CHAPTER 4

PHOTOCHEMICAL DEGRADATION OF BENZENE AND TOLUENE, ETHYLENEDIAMINETETRA-ACETIC ACID AND HEXADECYLTRIMETHYL-AMMONIUM BROMIDE

4.1 INTRODUCTION

One of the major potential sources of pollution in Brunei Darussalam arises from the growing oil production industry. The pollutants that could be released from the water system are hydrocarbons from the oil and treatment chemicals such as surfactants. There is a need to have technology in place to deal with the pollutants. A photochemical degradation method has been developed to destroy potential and model pollutants from the oil industry such as benzene, toluene, ethylenediaminetetra-acetic acid (EDTA) and hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$). Organic compounds are molecules composed mainly of carbon and hydrogen but can also contain nitrogen, phosphorus, sulphur, and chlorine, among others. Some organic compounds in the aqueous environment have been identified as potentially harmful. Harmful compounds found in the Baltic sea, for example [1], include:-

- Dichloro-diphenyl-trichloroethane (DDT)
- Polychlorinated biphenyls (PCBs)
- Polychlorinated triphenyls (PCTs), dibenzo-dioxins (PCDDs), and dibenzo-furans (PCDFs)
- Chlorophenols
- Hexachlorocyclohexanes (HCHs)

Until a few years ago, DDT and PCBs were used as agricultural pesticides and, because of their uncontrolled use, large amounts have reached the sea, carried by wind or by rivers. These toxins can be taken up by various species of animal and cause damage to the overall health of the animals. A region-wide ban in ASEAN (Association of Southeast Asia Nations) [2] on DDT and PCBs has decreased the toxin concentrations being taken up by aquatic species in rivers and the sea population.

Water pollution caused by organic matter, pathogenic agents and hazardous and toxic wastes is a serious problem. Asia's record with regard to safe water supply is poor. One in three Asians has no access to a safe drinking water and the worst in South and Southeast Asia. Almost one in two Asians has no access to sanitation services and only 10 per cent of sewage is treated at primary level [3]. Effluent flows straight into surface or groundwater. Dirty water and poor sanitation is said to cause more than half a million infant deaths a year in the region, as well as causing a huge burden of illness and disability [4].

The identification of organic pollutants and their concentrations in water are important because of their social and economic impacts on communities. The analytical identification of the organic pollutants is considered, however, to be a difficult problem due to their complexity. Waste waters evacuated, directed or partially cleaned can still contain a large variety of natural or synthesized organic substances, resulting directly from production or social activities. These waters are responsible for many complex physico-chemical, biological and bacteriological processes within aquatic basins [5].

One of the main challenges of the 21st century is to supply the growing urban areas with drinking water. In this sense, humankind faces two major problems: diminishing water resources and the excessive pollution of those already available. Thus, to prevent any possible crisis, the existing resources should be conserved, implying the need for the existence of efficient water treatment systems.

This chapter deals with a number of significant toxic organic compounds, including, toluene and benzene. These two chemical compounds have been detected in the waters of the oil drilling district of Kuala Belait. Although Brunei Darussalam does not fully depend on river waters for its fresh water supply, it is rational to identify early symptoms of probable sources of organic pollutions to the river system.

4.1.1 Organic pollution in Asia

Organic chemicals exist in many forms but the most serious hazards posed for fish and water quality are those falling under the broad classification of pesticides. These chemicals are used pervasively in advanced countries like the US and Europe in large scale agriculture, but studies indicate that they may be hazardous to Pacific salmon and to humans. Legally used backyard chemicals, such as Diazinon, are now showing up in measurable levels in streams throughout the Pacific Northwest.

Organic compounds can cause major pollution of ground waters. Their presence in water can be hazardous to public health and the environment. One of the most common sources for the contamination of soil and groundwater arises from spills involving the release of petroleum products such as gasoline, diesel fuel and lubricating and heating oils from leaking oil tanks. Because of their polarity and very soluble characteristics, the organic chemicals of petroleum products will be able to enter the soil and groundwater systems and cause serious pollution problems. Petroleum consists predominantly of hydrocarbons with metals and compounds containing nitrogen, sulphur, and/or oxygen present in minor quantities.

Hazardous levels of organic chemicals do not exist in Brunei Rivers as uses of these chemicals are rather rare and unknown. The only way that Brunei Darussalam is seriously affected by water borne pollutants is by the erratic and sudden onset of "red-tide" in the coastal waters and some parts of major rivers [6].

Table 4.1 shows the water pollution in selected countries. Although Brunei's ASEAN neighbours such as Thailand and Indonesia are featured in this list, Brunei Darussalam remains absolutely unaffected.

TABLE 4.1

Water pollution in selected countries.

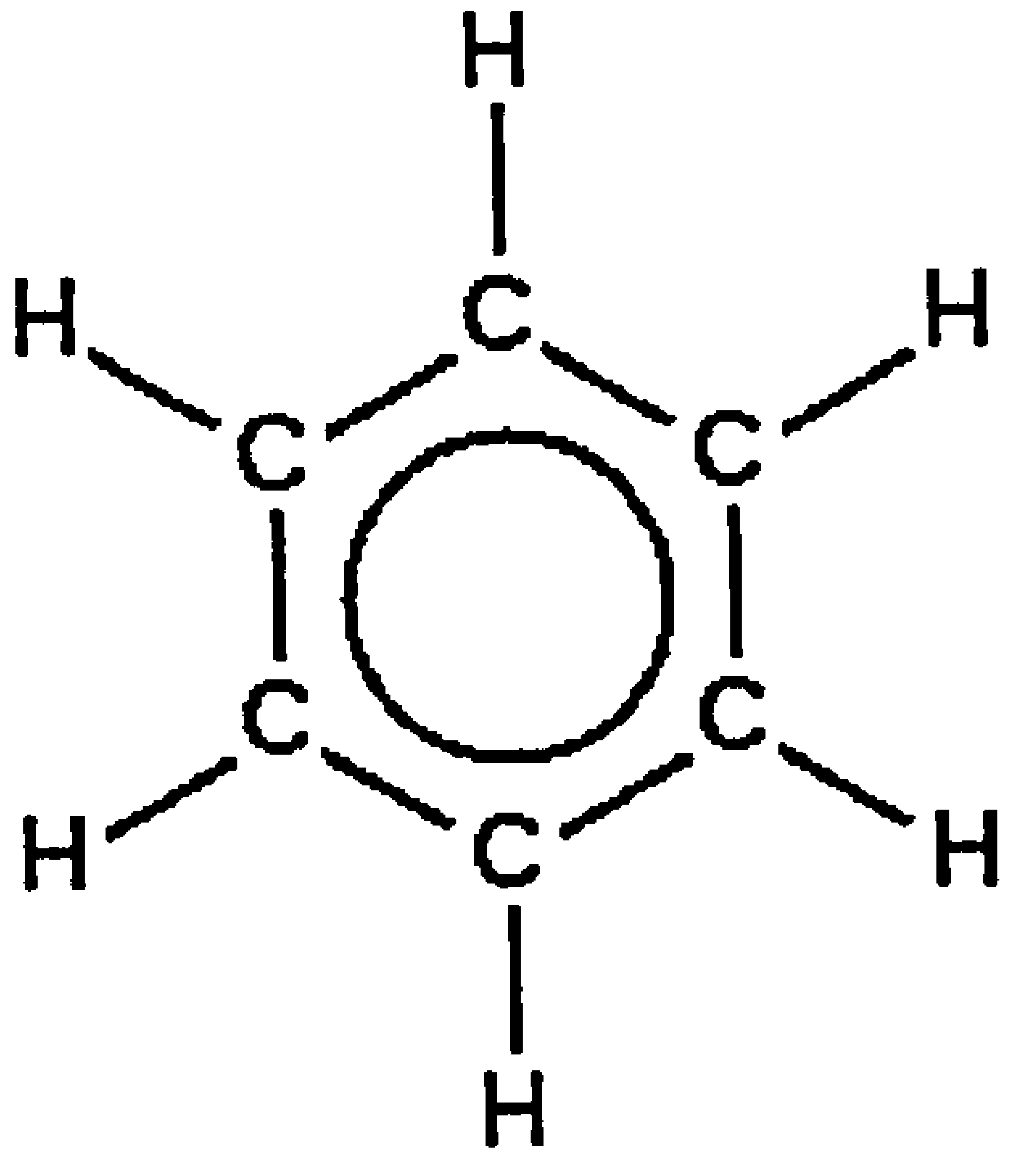
	Emission of organic water pollutants (kg)				Industry shares of emissions of organic pollutants (%)							
	Per day		Per worker per day		Primary metals	Paper & pulp	Chemicals	Food & beverage	Stone, ceramics & glass	Textiles	Wood	Other
	1980	1993	1980	1993	1993	1993	1993	1993	1993	1993	1993	1993
China	3,358,203	5,339,072	0.14	0.15	22.0	10.0	14.0	33.3	0.4	11.5	0.4	8.3
USA	2,742,993	2,477,830	0.14	0.15	8.3	32.7	9.5	28.2	0.1	7.8	2.4	10.8
Japan	1,456,016	1,548,021	0.14	0.14	9.9	22.0	8.8	36.5	0.2	7.9	1.9	12.8
India	1,457,474	1,441,293	0.21	0.20	15.6	8.1	7.3	50.9	0.2	12.9	0.3	4.8
Germany	-	1,046,176	-	0.12	15.6	15.3	15.1	27.9	0.2	6.4	2.0	17.6
Brazil	866,790	855,432	0.16	0.17	10.4	13.5	9.1	45.8	0.3	11.5	3.0	6.4
UK	964,510	680,865	0.15	0.16	8.9	24.7	10.1	37.1	0.2	7.2	1.7	10.0
Ukraine	-	666,233	-	0.14	18.3	3.7	7.3	46.9	0.5	10.1	2.0	11.3
France	716,285	609,940	0.14	0.15	11.9	20.7	11.0	37.0	0.2	6.7	1.8	10.8
Indonesia	214,010	537,142	0.22	0.19	-	7.8	10.4	58.9	0.2	15.4	4.8	2.6
Poland	580,869	365,580	0.14	0.16	13.4	6.6	7.7	48.4	0.3	12.5	2.4	8.7
Rep. of Korea.	281,900	358,610	0.14	0.13	12.8	15.4	11.2	25.8	0.3	20.8	1.5	12.2
Italy	442,712	353,906	0.13	0.13	17.0	16.1	10.5	25.8	0.3	16.1	2.1	12.1
Spain	376,253	318,506	0.16	0.17	10.7	15.4	9.3	45.6	0.3	8.7	2.8	7.2
Canada	330,241	300,071	0.18	0.18	10.1	30.1	8.7	34.5	0.1	5.9	3.3	7.3
Thailand	214,426	256,930	0.22	0.16	6.3	7.6	6.8	46.4	0.3	26.4	1.9	4.3

Source: World Bank: 1998 World Development Indicators. Washington.
Data downloaded from: www.worldbank.org/nipr/wdi98/index.htm

These are the 16 countries with the highest emissions of organic water pollutants for which data were available in the World Bank's 1998 development indicators. If these data are correct, then China has by far the highest emissions of organic water pollutants in the world. China's total daily emissions of about 5.3 million kg are equivalent to the emissions of the USA, Japan and India combined. They are 10 times higher than Indonesia's emissions. According to these World Bank data, the food industry is the largest water polluter in China. One-third of all organic water pollution is caused by the food and beverages industries.

4.2 BENZENE (C_6H_6)

Benzene



Benzene is an aromatic hydrocarbon that is produced by the burning of natural products. It is also a component of products derived from coal and petroleum. It is found in gasoline and other fuels and is used in the manufacture of plastics, detergents, pesticides and other chemicals [7]. It is a colourless liquid with a sweet odour and evaporates very quickly. It can dissolve slightly in water and is highly inflammable. Most people can begin to smell benzene in air at 1.5-4.7 parts of benzene per million parts of air (ppm) and can begin to taste benzene in water at 0.5-4.5ppm. Typical drinking water contains less than 0.1ppb benzene but it has been detected in some bottled water and in food. In the environment benzene as a pollutant can be found in water, air and soil.

The benzene found in the environment is from both human activities and natural processes. Benzene was first discovered and isolated from coal tar in the 19th century. Today, benzene is made mostly from petroleum sources. Because of its wide use, benzene ranks in the top 20 in production volume for chemicals produced in the United States. Benzene in water and soil breaks down slowly. Being slightly soluble in water it can pass through the soil into underground water. Leakage from underground gasoline storage tanks or from landfills and hazardous waste sites containing benzene can result in benzene contamination of well water. Individuals employed in industries that make or use benzene may be exposed to the highest levels of benzene. These industries include benzene production (petrochemicals, petroleum refining and coke or chemical manufacturing), rubber tyre manufacturing and storage or transport of benzene and petroleum products containing benzene. Benzene in the environment does not build up in plants or animals [8].

Research has shown benzene to be a carcinogen (cancer causing). With exposures from less than 5 years to more than 30 years, individuals have developed and died from leukaemia. Long term exposure may affect bone marrow and blood production. Short term exposure to high levels of benzene can cause drowsiness, dizziness, unconsciousness and death. Benzene can also be absorbed through the skin [7].

4.2.1 Environmental transport, distribution and transformation

Benzene in air exists predominantly in the vapour phase, with residence times varying between a few hours and a few days, depending on the environment, climate and the concentration of hydroxyl radicals, as well as nitrogen and sulphur dioxides. It can be removed from air by rain, leading to contamination of surface and ground water, in which it is soluble to about 1000mg/litre. Due primarily to volatilization, the residence time of benzene in water is a few hours, with little or no adsorption to sediments. Benzene in soil can be transported to air via volatilization and to surface waters by run off. If benzene is buried or is released well below the surface, it will be transported into ground water. Under aerobic conditions, benzene in water or soil is rapidly (within hours) degraded by bacteria to lactate and pyruvate through phenol and catechol intermediates. However, under anaerobic conditions (for example, in ground water) bacterial degradation is measured in weeks and months rather than hours. In the absence of bacterial degradation benzene can be persistent. It has not been shown to bioconcentrate or bioaccumulate in aquatic or terrestrial organisms [7].

4.2.2 Kinetics and metabolism

Benzene is well absorbed in humans and experimental animals after oral and inhalation exposures, but in humans dermal absorption is poor. Approximately 50% absorption occurs in humans during continuous exposures to 163-326mg m^{-3} for several hours. After 4 hours exposure to 170-202mg m^{-3}, retention in the human body was approximately 30%, with 16% of the retained dose having been excreted as unchanged benzene in expired air. Women may retain a greater percentage of inhaled benzene than men. Benzene tends to accumulate in tissues containing high amounts of lipids, and it crosses the placenta [8].

4.2.3 Genotoxicity and carcinogenicity

Benzene has given negative results in mutagenicity assays in vitro. In *in vivo* studies, benzene or its metabolites cause both structural and numerical chromosome aberrations in humans and laboratory animals. In addition, benzene administration results in the production of sister chromatid exchanges and polychromatic erythrocytes with micronuclei. Benzene can reach germ cells, after intraperitoneal dosing, as shown by the production of abnormalities in sperm head morphology. Benzene has been reported to cause the production of several types of neoplasms in both rats and mice after either oral dosing or inhalation exposures. These include various types of epithelial neoplasms, e.g., Zymbal gland, liver, mammary tissue and nasal cavity neoplasms, and a few lymphomas and leukaemias. In those inhalation studies where a positive carcinogenic response was reported, exposure levels were between 100 and 960mg m^{-3} for 5-7h/day, 5 days/week. Oral benzene doses of between 25 and 500mg/kg body weight in mice and rats resulted in the production of neoplasms. The length of exposure was usually 1-2 years [7,8].

4.2.4 Reproductive toxicity, embryotoxicity and teratogenicity

Benzene crosses the placental barrier freely. There are no data showing that it is teratogenic after numerous experiments in experimental animals even at maternally toxic doses. However, it has been shown to be fetotoxic following inhalation exposure in mice (1600μ gm^{-3}, 7h/day, gestation days 6-15) and in rabbits [7,8].

4.2.5 Effects on humans

It is known that benzene produces a number of adverse health effects. The most frequently reported health effect of benzene is bone marrow depression leading to aplastic anaemia. At high levels of exposure a high incidence of these diseases is probable. Benzene is a well-established human carcinogen. Epidemiological studies of benzene-exposed workers have demonstrated a causal relationship between benzene exposure and the production of myelogenous leukaemia. A relationship between benzene exposure and the production of lymphoma and multiple myeloma remains to be clarified. The epidemiological evidence is not capable of distinguishing between:-

a) a small increase in mortality from leukaemia in workers exposed to low levels of benzene, and

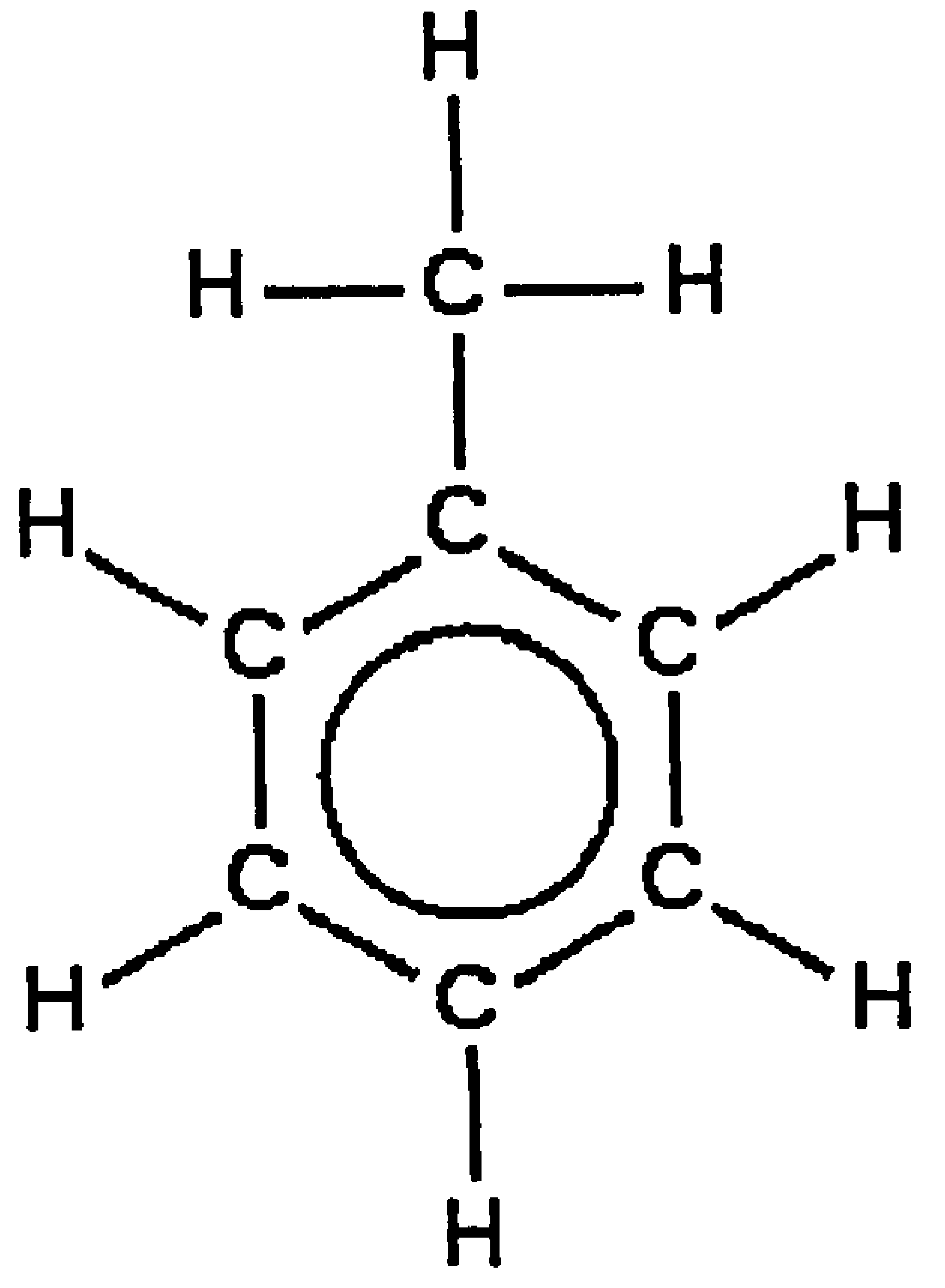
b) a non-risk situation. [7,8]

4.2.6 Effects on laboratory mammals and in vitro test systems

Benzene appears to be of low acute toxicity in various animal species, with LD50 values after oral exposure ranging between 3000 and 8100mg kg^{-1} body weight in the rat. Reported LC50 values range from 15,000mg m^{-3} (8 hour) in mice to 44,000mg m^{-3} (4 hour) in rats. Benzene is a moderate eye irritant and is irritating to rabbit skin after multiple applications of the undiluted chemical. No information is available on the skin-sensitizing potential of benzene. Exposure of mice to benzene by inhalation results in a significant lowering of blood parameters such as haematocrit, haemoglobin level and erythrocyte, leucocyte and platelet counts. Long-term exposure at high doses results in bone marrow aplasia. Similar, but less severe, findings were noted in rats [7,8]

4.3 TOLUENE ($C_6H_5CH_3$)

Toluene



Toluene is a clear, colourless liquid with a distinctive smell [9]. It occurs naturally in crude oil fuels (including gasoline) and in the tolu tree. It is produced during the process of making gasoline and other fuels from crude oil, in making coke from coal and as a by-product of styrene manufacture. It is also used in the production of nylon, plastics soda bottles and other organic chemicals. It is also used in making paints, paint thinners, fingernail polish, lacquers, adhesives and rubber in some printing and leather tanning processes [10].

When toluene is spilled on the ground or improperly disposed of, it can seep into soil and contaminate nearby wells and streams. It can remain unchanged for a long time in soil or water that is not in contact with air [11]. Toluene enters the environment when materials that contain it are used. It can also enter surface-water and groundwater from spills of that contain it are used. It can also enter surface-water and groundwater from spills of solvents and petroleum products as well as leaking underground storage tanks at gasoline stations and other facilities [9].

Toluene causes health effects from both short term (acute, less than 14 days) and also long term (chronic, greater than 365 days) exposure. Acute exposure at high levels can cause dizziness, sleepiness, unconsciousness and death. Chronic exposure at low to moderate levels can cause tiredness, confusion, weakness, drunken-like behaviour, memory loss, nausea, loss of appetite and hearing loss. At high levels exposure can cause permanent brain and speech damage, vision and hearing problems, loss of muscle control, poor balance, memory loss, decreased mental ability, irritation of the upper respiratory tract, eyes and throat, sleeplessness and damage to the kidney, liver and brain [10].

4.3.1 Absorption, distribution and metabolism

Toluene is readily absorbed from the respiratory and gastrointestinal tracts and, to a lesser extent, through the skin. Animal studies suggest that absorption from the gastrointestinal tract is complete. Absorption data for humans and animals indicate that pulmonary absorption is 85-90% during brief exposures but nearer to 50% during extended exposures (< 1 hour). In humans, toluene has been detected in the arterial blood within 10 seconds after initiation of inhalation exposures; exercise greatly increases the absorption of toluene. Cutaneous absorption is approximately 1% of that absorbed by the lungs when there is exposure to the vapour; dermal absorption, however, of the liquid may be higher. Because toluene evaporates readily, it is unlikely that significant absorption will occur by this route.

Distribution of toluene following absorption occurs throughout the body, with accumulation in adipose tissue, other tissues with high fat content and highly vascular tissues. High levels of toluene were found in the brain and liver of an individual who had died following an episode of glue sniffing. Autoradiography studies using mice indicate that immediately after inhalation exposure, a high level of radioactivity is present in the body fat, bone marrow, spinal nerves, spinal cord, and white matter of the brain.

Radioactivity was also observed in the blood, kidney, and liver but at lower levels. In one individual who died 30 minutes after ingestion of toluene, the liver had the highest concentration of toluene, followed by the pancreas, brain, heart, blood, body fat, and cerebrospinal fluid. Since retention time of toluene is usually considered to be less than 24 hours, bioaccumulation of toluene is unlikely.

The initial step in toluene metabolism is side-chain hydroxylation to benzyl alcohol by P-450 enzymes in the liver, followed by oxidation to benzaldehyde by alcohol dehydrogenase and subsequently to benzoic acid by aldehyde dehydrogenase. Benzoic acid is then conjugated with glycine to form hippuric acid, the major urinary metabolite. Benzoic acid can also react with glucuronic acid to form benzoyl glucuronide. Ring hydroxylation to o- and p-cresol is considered a minor metabolic pathway [7-11].

4.3.2 Production, uses and sources of exposure

Toluene is a commercially important intermediate chemical produced throughout the world in enormous quantities ($0.5 - 1.0 \times 10^7$ tonnes). It is produced both in the isolated form and as a component of mixtures. Toluene produced in the form of a mixture is used to back-blend gasoline. Isolated toluene, on the other hand, is used in:-

(a) the production of other chemicals;

(b) as a solvent carrier in paints, thinners, adhesives, inks and pharmaceutical products; and

(c) as an additive in cosmetic products. Purified toluene usually contains less than0.01% benzene, but the industrial grade may contain up to 25% benzene.

The primary man-made sources of toluene released into the environment are:-

(a) Inadvertent sources (65%), i.e., emission from motor vehicles and aircraft exhaust, and losses during gasoline marketing activities, spills, and cigarette smoke;

(b) Processes in which toluene is used (33%); and

(c) Toluene production (2%).

The significance of each of these sources is expected to vary widely from country to country. On the basis of available data and estimates, 86% of the toluene produced is eventually released into the biosphere (predominantly the troposphere). The life-time of toluene ranges from several days to several months [7-11].

4.3.3 Effects on experimental animals

Acute inhalation data indicate that the species sensitivity decreases as follows: rabbit, guinea pig, mouse and rat. Inhalation LC_{50} values have been reported in the range of approximately 20,000 – 26,000mg m^{-3} for mice and approximately 45,000mg m^{-3} for rats. The oral LD_{50} in the rat is between 2.6 and 7.5g kg^{-1} body weight, depending on the strain, age and sex. Toluene is a slight dermal and a moderate eye irritant in animals and man. Acute dermal toxicity appears to be quite low (rabbit: LD_{50} 14.1ml kg^{-1} body weight).

In short- and long-term inhalation studies on experimental animals, no effect was seen with exposure to 375mg m^{-3} toluene for 24 months. In oral studies, administration of 590mg kg^{-1} toluene body weight, per day, for 6 months did not produce any effects. At low dose levels, in rats, the target organs seem to be the kidneys and testes, while at high dose levels, liver changes and effects on the central nervous system are predominantly seen. Reversible functional and/or morphological changes are dose-related.

Toluene does not appear to be teratogenic in mice, rats, or rabbits, but embryotoxic/foetotoxic effects were seen in rats at a dose that was non-toxic for the dams exposed to toluene concentrations of 1000mg m^{-3} air. Spontaneous abortion occurred in rabbits exposed to 1000mg m^{-3} during the entire period of organogenesis. Orally administered toluene, however, was reported to be teratogenic in CD-1 mice. Exposure to 870mg kg^{-1} body weight on days 6 - 15 significantly increased the incidence of cleft palate. A level of 430mg kg^{-1} body weight was without effect [7-11].

The ability of toluene to interfere with biotransformation and alter the toxic effects of several solvents has been documented by several investigators. For example, toluene decreased *n*-hexane metabolism and neurotoxicity, benzene metabolism and its effects on the haematopoietic system. It increased the hepatotoxicity of carbon tetrachloride, however.

4.3.4 Effects on human beings

Toxicity studies on human beings have primarily involved individuals exposed to toluene via inhalation either in experimental occupational settings or during episodes of intentional abuse of solvent mixtures containing toluene. The primary effect of toluene is on the central nervous system (CNS). The effect may be depressant or excitatory, with euphoria in the induction phase followed by disorientation, tremulousness, mood lability, tinnitus, diplopia, hallucinations, dysarthria, ataxia, convulsions and coma [8-10].

Acute controlled and occupational exposures to toluene in the range of 750 - 5625mg m^{-3} (200 - 1500ppm) caused dose-related CNS effects. Acute exposure to high levels of toluene (e.g. 37,500 mg m^{-3} or higher for a few minutes) during industrial accidents was characterized by initial CNS excitative effects (e.g., exhilaration, euphoria, hallucinations) followed by progressive impairment of consciousness, eventually resulting in seizures and coma. Single, short-term exposures to toluene (750mg m^{-3} for 8 hours) have reportedly caused transient eye and respiratory tract irritation with lachrymation at 1500mg m^{-3}. Repeated occupational exposures to toluene over a period of years at levels of 750 - 1500mg m^{-3} (200 - 400ppm) have resulted in some evidence of neurological effects [7-11].

4.3.5 Carcinogenicity

There have been several human population studies which have examined the possible relationship between toluene exposure and cancer. Cancers of most sites were not significantly associated with toluene exposure in any study. Stomach cancer mortality, lung cancer rates and colorectal cancers were evaluated in some studies, but not others.

Considering the multiple exposures in most studies and the inconsistencies in findings, it is not possible to conclude that toluene exposure is associated with cancer in humans. The International Agency for Research on Cancer (IARC) has concluded there is inadequate evidence for the carcinogenicity of toluene in humans. There is evidence suggesting a lack of carcinogenicity to o-toluene in experimental animals. IARC has concluded that this chemical is not classifiable as to its carcinogenicity to humans (Group 3). The American Conference of Governmental Industrial Hygienists has designated this chemical as not classifiable as a human carcinogen. The US National Toxicology Program has not listed this chemical in its report on carcinogens [9-11].

4.3.6 Teratogenicity and Embryotoxicity

Toluene is a developmental toxicity hazard, based on information obtained from animal studies. Foetotoxicity (reduced foetal weight), behavioural effects (effects on learning and memory) and hearing loss (in males) have been observed in the offspring of rats exposed by inhalation to 1200 or 1800ppm toluene. These effects were observed in the absence of maternal toxicity [9].

A detailed review of toluene and its potential to cause teratogenicity/embryotoxicity in occupational situations has been published. This review concludes that although many occupational studies have evaluated general solvent exposure and pregnancy outcomes, few studies have specifically investigated toluene exposure. Most of these studies have involved exposure to solvents in general or to certain solvent classes, with toluene exposure addressed as a co-exposure or identified as a common exposure in a sub-group. Outcomes of concern included spontaneous abortion (miscarriage) and teratogenicity (congenital malformations) [9,10]

Six studies examined the association of toluene exposure with spontaneous abortions. Four of the six studies were performed on similar groups of Finnish workers, by the same group of researchers, which can reduce overall confidence in the conclusions. Despite this and other limitations (e.g. recall bias, multiple chemical exposures), these studies do provide evidence suggesting there may be an association between occupational toluene exposure and the occurrence of spontaneous abortions. Nevertheless, further research is required before it will be possible to conclude that there is a causal relationship between toluene exposure and an increased incidence of spontaneous abortions. One study has reported an increased incidence of malformations (renal-urinary and gastrointestinal) in children born to women with a history of exposure to aromatic solvents, particularly toluene. It is not possible, however, to draw specific conclusions regarding toluene from this study, because the toluene-specific results were based on a very small number of workers who were exposed to multiple chemicals. Concerns about the potential teratogenicity of toluene in humans have also arisen due to effects (usually renal/urinary) seen in solvent abuse cases (glue-sniffing). These extreme exposures to toluene, as well as other confounding factors such as tobacco and alcohol abuse, are not relevant to occupational situations [7-11].

4.3.7 Reproductive Toxicity

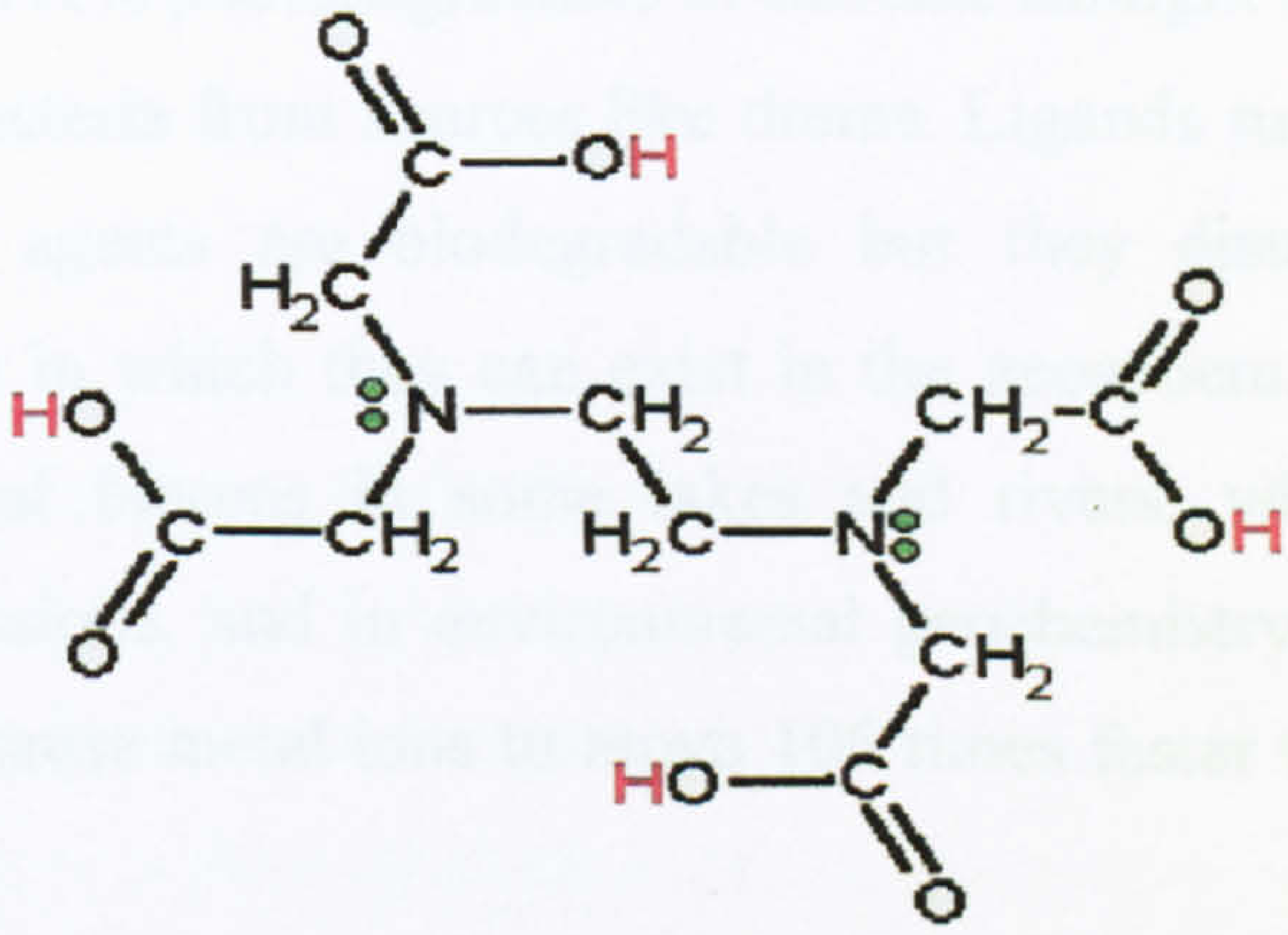
No conclusions can be drawn based on the available human information. Reproductive effects have not been observed in animal studies. A review of toluene and its potential to cause reproductive toxicity in workers has been published. Three cross-sectional studies evaluated fertility in women exposed to toluene or in the wives of exposed men. No conclusions can be drawn based on these studies, due to limitations such as selection bias, recall bias and the fact that the workers were exposed to other potentially harmful chemicals. Another study suggests that menstrual function is not affected by exposure to toluene. Another report describes testicular atrophy and reduced spermatogenesis in one man who abused toluene for 10 years. This extreme exposure situation is not relevant to occupational exposures. [7-11]

4.3.8 Mutagenicity

Results from the available human studies are inconclusive. Both positive and negative results have been obtained in human studies, but no studies were carried out with toluene exposure only, or with adequate control of other factors. Positive results have been obtained in some studies using live animals, but the studies either used an irrelevant route of exposure (intraperitoneal) or there are insufficient details available for evaluation [7].

