	44.23	42.81
7	43.64	44.55	44.47	44.9	44.13	42.65	45.66	42.11	45.47	49.26
8	44.18	44.78	43.98	45.03	44.16	46.91	46.77	45.18	46.19	42.63
9	43.58	44.91	43.58	44.6	43.54	47.12	41.81	43.51	46.01	42.00
10	48.45	46.57	48.69	49.17	43.09	43.85	48.02	40.25	42.22	43.20

Note ER1 : No TCE and Cd (control); ER2 : TCE 50 ppm, Cd 0 ppm; ER3 : TCE 1000 ppm, Cd 0 ppm; ER4 : TCE 0 ppm, Cd 3 ppm; ER5 : TCE 0 ppm, Cd 30 ppm; ER6 : TCE 50 ppm, Cd 3 ppm; ER7 : TCE 50 ppm, Cd 30 ppm; ER8 : TCE 1000 ppm, Cd 3 ppm; ER9 : TCE 1000 ppm, Cd 30 ppm and ER10 : TCE 11.18 ppm, Cd 0 ppm.

Appendix Table C4 Average weekly carbon content record of compost for the experiment period.

No.	Experiment									
	ER1	**ER2**	**ER3**	**ER4**	**ER5**	**ER6**	**ER7**	**ER8**	**ER9**	**ER10**
0	23.89	26.88	23.79	24.89	24.78	24.15	24.63	24.09	24.84	23.98
1	22.86	21.18	22.29	23.17	22.41	22.74	22.29	22.94	22.53	21.52
2	21.03	22.93	23.75	22.21	22.07	22.99	23.38	22.87	23.01	22.84
3	22.21	22.06	21.47	22.58	21.5	22.74	22.07	22.25	21.83	22.2
4	22.62	23.55	22.33	22.43	22.42	22.41	22.86	22.25	22.70	22.08
5	21.71	22.44	21.40	22.62	22.13	21.75	21.44	22.96	22.53	22.42
6	22.38	22.35	21.99	21.77	21.11	22.36	21.72	22.05	22.05	22.4
7	21.86	21.24	21.62	21.44	21.68	20.69	19.58	20.80	22.41	21.25
8	21.90	20.90	21.15	21.46	21.24	20.06	19.46	20.68	22.49	21.02
9	20.21	21.57	20.09	21.59	21.28	20.19	22.56	20.94	21.50	13.94
10	16.28	16.61	18.94	16.81	16.48	20.01	18.03	20.40	20.54	12.27

Note ER1 : No TCE and Cd (control); ER2 : TCE 50 ppm, Cd 0 ppm; ER3 : TCE 1000 ppm, Cd 0 ppm; ER4 : TCE 0 ppm, Cd 3 ppm; ER5 : TCE 0 ppm, Cd 30 ppm; ER6 : TCE 50 ppm, Cd 3 ppm; ER7 : TCE 50 ppm, Cd 30 ppm; ER8 : TCE 1000 ppm, Cd 3 ppm; ER9 : TCE 1000 ppm, Cd 30 ppm and ER10 : TCE 11.18 ppm, Cd 0 ppm.

Appendix Table C5 Nitrate content record of compost before and after composting.

Experiment	Before Composting			After Composting		
	1	2	Average	1	2	Average
ER1	0.108	0.108	0.108	0.251	0.238	0.245
ER2	0.106	0.107	0.107	0.275	0.270	0.272
ER3	0.089	0.091	0.090	0.249	0.248	0.248
ER4	0.063	0.061	0.062	0.249	0.243	0.246
ER5	0.139	0.136	0.137	0.289	0.267	0.278
ER6	0.101	0.099	0.100	0.278	0.307	0.292
ER7	0.093	0.091	0.092	0.307	0.305	0.306
ER8	0.097	0.087	0.092	0.304	0.303	0.303
ER9	0.085	0.083	0.084	0.311	0.298	0.304
ER10	0.153	0.171	0.162	0.366	0.326	0.346

Note ER1 : No TCE and Cd (control); ER2 : TCE 50 ppm, Cd 0 ppm; ER3 : TCE 1000 ppm, Cd 0 ppm; ER4 : TCE 0 ppm, Cd 3 ppm; ER5 : TCE 0 ppm, Cd 30 ppm; ER6 : TCE 50 ppm, Cd 3 ppm; ER7 : TCE 50 ppm, Cd 30 ppm; ER8 : TCE 1000 ppm, Cd 3 ppm; ER9 : TCE 1000 ppm, Cd 30 ppm and ER10 : TCE 11.18 ppm, Cd 0 ppm.