4.4 ETHYLENEDIAMINETETRAACETIC ACID (EDTA)

Ethylenediaminetetra-acetic acid (EDTA) is a novel molecule for complexing metal ions. It is a polyprotic acid containing four carboxylic acid groups (acidic hydrogens are red) and two amine groups with lone pair electrons (green dots). The classic structural formula is given below.



Ethylenediaminetetraacetic Acid (EDTA)

Industrial effluents contain chelating ligands such as Ethylenediaminetetraacetic Acid (EDTA). The EDTA is deliberately added to some process solutions to remove metal ions [12]. Legislative fulfilment requires successful effluent treatment.

The success of effluent treatment depends on two factors, namely, the effect of heavy metal presence in the process of degradation and the presence of organic molecules which disturb the removal of heavy metal. This type of effluent is related to cleaning, agricultural and textile industries.

4.4.1 A Complexing Agent

Citric acid is one of the chelating ligands. In printing and textile industries, it has been used extensively as an additive to avoid the forming of stains due to calcium from hard water. These ligands can bind metal ions which can cause product degradation, discolouration and spotting of garments [12-25] if they are not checked. Later citric was replaced by nitrilotriacetate NTA and EDTA came into use as chelating agents during the 1950's in the USA and Germany. Unfortunately these ligands have poor biodegradability. Even after years of disposal they persist and EDTA is the main culprit. In fact, its use has been banned in parts of the USA and some countries have set up limits for maximum levels for river water. EDTA is photodegradable in extreme sunlight but it is not so if it is exposed to a variety of bacteria from sources like drains. Ligands such as agrochemicals detergents and washing agents are biodegradable but they disturb the balance of distribution of metal ions in which they can exist in the geosphere. This is seen in the excessive growth of algal blooms in some lakes and rivers, which is traceable to phosphate detergent emissions, and in environmental geochemistry data demonstrating that organic ligands can cause metal ions to move 106 times faster than in their absence [26-38].

4.4.2 Toxicity of EDTA

More than the problem of biodegradability, the EDTA poses the danger of toxicity. A research by Stephanie HugenSchmidt and co-workers (10) at the Institute for Toxicology in Karlsruhe, Germany in 1993 brought out an interesting discovery. While working on an investigation into the effects of sodium salt of EDTA on living rat kidney cell, they realized that many of the cells were seen to die, and the ability of cells to reproduce was severely impaired at concentrations of Na_2H_2EDTA less than 100μ mol dm^{-3}. HugenSchmit et.al (10) have interpreted the WHO median value for EDTA (0.044μ mol dm^{-3}) as 17% which is the maximum recommended level. But the EU wishes to review any level above 10%.

As far as human health exposure is concerned, however concentrations of EDTA are relatively low. EDTA levels from 25 river water and sewage effluent sampling points in the UK were within the range 0 - 0.44μ mol dm^{-3}. Further, in a recent study carried out at the Health and Safety Laboratory in Sheffield, using cells related to humans keratinocytes, it was found that Na_2H_2EDTA had little effect up to a concentration of 1000μ mol dm^{-3}. This is consistent with observations made by other researchers such as Konrad Heindroff and colleagues at Gatersleben in Germany [14]. After reviewing the genetic effects of EDTA, Heindroff concluded that although EDTA produces a whole set of genetic effects; it seems to be a harmless compound to man as far as genotoxicity is concerned.

4.4.3 Uses of EDTA

There are several industrial applications based both EDTA and DTPA (diethylenetriaminepentaacetic Acid). Most popular uses include the binding of metal ions in production, textile, leather, metal and agricultural industries. It is also used paper industries to prevent metal ions from catalyzing the decomposition of bleach.

EDTA in its disodium salt or calcium disodium salt form is frequently used in foods such as mayonnaise and salad dressing, canned foods such as crab meat, mushroom and cooked legumes. In Japan, USA and in certain European community countries where EDTA is used as a sequestrant at permitted levels. In canned molluscs, EDTA is used to avoid the precipitation of ammonium magnesium phosphate if the product is not too fresh.

4.5 DETERGENTS / SURFACTANTS

A synthetic cleansing agent resembling soap in the ability to emulsify oil and hold dirt, and containing surfactants which do not precipitate in hard water, may also contain protease enzymes and whitening agents. Surfactants constitute the most important group of detergent components. Generally, these are water-soluble surface-active agents comprised of a hydrophobic portion, usually a long alkyl chain, attached to hydrophilic or water solubility enhancing functional groups. Surfactants can be categorized according to the charge present in the hydrophilic portion of the molecule:-

- Anionic surfactants
- Non-ionic surfactants
- Cationic surfactants
- Ampholytic surfactants

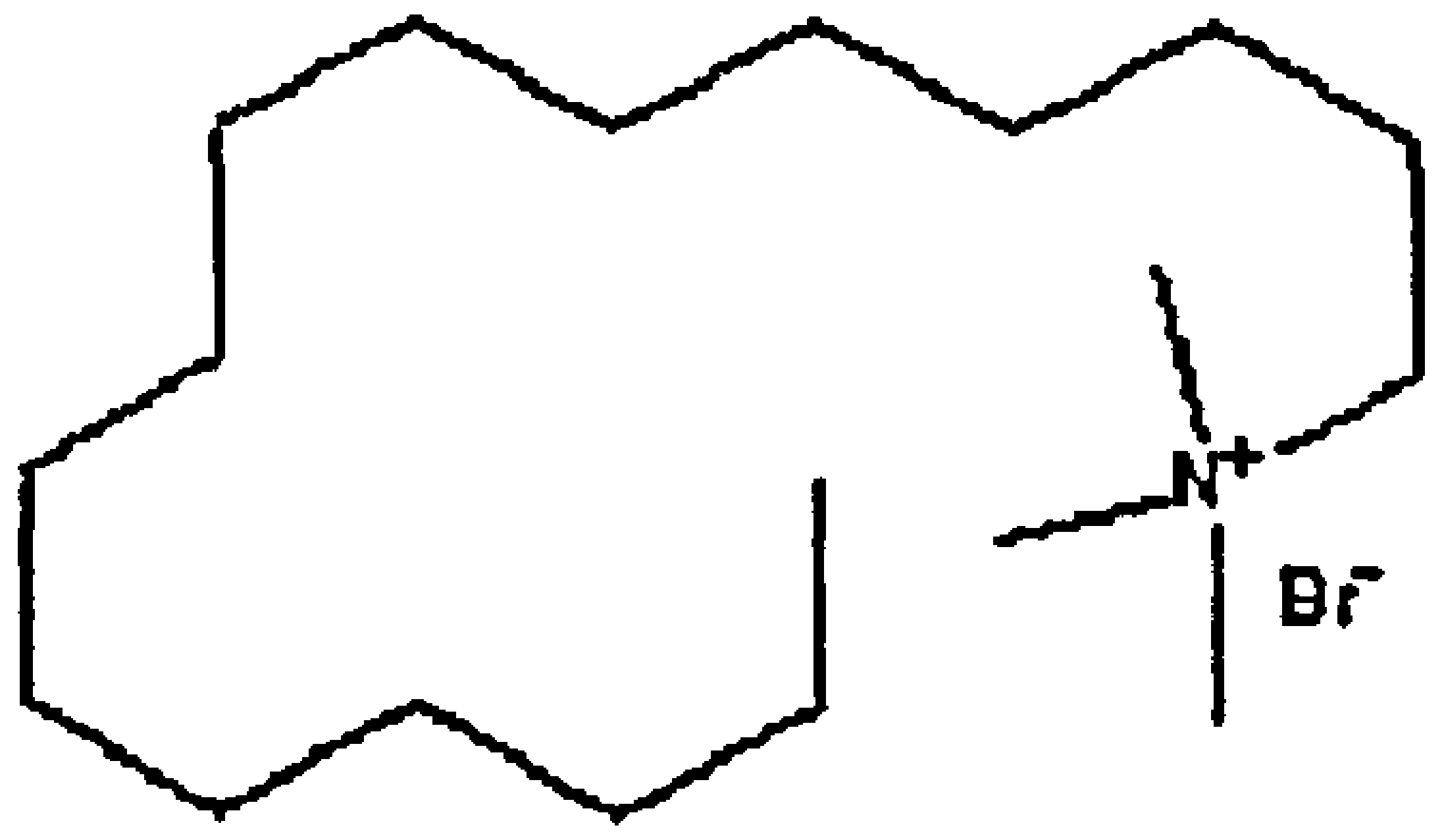
Detergents contain a combination of both anionic and non-ionic surfactants. They may also have anti-caking agents, whiteners or fluorescent brighteners, and fragrance. Most of these materials contain toxic chemicals which can be lethal if swallowed. Detergents may contain:-

- Sodium dichloro-traizinetrione (toxic if swallowed, eye and skin irritant)
- Sodium hypochlorite (toxic, mutagenic)
- Sodium carbonate (corrosive, eye irritant)

Detergents have gone through changes since then. Today's detergents include synthetic surfactants, which in addition to helping lift soil from clothes improve the wetting ability of water by reducing its surface tension. Anionic surfactants, the most widely used, are negatively charged, which means they attract the positively charged molecules (calcium and magnesium) that cause hardness and tend to deactivate them. They're really good at removing oily soil and clay, but their reaction with hardness molecules tends to deactivate them, too, so they need help from other ingredients. Nonionic surfactants don't carry any charge at all, so they aren't deactivated by water hardness, but then neither do they deactivate it. They're good on oily soils as well and are frequently used in low-sudsing detergents and liquid detergents. They're often mixed with anionic surfactants to better deal with hard water. Cationic surfactants carry a positive charge in water, so they don't react with hardness molecules either. They're often used in fabric softeners or fabric-conditioning detergents; their positive charge reduces static electricity.

4.5.1 Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$)

Hexadecyltrimethylammonium bromide is a cationic surfactant with a chemical formula of $CH_3(CH_2)15NBr)(CH_3)_3$. It has a molecular weight of 364.45 and goes with synonyms such as Cetrimonium bromide and abbreviations such as HTAB, CTAB AND CTABr.



Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$)

In physical state it is either clear or pale yellowish viscous liquid. It has a melting point of >0 C and a boiling point of >100 C with a specific gravity of > 1.0. and slightly soluble in water. Any group of ammonium salts in which organic radicals have been substituted for all four hydrogens of the original ammonium cation are called **Quaternary ammonium compounds.** Structurally, a central nitrogen atom is connected to four organic radicals and one acid radical. The organic radicals can be alkyl, aryl or aralkyl whereas the nitrogen can be a part of a ring system. They are strong electrolytes and soluble in water. Their properties include disrupting of micro-organisms' processes and surfactants. They can be used as active ingredients for conditioners, detergent sanitisers, textile softener, antimicrobiols, emulsifying agents, algaecide [13].

4.5.2 Potential Health Effects

The use of Hexadecyltrimethyl-ammonium bromide has a variety of toxicity. Inhalation, skin contact and ingestion are the ways of harmful links. The target organs are related to behaviour, thorax, lungs, embryo, craniofacial and musculoskeletal systems. According to the National Institute for Occupational Safety and Health (NIOSH) USA, tests have been conducted with certain animals such as rabbit and mouse for toxicity effects of Hexadecyltrimethyl-ammonium bromide. When a 450 mg was introduced into the eye of a rabbit, the irritation level was severe [39]. On the other hand the skin of a mouse responded with severe irritation when put under a 50mg / open irritation test [40]. In terms of reproductive effects, interesting data have emerged. With an intraperitoneal exposure of 10,500ug kg^{-1} toxic dose on a eight days pregnant mouse, the developmental abnormalities were clearly seen in its musculoskeletal system [41]. With an intraperitoneal exposure of 35 mg kg^{-1} toxic dose on an eight days pregnant mouse, the developmental abnormalities were clearly seen in post-implantation mortality rate [41]. Further experiments with 10 and 12 day pregnant mice showed abnormalities ranging from Craniofacial (including and nose and tongue) to Fetotoxicity such as stunted fetus [41].

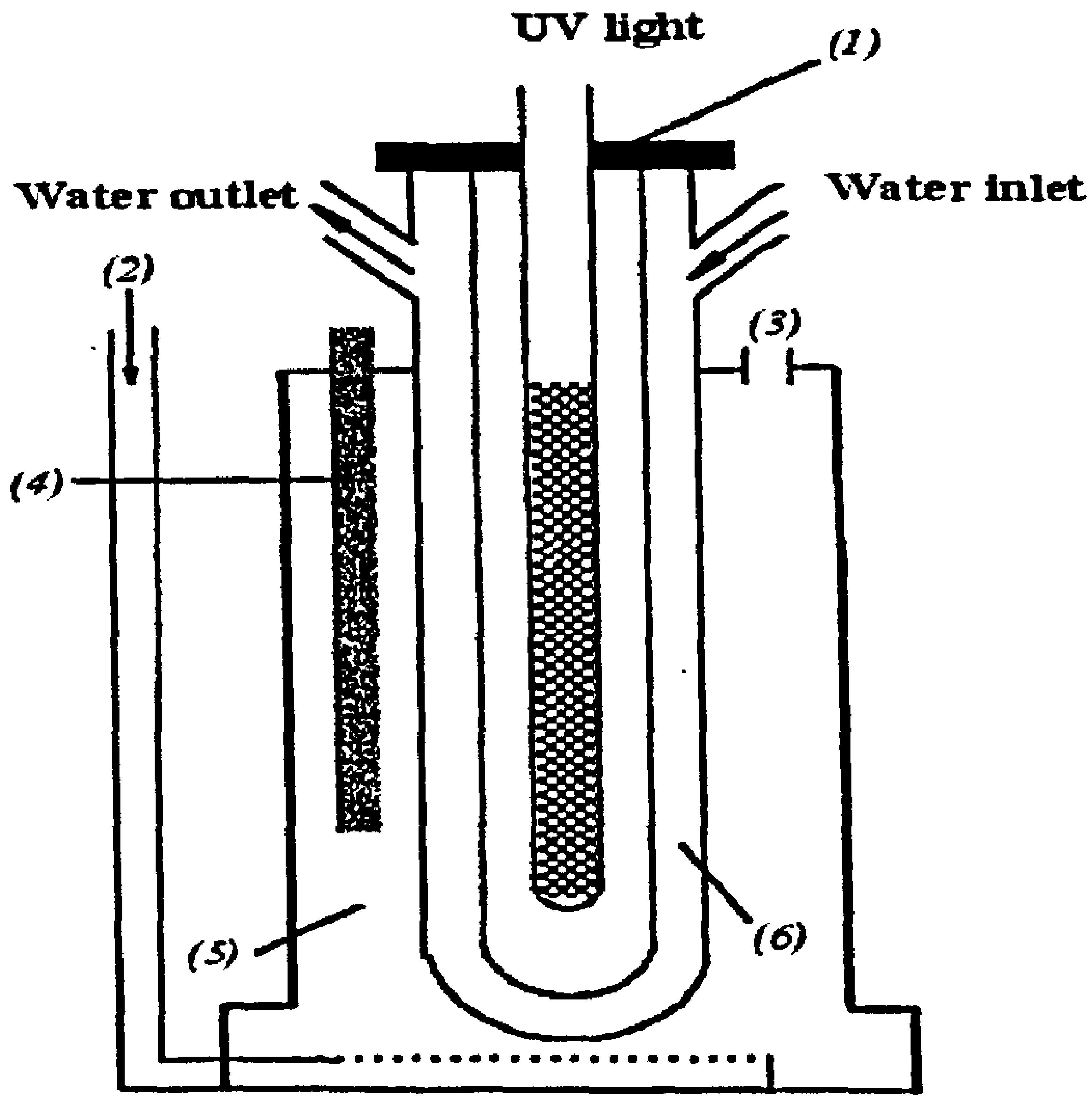
On the other hand, a dose of 106mg became lethal when given intraperitoneally resulting in convulsion and respiratory depression and ultimate death [41]. Intravenous injection of 32 mg kg^{-1} in the case of mouse and 44 mg kg^{-1} in the case of rat also proved to be lethal resulting from thorax and lung failures [42].

4.6 DESIGN AND OPERATION OF THE PHOTOLYTIC CELL SYSTEM

Photolytic degradation of organic pollutants was carried out using 150 and 400W UV-sources (Plate 4.1), supplied by Photochemical Reactors Ltd., UK. Figure 4.1 shows the output characteristics of these two UV-sources. These UV-probes produce hydroxyl free radicals which are responsible for the degradation of organic pollutants.

The photolytic cell system used in Figure 4.2 consists of a UV probe (1) surrounded by a reaction chamber (5) of 3.5dm^3 capacity in plate 4.2. Compressed air was used as the oxidant in the photolysis and is supplied through the inlet (2) and exits through the outlet (3). The temperature in the system was measured by a thermometer (4) and the reaction chamber was maintained at 25-30°C by a water-cooling jacket (6) which surrounded the UV probe.

Figure 4.2
Schematic illustration of the photolytic cell system.



(1) uv probe (2) inlet (3) outlet (4) thermometer (5) reaction chamber (6) Cooling jacket

Plate 4.1

150 and 400 Watt UV-probes

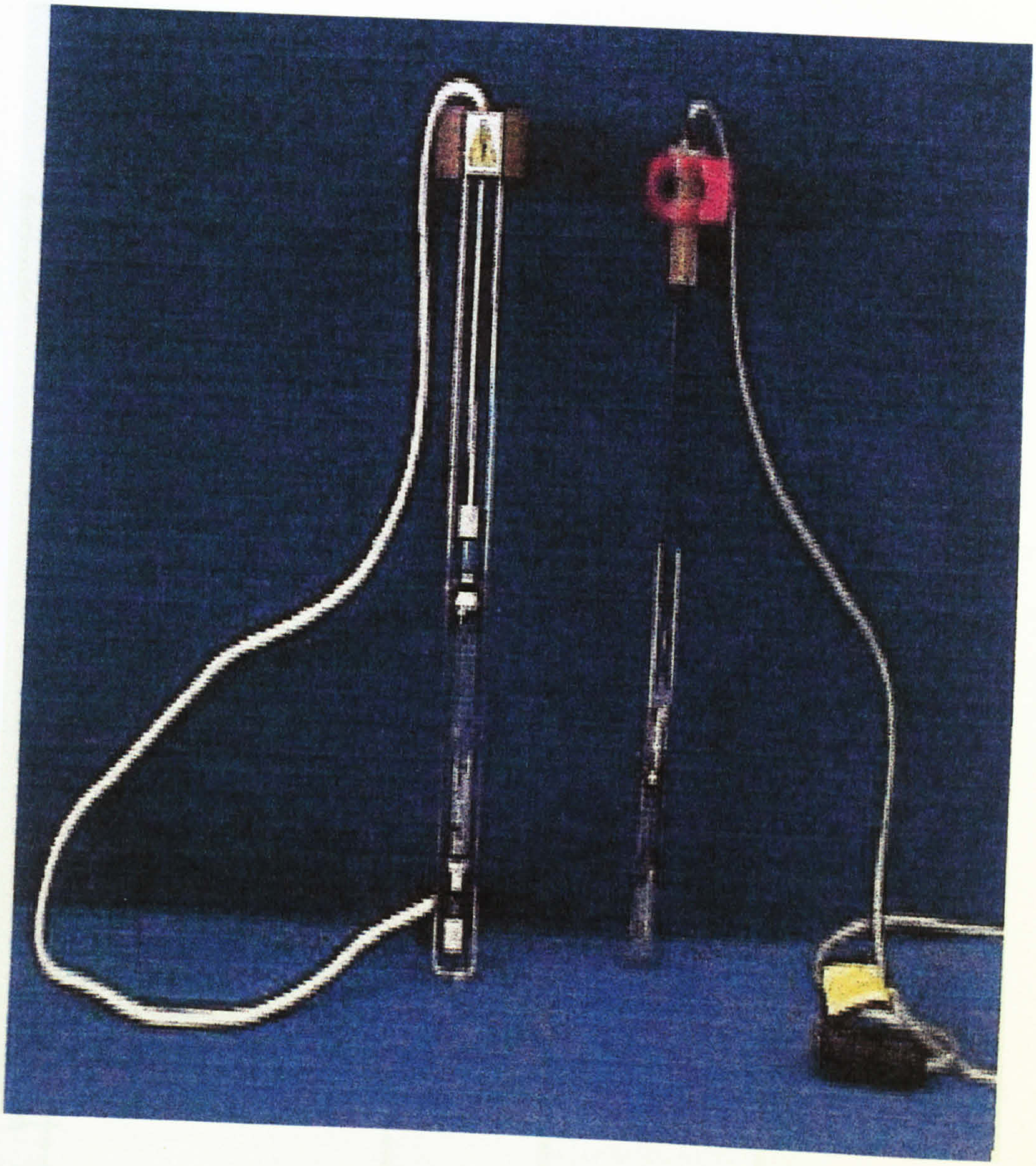


Figure 4.1
Output Characteristics of 150 Watt and 400 Watt UV-lamps

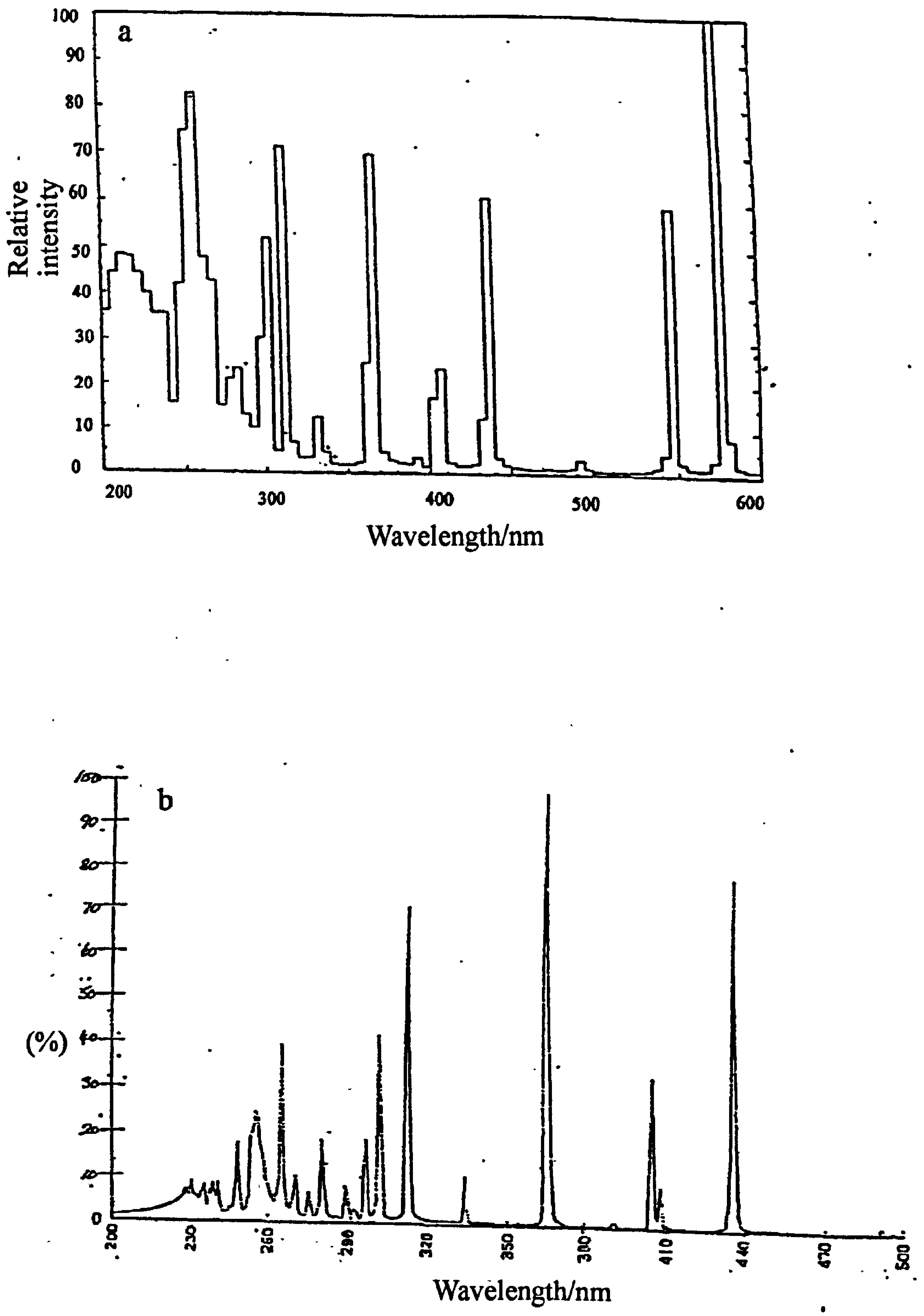


Plate 4.2
Photolytic Reaction Chamber

4.7 AIM OF THE EXPERIMENT

The work described in this chapter aims to investigate the effect of various catalysts on the photolytic degradation of hydrocarbons such as benzene and toluene including ethylenediaminetetra-acetic acid (EDTA) and hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$). These solvents can cause major pollution to river waters and can create a hazard to public health and environment.

4.7.1 Experimental

Experiments were carried out to investigate the effect of catalysts on the photolytic degradation of benzene and toluene by using a photolytic cell system. The degradation rate was monitored by using ultra-violet (UV) spectroscopy and high performance liquid chromatography (HPLC) and infrared (IR) spectroscopy.

4.7.2 Degradation of Benzene,Toluene, ethylenediaminetetra-acetic acid (EDTA) and hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$) in Photolytic Cell with and without Catalysts

The photolytic cell system used consists of a UV probe surrounded by a reaction chamber of 3.5dm^3 capacity through which the fluid to be treated is pumped from the reservoir via an inlet, and back to the reservoir via an outlet. Compressed air is used as an oxidant in the photolysis and is supplied through the inlet and exits through the outlet. The temperature in the system can be measured by a thermometer. The temperature in the reaction chamber is maintained at 25-30°C by passing water through a cooling jacket surrounding the UV probe. The effect of hydrogen peroxide (H_2O_2) and titanium dioxide (TiO_2) on the degradation of benzene and toluene were studied.

Model solution containing 1 ml dm^{-3} of benzene was added into distilled water. The experiments were carried out without catalyst. The degradation was followed by UV spectroscopy and also followed by HPLC using a 25cm x 3mm i.d. separation column in methanol (95%), water (5%) eluent containing 1m/l Acetic acid and using a UV-detector to monitor the benzene absorbance at 240nm. The same methods and concentrations were used for the degradation of toluene in the absence of catalyst.

Model solution containing 1ml dm^{-3} of benzene and 5ml dm^{-3} of hydrogen peroxide (H_2O_2) were added into distilled water. The degradation was followed by UV spectroscopy and HPLC. Further model solution containing 1ml dm^{-3} of benzene and 10ml dm^{-3} of H_2O_2 were added into distilled water.

The next experiment involved a different type of catalyst which is titanium dioxide (TiO_2). Model solution containing 1ml dm^{-3} of benzene and 1g dm^{-3} of TiO_2 were added into distilled water. The degradation was followed by UV spectroscopy and HPLC. Further model solution containing 1ml dm^{-3} of benzene and 2g dm^{-3} of TiO_2 were added into distilled water. The same methods and concentrations were done for the degradation of toluene.

Model solution containing 50ppm of EDTA was added into distilled water. The experiment was carried out with no catalyst. The degradation was followed by UV spectroscopy and also followed by HPLC using 25cm x 3 mm i.d. separation column in methanol (95%), water (5%) eluent containing 1ml Acetic acid and using a UV-detector to monitor the EDTA absorbance at 240nm. The same methods and concentrations were done for the degradation of $C_{19}H_{42}NBr$ in the absence of catalyst.

Model solutions containing 50ppm of EDTA and 5ml dm^{-3} of hydrogen peroxide (H_2O_2) added in distilled water. The degradation was followed by UV spectroscopy and HPLC. Further model solutions containing 50ppm of EDTA and 10ml dm^{-3} of H_2O_2 were added into distilled water. The next experiment involved the use of a different catalyst which is titanium dioxide (TiO_2). Model solutions containing 50ppm of EDTA and 1g dm^{-3} of TiO_2 added into distilled water in 5 litres of volumetric flask. The degradation was followed by UV spectroscopy and HPLC. Further model solutions containing 50ppm of EDTA and 2g dm^{-3} of TiO_2 were added into distilled water.

The same methods and concentrations were done for the degradation of $C_{19}H_{42}NBr$. In addition to that, infrared (IR) spectroscopy was used in the analysis of $C_{19}H_{42}NBr$ under the condition of Perkin-Elmel 683 Infrared Spectrophotometer and scanning from $4000cm^{-1}$ to $2000cm^{-1}$.

4.7.3 HPLC operating conditions:

Column	25cm x 3mm i.d.
Packing	pinnacle ODS 5mv/v
Flow rate	1ml/min
Detector	spectroflow 757 UV
Eluent	methanol (95%), water (5%), 1 m/l Acetic acid
Wavelength	240nm
Injector	Rheodyne 7125 with 20μl loop

4.7.4 UV spectrometric conditions:

The degradation of Ethylenediaminetetra-acetic Acid was carried out using the Perkin-Elmer Lambda 9 uv/vis/NIR spectrophotometer under the following conditions

Slit	2.0 nm
Scan speed	240 nm/min
Response	0.5s
Lamp/Det.	319.2/860.8 nm
Peak threshold	0.02 A

4.7.5 IR spectrometric Conditions:

Perkin-Elmel 63 Infrared Spectrophotometer

Scan: $4000cm^{-1}$ to $2000cm^{-1}$

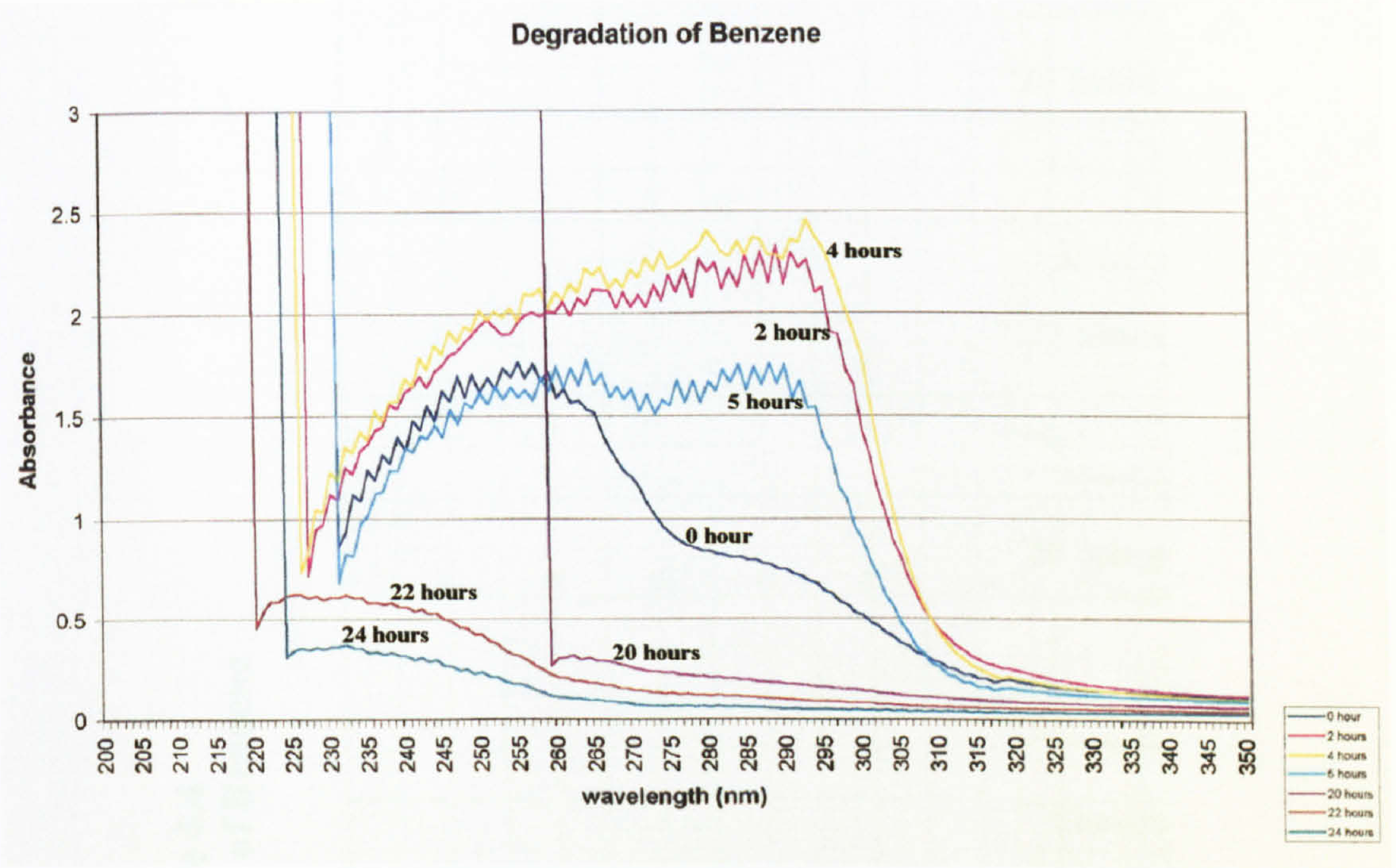
4.8 RESULTS FOR BENZENE AND TOLUENE

The following results show with and without the catalyst. The experiments are based on:

- Degradation of Benzene and Toluene without catalyst
- Degradation of Benzene and Toluene with the oxidant (H_2O_2) and a catalyst (TiO_2).

The results show that after 24 hours, complete degradation of benzene and toluene is achieved. In UV Spectroscopy in Figure 4.3, shows the changes in the UV absorbance of benzene and toluene spectrums are due to the formation of intermediates. In Figures 4.4 and 4.5 show the degradation of benzene and toluene using High Performance Liquid chromatography (HPLC). Tables 4.4 and 4.5 show the effect of hydrogen peroxide and titanium dioxide on the degradation of benzene and toluene and the rate of reaction. Figures 4.6 and 4.7 are also showing the graphs of rate of reaction on the degradation of benzene and toluene.

Figure 4.3
Degradation of Benzene and Toluene



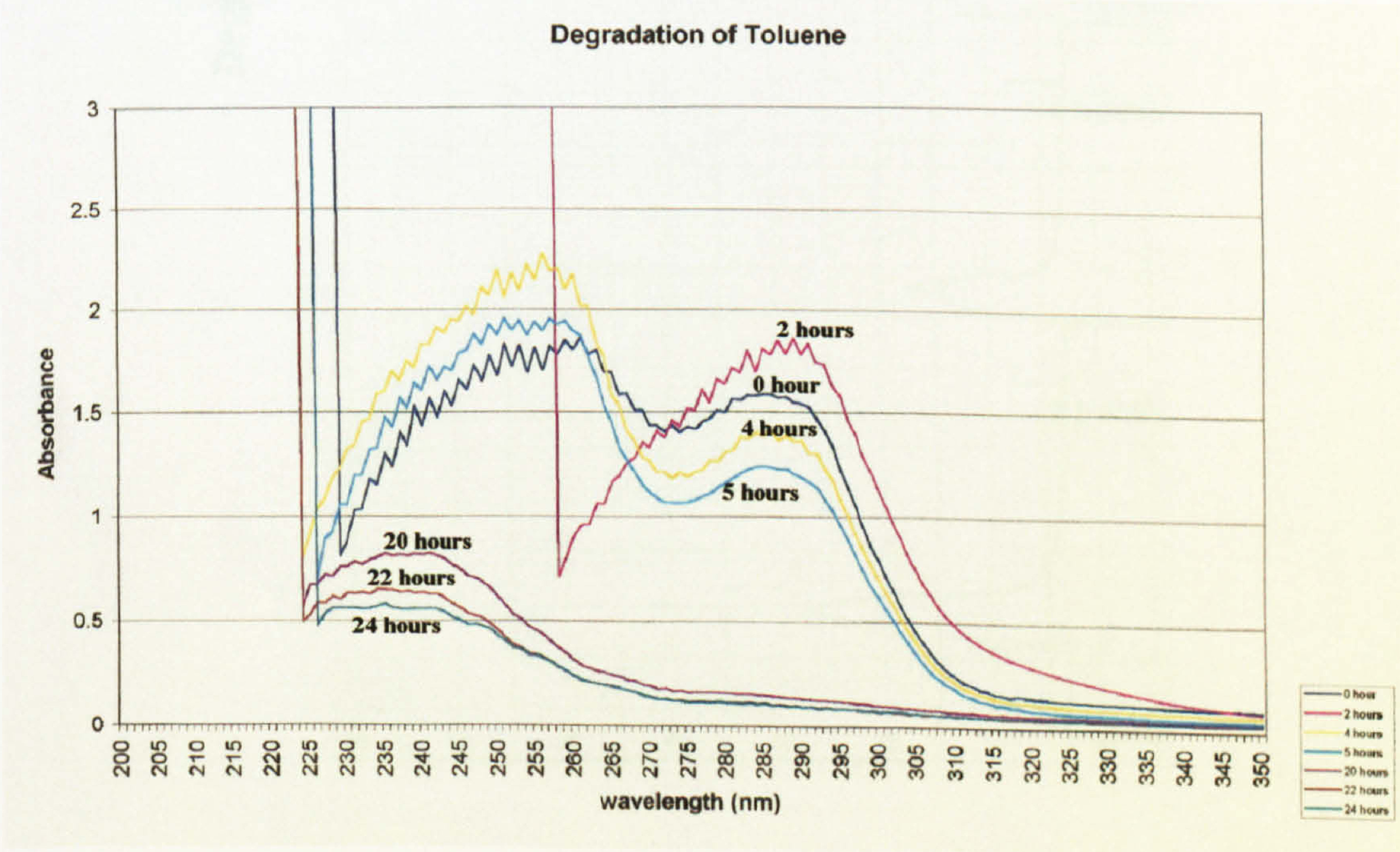


Figure 4.4
Degradation of Benzene

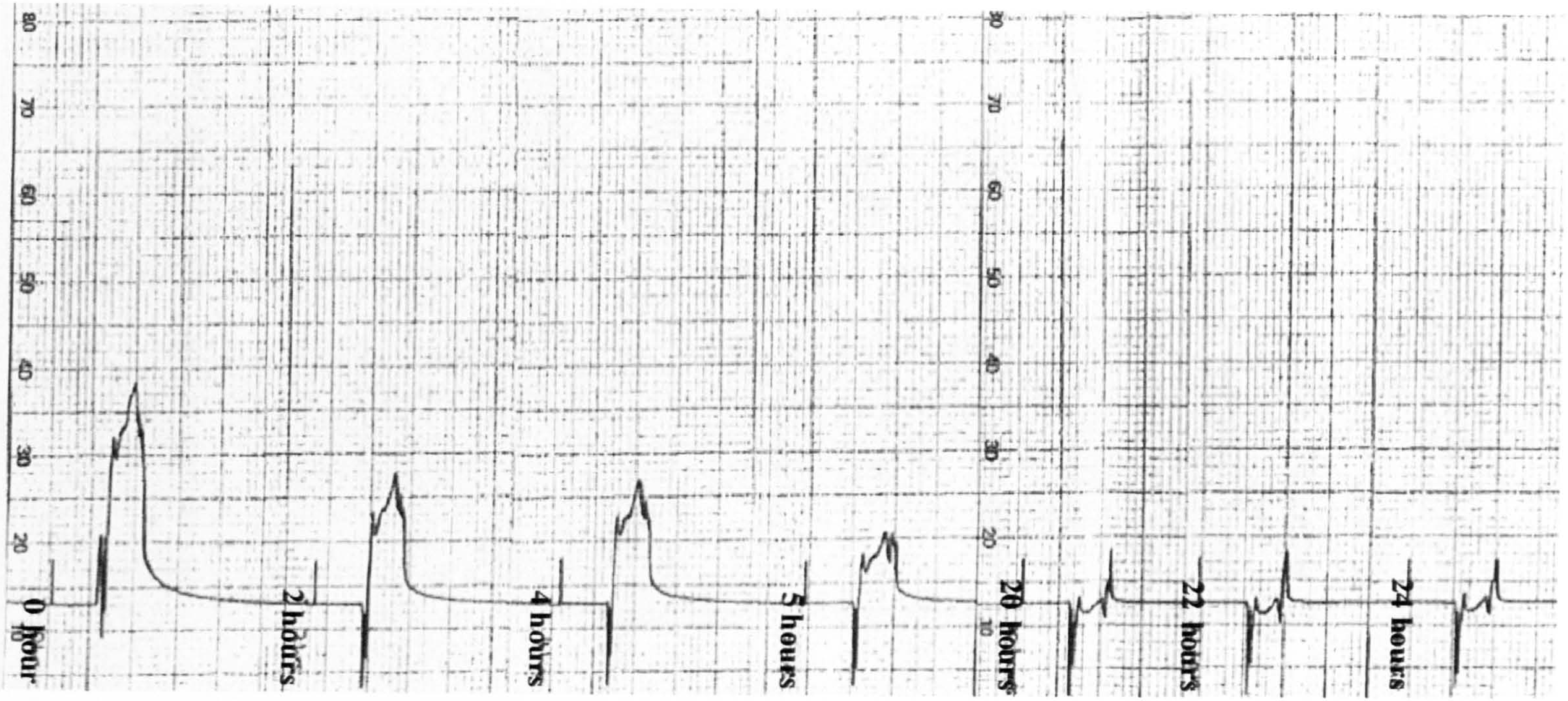


Figure 4.5
Degradation of Toluene

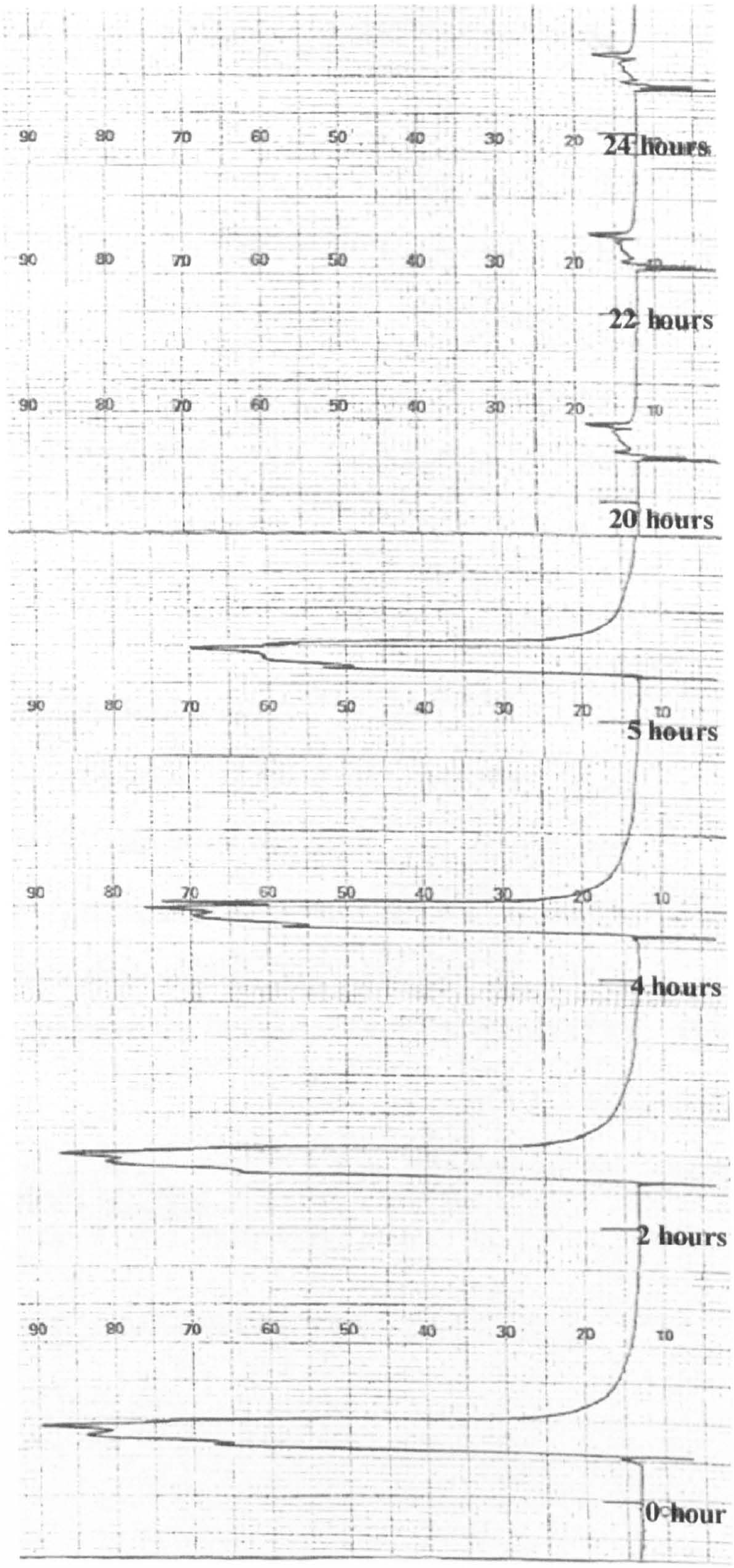


Table 4.2

Effect of Hydrogen Peroxide (H_2O_2) and Titanium dioxide (TiO_2) on the degradation of Benzene using a photolytic cell system

Time (h)	Degradation of Benzene					
	No Catalyst		H_2O_2 ($5cm^3dm^{-3}$)		H_2O_2 ($10cm^3dm^{-3}$)	
	Conc. (ppm)	%Degradation	Conc. (ppm)	%Degradation	Conc. (ppm)	%Degradation
2	74.7	25.3	52.7	47.3	42.7	57.3
4	70.8	29.2	48.8	51.2	38.8	61.2
6	45.8	54.2	23.8	76.2	13.8	86.2
20	38.1	61.9	16.1	83.9	6.3	93.7
22	36.2	63.8	14.2	85.8	4.1	95.9
24	34.2	65.8	12.2	87.8	2.2	97.8

Time (h)	Degradation of Benzene					
	No Catalyst		TiO_2 ($1gdm^{-3}$)		TiO_2 ($2gdm^{-3}$)	
	Conc. (ppm)	%Degradation	Conc. (ppm)	%Degradation	Conc. (ppm)	%Degradation
2	74.7	25.3	48.3	51.7	45.3	54.7
4	70.8	29.2	44.4	55.6	41.4	58.6
6	45.8	54.2	19.4	80.6	16.4	83.6
20	38.1	61.9	11.7	88.3	8.9	91.1
22	36.2	63.8	9.8	90.2	6.7	93.3
24	34.2	65.8	7.8	92.2	4.8	95.2

Table 4.3

Effect of Hydrogen Peroxide (H_2O_2) and Titanium dioxide (TiO_2) on the degradation of Toluene using a photolytic cell system

Time (h)	Degradation of Toluene					
	No Catalyst		H_2O_2 ($5cm^3dm^{-3}$)		H_2O_2 ($10cm^3dm^{-3}$)	
	Conc. (ppm)	%Degradation	Conc. (ppm)	%Degradation	Conc. (ppm)	%Degradation
2	98.7	1.3	91.7	8.3	83.9	16.1
4	84.8	15.2	77.8	22.2	69.0	31.0
6	76.2	23.8	69.4	30.6	59.2	40.8
20	32.9	67.1	4.9	95.1	3.0	97.0
22	32.3	67.7	4.3	95.7	2.1	97.9
24	31.6	68.4	3.6	96.4	1.2	98.8

Time (h)	Degradation of Toluene					
	No Catalyst		TiO_2 ($1gdm^{-3}$)		TiO_2 ($2gdm^{-3}$)	
	Conc. (ppm)	%Degradation	Conc. (ppm)	%Degradation	Conc. (ppm)	%Degradation
2	98.7	1.3	87.3	12.7	82.7	17.3
4	84.8	15.2	73.4	26.6	68.6	31.4
6	76.2	23.8	64.8	35.2	59.9	40.1
20	32.9	67.1	3.9	96.1	2.0	98.0
22	32.3	67.7	3.3	96.7	1.2	98.8
24	31.6	68.4	2.6	97.4	0.9	99.1

Table 4.4

Effect of Hydrogen Peroxide (H_2O_2) and Titanium dioxide (TiO_2) on the degradation of Benzene and the rate of reaction

Time (hour)	Degradation of Benzene (%)						Standard Deviation
	No Catalyst		H_20_2($5cm^3dm^{-3}$)		H_20_2($10cm^3dm^{-3}$)		
	In(C/C_o)	k/s	In(C/C_o)	k/s	In(C/C_o)	k/s	
2	-0.29	$9.85x10^{-6}$	-0.64	$1.84x10^{-5}$	-0.85	$3.75x10^{-5}$	$\pm 1.4x10^{-5}$
4	-0.35		-0.72		-0.95		
6	-0.78		-1.44		-1.98		
20	-0.96		-1.83		-2.76		
22	-1.02		-1.95		-3.19		
24	-1.07		-2.10		-3.82		

Time (hour)	Degradation of Benzene (%)						Standard Deviation
	No Catalyst		TiO_2($1gdm^{-3}$)		TiO_2($2gdm^{-3}$)		
	In(C/C_o)	k/s	In(C/C_o)	k/s	In(C/C_o)	k/s	
2	-0.29	$9.85x10^{-6}$	-0.73	$2.30x10^{-5}$	-0.76	$3.52x10^{-5}$	$\pm 1.3x10^{-5}$
4	-0.35		-0.81		-0.88		
6	-0.78		-1.64		-1.81		
20	-0.96		-2.15		-2.42		
22	-1.02		-2.32		-2.70		
24	-1.07		-2.55		-3.04		

Table 4.5

Effect of Hydrogen Peroxide (H_2O_2) and Titanium dioxide (TiO_2) on the degradation of Toluene and the rate of reaction

Time (hour)	Degradation of Toluene (%)						Standard Deviation
	No Catalyst		$H_20_2(5cm^3dm^{-3})$		$H_20_2(10cm^3dm^{-3})$		
	In(C/C$_o$)	k/s	In(C/C$_o$)	k/s	In(C/C$_o$)	k/s	
2	-0.013	$1.44x10^{-5}$	-0.087	$4.08x10^{-5}$	-0.18	$5.35x10^{-5}$	$\pm2.0x10^{-5}$
4	-0.16		-0.25		-0.37		
6	-0.27		-0.37		-0.52		
20	-1.11		-3.02		-3.51		
22	-1.13		-3.15		-3.86		
24	-1.15		-3.32		-4.42		

Time (hour)	Degradation of Toluene (%)						Standard Deviation
	No Catalyst		$TiO_2(1gdm^{-3})$		$TiO_2(2gdm^{-3})$		
	In(C/C$_o$)	k/s	In(C/C$_o$)	k/s	In(C/C$_o$)	k/s	
2	-0.013	$1.44x10^{-5}$	-0.14	$4.43x10^{-5}$	-0.19	$5.71x10^{-5}$	$\pm2.1x10^{-5}$
4	-0.16		-0.31		-0.38		
6	-0.27		-0.43		-0.51		
20	-1.11		-3.24		-3.91		
22	-1.13		-3.41		-4.42		
24	-1.15		-3.65		-4.71		

Calculation:

In(C) / (C$_o$) = -*k*t

k = - In(C)/ (Co) / t

In (C) / (Co) = 1.07 – 0.29 = **0.78**

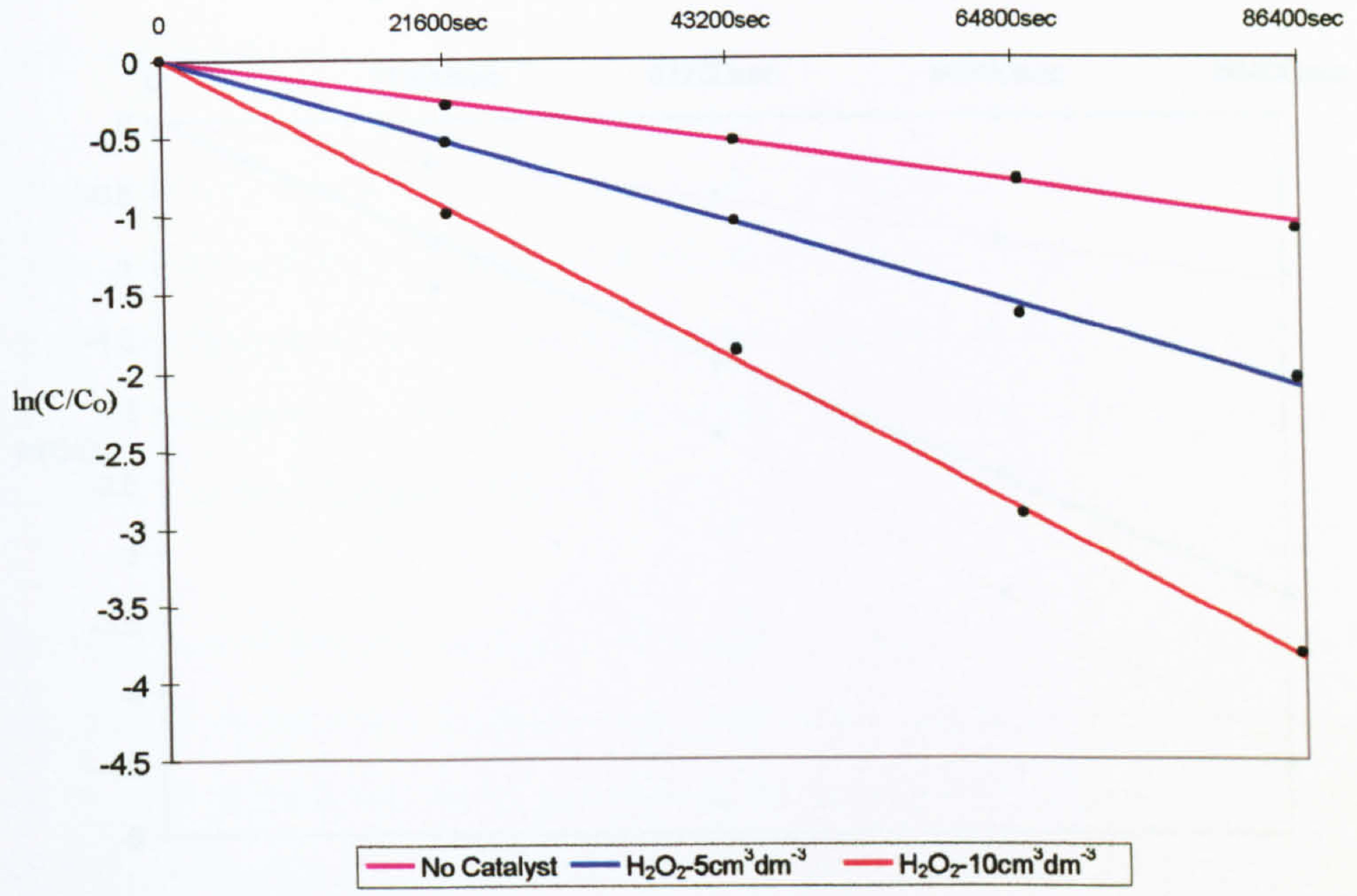
24 hours = 60 x 60 x 24 = 86400 seconds
2 hours = 60 x 60 x 2 = 7200 seconds

t = 86400 – 7200 = **79200 seconds**

Therefore, rate of reaction for degradation of benzene without catalyst:

***k* = - 0.78 / 79200**
= - $\underline{9.85x10^{-6}\ s}$

Figure 4.6


Degradation of Benzene with Hydrogen Peroxide (H_2O_2)

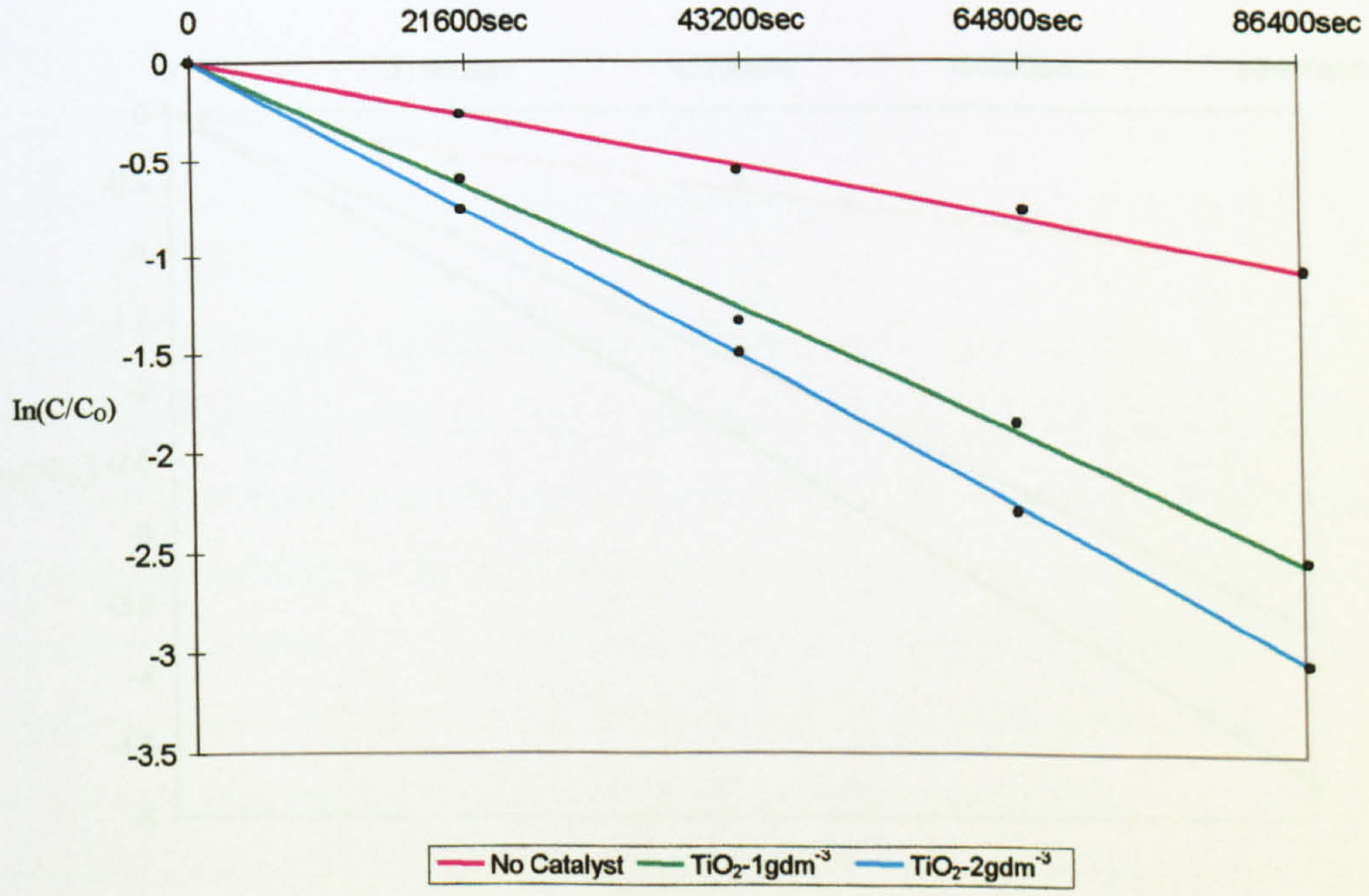
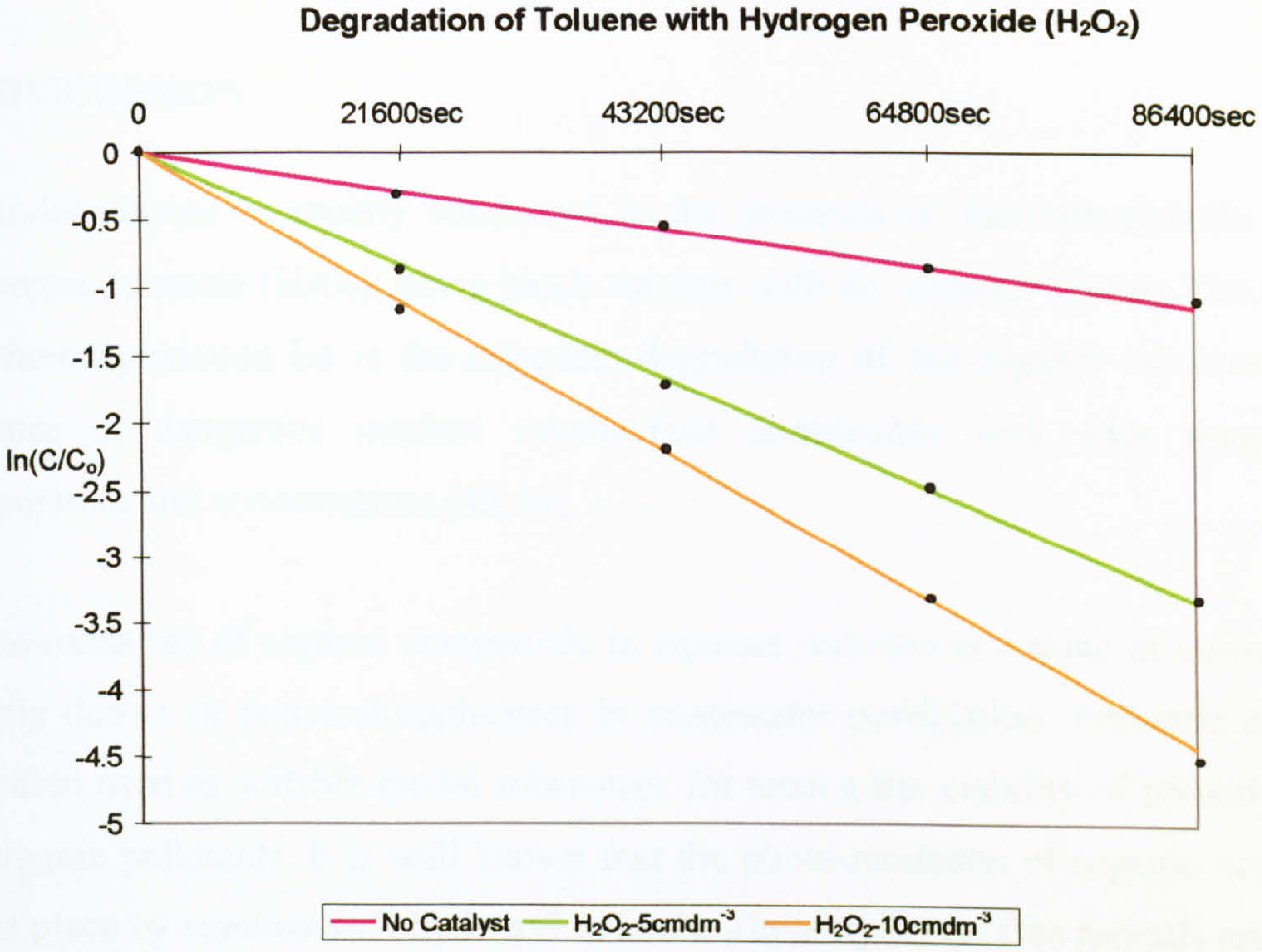
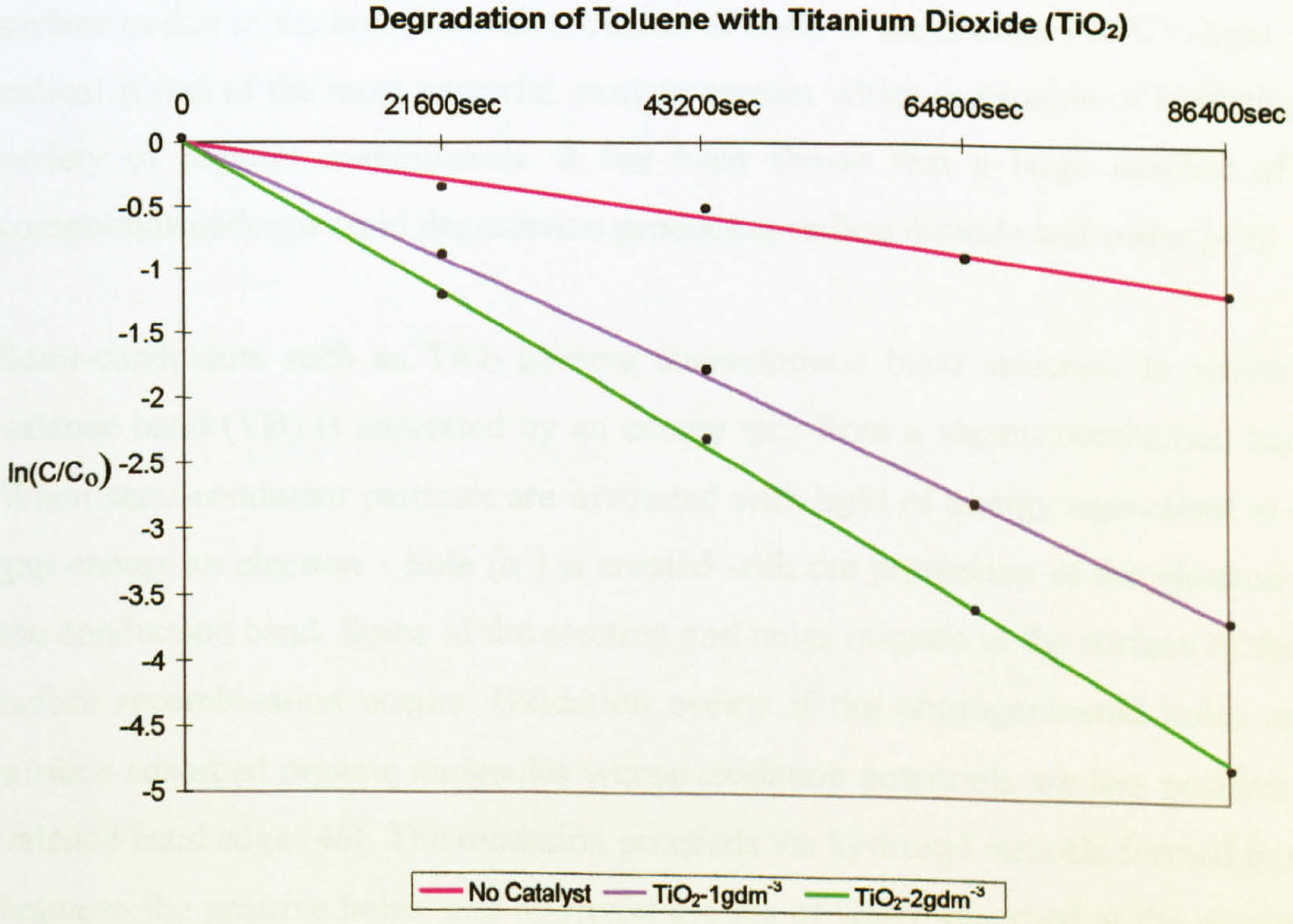

Degradation of Benzene with Titanium Dioxide (TiO_2)

Figure 4.7


Degradation of Toluene with Hydrogen Peroxide (H_2O_2)


Degradation of Toluene with Titanium Dioxide (TiO_2)

4.8 DISCUSSION

Photodegradation is usually conducted in the presence of titanium dioxide (TiO_2) or hydrogen peroxide (H_2O_2), using batch reactors with an immersed lamp. The advantage of photodegradation lie in the complete degradation of the organic substrate with the absence of dangerous residual intermediate compounds with wide range of pH, temperature and concentration [43,44].

Photo-oxidation of organic compounds in aqueous solution is a topic of current interest mainly due to its potential application in wastewater purification. Aromatic compounds are often used as suitable model substances for testing the viability of photodegradation of organic pollutants. It is well known that the photo-oxidation of organic contaminants takes place by reaction with hydroxyl radicals. These hydroxyl free radicals are produced by hole capture of either water molecules or OH^- anions adsorbed on the semi-conductor surface or due to the homolytic dissociation of H_2O_2 in the presence of UV-light. The OH radical is one of the most powerful oxidant species which is capable of oxidizing a wide variety of organic contaminants. It has been shown that a large number of organic compounds undergo rapid degradation producing carbon dioxide and water [45].

Semi-conductors such as TiO_2 possess characteristic band structure in which a filled valence band (VB) is separated by an energy gap from a vacant conduction band (CB). When semi-conductor particles are irradiated with light of energy equivalent to the band gap energy an electron – hole (h^+) is created with the promotion of the electron (e-) into the conduction band. Some of the electron and holes migrate to the surface of the particle before recombination occurs. Oxidation occurs if the photogenerated holes react with surface-adsorbed organic molecules whose oxidation potentials are less positive than the valence band edge [46]. The oxidation proceeds via hydroxyl radicals formed in reactions between the positive holes, and hydroxyl groups or water adsorbed at the semiconductor surface [47].