Appendix Table C6 Phosphate content record of compost after composting.

Experiment	Before Composting			After Composting		
	1	2	Average	1	2	Average
ER1	0.027	0.027	0.027	0.031	0.030	0.031
ER2	0.019	0.020	0.019	0.028	0.027	0.027
ER3	0.013	0.015	0.014	0.028	0.029	0.028
ER4	0.015	0.015	0.015	0.028	0.027	0.028
ER5	0.017	0.017	0.017	0.036	0.033	0.035
ER6	0.023	0.023	0.023	0.036	0.040	0.038
ER7	0.020	0.019	0.020	0.038	0.038	0.038
ER8	0.016	0.014	0.015	0.036	0.036	0.036
ER9	0.021	0.021	0.021	0.039	0.037	0.038
ER10	0.006	0.006	0.006	0.011	0.010	0.010

Note ER1 : No TCE and Cd (control); ER2 : TCE 50 ppm, Cd 0 ppm; ER3 : TCE 1000 ppm, Cd 0 ppm; ER4 : TCE 0 ppm, Cd 3 ppm; ER5 : TCE 0 ppm, Cd 30 ppm; ER6 : TCE 50 ppm, Cd 3 ppm; ER7 : TCE 50 ppm, Cd 30 ppm; ER8 : TCE 1000 ppm, Cd 3 ppm; ER9 : TCE 1000 ppm, Cd 30 ppm and ER10 : TCE 11.18 ppm, Cd 0 ppm.

APPENDIX D

Methodlogy

1. Determination of soil moisture

Ten grams of sample was weighed into a porcelain cup, dried in oven at 105°C for 24 hours and then reweighed. Weight of the container was subtracted and moisture content was determined using the following formula.

$$MC = (Ww - Wd)/ Wd) \times 100$$

MC = moisture content (%) of sample
Ww = wet weight of sample
Wd = weight of the sample after drying

2. Determination of soil pH and Temperature

To determine with soil pH meter and soil thermometer.

APPENDIX E

Analysis of Variance in the experiment

Appendix Table E1 Analysis of Variance for carbon contents in composting of each experiment.

Source of Variation	Sum of Squares (SS)	Degree of Freedom (df)	Mean Square (MS)	F Values
Between levels	23.4212	9.0000	2.6024	0.6195
Within levels	420.0663	100.0000	4.2007	
Tatal	443.4874	109.0000		

F_{CRIT} (9,100) in significant 0.05 and 0.01 is 1.99 and 2.61 respectively and F value (F_0) from calculate is 0.6195. Since $F_0 < F_{CRIT}$, it was conclude that carbon content in composting of each experiment had no different in significance.

Appendix Table E2 Analysis of Variance for TCE-degradation in composting of each experiment.

Source of Variation	Sum of Squares (SS)	Degree of Freedom (df)	Mean Square (MS)	F Values
Between levels	10644745.1709	6.0000	1774124.1951	0.0737
Within levels	1684958952.9794	70.0000	24070842.1854	
Tatal	1695603698.1503	76.0000		

F_{CRIT} (6,70) in significant 0.05 and 0.01 is 2.24 and 3.09 respectively and F value (F_0) from calculate is 0.0737. Since $F_0 < F_{CRIT}$, it was conclude that the decreasing of TCE in composting of each experiment had no different in significant.

Appendix Table E3 Analysis of Variance for VC concentration in composting of each experiment.

Source of Variation	Sum of Squares (SS)	Degree of Freedom (df)	Mean Square (MS)	F Values
Between levels	53049169.7077	6.0000	8841528.2846	4.0868
Within levels	90863535.7634	42.0000	2163417.5182	
Tatal	143912705.4711	48.0000		

F_{CRIT} (6,42) in significant 0.05 and 0.01 is 2.33 and 3.27 respectively and F value (F_0) from calculate is 4.0868. Since $F_0 > F_{CRIT}$, it was conclude that the concentration of VC had the significance different at significance 0.05 and 0.01.