For complete photocatalytic degradation of organic pollutants, the presence of light, photocatalyst, oxygen, and water is required. The hydroxyl radical ($^{\bullet}OH$), the primary oxidant in the photocatalytic oxidation process, can be generated via two main routes: by the reaction of valence band holes (h^+) with either adsorbed water or with surface hydroxyl groups as shown in the following equations [48,49].

$$\text{Semiconductor} + h\nu \rightarrow h^+ + e^-$$

$$h^+ + H_2O_{(ads)} \rightarrow {}^{\bullet}OH + H^+$$

$$h^+ + OH^-_{(surface)} \rightarrow {}^{\bullet}OH$$

By and large it is accepted that surface-adsorbed oxygen promotes the photocatalytic process by trapping the conduction band electron as a superoxide ion $O_2^{\bullet -}$ thus making the recombination reaction less competitive.

$$O_2 + e^- \rightarrow O_2^{\bullet -}$$

H_2O_2 can then be produced from $O_2^{\bullet -}$ through the following reactions

$$O_2^{\bullet -} + H+ \rightarrow HO_2^{\bullet}$$

$$HO_2^{\bullet} + HO_2^{\bullet} \rightarrow H_2O_2 + O_2$$

$$O_2^{\bullet -} + HO_2^{\bullet} \rightarrow HO_2^- + O_2$$

$$HO_2^- + H^+ \rightarrow H_2O_2$$

Cleavage of H_2O_2 by any of the following reactions yields $^{\bullet}OH$ radicals

$$H_2O_2 + e^- \rightarrow {}^{\bullet}OH + OH^-$$

$$H_2O_2 + h\nu \rightarrow 2\,{}^{\bullet}OH$$

The adsorption and activation of oxygen molecules (which act as traps for photogenerated electrons, thus preventing electron-hole pair recombination) is an essential step in the photocatalytic process. Photodegradation in aqueous TiO_2 dispersions does not occur in the absence of oxygen in the reaction mixture [50,51].

The types of organic compounds on which degradation research has been carried out range from herbicides, organic dyes and non-ionic surfactant to organohalides and nitrogen / sulphur containing organics. All organic compounds studied eventually undergo complete degradation [52,53].

The addition of H_2O_2 to a reaction solution has the effect of increasing the degradation rate. An important step in the formation of radical species is the cleavage of H_2O_2 in the presence of UV light. The addition of H_2O_2 increases the rate of radical formation and ultimately increase the degradation rate. The hydrogen peroxide decomposition to produce two different radicals species (**$^{\bullet}OH$, $HO_2^{\bullet}$**) which are able to degrade organic species[54,55]:

$$H_2O_2 + e^- \rightarrow {}^{\bullet}OH + OH^-$$

$$H_2O_2 + h\upsilon \rightarrow HO_2^{\bullet}$$

$$H_2O_2 + h\upsilon \rightarrow 2\,{}^{\bullet}OH$$

Oxygen completes with H_2O_2 in the process of electron trapping

$$O_2 + 2e^- + 2H^+ \rightarrow H_2O_2$$

4.8.1 Photolytic degradation of benzene and toluene

The photolytic degradation of benzene and toluene were optimised by investigating the effects of the following variables: (1) addition of hydrogen peroxide (H_2O_2) as an oxidant and (2) addition of titanium dioxide (TiO_2) as a catalyst.

4.8.2 Effect of H_2O_2 on the degradation of benzene

The effect of hydrogen peroxide on benzene degradation was determined by adding different concentration (5ml dm^{-3} and 10ml dm^{-3}) of hydrogen peroxide to a solution containing the same initial concentration of benzene and toluene. The addition of H_2O_2 (5ml dm^{-3}) increases the extent of degradation of benzene and toluene and complete degradation is achieved after 24 hours. The degradation rate is faster during the initial 2 hours period being 47.3% while the percentage degradation after 6 hours was 76.2% and a complete degradation is achieved after 24 hours. The rate of degradation increases further after increasing the volume of H_2O_2 above 5ml dm^{-3}. This can be shown in Table 4.2.

4.8.3 Effect of TiO_2 on the degradation of benzene

Experiments were carried out to investigate the effects of TiO_2 on the degradation of benzene. The results obtained show that the addition of 1g dm^{-3} of TiO_2 increases the initial degradation of benzene. Like H_2O_2, the degradation rate is faster during the initial 2 hours period being 51.7% while the percentage degradation after 6 hours was 80.6% and a complete degradation is achieved after 24 hours. The rate of degradation increases further after increasing the weight of TiO_2 above 2g dm^{-3}. The results are shown in Table 4.2.

4.8.4 Effect of H_2O_2 on the degradation of toluene

The addition of hydrogen peroxide on the degradation of toluene increases the initial degradation of toluene without catalyst. The degradation rate is faster during the initial 2 hours period being 8.3% while the percentage degradation after 6 hours was 30.6% and a complete degradation is achieved after 24 hours. By increasing the volume of H_2O_2 to 10ml dm^{-3}, the rate increases by almost double. The results can be shown in Table 4.3.

4.8.5 Effect of TiO_2 on the degradation of toluene

By introducing another type of catalyst (TiO_2), the results obtained show that the rate increases the initial degradation of toluene. Like degradation of toluene with H_2O_2, the degradation rate is faster during the initial 2 hour period which is 12.7% while the percentage of degradation after 6 hours was 35.2% and a complete degradation is achieved after 24 hours. When the concentration is increased further (above 1g dm^{-3}), the rate increases by almost double. The results can be seen in Table 4.3.

4.9 RESULTS FOR ETHYLENEDIAMINETETRA-ACETIC ACID (EDTA) AND HEXADECYLTRIMETHYL-AMMONIUM BROMIDE ($C_{19}H_{42}NBr$)

The results of degradation of Ethylenediaminetetra-acetic acid (EDTA) and Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$) under ultraviolet (UV) spectroscopy and high performance liquid chromatography (HPLC) are shown in Figures 4.8, 4.9 and 4.10. Tables 4.8 and 4.9 shows the degradation percentage of EDTA and $C_{19}H_{42}NBr$ with and without catalysts. Tables 4.10 and 4.11 shows the rate of reaction for EDTA and $C_{19}H_{42}NBr$ with and without catalysts. Figures 4.13 and 4.14 show the rates of reaction on the degradation of Ethylenediaminetetra-acetic acid (EDTA) and Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$). Figure 4.15 shows the result of Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$) under Infra-red (IR) Spectroscopy.

In Table 4.12 shows the characteristics infrared absorption frequencies between Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$) and carboxylic acid.

4.10 DISCUSSIONS

The results and discussions were based on EDTA and detergent/surfactant ($C_{19}H_{42}NBr$), which will involve:-

- Degradation of Ethylenediaminetetra-acetic acid (EDTA)
- Degradation of Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$)

4.10.1 Photolytic degradation of Ethylenediaminetetra-acetic acid (EDTA) and Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$)

The photolytic degradation of Ethylenediaminetetra-acetic acid (EDTA) and Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$) were optimised by investigating the effects of the following variables: (1) addition of hydrogen peroxide (H_2O_2) as an oxidant and (2) addition of titanium dioxide (TiO_2) as a catalyst.

4.10.2 Effect of UV source irradiation sources

The effect of the UV-source on the photolytic degradation of Ethylenediaminetetra-acetic acid (EDTA) and Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$) were studied by carrying out duplicate experiments under identical conditions using 150 watt and 400 watt UV-sources. (Tables 4.6 and 4.7)

4.10.3 Effect of H_2O_2 on the degradation of EDTA

The effect of hydrogen peroxide (H_2O_2) on EDTA degradation was determined by adding different volumes (5ml dm^{-3} and 10ml dm^{-3}) of hydrogen peroxide to a solution containing the same initial concentration of EDTA. The addition of 5ml m^{-3} of H_2O_2 increases the extent of degradation of EDTA and complete degradation is achieved after 8 hours. No further increase in the degradation rate is observed by increasing the H_2O_2 volume above 5ml dm^{-3}. The results are shown in Table 4.8 and Figure 4.11.

4.10.4 Effect of TiO_2 on the degradation of EDTA

Experiment was carried out to investigate the effects of TiO_2 on the degradation of EDTA. The results obtained show that the addition of 1g dm^{-3} of TiO_2 increases the initial degradation of EDTA. This increase is attributed to the ease of free radical formation in the presence of TiO_2 as semiconductor material. The addition of further concentration of TiO_2 (2g dm^{-3}) increases even more the initial degradation of EDTA. The results are shown in Tables 4.8 and 4.11.

4.10.5 Effect of H_2O_2 on the degradation of $C_{19}H_{42}NBr$

Experiment on hydrogen peroxide on $C_{19}H_{42}NBr$ was determined by adding different volumes (5ml dm^{-3} and 10ml dm^{-3}) of H_2O_2 to a solution containing the same initial concentration of $C_{19}H_{42}NBr$. The addition of 5ml dm^{-3} of H_2O_2 increases the extent of degradation of $C_{19}H_{42}NBr$ and further increases the concentration of H_2O_2 (10ml dm^{-3}). A complete degradation is achieved after 8 hours. The results are shown in Table 4.9 and Figure 4.12.

4.10.6 Effect of TiO_2 on the degradation of $C_{19}H_{42}NBr$

The effect of titanium dioxide (TiO_2) on $C_{19}H_{42}NBr$ was determined by adding different volumes (1g dm^{-3} and 2g dm^{-3}) of Titanium dioxide to a solution containing the same initial concentration of $C_{19}H_{42}NBr$.

The results obtained show that the addition of 1g dm^{-3} of TiO_2 increases the initial degradation of $C_{19}H_{42}NBr$. As in EDTA, this increase is attributed to the ease of the free radical formation in the presence of TiO_2 assemiconductor material. The results are shown in Table 4.9 and Figure 4.12.

4.10.7 Kinetics of Degradation of Ethylenediaminetetra-acetic acid (EDTA) and Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$)

The degradation rate for EDTA and the surfactant ($C_{19}H_{42}NBr$) using the photolytic system was calculated by following the kinetics of destruction of EDTA and the surfactant at different time intervals. The comparisons of the rate of reaction in the absence and in the presence of catalysts are presented in the Tables 4.10 and 4.11 respectively.

The rate of degradation can be calculated using the following equation.

$$\mathrm{In}\ \frac{[C]}{[C_0]} = -kt$$

A complete degradation of EDTA and the surfactant is achieved with the photolytic cell system. A complex reaction, like photodegradation of organic pollutants, the reaction might not follow the rate law because the reaction intermediates affect the rate of reaction. To avoid this difficulty, the rate law should be done, in simple cases at least, by using a proposed rate law to predict the concentration of any component at any time, and comparing it with the data. A law should also be tested by observing whether the addition of products or change in the surface-to-volume ratio in the reaction chamber affects the rate of reaction.

Since the rate laws are differential equations, they must be integrated if to find the concentrations as a function of time. The degradation of EDTA and the surfactant appear to follow the first order reaction.

First-order reactions

The first-order rate law for the consumption of a reactant A is

$$-d[A] / dt = k[A]$$

It rearranges to

$$d[A] / A = - k dt$$

which can be integrated directly. Since initially (at $t = 0$) the concentration of A is $[A]_o$, and at a later time t it is [A],

$$d[A] / A = - k dt$$

and obtained

$$\ln [A] / [A]_o = - kt$$

$$[A] = [A]_o e^{-kt}$$

Table 4.6

Effect of UV source on the degradation of Ethylenediaminetetra-acetic acid (EDTA)

Effect of UV Source

Time (h)	Degradation of EDTA (%)	
	150W Lamp	400W Lamp
2	11.0	19.9
4	16.2	40.0
6	28.3	60.1
8	35.5	80.2

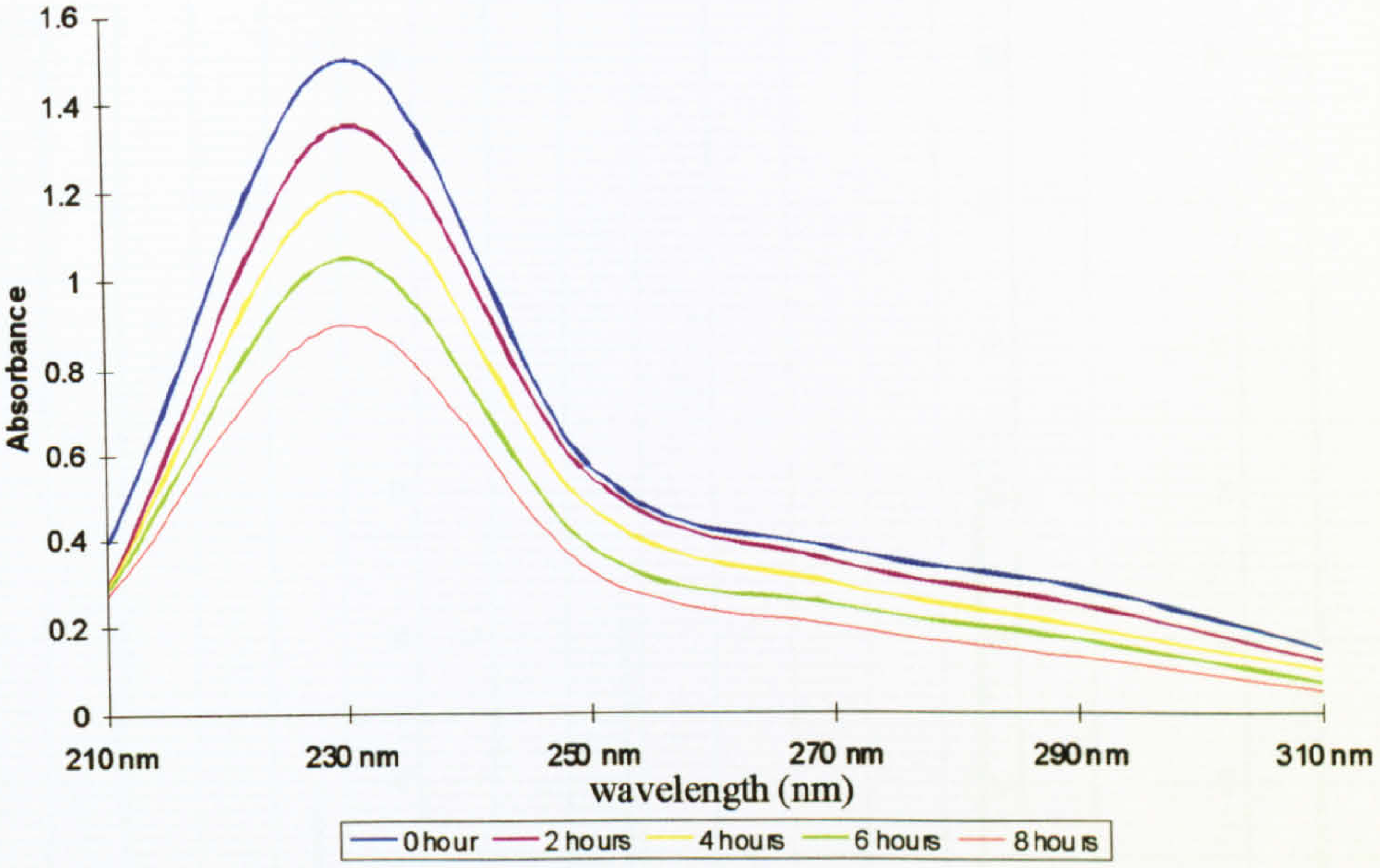
Table 4.7

Effect of UV source on the degradation of Hexadecyltrimethyl-ammonium Bromide ($C_{19}H_{42}NBr$)

Effect of UV Source

Time (h)	Degradation of $C_{19}H_{42}NBr$ (%)	
	150W Lamp	400W Lamp
2	7.7	10.2
4	12.9	20.8
6	21.5	45.1
8	32.7	60.3

Figure 4.8
Degradation of Ethylenediaminetetra - acetic (EDTA)



Effect of H_2O_2 on the Degradation of EDTA

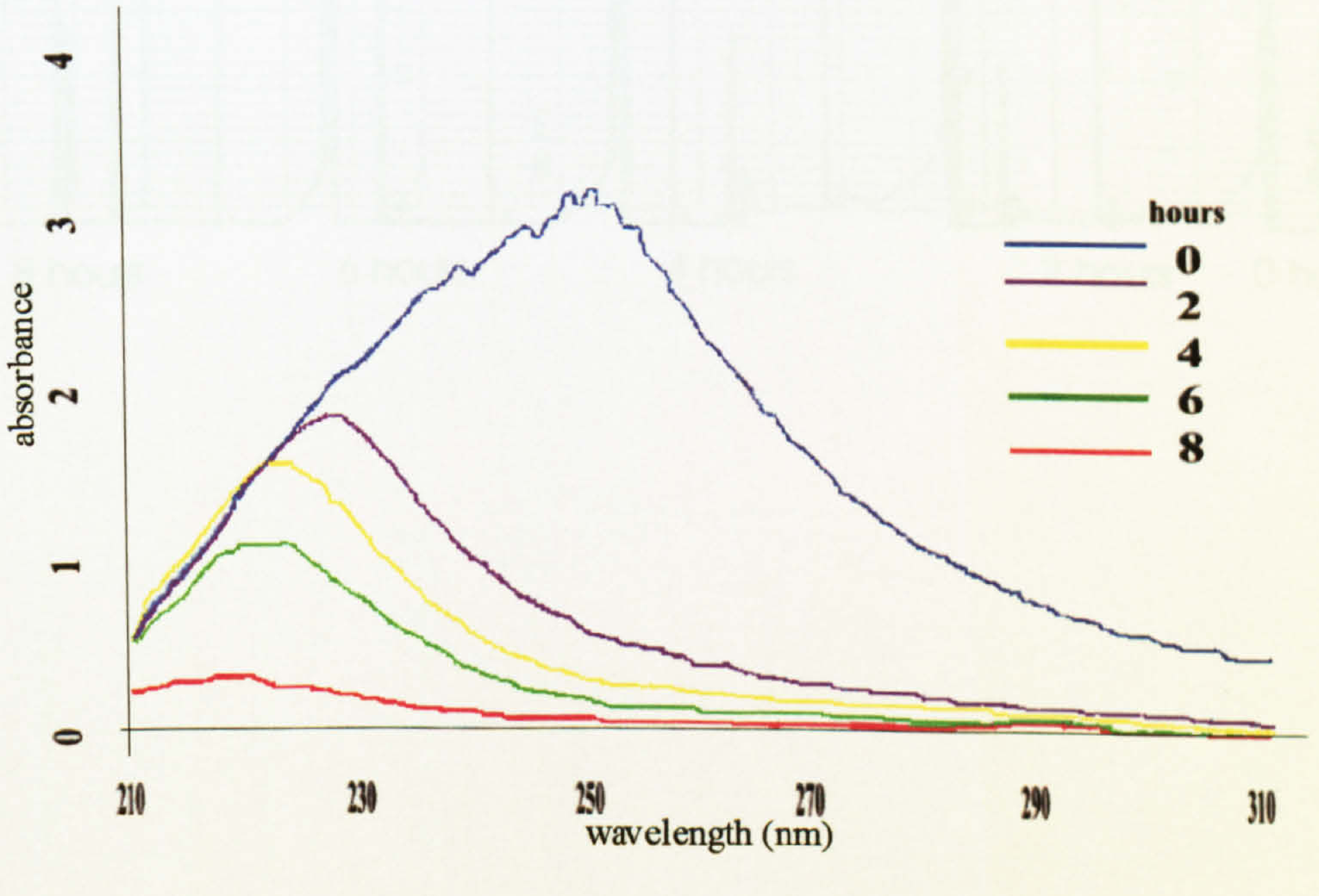


Figure 4.9

The Degradation of Ethylenediaminetetra-acetic acid (EDTA)

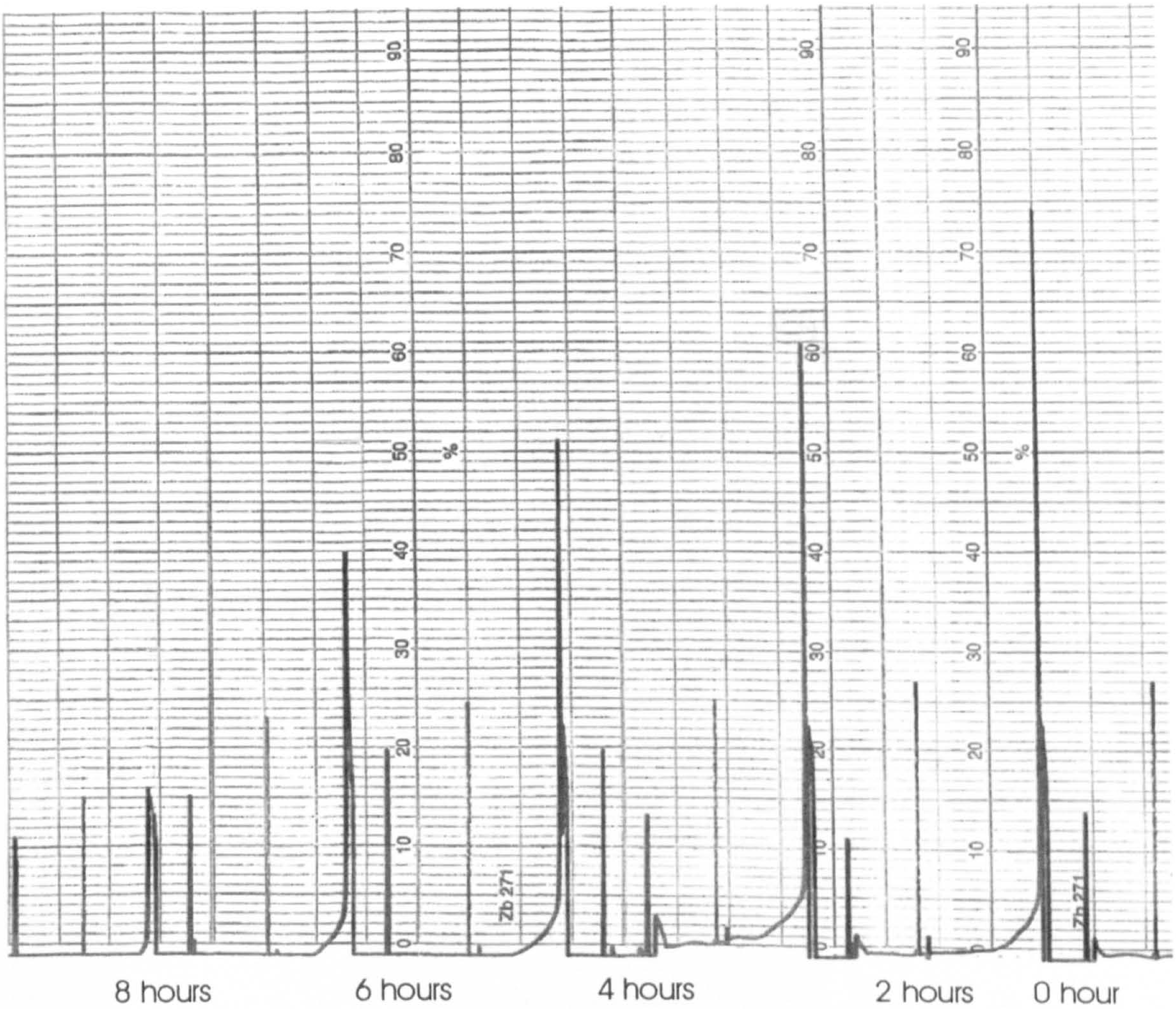


TABLE 4.8

Effect of Hydrogen Peroxide (H_2O_2) and Titanium dioxide (TiO_2) on the degradation of Ethylenediaminetetra-acetic acid (EDTA) using a photolytic cell system

Time (h)	Degradation of EDTA (%)		
	No catalyst	H_2O_2 (5 cm^3 dm^{-3})	H_2O_2 (10 cm^3 dm^{-3})
2	19.9	22.6	24.9
4	25.0	45.1	49.7
6	45.1	67.6	74.5
8	65.2	90.1	99.3

Time (h)	Degradation of EDTA (%)		
	No catalyst	TiO_2 (1g dm^{-3})	TiO_2 (2g dm^{-3})
2	19.9	22.3	26.7
4	25.0	44.7	49.0
6	45.1	67.1	73.6
8	65.2	89.5	98.2

TABLE 4.9

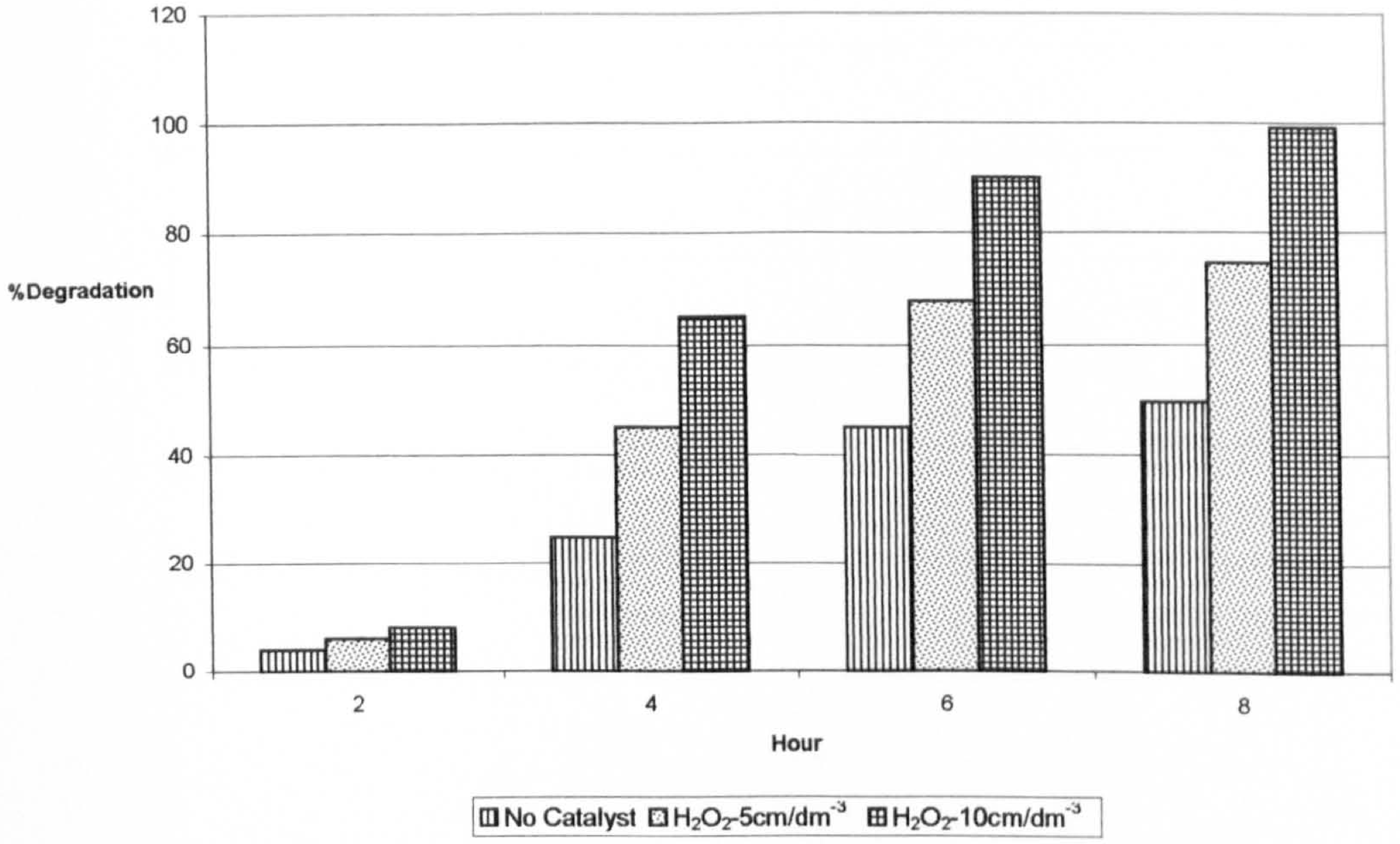
Effect of Hydrogen Peroxide (H_2O_2) and Titanium dioxide (TiO_2) on the degradation of Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$) using a photolytic cell system

Time (h)	Degradation of $C_{19}H_{42}NBr$ (%)		
	No catalyst	H_2O_2 (5 cm^3 dm^{-3})	H_2O_2 (10 cm^3 dm^{-3})
2	10.2	19.8	25.1
4	20.8	39.5	50.0
6	45.1	62.6	74.9
8	60.3	82.7	99.8

Time (h)	Degradation of $C_{19}H_{42}NBr$ (%)		
	No catalyst	TiO_2 (1g dm^{-3})	TiO_2 (2g dm^{-3})
2	10.2	31.6	44.1
4	20.8	49.5	58.0
6	45.1	69.6	76.9
8	60.3	82.7	95.8

Figure 4.11

Degradation of Ethylenediaminetetra-acetic acid (EDTA) with Hydrogen Peroxide (H_2O_2)



Degradation of Ethylenediaminetetra-acetic acid (EDTA) with Titanium Dioxide (TiO₂)

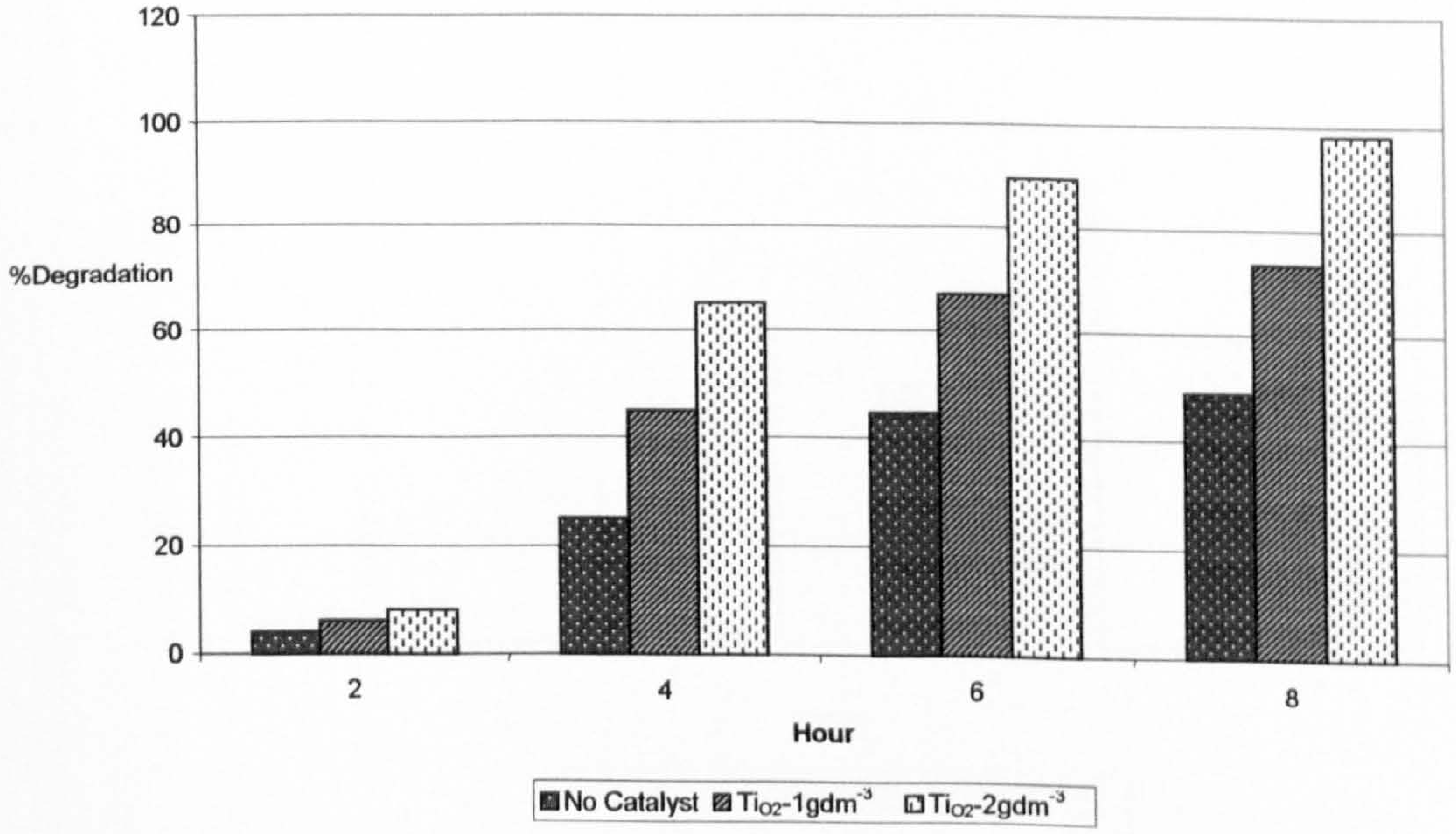
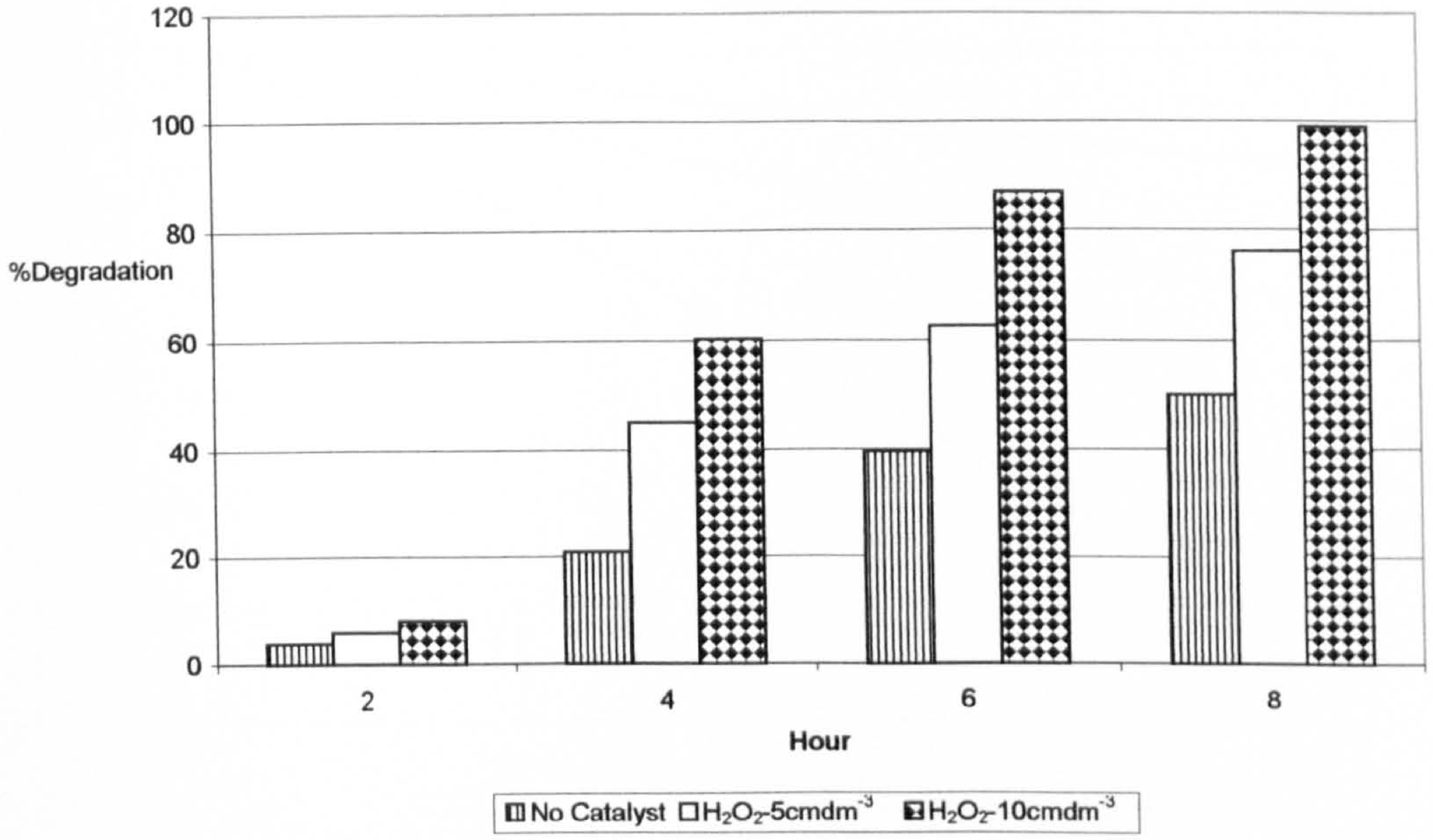
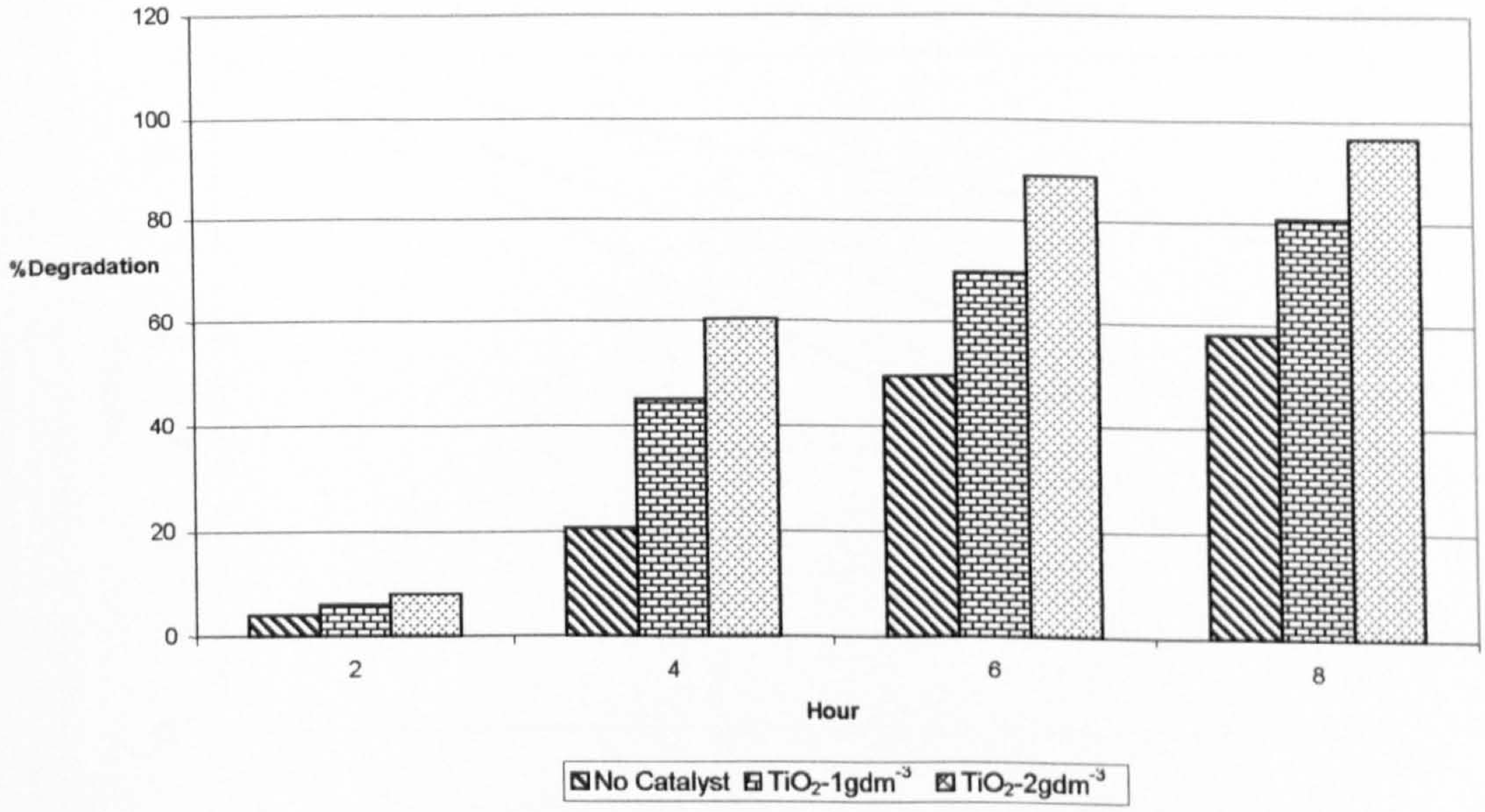


Figure 4.12



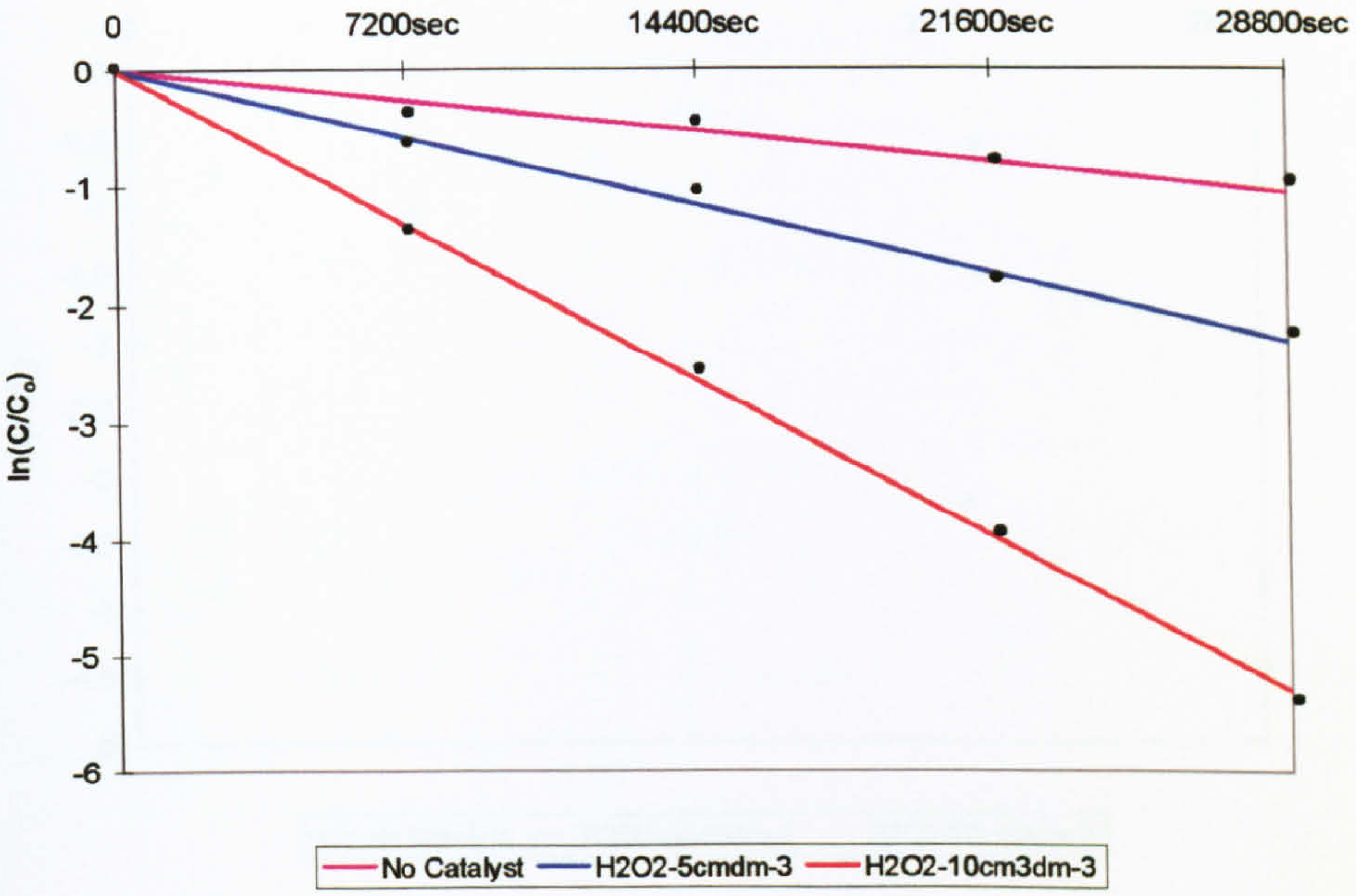
Degradation of Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}BrN$) with Hydrogen Peroxide (H_2O_2)



Degradation of Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}BrN$) Titanium Dioxide (TiO_2)

Figure 4.13

Degradation of Ethylenediaminetetra-acetic Acid (EDTA) with Hydrogen Peroxide (H_2O_2)



Degradation of Ethylenediaminetetra-acetic Acid (EDTA) with Titanium Dioxide (TiO_2)

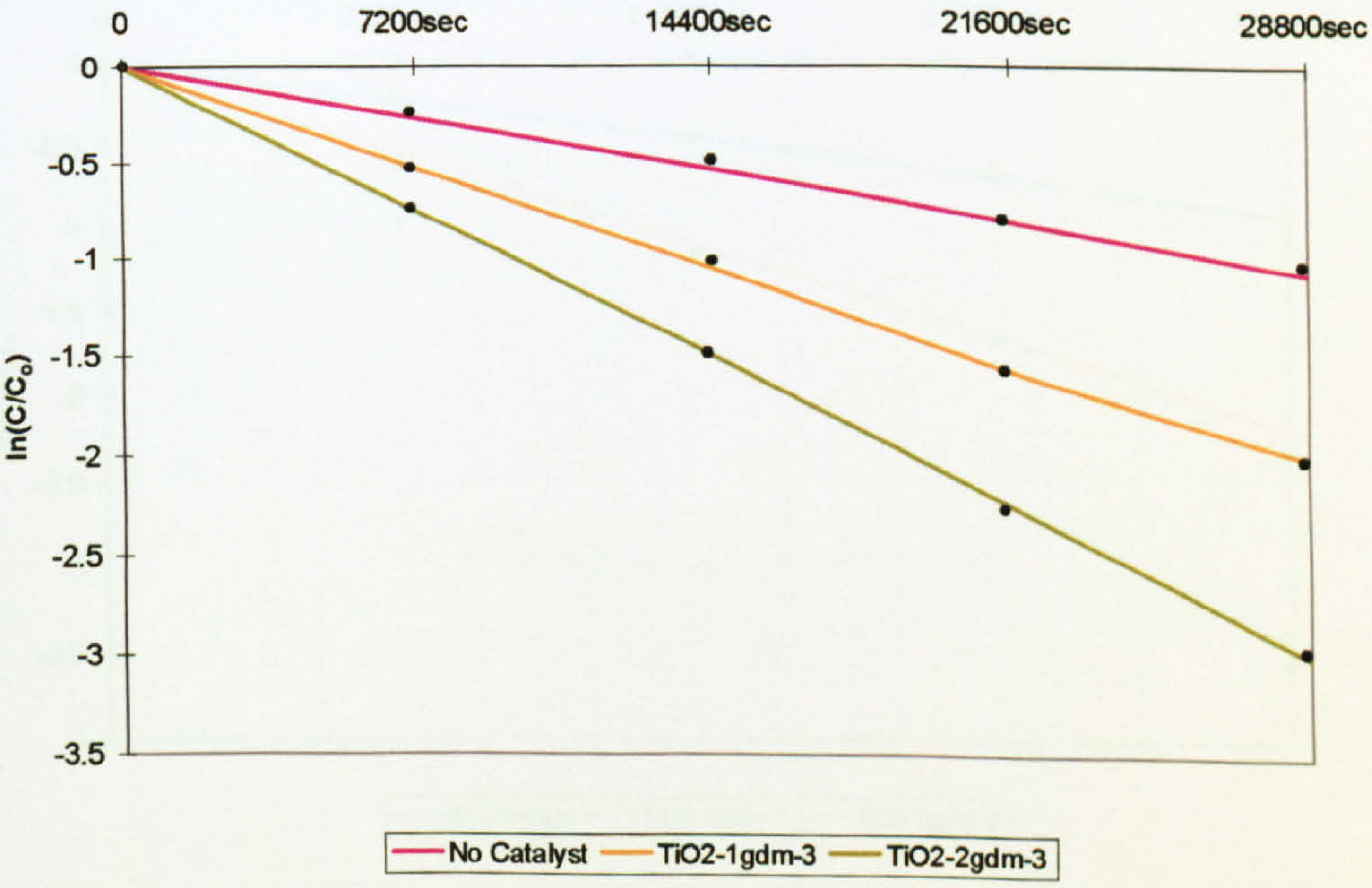
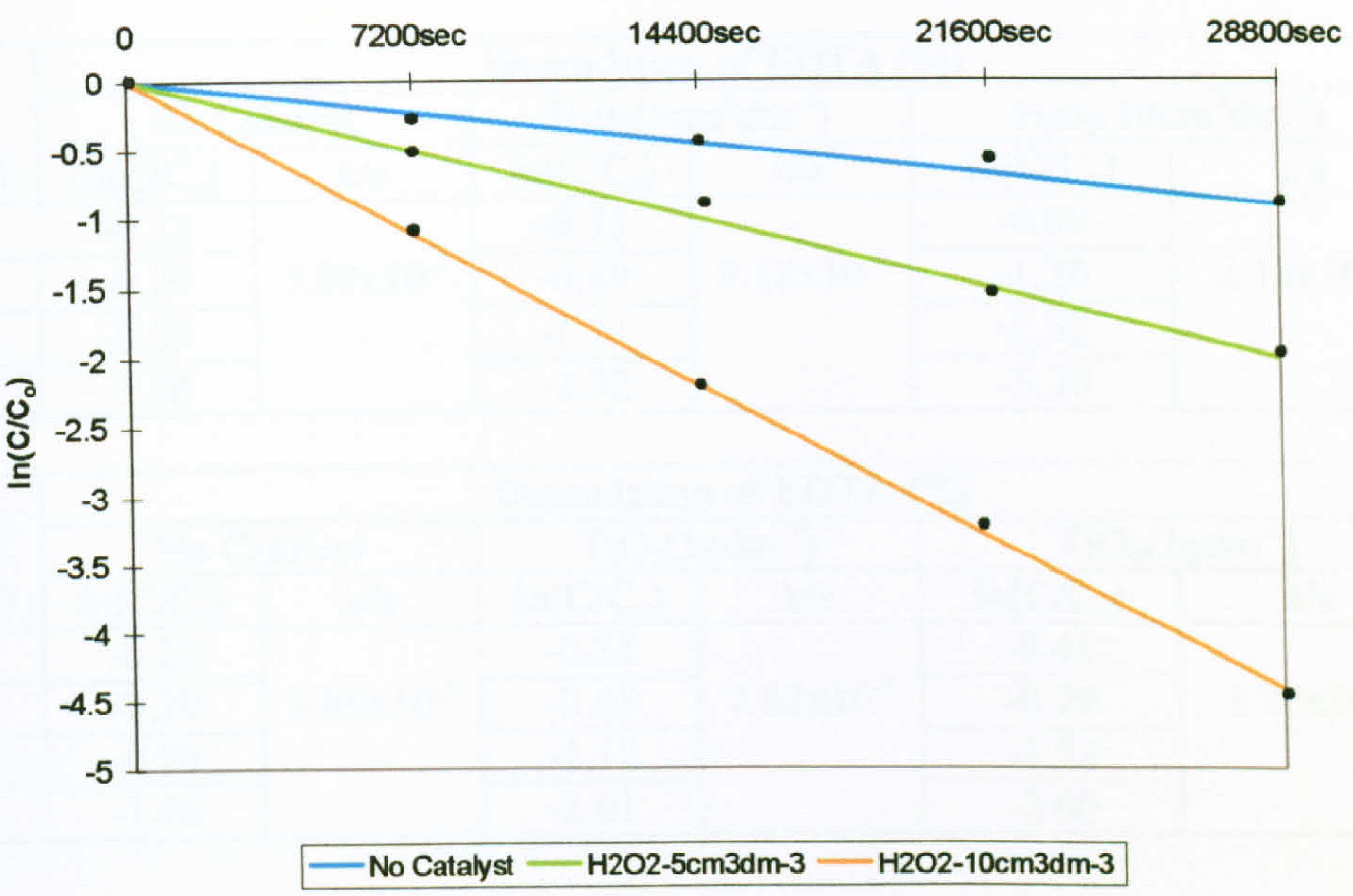
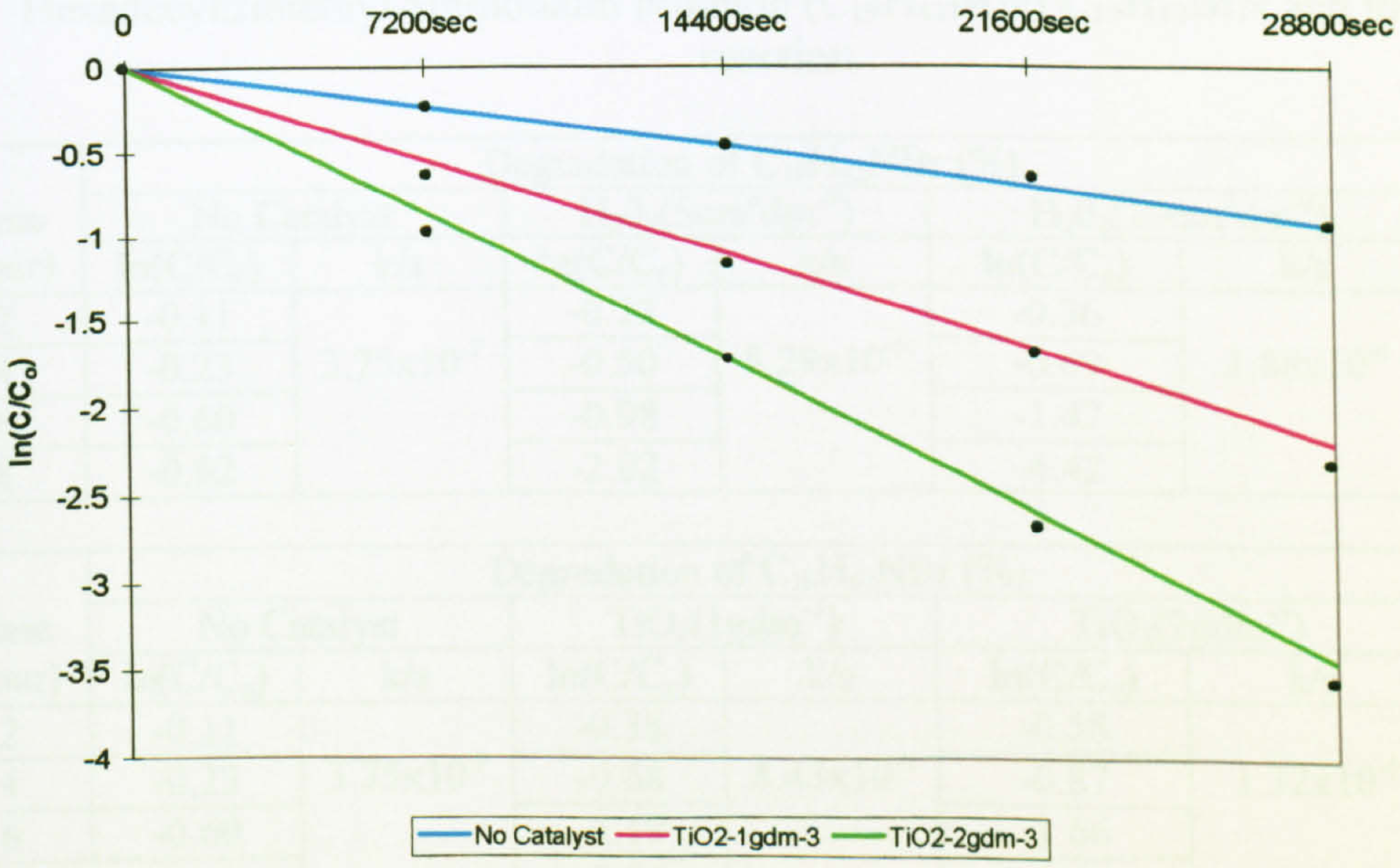


Figure 4.14



Degradation of Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}BrN$) with Hydrogen Peroxide (H_2O_2)



Degradation of Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}BrN$) with Titanium Dioxide (TiO_2)

Table 4.10

Effect of Hydrogen Peroxide (H_2O_2) and Titanium dioxide (TiO_2) on the degradation of Ethylenediaminetetra-acetic acid (EDTA) and the rate of reaction.

Time (hour)	Degradation of EDTA (%)						Standard Deviation
	No Catalyst		$H_20_2(5cm^3dm^{-3})$		$H_20_2(10cm^3dm^{-3})$		
	In(C/C_o)	k/s	In(C/C_o)	k/s	In(C/C_o)	k/s	
2	-0.22	3.89x10^{-5}	-0.35	9.12x10^{-5}	-0.69	2.13x10^{-4}	±8.9x10^{-5}
4	-0.29		-0.69		-1.20		
6	-0.59		-1.21		-2.32		
8	-1.06		-2.32		-5.30		

Time (hour)	Degradation of EDTA (%)						Standard Deviation
	No Catalyst		$TiO_2(1gdm^{-3})$		$TiO_2(2gdm^{-3})$		
	In(C/C_o)	k/s	In(C/C_o)	k/s	In(C/C_o)	k/s	
2	-0.22	3.89x10^{-5}	-0.32	7.82x10^{-5}	-0.41	1.20x10^{-4}	±4.1x10^{-5}
4	-0.29		-0.63		-0.79		
6	-0.59		-1.12		-1.53		
8	-1.06		-2.01		-3.00		

Table 4.11

Effect of Hydrogen Peroxide (H_2O_2) and Titanium dioxide (TiO_2) on the degradation of Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}BrN$) $C_{19}H_{42}BrN$ and the rate of reaction.

Time (hour)	Degradation of $C_{19}H_{42}NBr$ (%)						Standard Deviation
	No Catalyst		$H_20_2(5cm^3dm^{-3})$		$H_20_2(10cm^3dm^{-3})$		
	In(C/C_o)	k/s	In(C/C_o)	k/s	In(C/C_o)	k/s	
2	-0.11	3.75x10^{-5}	-0.23	8.29x10^{-5}	-0.36	1.88x10^{-4}	±7.7x10^{-5}
4	-0.23		-0.50		-0.69		
6	-0.60		-0.98		-1.42		
8	-0.92		-2.02		-4.42		

Time (hour)	Degradation of $C_{19}H_{42}NBr$ (%)						Standard Deviation
	No Catalyst		$TiO_2(1gdm^{-3})$		$TiO_2(2gdm^{-3})$		
	In(C/C_o)	k/s	In(C/C_o)	k/s	In(C/C_o)	k/s	
2	-0.11	3.75x10^{-5}	-0.38	8.43x10^{-5}	-0.58	1.32x10^{-4}	±4.7x10^{-5}
4	-0.23		-0.68		-0.87		
6	-0.60		-1.19		-1.66		
8	-0.92		-2.20		-3.44		

Calculation:-

In(C) / (C_o) = -*k*t

k = - In(C)/(Co) / t

In (C) / (Co) = 1.06 – 0.22 = **0.84**

8 hours = 60 x 60 x 8 = 28800 seconds

2 hours = 60 x 60 x 2 = 7200 seconds

t = 28800 – 7200 = **21600 seconds**

Therefore, rate of reaction for the degradation of EDTA without catalyst:

***k* = - 0.84 / 21600**

= - 3.89×10^{-5} s

Table 4.12

CHARACTERISTIC INFRARED ABSORPTION FREQUENCIES FOR HEXADECYLTRIMETHYL-AMMONIUM BROMIDE ($C_{19}H_{42}NBr$)

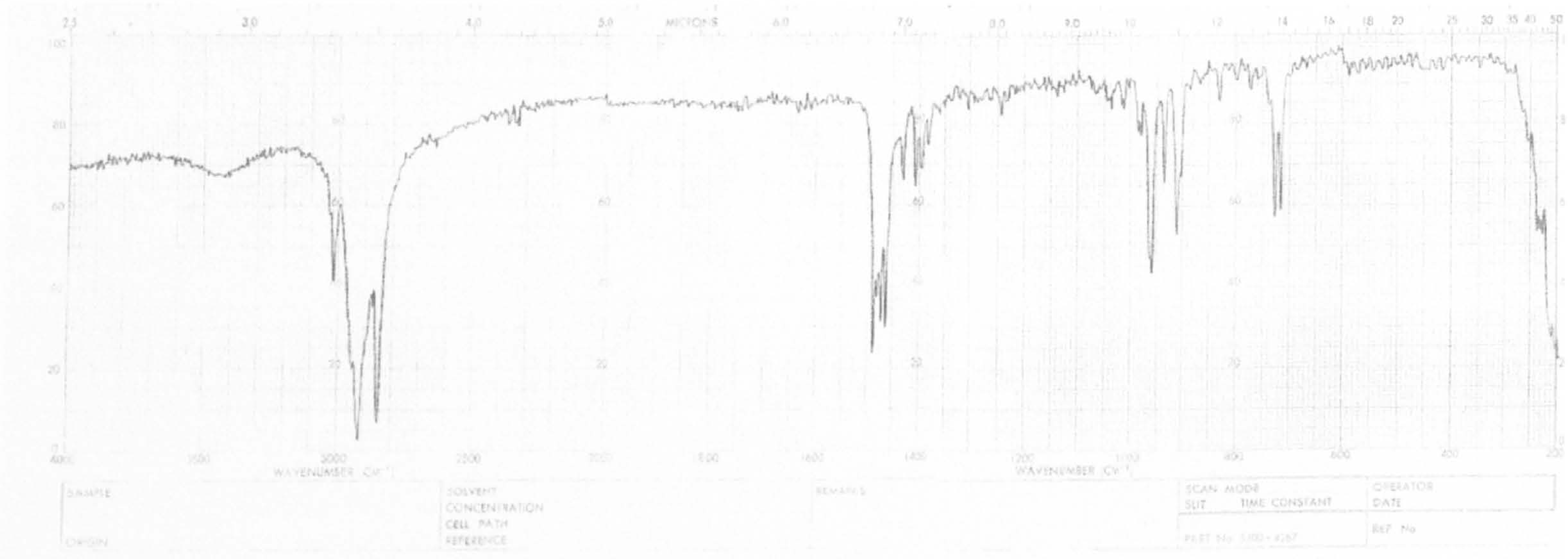
Bond Type	υ, cm^{-1}
C-H	2700-3100
C-C	1350-1500
C-N	900-1100
C-BR	680-750

CHARACTERISTIC INFRARED ABSORPTION FREQUENCIES FOR CARBOXYLIC ACID

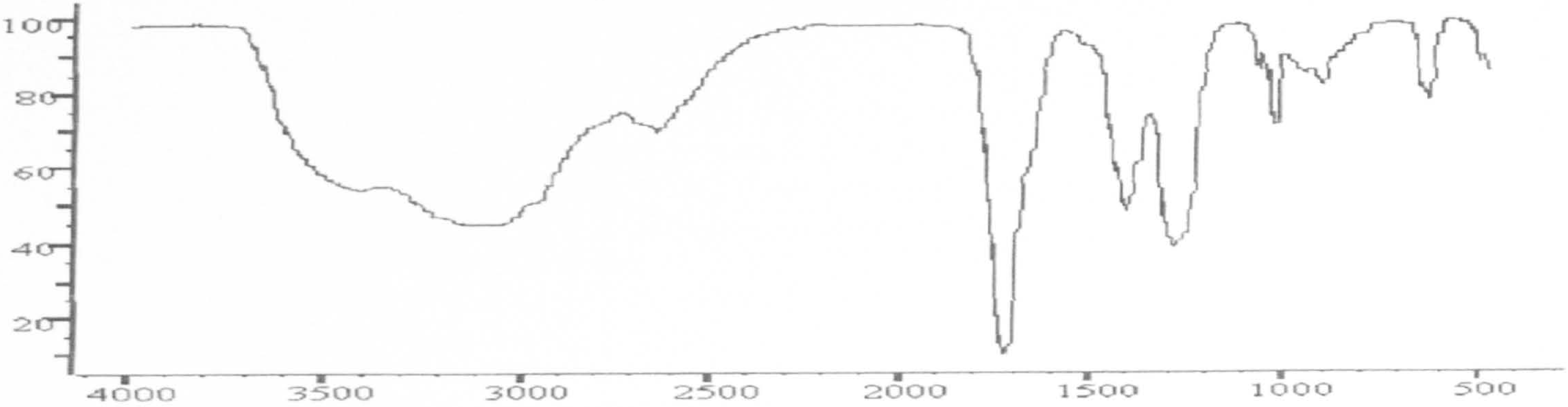
Bond Type	υ, cm^{-1}
O-H	2400-3400
C=O	1700-1730
C-O	1210-1320

Figure 4.15

Spectral Analysis - ***Hexadecyltrimethyl ammonium bromide*** $C_{19}H_{42}NBr$



Spectral Analysis - ***Carboxylic Acid***



4.11 CONCLUSION

The photochemical processes developed in this work are capable of destroying the potential pollutants such as benzene, toluene, ethylenediaminetetra-acetic acid (EDTA) and Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$). The availability of such a method will be important in the future protection of the waters in Brunei Darussalam.

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CHAPTER 5

BRUNEI'S ENVIRONMENTAL MANAGEMENT AND ITS CONTRIBUTION TO THE CLEANLINESS OF BRUNEI RIVERS

5.1 INTRODUCTION

The results of the analyses of the water from Brunei Rivers described in chapter 3 show that the waterways of Brunei Darussalam are safe, clean and not yet polluted. In other words, Brunei can be pleased with the existing situation but this is not enough, as there is a huge challenge to maintain the cleanliness of the environment.

Like other countries with polluted rivers and the growth of oil production and other operations, Brunei could also face problems if management is not modernised. While some rivers in neighbouring countries such as Thailand and Indonesia can afford to be polluted in parts, Brunei cannot do so because if one stretch of any river is polluted it may carry the same pollution to other rivers because of the tiny size of the country. Thailand and Indonesia are about 90 and 333 times bigger than Brunei which is also about 40 times smaller than United Kingdom.

In the light of this, Brunei must have an efficient environmental management programme to make sure the present level of cleanliness is protected and prolonged. The greatest source of water pollution in developing countries like Brunei is Municipal Solid Waste (MSW). This consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint and batteries the disposal of which causes surface and ground waters to be polluted [1]. There is therefore a clear need to integrate solid waste disposal and pollution prevention with water management.

Some of the problems in MSW management arise from dumping into the rivers, insufficient cover material for landfills, aging machinery, untrained plant operators, collection vehicle drivers, severe weather conditions, fires, bulky waste and tyres, vermin, birds, wind blown refuse, fly-tipping etc.

An EMS is a system by which an agency controls the activities, products and processes that cause, or could cause, environmental impacts. An EMS can be a formal and standardised certification system such as International Organisation for Standardisation (ISO) 14001, or it can be informal such as an internal waste minimisation programme or the unwritten means and methods by which an organisation manages its interaction with the environment. [2]

Experts and city managers particularly in developing countries recognise and highlight a lack of education and training tools specifically designed to enable local governments assess the benefits, design and implement an EMS that meets their specific needs. [3]
The benefits of an EMS can be internal and external. The internal benefits of an EMS are said to be:-

- By adopting an EMS (ISO 14001), cities can effect a substantial saving of everyday resources.
- Costs can be cut on several fronts.
- Improvement in staff commitment and morale can be achieved by highlighting their contribution to 'saving the earth'.

The external benefits are:-

- An EMS and ISO 14001 acquisition demonstrate a city's 'green face' to its residents and helps in emphasising the need for greater environmental action.
- An EMS helps in serving as a model for other cities.
- An EMS can have far-reaching and long-term impacts such as improved health conditions, environmental cleanliness and so on.
- For cities an EMS also emphasises the concept, 'environmental-action-starts-at-home', where local actions at the grassroots can be taken.

The principles of a well-organised system of EMS have been outlined in a handbook referring to all aspects [4].

In the context of Brunei, the government has continued to address the need to protect and conserve the country's environment from pollution and excessive exploitation of natural resources. At the same time, efforts have been undertaken to strengthen existing administrative machinery. The National Committee on the Environment and the Environment Unit under the Ministry of Development were both created in 1993. The main aim was to achieve better co-ordination of environmental programmes undertaken by the various agencies. [5] A Solid Waste Management System has been introduced by the government and the steps and techniques needed to overcome the continuing problem identified. [6]

5.1.1 International Organisation for Standardisation application – ISO 14001

ISO 14001 is a series of standards that allow organisations from around the world to pursue environmental efforts and measure performance according to internationally accepted criteria. It specifies the requirements of an Environmental Management System. It is intended to be applicable to all types and sizes of organisations and accommodate diverse geographical, cultural and social conditions [7]. It can be applied to any organisation that wishes to improve and demonstrate its environmental performance to others through the presence of a certified environmental management system. The overall aim of the standards series is to support environmental protection and prevention of pollution in harmony with socio-economic needs. The standards concept is to provide continual improvement in environmental performance with a management system which complies with the relevant legislation and regulation. Developing and implementing an environmental management system lies at the core of the requirements of ISO 14001.

The following are the three key issues of ISO 14001[3]:-

1. The obligations under the standard are voluntary and greatly depend on the objectives and targets that the city sets for itself
2. ISO certification embodies a comprehensive, annual, external monitoring and evaluation system ensuring that the EMS put in place is indeed followed through and maintained
3. The existing environmental and management practices can be incorporated with the EMS framework, avoiding duplication and overlap.

The benefits of implementing ISO 14001 are as follows: -

- Positioning the organisation as an environmental leader
- Provide a framework for establishing an integrated approach to environmental management that is system–dependent and not person-dependent
- Promoting a positive image in the community and with governmental agencies
- Providing a systemic, repeatable process to achieve continual improvement in the organisation's environmental management system, thereby promoting improvement of environmental performance
- Supporting an integration of relevant levels and functions into the environmental management system
- Providing an internationally recognised standard for the organisation to use to demonstrate to employees and interested parties its commitment to sound environmental management

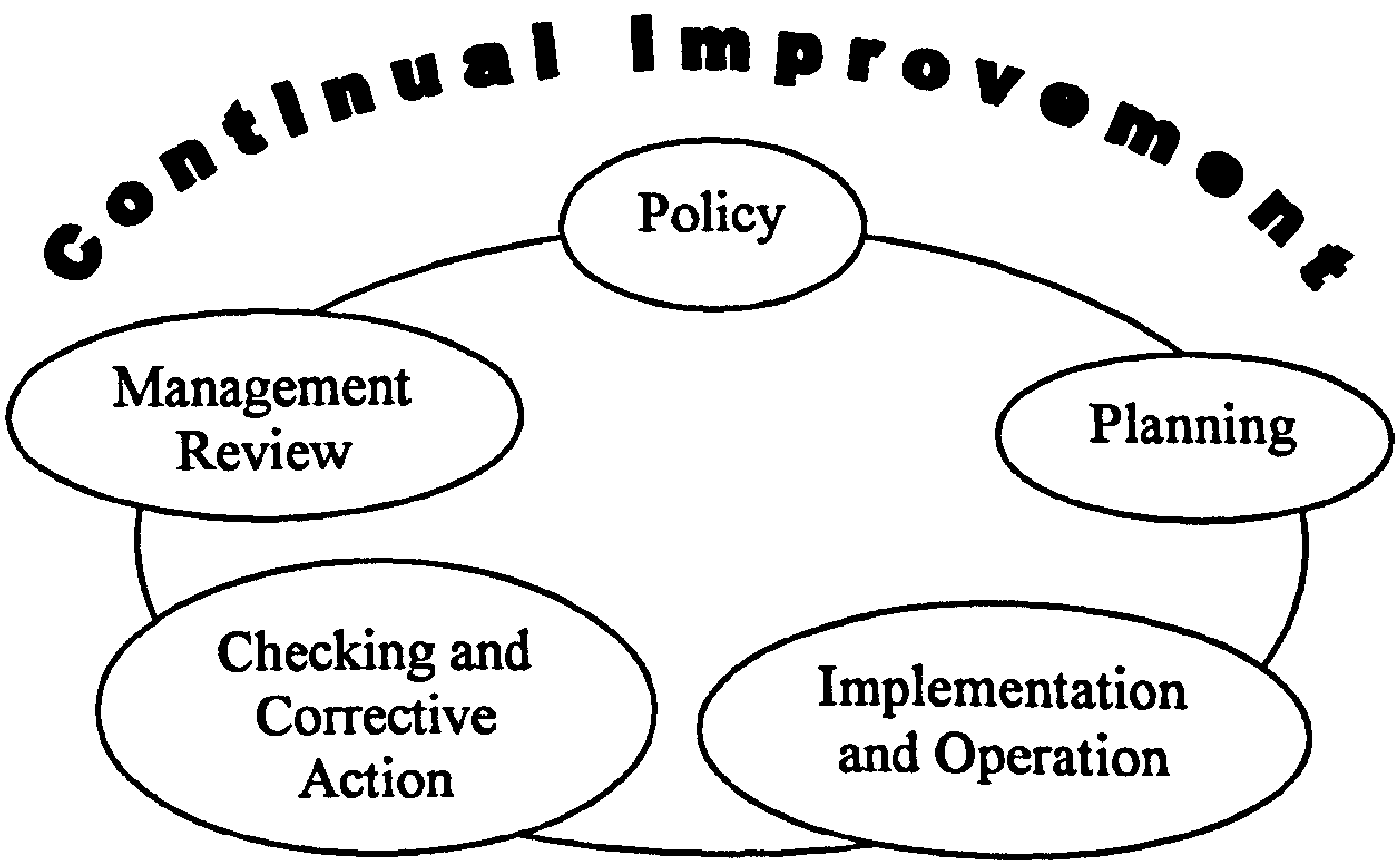
5.1.2 ISO 14001 – Environmental Management System model

ISO 14001 is the most widely recognised environmental management standard. It is a specification standard, which means that organisations which conform to its requirements can become registered to the standard. ISO 14001 was written as a consensus standard with nearly 50 countries participating. The standard is applicable to all types and sizes of organisations and it accommodates diverse geographical, cultural and social conditions.

It can be applied to all parts or any single part of an organisation and/or its activities, products, and services. A very basic model of the framework that the standard sets (Figure 5.1) shows the 4 major elements involved and the concept of continual improvement [8].

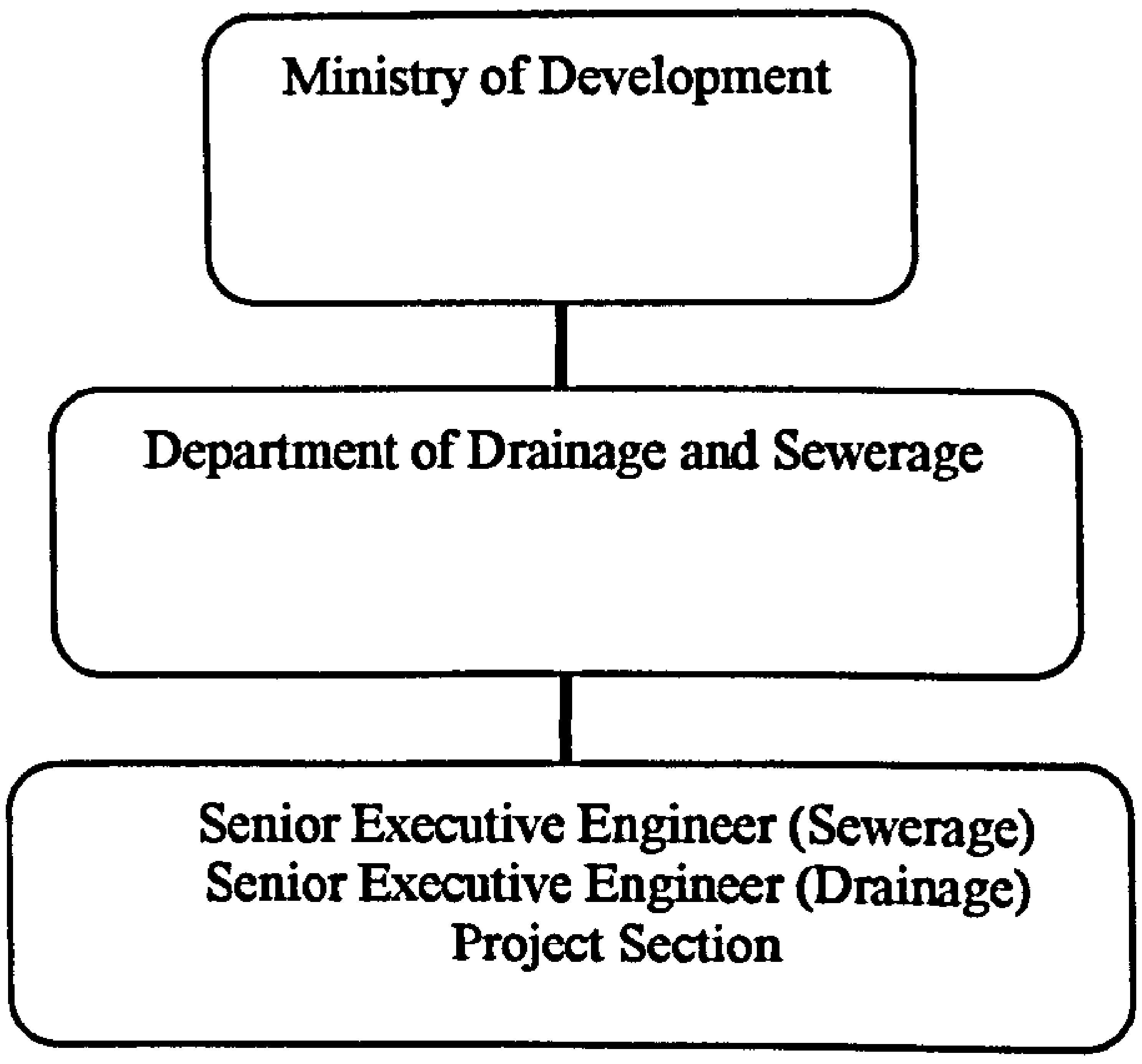
Figure 5.1

Environmental Management System Model



5.2 WATER MANAGEMENT IN BRUNEI

Management of the Brunei Rivers does not currently include provision for dealing with future potential oil industry pollutants or for the dumping of solid waste in the rivers. The current organizational structure of water management is as follows: -



5.2.1 Functions

Department of Drainage and Sewerage is Brunei's authority for the planning, construction, maintenance and operation of land drainage and water borne systems. It formulates policies and strategies to safeguard the infrastructure and environment through its activities.

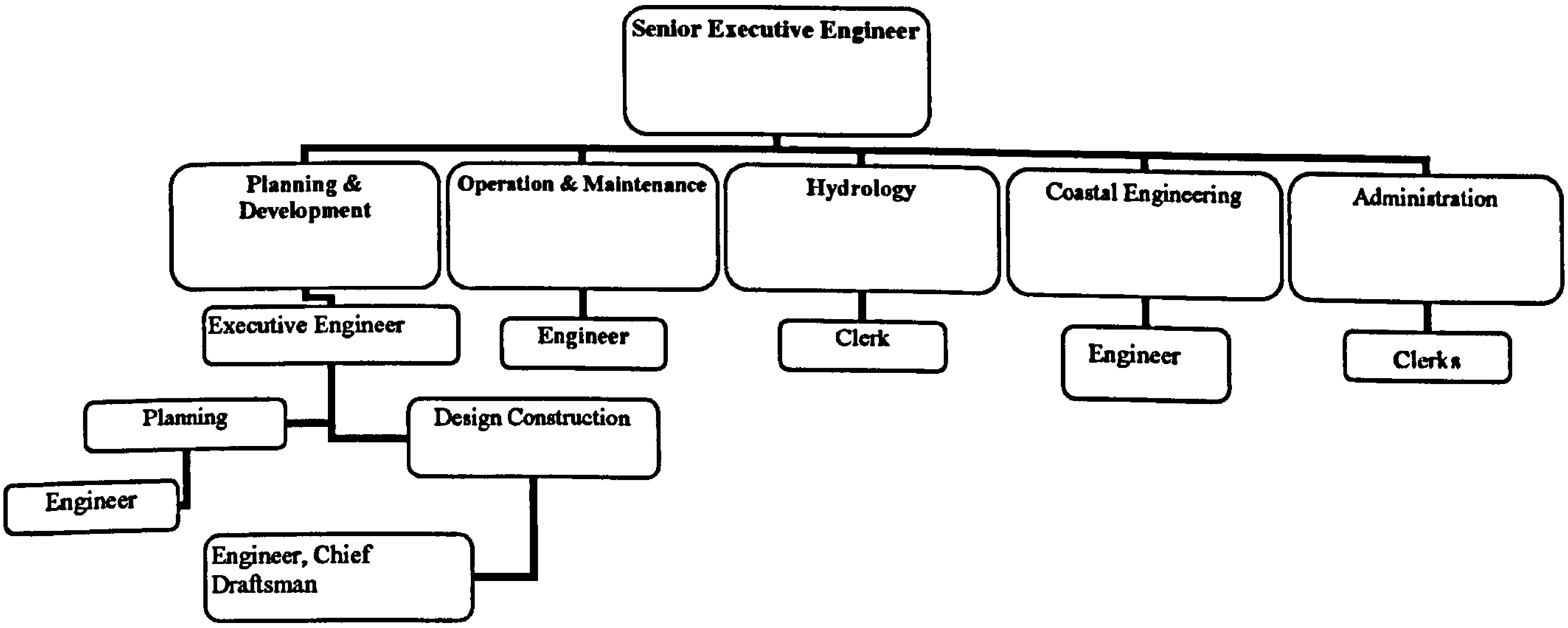
5.2.2 The Drainage Section

Formerly known as the Drainage and Irrigation Section, the Drainage Section is the main authority for matters relating to flood mitigation, flood control, land drainage, rivers, streams and coastal protection works.

Its main functions are:-

1. plan, design and implement drainage schemes to prevent flooding
2. control and advise on the provision of flood control measures and drainage infrastructure by land developers
3. improve rivers and waterways
4. maintain and safeguard the national drainage network
5. advise and co-ordinate with the Department of Agriculture on irrigation and water resources
6. plan and implement projects for the protection of the coasts.

Organisation Structure (Drainage)

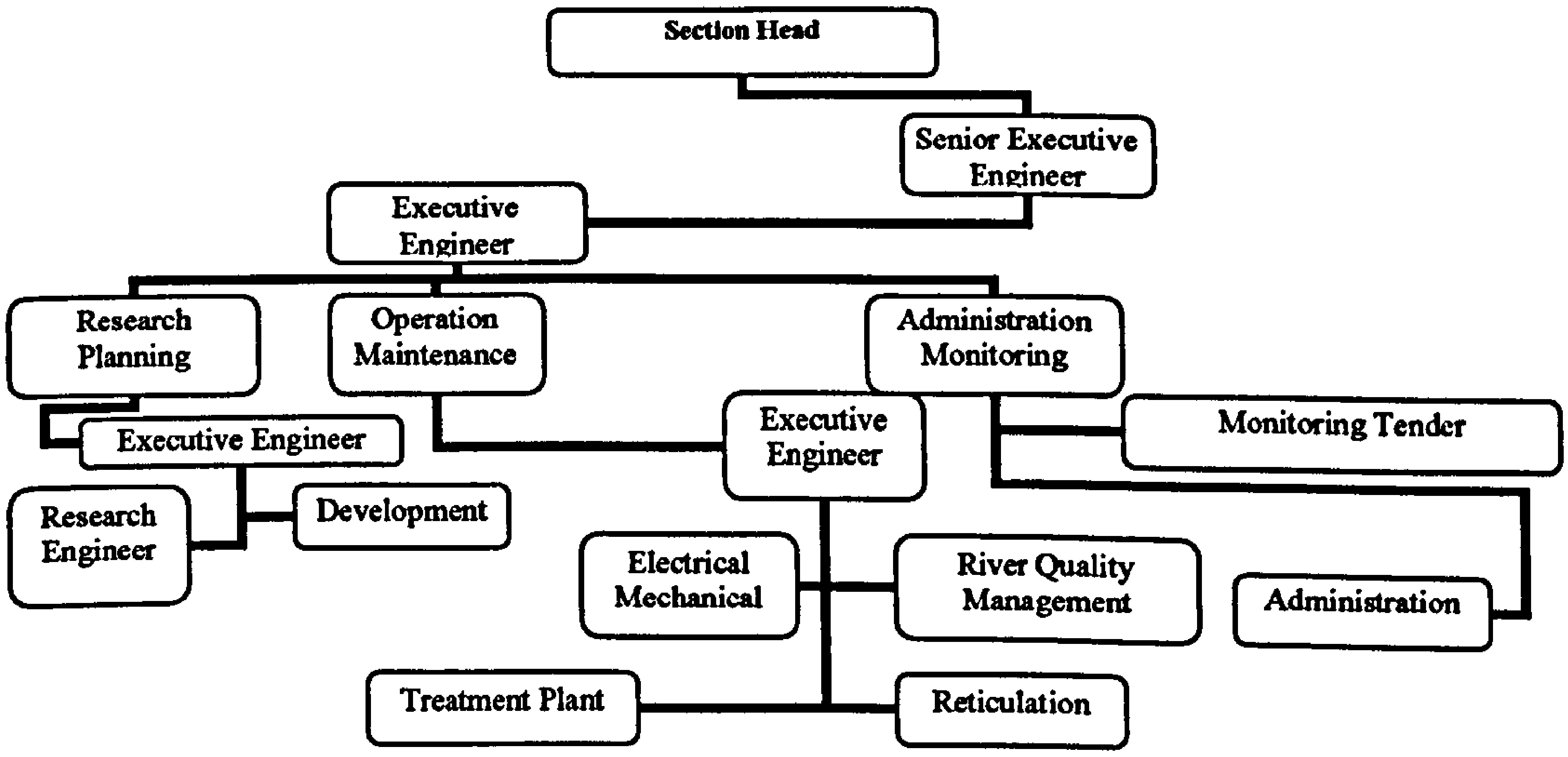


5.2.3 The Sewerage Section

The objectives of the Sewerage Section are:-

1. plan and design the public sewerage system
2. operate and maintain the sewerage system and sewage treatment plants to ensure effluent quality
3. develop control on all sewerage systems and sewage plants to make sure that effluent qualities are complied with.
4. monitor of water quality at sewage outfalls and receiving waters from rapid run-off.

Organisation Structure (Sewerage)



5.2.4 The Project Section

This section works directly under the control of the Director of Drainage and Sewerage and provides technical support for the implementation of large development projects. The objectives of this section are [9]:-

1. investigate, collect data and prepare reports on the Drainage and Sewerage system.

2. process developmental projects for their feasibility
3. monitor consultants in the design and implementation of large scale projects
4. check the design submitted
5. visit and co-ordinate site meetings

5.3 WASTE MANAGEMENT

In response to a November 2002 Strategy Unit (SU) report, *Waste Not, Want Not,* and as part of its reform of the Landfill Tax Credit Scheme, Defra (*the Department for Environment, Food and Rural Affairs*) set up in autumn 2003 a programme dedicated to waste-related research [10]. Defra is responsible for progressing a package of strategic investment measures recommended by the SU. A key element of Defra's approach is the establishment of the Waste Implementation Programme (WIP) [11].

Defra has been working to encourage the exploration of new approaches to waste management, and to stimulate the provision of additional capacity outside the landfill sector. Among the initiatives promoted by DEFRA are [11]:-

- Encouraging investment in new technologies.
- Generating awareness of relevant developments oversea, including provision of training and 'road shows' to local authorities and industry.

The aim of the programme is to deliver a sound evidence base for better-informed policy development, implementation, monitoring and evaluation for sustainable waste management at both the national and local levels, which incorporates an effective mechanism for access to, and dissemination of, research results [12]. The core role of the Waste Research Team (WRT) is to distribute funds for research in alignment with the Government's strategies priorities.

The first call was preceded with the publication in September 2004 of Defra's strategy for a £15m three year waste and resources R&D programme. Waste and Resources R&D Strategy (2004/05 to 2006/07) presents an overview of waste and resources issues and associated R&D requirements, dividing them into eight theme areas which are in turn broken down into a number of broad programme areas. The eight themes are [10]:

1. Sustainable resource consumption and management
2. Systems for resource recovery
3. Residual wastes management
4. Market development and intervention
5. Social dimension
6. Environment and health (risk assessment and impact management)
7. Economics
8. Decision tools

One of the first stages in the development of the research framework was to identify the relevant drivers. The key drivers of relevant to the R&D strategy can be grouped as follows [10]:-

1. Thematic Strategy on Recycling and Prevention of Waste (which encompasses the Sewage Sludge Directive, and the proposed Biowaste Directive).
2. Thematic Strategy on Sustainable Use of Natural Resources (which encompasses issues in relation to Integrated Product Policy {IPP} and Integrated Product Design {IPD}, and a proposed framework for Eco design).
3. Thematic Strategy on the Prevention and Recycling of Waste.
4. Management Techniques/Treatment EU Directives (including landfill, IPPC and Incineration).
5. Waste Specific EU Directives (which include all the Producer Responsibility Directives e.g. End of Life Vehicles {ELV}, Packaging, Batteries, Waste Electrical and Electronic Equipment {WEEE}, Extraction Industries, in addition to Hazardous, Waste Oil, PCB's and PCT's etc.).
6. National Waste Strategies (including the drivers associated with their implementation).

5.3.1 Sustainable resource consumption and management

The aim of the sustainable resource consumption and management is that contributing to our understanding of the resource cycle, specifically material flows and the development of techniques for increasing resource efficiency. The broad programme areas under sustainable resource consumption and management is understanding resource flows, design for the environment (IPD), exploring techniques and methodologies for effective, which can be categorised into industrial/commercial waste minimisation and household waste prevention and understanding waste composition and trends.

The examples projects/specific programmes are:-

- A literature review / scoping study of existing research into resource flows to establish baseline information, progress to date, and assess appropriateness of methodologies.
- Identification and evaluation of mass balance data gap.
- Identify resource intensive sectors, target sources of materials and substitution opportunities and match surplus materials to demand.
- Development of boundary conditions for mass balance studies, and also to address issues such as achieving IPP
- Sustainable consumption patterns
- Research into impact of design for recycling or design for repair/reuse
- Research into the use of 'wastes' as inputs to industry
- Cleaner production techniques (including minimising generation of hazardous waste from production processes)
- Waste avoidance techniques and applications
- Household waste prevention
- Policy and legislative measures (support studies)
- Understanding and evaluation of the nature of MSW increases
- Identification and understanding of basic trends within commercial and industrial waste streams

- Accounting for external trends in waste growth, such as packaging
- Predicting future C&D waste management issues from a study of the construction and building industry
- Research on characterisation of waste and on testing criteria applied by Landfill Directive, and application to extractive wastes.

5.3.2 Systems for resource recovery

The aim is to research into systems and their logistics to maximise recovery of high quality, uncontaminated material flows and their subsequent processing to realise any potential environmental and economic gain. The broad programme areas under this section is waste collection and handling, producer responsibility and priority waste streams, sorting systems including processing and reprocessing technologies and biowaste.

The examples projects/specific programmes are:-

- International review of best practice and new technologies in waste management logistics
- Interactions between collection methods in terms of the quantities and types of waste collected and the impact of different schemes.
- International review of new organisational structures and funding mechanisms being developed for the implementation of extended producer responsibility programmes plus targeting of specific waste streams with potential to come under producer responsibility requirements
- International technology review of best practice and new technologies in the sorting and processing of dry recyclables
- Identifying the links between different processing technologies and the way different social groups use them
- Research into development of sorting/processing systems to manage organics mixed with e.g. packaging materials
- Resource intergration of biowastes between industry / agriculture / household

- Development of reprocessing technologies for hazardous waste
- Best practice and quality standards in the separate collection of biowaste and its separation from hazardous materials (a) international review and (b) R&D into achieving this.

5.3.3 Residual wastes management

The aim is to research into development of existing and new technologies to help manage residual waste streams. The broad programme areas under this section is processing technologies for (1) Biodegradable MSW and (2) Intermediate technologies focussed on treatment and/or energy recovery and managing residual wastes in landfill.

The examples projects/specific programmes are:-

- New technologies for biodegradable MSW are not applicable (dealt with under WIP TRIP)
- Research into the development and commercialisation of technologies for residual waste management
- Review / identification of waste streams other than MSW that will require technology development over the longer term
- Assessment of planning risks associated with (new) and (current) technologies
- Advanced energy from waste technologies and the effect of recycling strategies on Energy-from-Waste plants
- Developing underlying scientific understanding, and methods and techniques to forecast, assess and manage the long term behaviour of landfills receiving post Landfill Directive inputs
- Evaluating the role of and potential impact of instigating a concept change away from landfill towards long term storage (including future access to waste as a potential resource)
- Research into the range of waste types entering post-directive landfill
- Monitoring of closed landfills – early warning systems, for example remote sensing

5.3.4 Market development and intervention

The aim is to research that contributes to our understanding of existing markets as well as the identification and stimulation of new market development, for secondary materials and recycled products. The broad programme areas under this market development and intervention is WRAP short term, material, specific and research areas, uncovering market opportunities outside of WRAP's remit, technological advancements in product design and implications for market development and use of different tools to stimulate market development.

The examples projects/specific programmes are:-

- An evaluation, in terms of the future need for market development and intervention of specific waste streams such as textiles, household hazardous waste, organic waste, etc
- Identify material substitution opportunities via market research – blending and/or replacing primary raw materials
- Identify the role and potential development of the refuse derived fuel market (in conjunction with facility and technology developments)
- Identify the potential development of the reuse market for specific waste streams
- Review current technologies advancements in consumer products and the potential implications for reuse and recycling markets
- Linking consumer demand for new technology with future market development
- Understanding the potential of standards and products specifications to stimulate the market

5.3.5 Social dimension

The aim is to contribute to our understanding of perceptions, attitudes and responsibilities towards waste and resource management, and investigate means of facilitating environmentally beneficial behavioural changes. The broad programme areas under the social dimension is understanding pro-environmentally behaviour and how to enhance it, understanding socio-economic benefits of recycling: local and regional level, development of tools and instruments to facilitate behaviour change and local acceptability of waste and resource management facilities.

The examples projects/specific programmes are:-

- Identification and collation of new and recently completed research undertaken in this area
- Research to investigate which lifestyle decisions that bear on wastes management are actually influential compared to what people think is important (i.e. uncovering the relative impacts of human behaviour)
- Research into influencing environmental behaviour, for example through communication and infrastructure development and/or 'environmental citizenship' approach
- Understanding household drivers and behaviour in order to optimise collection systems and home composting
- Identifying local economic multipliers
- Influencing recycling participation rates
- Understanding and evaluating different inclusive approaches to the siting of new waste management facilities in the UK and overseas (e.g. community compensation funds)

5.3.6 Environment and health (risk management and impact assessment)

The aim is to promote understanding and strengthens the evidence base in relation to potential impacts and risks associated with different waste management options. The broad programme areas under this section is risk assessment and management, impact assessment and indicators and benchmarking.

The examples projects/specific programmes are:-

- International review of methodologies to establish comparative risks
- Development of systems to manage assertions of health risks from waste technologies
- Identify exposure risks with hazardous substances (occupational exposure standards)
- Understanding emissions and pathways (modelling, data collation and evaluation) including climate change effects
- Research into health impacts resulting from changes to the composition of the waste stream arising from new EU Directives e.g. on WEEE
- Research into health effects of waste management at the household level (including research into the relative hazardousness of consumer products); all/selected waste management facilities; recycling methods; reuse or disposal of organic wastes
- Development of research into ecotoxicological methodologies
- Development of specialised indicators, such as ecological health indicators, as required by the Water Framework Directive

5.3.7 Economics

The aim is to promote better understanding of the true costs and interactions of economic growth, resource use and waste production, and the exploration of potential indicators and instruments to stimulate change. The broad programme areas under this section is understanding true costs of waste management, better understanding of factors affecting decoupling waste growth from comsumption, role/use of economic incentives and penalties to promote and support change in resource use and waste generation. It also include the economic performance indicators and understanding economic and political causal factors and connections, from local to global scale.

The examples projects/specific programmes are:-

- Whole-life costs of materials from cradle to cradle for alternative waste/resource management systems
- Evaluate financial costs of poor waste management
- Evaluate compliance costs and benefits of producer responsibility legislation
- Evaluate compliance costs and benefits of regulatory instruments
- Cost effectiveness of different procurement routes for municipal waste contracts
- Identification of costs and benefits of adopting environmental management systems and standards
- Review of international case studies and examples of good practice
- Evaluation of the role of industry and the effect that compulsory economic policies will have downstream on waste growth
- International review of the application of economic incentives and penalties to promote and support change
- Evaluate the role of voluntary agreements versus regulatory and economic instruments in selected areas of waste management
- Establish economic performance indicators that account for resource intensity, throughput of scarce resources and/or environmentally disruptive goods and materials
- Impacts on sustainable resource use: incompatibility with the proximity principle and other environmental impacts; social and employment consequences of increased global flows of resources; cost to the economy

5.3.8 Decision support tools

The aim is to promote better understanding and further development of tools and instruments to support resource and waste management decision-making at national, regional and local level. The broad programme areas under this section is the decision support tools for strategic development at all levels, innovative methodologies and forecasting tools for data collection and management and performance measurement and benchmarking.

The examples projects/specific programmes are:-

- Review and evaluate tools available, and usage at local, regional and national level in light of technologies and newly accessible approaches – are they being used, and if not why not?
- Develop systems to account for costs and benefits of sustainable waste management at local level
- Develop the use of new spatial analysis/GIS techniques to estimate waste arisings/growth (e.g.agricultural waste)
- Develop validation and verification techniques to improve municipal waste statistics
- Develop value for money assessment
- Developing tools to measure waste prevention

5.4 WASTE POLICY IN DEVELOPING COUNTRIES

Environmental problems arising from waste are extensive, can be serious and in many cases are transferred to the next generation. The Governments has therefore set out three specific goals for the policy on waste in order to show clearly the ambitious target level of the policy and in order to be able to test whether things are developing in the desired direction. The Governments will report to Parliament every year about developments in relation to these objectives.

The objectives of the policy are [13-17]:-

- Growth in the volume of waste that is generated should be significantly lower than the rate of economic growth.
- Given the fact that the quality of waste for final treatment is to be reduced to a socio-economical and environmentally reasonable level, the aim is that the quantity of waste dealt with by final treatment should, by the year 2010, be equal to approximately 25% of the quantity of waste generated.

- Practically speaking all special waste is to be dealt with in a safe and acceptable manner, and is either to be sent to recycling or is to be guaranteed sufficient national capacity for its treatment.

5.4.1 Methods and Strategies

In the further development of methods and measures to be taken in the waste sphere, the Governments will emphasise that:-

- The principle that is to be adhered to is that it is the polluter who must pay.
- Great emphasis should be given to the principle of "being prepared" when the suggested measures or methods reduce serious threats to the ecological system.
- Suggestions for the methods and measures to be taken are to build upon socio-economic assessments.
- In a choice between different alternatives, the most cost-effective measure is to be chosen.

The sphere of waste is, should continue to be, regulated through a combination of different measures and of various central and local regulations. New measures are first and foremost intended to augment and complement those that already exist.

5.4.2 Less Waste

The Government will:-

- *Increased awareness at all levels* – An important part of the Government's waste policy is to prevent waste. In order to succeed in the work with the reduction of waste it is necessary to increase the public's knowledge, commitment and environmental interest. Increased exposure in the marketplace can also contribute to companies giving greater emphasis to the work of reducing waste. It is also important that efforts made to reduce waste are rewarded, for example that less waste disposed of in the residual waste container results in less duty on waste.

- *Developing green taxes further* – Taxation in the sphere of waste is an important tool in the work of making the transition from taxation on income and work (red tax) to taxation on pollution and use of resources (green tax). Green taxes will be used to put a price on the environmental consequences of dumping and pollution from the treatment of waste. This is to safeguard the principle that the polluter shall pay.

5.4.3 More Recycling

The Government will:-

- *Recycling should profit society* – Recycling contributes in general to reducing the burden that waste is on the environment. In this way environmental costs will also be reduced. In order to achieve the best solutions, the advantages and disadvantages have to be weighed up. The correct level of recycling will be different for the different types of waste because business management costs and environmental costs vary. The prices of recycled materials, of new raw products and of energy also change.

- *Energy from waste is to be better utilised* – A lot of waste is not suitable for material recycling. Some of this is organic waste like timber, bark, chippings, bits of paper/cardboard, plastic and textiles. It this waste ends up on a landfill it will lead to emissions of the climatic gas, methane. It is therefore desirable to keep the organic waste away from the landfills. Some of the waste can be made into pellets and briquettes, which can be used for heating. The utilisation waste for energy purposes can replace other sources of energy and will often lead to a reduction in the usage of fossil fuels like oil.

- *More recycling of wet organic waste* – Wet organic waste, i.e. waste from the food industry, food waste from large-scale catering and private households, as well as garden waste, is one of the most polluting types of waste. The disposal of wet organic waste leads to emissions of methane gas and emissions of environmental toxins into the earth and water through seepage water. The waste contains important nutrients that it is important to utilise better than we do today. There is a huge potential for increased recycling of wet organic waste both as fodder and as fertilizer or a means of improving the land and thereby returning it into nature's cycle.

5.4.4 Better final treatment and reduced illegal management of waste.

Illegal management of waste – Dumping and uncontrolled waste incineration is forbidden. Nonetheless this illegal management of waste goes on to a certain extent; burning in the back garden and dumping in ditches and woods. It is also important authorities use their power to stop illegal dumping. In addition the Government will give the local authorities power to regulate and implement measures against incineration of waste and draw up directives and guidelines for the local authorities' work in this area.

5.4.5 Management of special waste

Special waste not accounted for – Chemical policy has the goal of reducing emissions that are hazardous to health and the environment. It constantly evaluates the need for classifying new types of waste as special waste and reduce the volume of special waste that is unaccounted for by:-

- Making sure that the local authorities have satisfactory facilities for receiving waste.
- Examining special measures for specific types of special waste, e.g. nickel cadmium batteries and special waste packaging.

5.4.6 Changes in work forms and distribution of responsibility

Increased freedom of action for industry – By giving these industries the possibility of choosing who collects and disposes of their waste, more flexible solutions can be promoted and lead to a reduction in waste and an increase in recycling.

Increased responsibility for the manufacturers – A good solution may be increased responsibility for the manufacturers which means the manufacturers and importers would bear the waste costs for their products. This would contribute to increased recycling, stimulate reduction in waste and reduced usage of substances in products which are hazardous to health and the environment.

5.4.7 General measures and methods

The Government will:-

- Use information as a tool and encourage the participants in the waste sphere to co-ordinate information.
- Increase the quality of waste statistics and increase knowledge about the connection between development in society and the reduction of waste, and about technology for improved waste management and utilisation of energy.

5.5 WASTE MANAGEMENT IN BRUNEI DARUSSALAM

There is hardly any other area of environmental protection where every single person can contribute as much to the success of the common strategy as in waste management. The management of urban solid wastes has become a serious problem in most economically developing countries. In such countries, the majority of the wastes that are collected are simply disposed of in open dumps. Rarely are such disposal sites scientifically selected, well planned or properly managed and they are usually accessible to scavengers and animals. In many instances, the wastes are even deliberately set on fire to achieve some degree of volume reduction.

Those responsible for the management of the wastes also face difficulties due to the lack of readily available, reliable information on the subject. Land filling is perhaps one of the most common solutions for the final disposal of wastes in developing countries, though most communities in such countries do not possess sufficient information on the siting, design and operation of landfills. Furthermore, municipalities do not have criteria or guidelines available on the subject, while in some cases in large metropolitan areas, there is a tendency to adopt guidelines or regulations promulgated by industrialised countries, without modifying or adapting these to local conditions.

Environmentally sound and cost-effective management of municipal solid wastes requires the use of several strategies. Some involve the siting, design and construction of different types of facilities to store, transfer, process or dispose of the material. Siting of such facilities should be conducted in accordance with minimum acceptable criteria, with the aim of protecting public health and preserving the environment. The first step in the process of establishing a landfill is determining the need for disposal capacity.

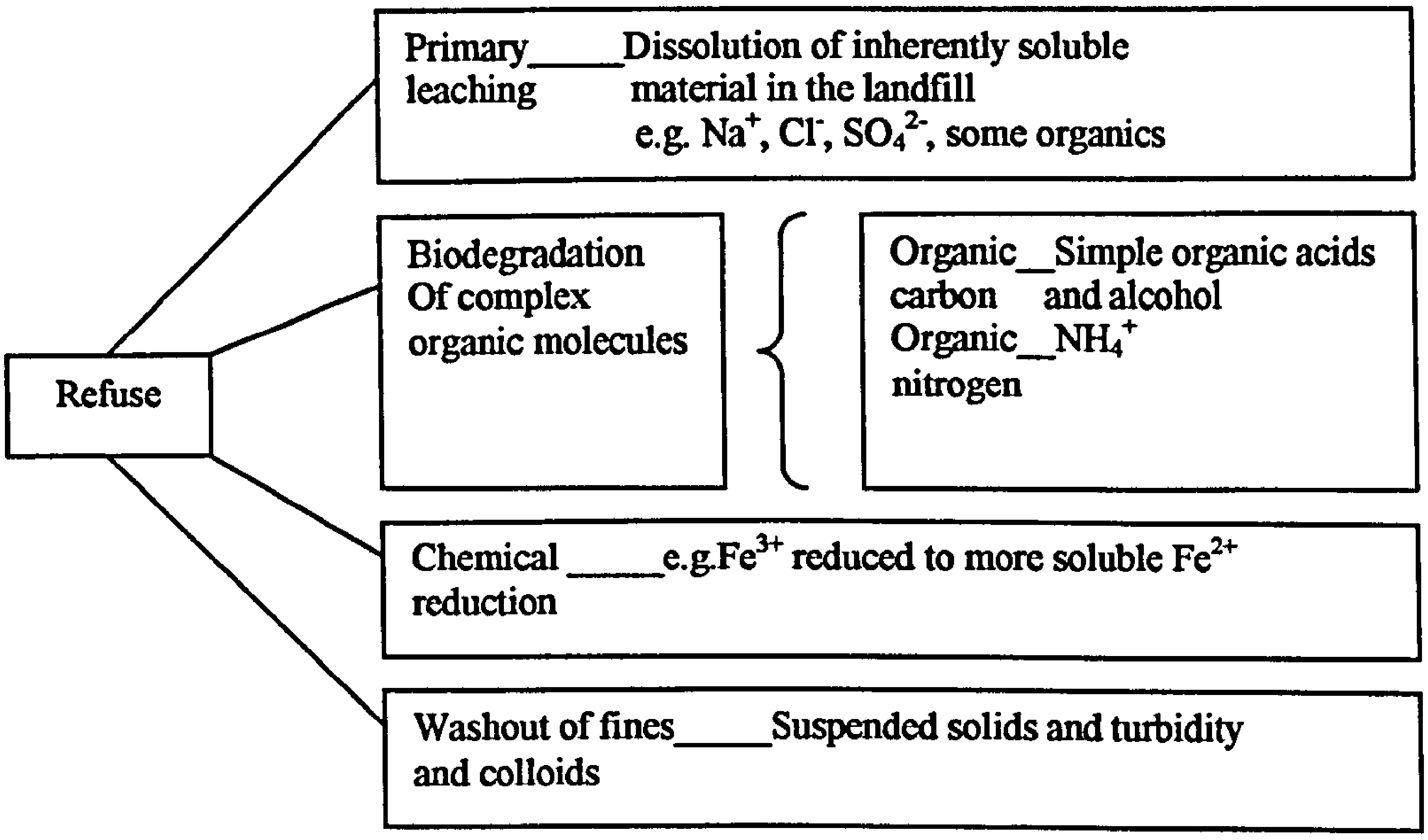
One of the key considerations in the design of a landfill is the composition of the waste. Landfills should not be sited where there is significant risk of seismic activity, there should be no fault lines, or fractured geological structure within 500 metres of the site's perimeter. Run-off and run-on from the site should be minimised through the use of adequate methods of diversion and collection and other methods of control. Precipitation water or other surface water that has come into contact with solid wastes at a landfill working area should not be mixed with other storm water and should be treated. Waste composed of significant quantities or concentrations of dangerous or toxic materials requires a complex landfill system, in order to minimise potential harm to the public, to the environment or both. As opposed to waste in most industrialised countries, the great majority of waste in many developing countries is of domestic origin, with considerable concentrations of green and food wastes and relatively low concentrations of toxic materials [18].

Landfill sites should be located reasonably close to the centre of waste generation or to a transfer station. Typically, the maximum recommended distance is 50km, as a radius from the waste generation node. Although a truck weighbridge is a very useful and recommended tool for accurately determining the amounts of solid waste being disposed of at a site, its cost or availability may represent an unacceptable financial burden. Alternatives (to weighing vehicles) such as determining volumes and using average densities of wastes can be used for management purposes, although the accuracy of the weights will not be as great as actual weighing or periodic weight surveys.

One of the important aspects associated with siting and design of landfill is the safe disposal of the wastes, so that they do not have any adverse impact on the quality of surface water or groundwater. One major source contaminated of water is leachate. In addition to the problems already indicated with landfill, a major environmental problem is the production of leachate, which is caused by water passing through the tip and becoming contaminated with various organic and inorganic pollutants. The subsequent movement of the leachate into the surrounding soil, groundwater or surface water can cause secondary pollution problems. Figure 5.2 shows a schematic representation of the main mechanisms by which material is leached from a landfill. Dissolved organic material such as humic acids will produce a brownish colour in the leachate.

Figure 5.2

Schematic representation of the main mechanisms by which material is leached from a landfill [19].



Variations in leachate composition occur because of variations in refuse composition, age of fill, hydrogeology of the site, climate, season and moisture routing through the fill. Consequently, the following suggestions have been made relating to groundwater:-

- The ten-year high level of the groundwater should be at least 1.5 metres below the base of the fill or of any planned excavation.
- The existing soils should have relatively low permeability, i.e. 10^{-6}cm/sec or lower.
- The site should not be within or near the ten-year groundwater recharge area for current or future water supply development.
- No type of porous rock formations (such as carbonate and limestone) should be part of the uppermost geologic layer, as these types of rock would not be barriers to gas or leachate migration.
- The site should not be located within a flood plain that may be subject to 25-year floods.

The first step in setting groundwater performance standards is to establish a containment boundary. The boundary should surround the area where the waste is going to be deposited, as well as the leachate management system and should be located within the facility property. The location of the containment boundary should be established according to the following factors:-

- Hydrogeology
- Groundwater monitoring
- Corrective actions
- Leachate characteristics
- Groundwater usage
- Public health

Solid waste management has been identified as a significant problem in Brunei Darussalam and consideration is being seen to the problems of:-

- Domestic wastes
- Industrial wastes
- Commercial wastes
- Sewage Sludge
- Oily waste
- Hazardous waste
- Clinical waste

Solid waste generation rate has been estimated to be 1 kg/capita/day and is likely to increase in the future. Solid wastes generated in Brunei Darussalam mainly consist of paper products (33%), food wastes (25%), plastics (16%), metals (14%), glass (5%) and others (7%). Plastics in particular, pose a significant pollution problem as they degrade very slowly and will accumulate in the environment. The current consumer preference for plastic products will result in their increased use in the future, thereby worsening the problem. Collection and disposal systems are in place but problems are evident by the occurrences of indiscriminate dumping in housing areas and roadsides (Plate 5.1)

Plate 5.1

Waste Storage System

Limitations in manpower resources and technical capabilities have resulted in poorly managed landfills, which present potential environmental and water contamination health hazards. Efforts are being undertaken to promote the concept of 'Reduce, Reuse and Recycle' or the '3Rs' which comprises the following steps; first - reduce the quantities of materials used, second - reuse existing materials and finally - recycle used materials.

Efforts are being made to better coordinate the management of solid wastes to improve the system of collection and coverage of refuse collection as well as increase the number of public facilities for refuse disposal (Plate 5.1). Land filling is the main method of disposing solid wastes, but the use of incinerators will have to be considered when feasible. In recent years, considerable attention has been paid to the practice of using combustible components of municipal wastes as a fuel. At present, Brunei does not have such a practice nor will it require any in the near future but it is a useful piece of information for managers of MSW of Brunei.

5.5.1 Brunei's Administration

The Brunei Town Sanitary Board, administered by the British Resident, was established on the 1st January 1921. The Board served as an appropriate authority to deal with the development of the new town. Starting from 1959, the Brunei-Muara District Officer acted as the Chairman of the Brunei Town Municipal Board and Head of the Brunei Town Municipal Department. However, the day-to-day affairs of the Department were run by a full-time Municipal Secretary. Changes to the management and administration of the Brunei Town Municipal Board and Department took place in 1972 when the Chairman of the Municipal Board was appointed to the chairmanship of the Brunei Town Municipal Board and as the department-head of the Brunei Town Municipal Department. The Brunei Government and the relevant authorities are aware of the environmental impacts of household and industrial wastes. By controlling the amount of wastes produced and its composition, significant improvements can be achieved. Furthermore, by maintaining waste disposal at the highest possible standard, the environmental impact can be kept to a minimum. Therefore the relevant authorities must monitor waste disposal and management practises continuously and review their environmental policy when necessary to ensure that environmental issues are properly addressed.

Brunei is a signatory to some international agreements on the environment as listed below [20]:-

1. Vienna Convention For the Protection of the Ozone Layer (1985)
2. Montreal Protocol on Substances that Deplete the Ozone Layer (1987)
3. Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (1989)

4. Framework Convention on Climatic Change (1992)
5. Convention on Biodiversity (1992)

When establishing and reviewing the objectives of environmental policy, significant environmental aspects, the technological options and financial requirements have to be taken into consideration. At any point of time the objectives and targets have to comply with the agreed environmental policy. Appropriately, the environmental policy and its objectives and targets are set by the Ministry of Home Affairs, and are delegated to other authorities namely the Bandar Seri Begawan Municipal Board/Department. It is the duty of the Municipal Board to ensure that those targets are achieved within the set time frame. Figures 5.3.1 and 5.3.2 show the complete organisational structure of the Bandar Seri Begawan Municipal Board/Department.

Figure 5.3.1

Structure of the Bandar Seri Begawan Municipal Board/Department within the Ministry of Home Affairs

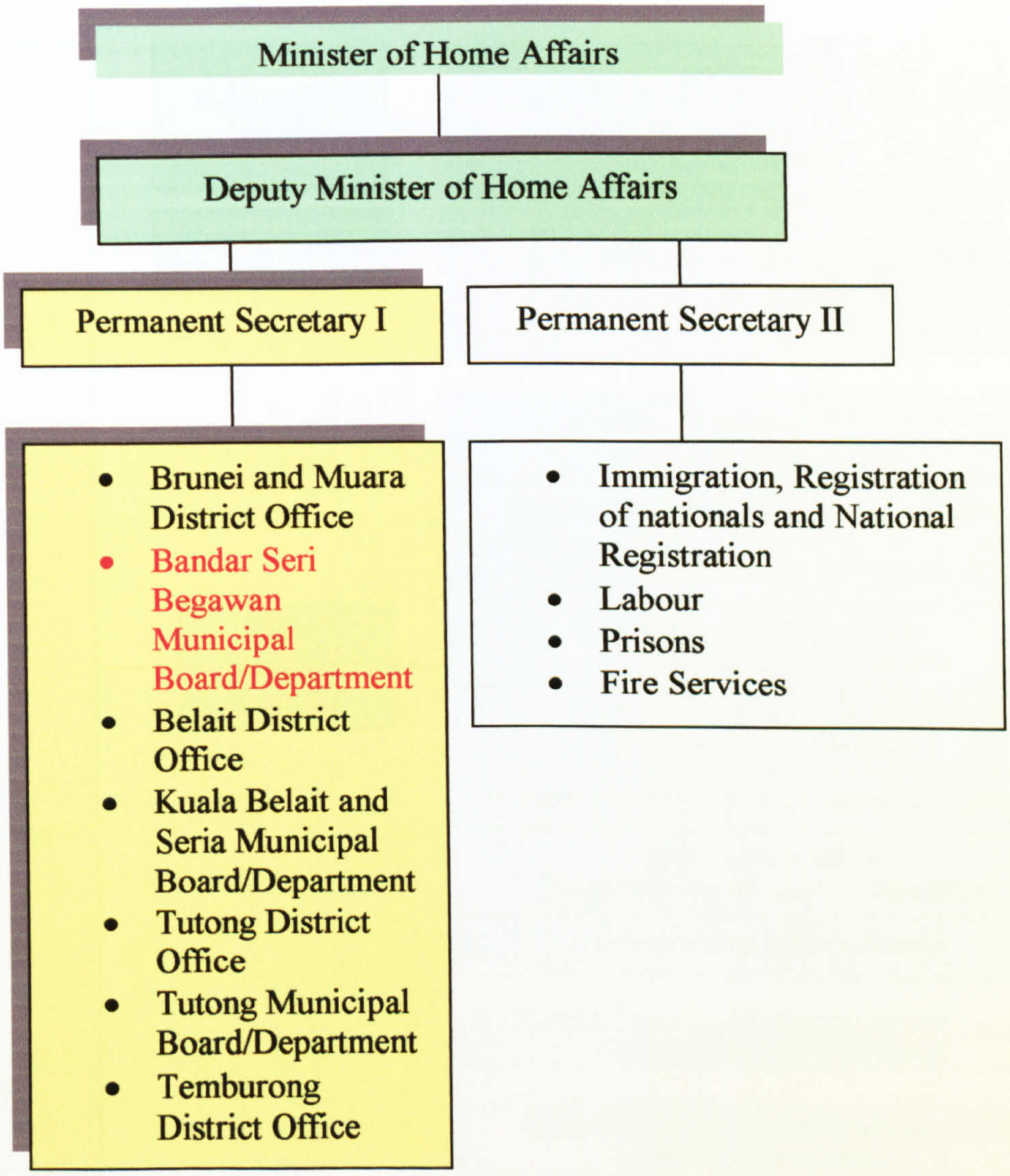
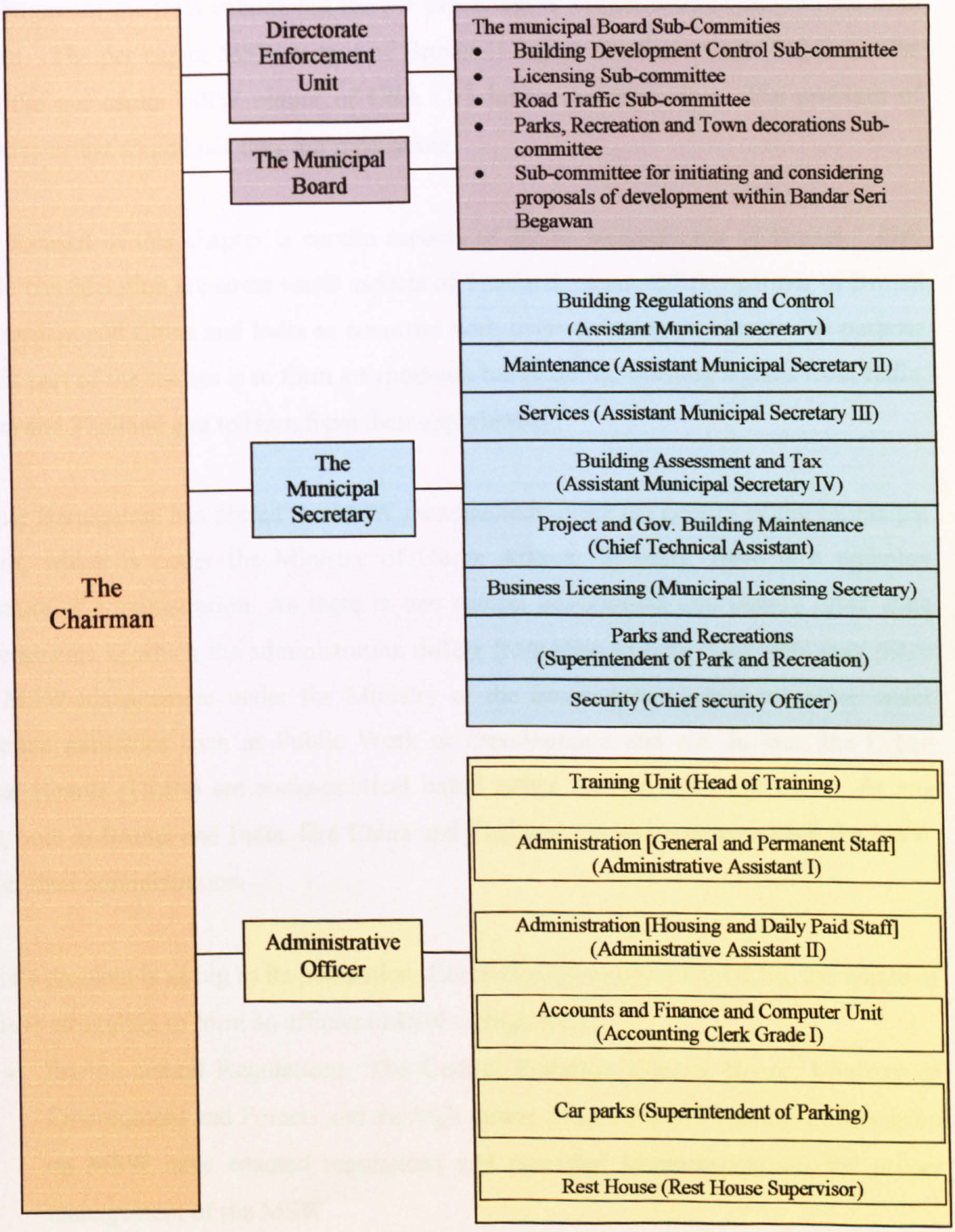


Figure 5.3.2

Bandar Seri Begawan Municipal Department (Organisation Structure)



5.5.2 MSW Management – A Comparative Study

Brunei Darussalam cannot take MSW Management for granted because of its tiny population and total volume of the solid waste output. The bottom line is that neither the population nor the total volume but the per capita MSW output which will give the final picture. The per capita MSW output of Brunei (1 kg/per head/per day) [21] is not far from the per capita MSW output of USA (1.1 kg/per head/per day). The problem of statistics is that sometimes they are misleading.

This focused of this chapter is certain aspects of MSW Management of Brunei. Also whole consideration are some waste aspects of Thailand, as an ASEAN partner of Brunei Darussalam and China and India as countries with overwhelming problems. The purpose of this part of the studies is to form a hypothesis based on the warning signals from India, China and Thailand and to learn from their experiences.

Brunei Darussalam has placed the MSW management under the control of the Municipal Board, which is under the Ministry of Home Affairs. In India, there is a complex structure of administration. As there is one central government and twenty other state governments in which the administration differs from state to state. One state may place the MSW management under the Ministry of the Environment while the other under different ministries such as Public Work or Development and etc. In fact, the Urban Local Boards (ULBs) are socio-political based rather than environment based. At any rate, both in Brunei and India, like China and Thailand, the governments keep the MSW under their administration.

India's problem is as big as its population. Controlled by nearly 4000 ULBs, the whole of India is struggling to form an efficient MSW management:-

- Environmental Regulations: The Central Pollution Control Board, Ministry of Environment and Forests and the high power committee of Planning Commission on MSW have enacted regulations and provided recommendations for proper management of the MSW.

- Constitutional Amendment: The 74th Constitutional Amendment Act (CAA), promulgated in 1992 envisages ULBs as the nodal agencies for the execution of various programmes. The 74th CAA aims to transfer power to local government thus emphasizing the decentralisation of power. This gives the ULBs greater power and autonomy in decision making and implementation
- Privatisation: Until about 1993, infrastructure and municipal projects were predominantly in the government sector. Due to the limited resources of the government and economic liberalization, however, the private sector is now being encouraged to participate in MSW management projects on Build-Own-Operate / Build-Own-Operate-Transfer to accelerate significant investment in this sector over the next 3 to 4 years

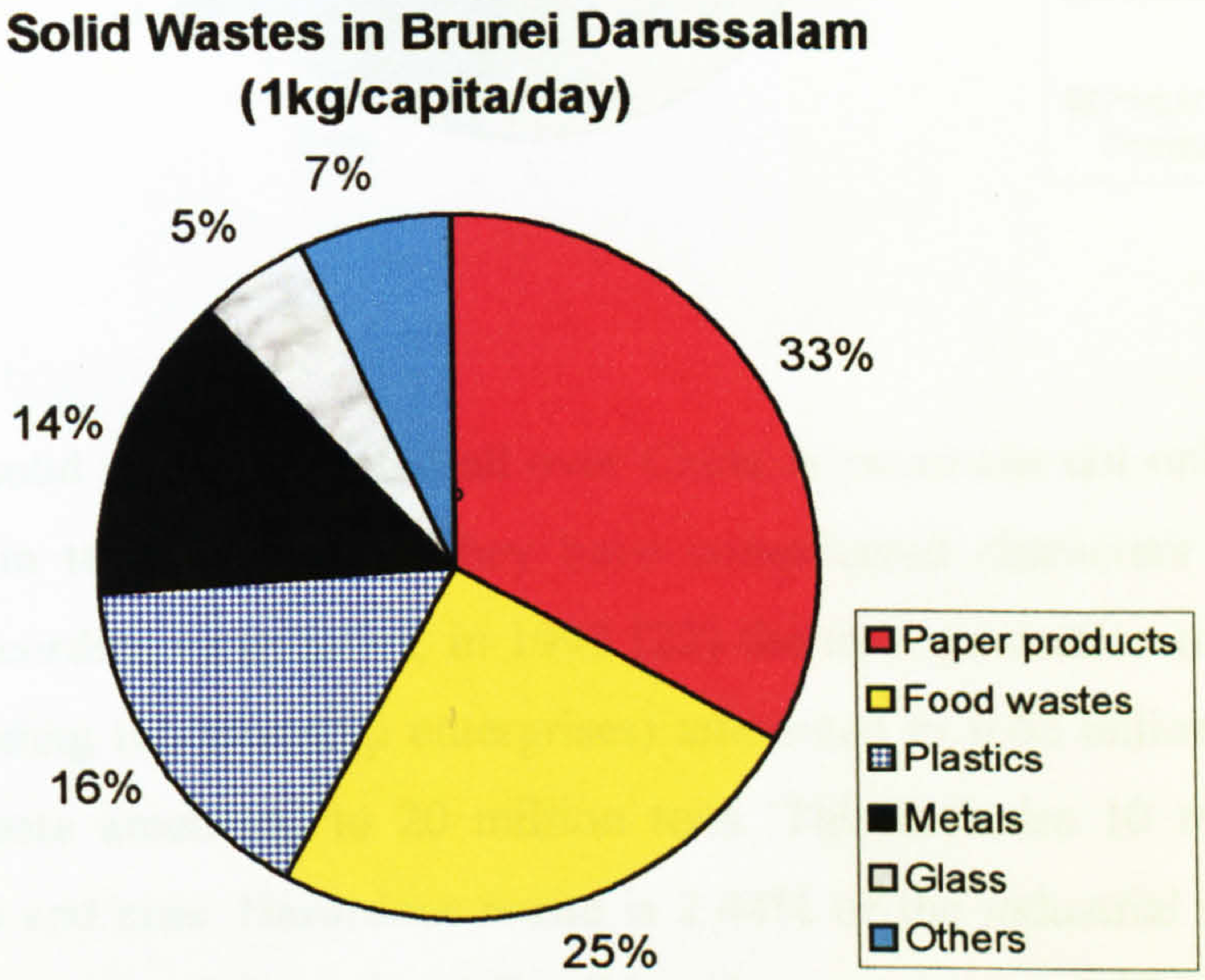
As such, by the size of the total volume of the MSW produced in Brunei, it is not necessary for Brunei to think of recycling. There is no need for recycling because the vast majority of the MSW is composed of organic and food waste, which it is not possible to recycle. Moreover, Brunei is abundant in oil and gas and so Brunei does not require recycling to produce any biogas or other reusable form of energy.

As for India, there is, as such, no national level recycling but it does happen in a of personal or unofficial manner. Even rag-picking should be considered a form of recycling. This is also the case in China and Thailand. It will be useful for India, which produces vast amount of MSW, to take this up seriously. For example, biogas is one area where India is already successful in rural areas.

5.3.3 Volume Analysis of the Total MSW – A Comparative Study

Brunei Darussalam produces roughly 1 kg/per head / per day (Figure 5.4.1).

Figure 5.4.1

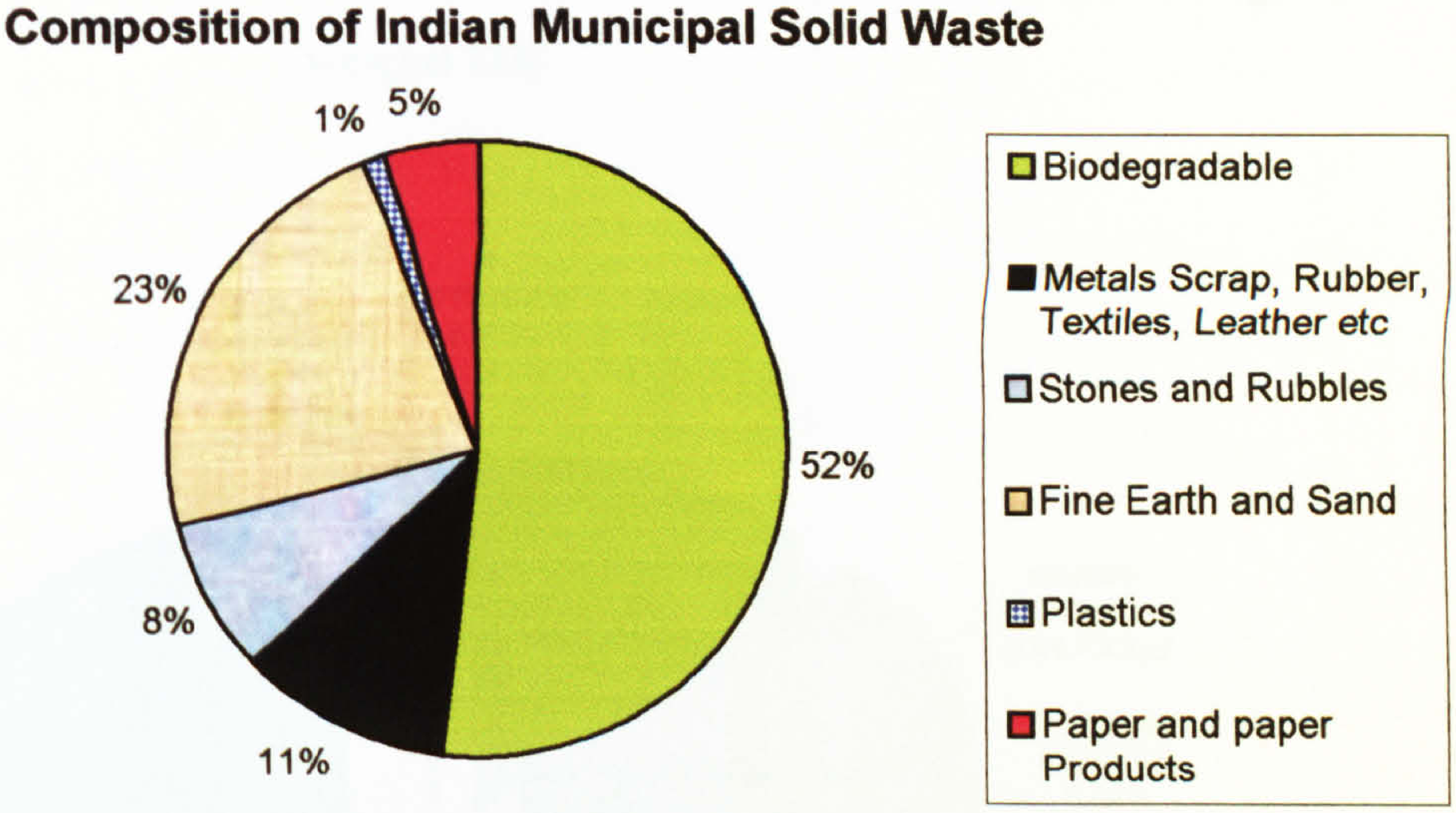


The Indian cities and towns currently generate about 60,000 tons of MSW per day and this figure has already reached 100,000 tons per day by 2000.

The composition of Indian MSW (Figure 5.5.2) is quite different from that of the USA and the European MSW; its distinctive features are the following:-

1. Low calorific value
2. High moisture content
3. High proportion of organic matter
4. Lower, recyclable content such as paper, plastics, metals

Figure 5.4.2

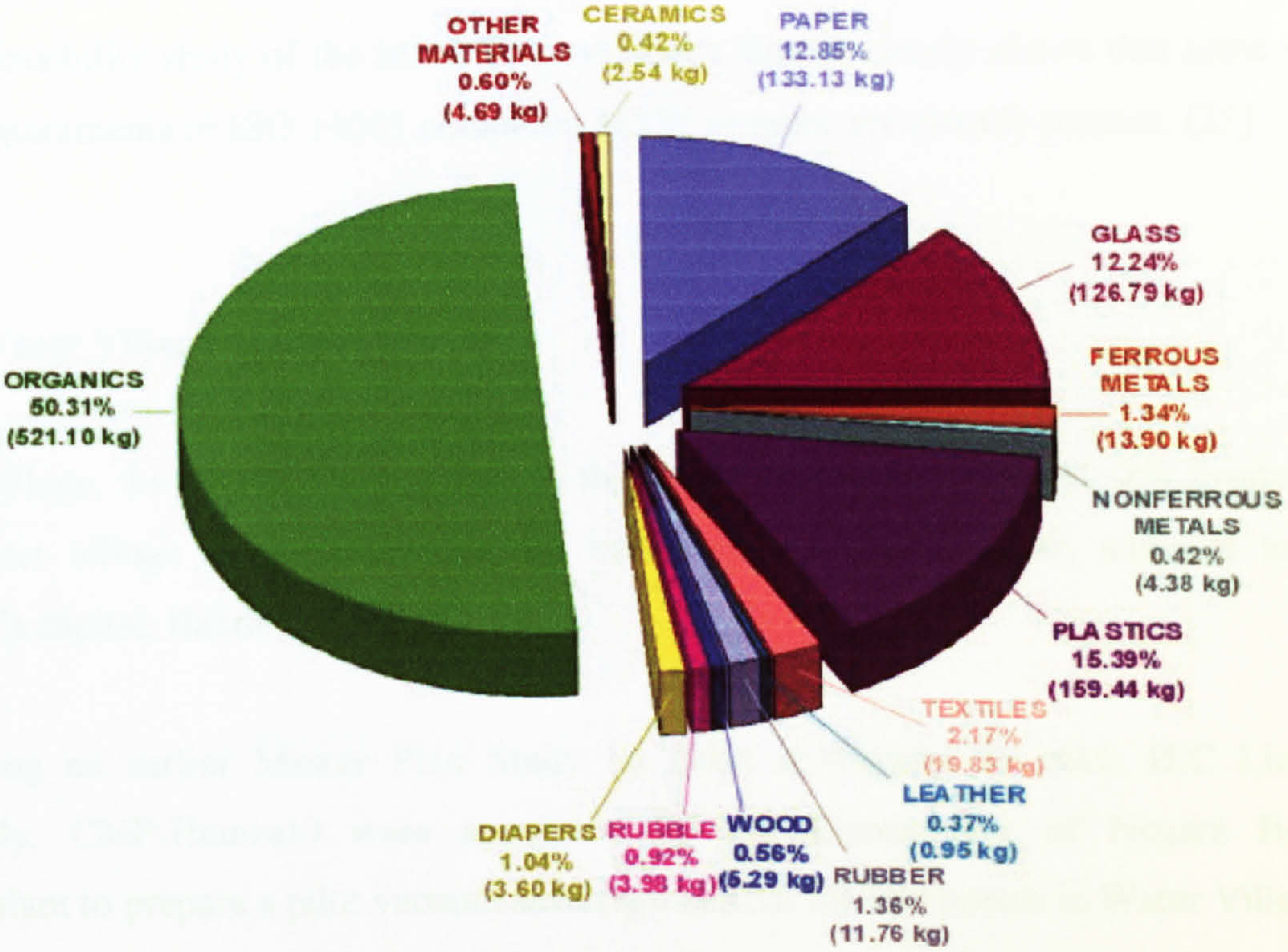


In China, the size of solid waste generated all over China is enormous not only in terms of amount, but also in terms of types. They have complicated characters and cause serious pollution. According to statistics, in 1993 [22] the total generation of industrial solid waste (not including the township enterprises) amounted to 0.62 billion tons. The discharge of solid waste amounted to 20 million tons. This includes 10 million tons discharged into rivers and seas. Hazardous waste is 2.44% of the industrial solid waste total. Currently, the storage of the industrial solid waste amounts to 5.92 billion tons, covers 55 hectare of land (including farmland, 3700 hectare). The municipal solid waste increases is 6% - 7% per year. The cleaning and transport of municipal solid waste in 1993 is 120 million tons, 2/3 of the cities is surrounded by municipal solid waste.

As far as Thailand is concerned, Laem Chabang is taken as a case study. The gross composition of kerbside municipal waste (percentage by weight) in Laem Chabang is presented in Figure 5.4.3. The largest fraction of the waste consists of organic matter (50.31%), followed by plastics (15.39%), paper (12.85%) and glass (12.24). In aggregate, these four material classes constitute 90.79% of the total weight, with each of the remaining components individually constituting less than 2%.

Figure 5.4.3.

Gross composition of municipal curb side waste in Laem Chabang, Thailand (percentage by weight) [23]



5.6 ACHIEVEMENTS

Since Brunei Darussalam's Independence in 1984, the Bandar Seri Begawan Municipal Board/Department was placed under the purview of the Ministry of Home Affairs. The fact that Begawan Municipal Board/Department was brought under the second most important ministry shows the importance given by the Government of His Majesty to the Environment Management of the country which has direct influence on its river water quality as rivers are the source of Brunei drinking water.

5.6.1 ISO 14001 accreditation

Although ISO 14001 is meant to be used by business organisations and private firms, it can still be applied to Brunei Darussalam because of the small size of its population (330,700) and relative affluence – one of the top per capita income countries in the world. [24] A feasibility study of the MSW Brunei-Muara district clearly shows that some very basic requirements of ISO 14001 compliant MSW systems are already present. [25]

5.6.2 Water Village vacuum sewerage

Water village, the largest water village in the world, is home to some 30,000 Bruneians. The water village is situated along the banks of the Brunei River, adjacent to the country's capital, Bandar Seri Begawan.

Following an earlier Master Plan Study by Scott & Furphy in 1986, IEC Limited (formally, CMP-Hamzah) were appointed by the Government of Negara Brunei Darussalam to prepare a pilot vacuum sewerage system for 400 homes in Water Village. The resultant design replaced traditional gravity plumbing from conventional WCs installed in each home to a purpose built vacuum chamber constructed in the shallow waters of Brunei River. The systems vacuum chambers are then connected by a series of vacuum sewer mains, suspended beneath the walkways, to a land based collection and forwarding station (Plates 5.3.1 to5.3.2).

A social study to determine the local communities' needs and acceptance to the proposed sewerage scheme formed an integral part of the project. (Figure 5.5 and Plates 5.2 to 5.3).

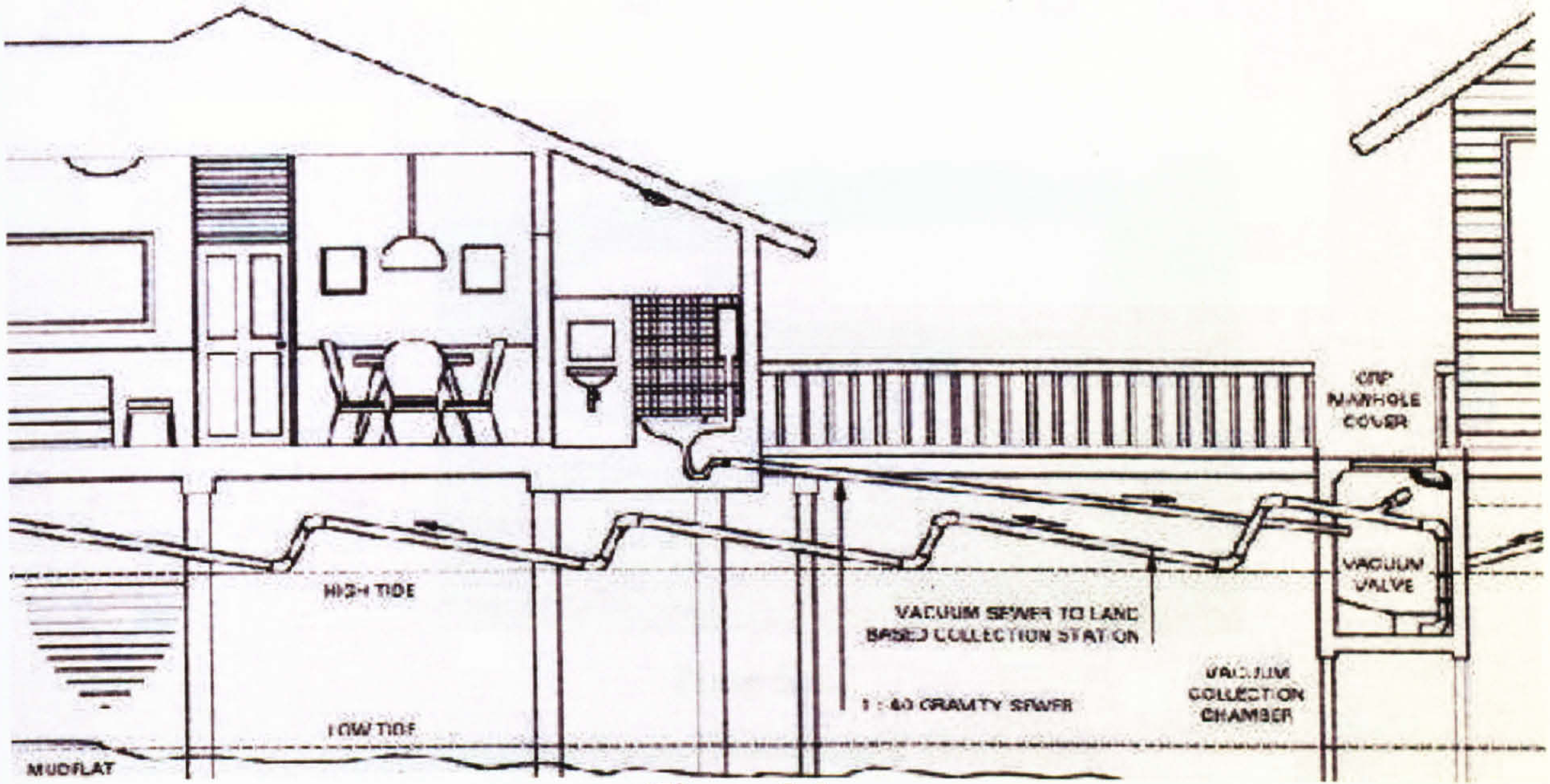


Figure 5.5 –

Kampung Bolkiah A and B Vacuum Sewerage Scheme

Plate 5.2

Gravity Sewer and Vacuum Collection Pot under walkways at Bolkiah "B".

Plate 5.3.1

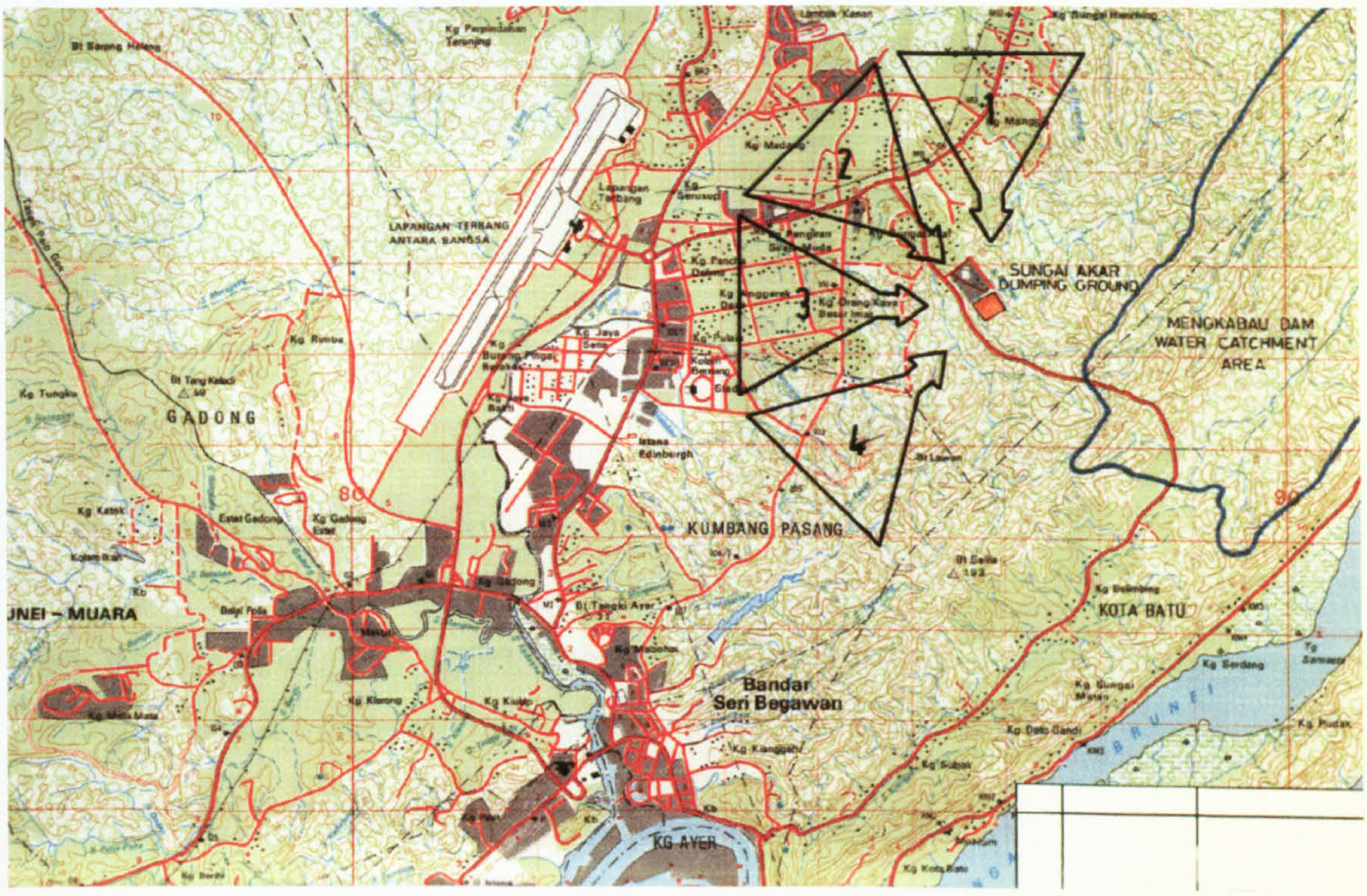
Vacuum Pump Station and Generator Set Building for Bolkiah "B".

Plate 5.3.2

Bolkiah "A" Blower House and Treatment Plant

5.6.3 Location of Landfills

The authorities have been very careful in selecting the location of the landfills by avoiding proximity to settlements and rivers. (Map 5.1 and Plate 5.4)



No.	Wind Direction	Month Active
1	North	Feb,March,Nov,Dec
2	Northwest	Apr,May,June,Oct
3	West	July, Oct
4	Southwest	August

Map 5.1

The Akar River Dumping Ground Wind Directions and Mengkabau Dam Water Catchments Area

Plate 5.4

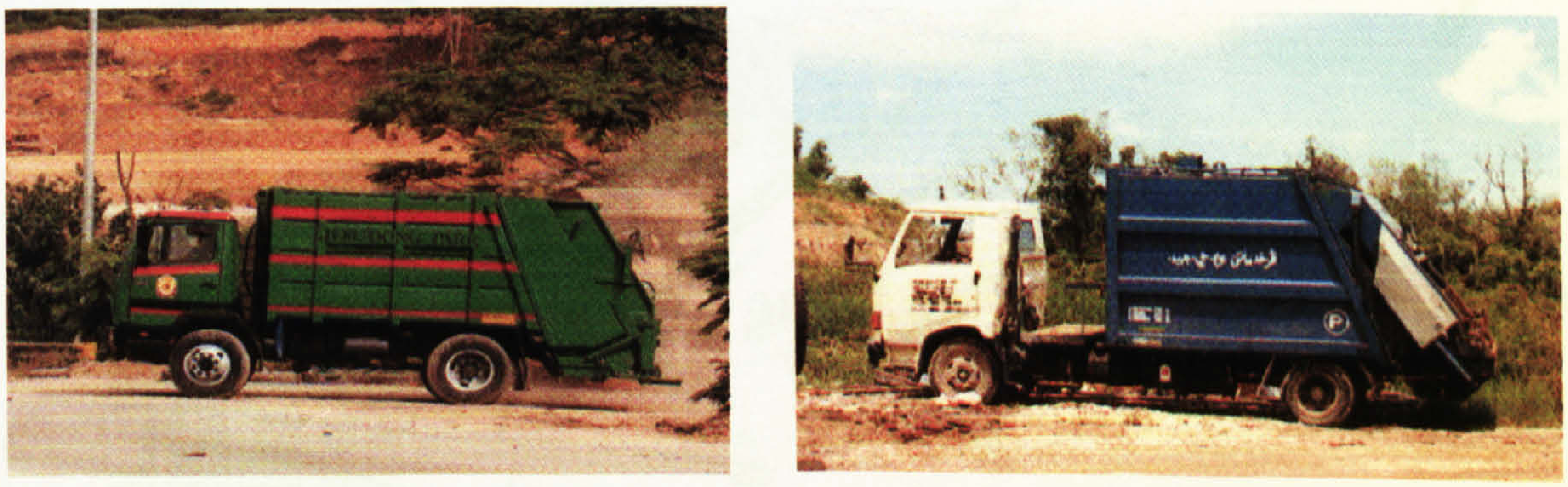
The Akar River Landfill Ground – View from the North East - 1995

The Akar River Landfill Ground – View from the North East - 1996

5.6.4 Transportation of MSW

Very modern trucks and vehicles have been employed to transport MSW from various locations to the landfills areas. (Plate 5.5).

Plate 5.5

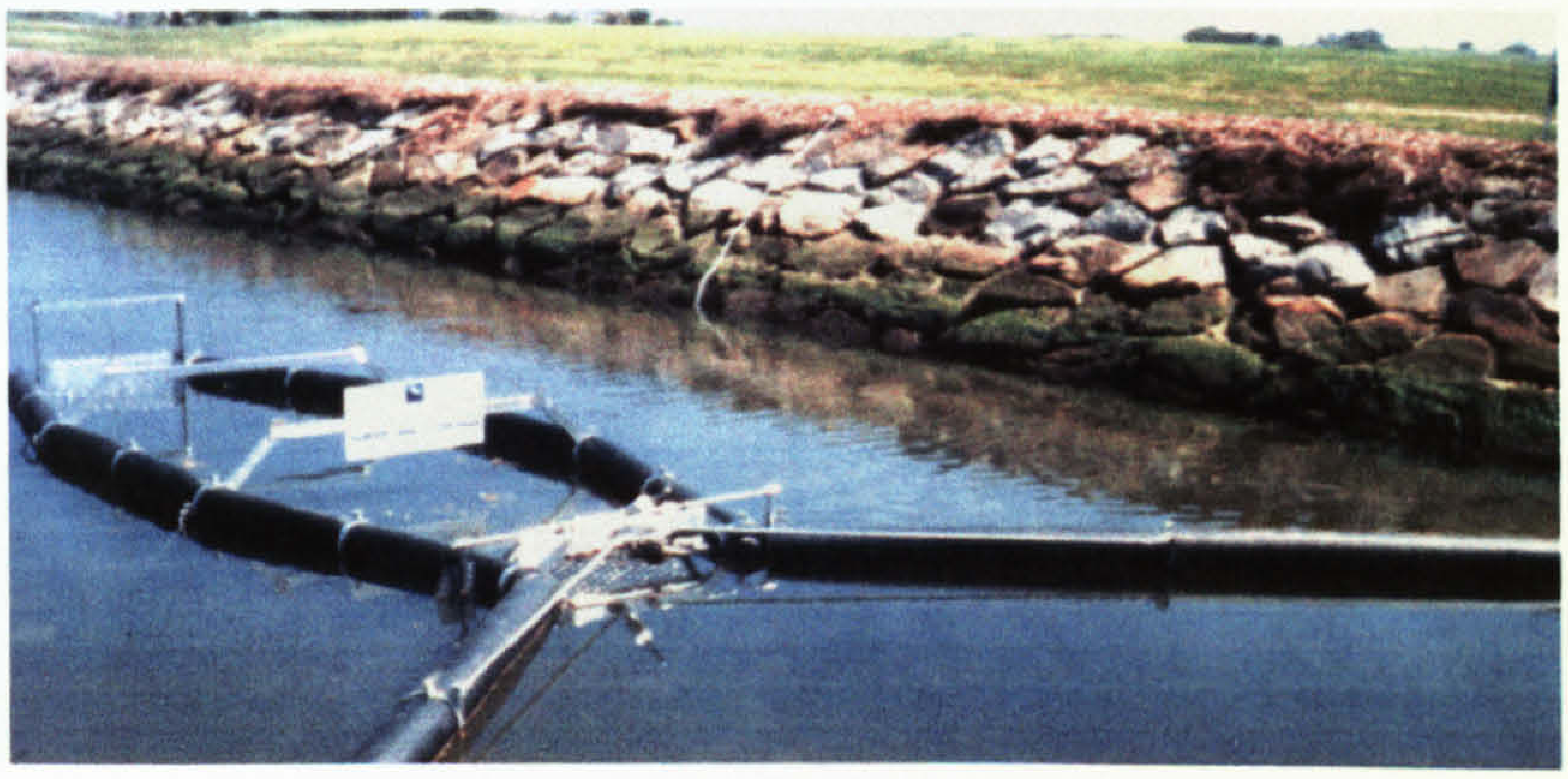


5.6.5 New approach to rubbish trap – a cost effective method (Map 5.2, Figure 5.7, Plate 5.6-5.8)

The Water Village presents rubbish trap problem, which is unique because of its water surrounding and the number of age old settlements. This has always been an eyesore to the public and a perennial problem for the government. In his paper currents collection of rubbish at Water Village, the chief technical assistant, Pengiran Haji Ismail bin Pengiran Haji Apong, has presented a very cost effective trap method [24].

Plate 5.6

Current Rubbish Trap by Drainage and District Office



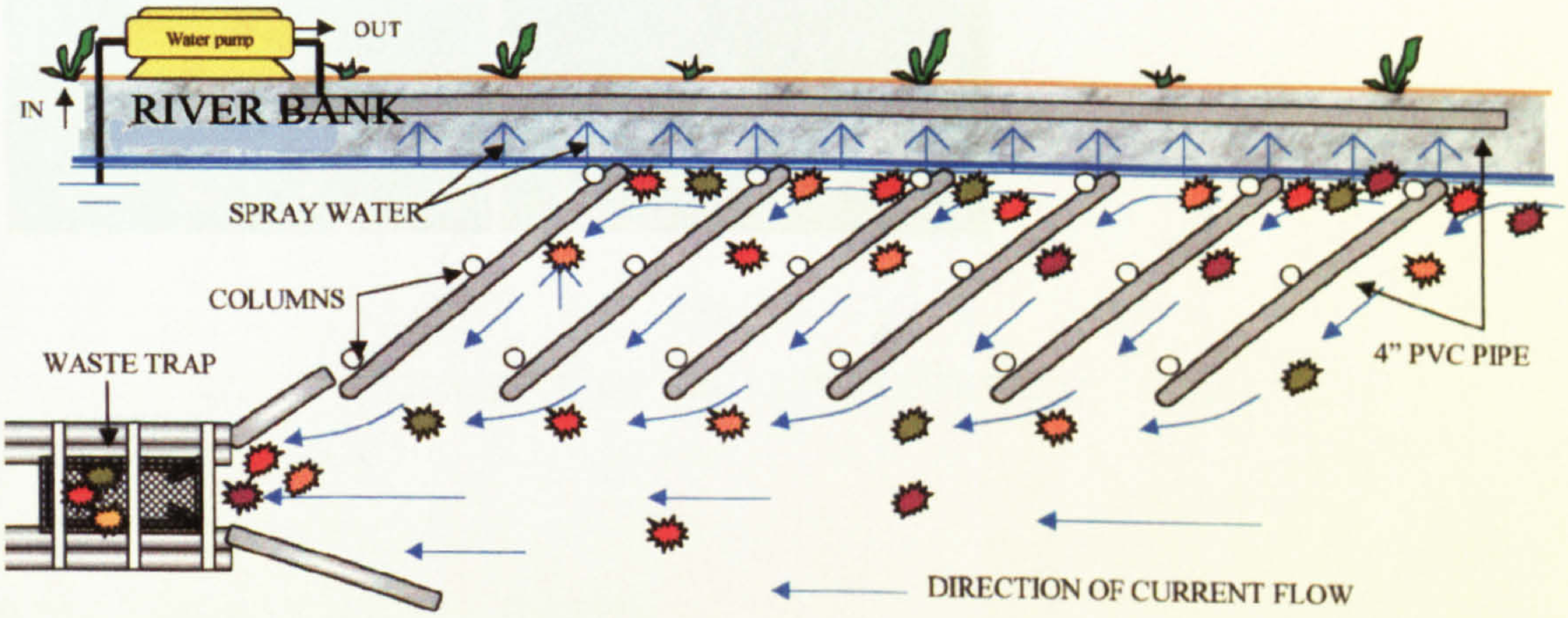


Figure 5.7

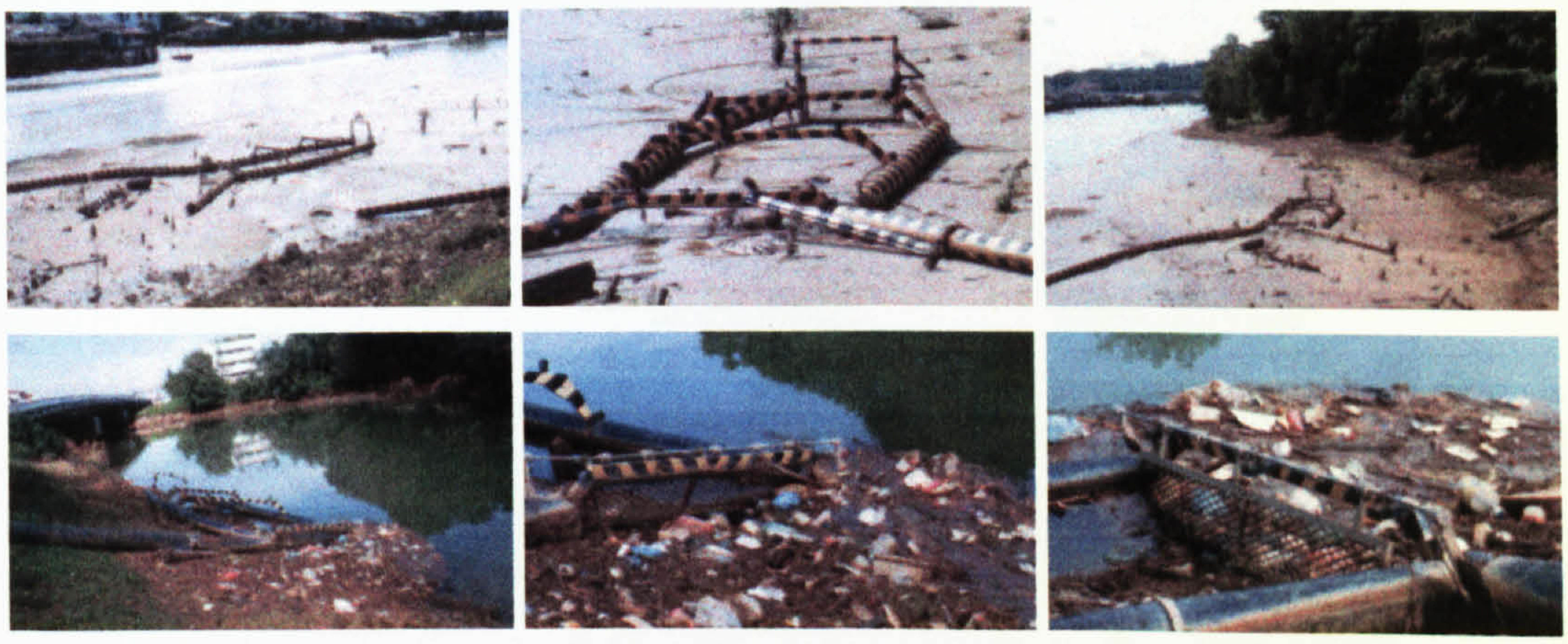
Rubbish Trap Position and Direction of Current Flow during Low Tide Level

Plate 5.7 - Current Problems with Operations and the General Public

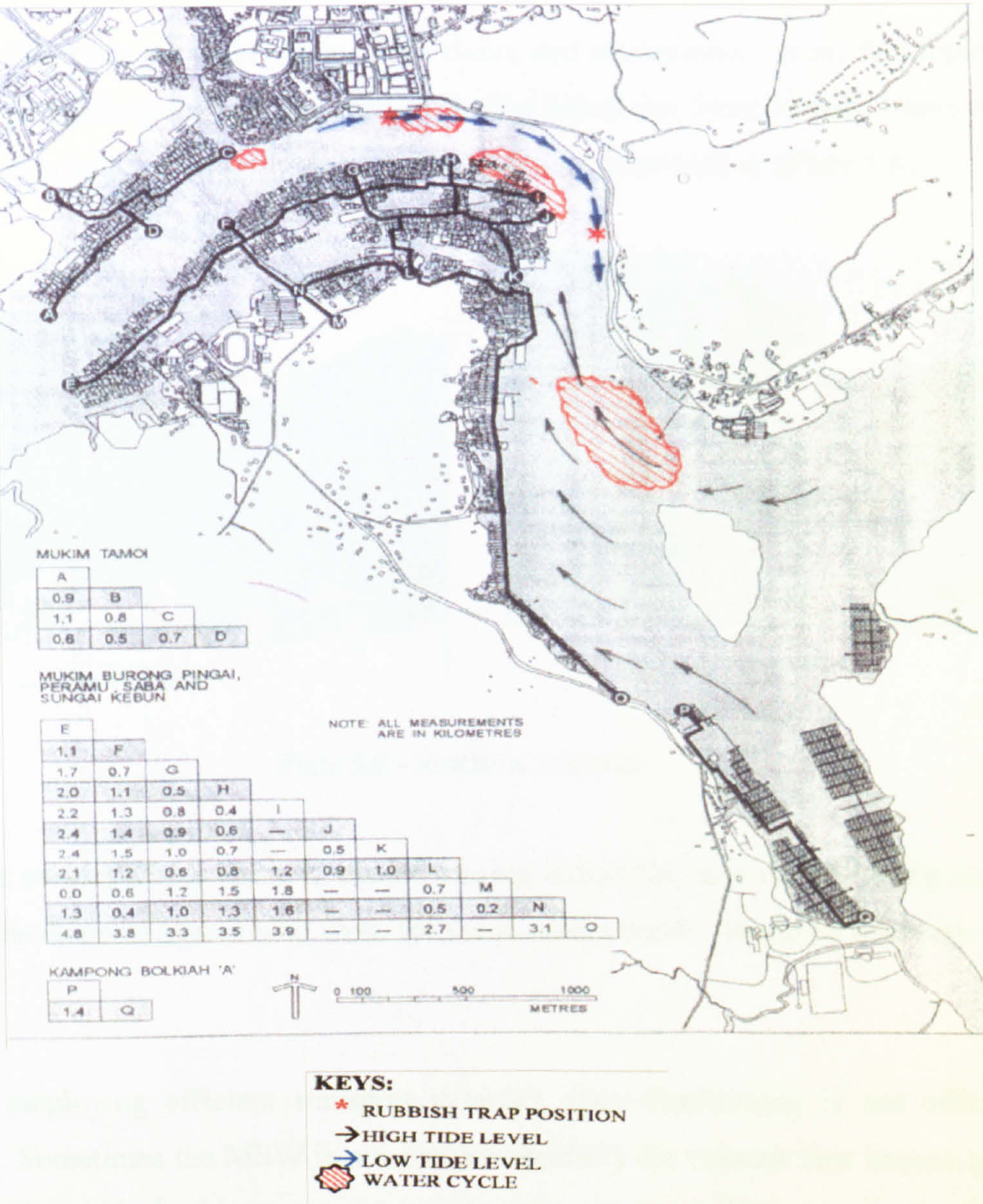
RUBBISH TRAP AT PANTAI SERASA

WRONG ASSASSAMBLE *UNSUCCESSED* *RUBBISH ESCAPE*

RUBBISH TRAP WITHOUT MONITORING



SCHOOL CLEANERS AND STUDENTS THROWING RUBBISH ON RIVER



MUKIM TAMOI

A			
0.9	B		
1.1	0.8	C	
0.6	0.5	0.7	D

MUKIM BURONG PINGAI, PERAMU, SABA AND SUNGAI KEBUN

E										
1.1	F									
1.7	0.7	G								
2.0	1.1	0.5	H							
2.2	1.3	0.8	0.4	I						
2.4	1.4	0.9	0.6	—	J					
2.4	1.5	1.0	0.7	—	0.5	K				
2.1	1.2	0.6	0.8	1.2	0.9	1.0	L			
0.0	0.6	1.2	1.5	1.8	—	—	0.7	M		
1.3	0.4	1.0	1.3	1.6	—	—	0.5	0.2	N	
4.8	3.8	3.3	3.5	3.9	—	—	2.7	—	3.1	O

KAMPONG BOLKIAH 'A'

P	
1.4	Q

Map 5.2

Current Rubbish Flow at Brunei River

5.7 PROBLEMS AND CHALLENGES

The report mentioned earlier in this chapter [25] shows that neither legal framework nor environmental policy has been formulated although awareness among government sectors and the general public in terms of health risk and water pollution is obvious.

Although landfill areas are safely away from rivers and settlements, recent development in industries, particularly the garment manufacturing industries, have brought heavy load of MSW which is dumped wrongly again to problems not seen before. (Plate 5.8)

Plate 5.8 - Roadside Disposal

Although the owners of the garment manufacturing industries have denied doing so, the culprits are the disposal agents who work for them, so the blame should be borne by both parties.

In spite of employing efficient transport vehicles, their functioning is not efficient. (Figure 5.8) Sometimes the MSW is not cleared regularly for reasons best known to the contractors who shift the blame on the people who are not willing to pay for MSW disposal [26]. This leaves the disposal contractors at a loss. People say the cost is high (B$15.00 per month per house), thus accusation and counter accusation leave certain areas of settlements very untidy and unhealthy. The government must step in and make the necessary legislation in Singapore, making payment for rubbish collection mandatory.

Rag mountain defiles Sg Akar

By Anwar Ismail & Sue

A MOUNTAIN of stinking, soggy textile waste left unattended and undisposed for almost a year continues to pollute the otherwise serene Kg Sg Akar neighbourhood.

Residents who have to bear up with the rotten odour day in and day out are furious, but nothing is being done so far to remedy their grievances.

"This mountain of textile garbage is an outrage. It not only pollutes the air, especially after rainfall. It's a hideous sight and does not speak well for the nation's own drive towards a clean and green environment," said one of the residents.

The Weekend received several complaints from disgruntled citizens about this unscrupulous dumping of industrial waste. The Weekend visited the site located in a residential area in Kg Sg Akar.

One could not miss this mountain of rag clothes. Millions of pieces of textile waste, rendered putrid and soggy being exposed to the elements, emanated a very damp and foul smell. It was a disgusting sight too as most of it was rotting.

"The waste has been left here for about a year now, and hardly anything has been done to remove it," said a person living nearby.

At first plastic sheets was put to cover everything but after some time the sheeting had decomposed exposing everything under it.

Residents blamed some irresponsible industrialists for dumping the waste.

But most of the garment factories who were contacted denied, saying that they disposed their waste properly.

It is learnt that the waste came from one of the troubled garment factories that closed down. According to sources they may have had problems disposing their waste.

A neighbour who is also living nearby said that the large pile of waste could also be a fire hazard especially during a long period of hot weather. Another claimed that it has become a breeding ground for snakes and other reptiles.

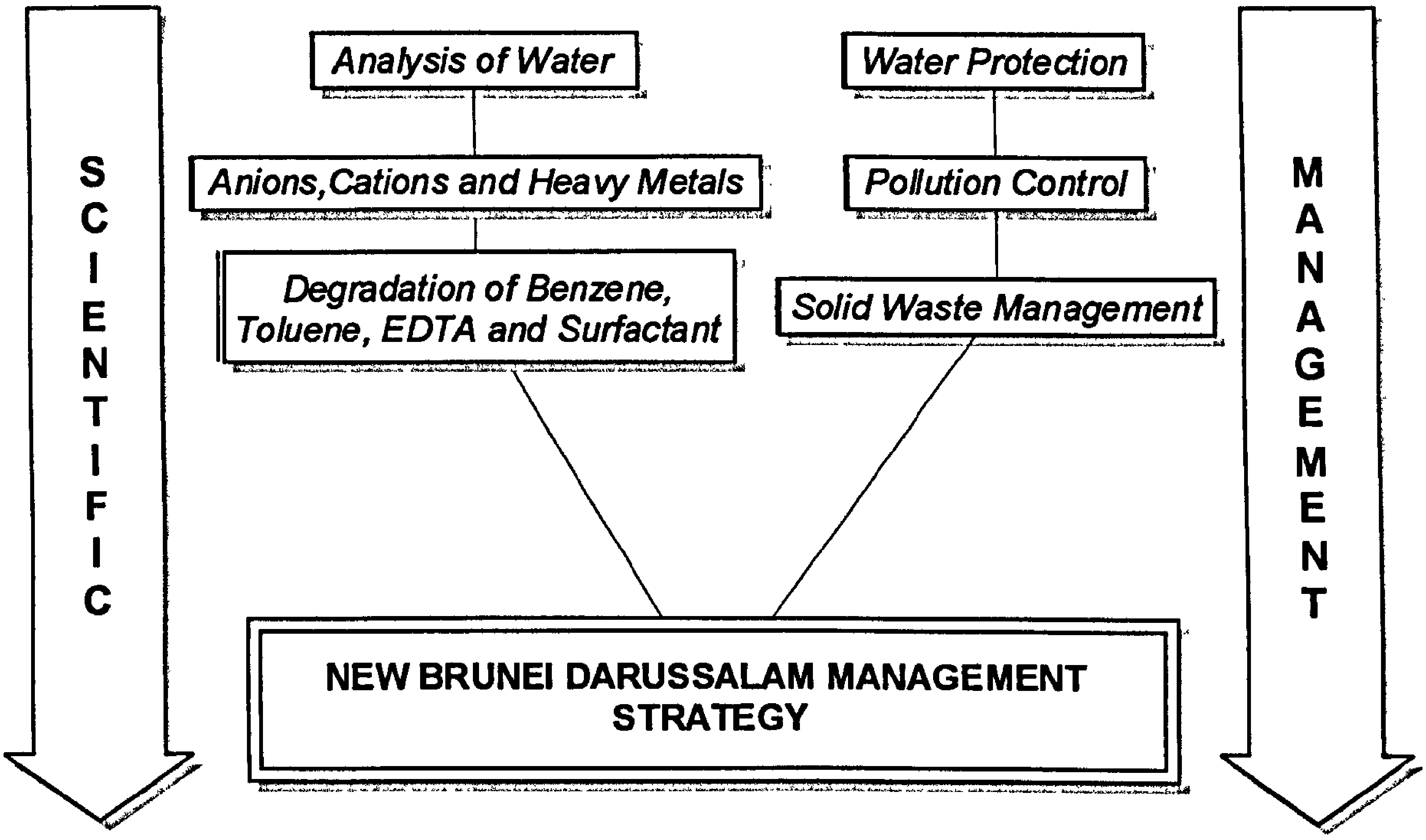
Textile waste that has become a stinking mountain of mould. *Photo: Anwar Ismail*

Figure 5.8

Borneo Bulletin - Saturday 14 December 2002

Textile waste that has become a stinking mountain of mould at akar River landfill.

Figure 5.9


SCIENTIFIC
Analysis of Water
Anions,Cations and Heavy Metals
Degradation of Benzene, Toluene, EDTA and Surfactant
Water Protection
Pollution Control
Solid Waste Management
MANAGEMENT
NEW BRUNEI DARUSSALAM MANAGEMENT STRATEGY

5.8 CONCLUSION

To maximise the effective preservation of high quality waters in Brunei Darussalam, the following management system is suggested as a mean of administration management system.

EFFICIENT WATER MANAGEMENT STRATEGY

ADMINISTRATIVE	SCIENTIFIC	EDUCATIONAL
• To separate the water board from the existing water and drainage board.	• A new culture of Research and Development (R&D) must be the guiding spirit of the Department of Water Management (DWM).	• To set up Public Education Unit on a level that is dynamic and attractive. • To design water safety and quality information activities, educative and entertaining.
• To establish an autonomous Department of Water Management (DWM).	• To setup sufficient laboratory facilities to undertake extensive research on water quality and safety.	• To target common public on national level to impart knowledge about water safety and quality.
• To create the post of a Permanent Secretary with ministerial powers.	• To interact with the Ministry of Health in setting standards for water quality and safety.	• To target educational institutions as the focal point to communicate how nation's water resources are to respected and protected.

- To divide the (DWM) into ancillary Units such as: a. River Management unit b. Rainfall Catchments unit c. Ground water control unit d. Water safety unit e. Water quality enforcement section f. Research and analysis wing	- To establish Regional & International cooperation. a. To seek assistance from the Environmental Protection Agency (EPA-USA) b. To consult the WHO for water safety levels and use their expertise and personnel c. To seek regional collaboration with bodies such ASEAN and ASEAN-EC bodies d. To identify probable new sources of water pollution and get ready for any eventualities.	- To target construction industries as probable polluters and approach information supply more as a legally binding advice rather than just information or education. - To encourage to them come with posters and hand-outs to be distributed to the public and exempt their expenditure for tax purposes. - To hold poster drawing competitions and award Prizes in primary and secondary schools to encourage early awareness.
- To appoint a Director and a Deputy Director for each of the above units.	- To setup lightning task force to face any unforeseen eventualities like industrial accidents that may harm Brunei waterways.	- To hold essay writing competitions in institutions of higher learning and award Merit certificates.

• To provide liberal budgetary concession suitable to the growing needs of the Department of Water Management (DWM).	• To establish special unit to interact with oil and natural gas based companies eg. SHELL, TOTAL & ELF to advise on water safety measures. • To lay strict guidelines for automobile workshops in disposing used oil and other oil based products.	• To organize national level debates on the Radio Television Brunei (RTB) the official channel of Brunei to kindle nationwide awareness.
• To declare all water resources as National Endowments. a. to declare any act of water pollution as an act of statutory offence b. to prosecute individual offenders with severe penalties and imprisonment and huge fines for corporate sectors. c. to make water usage more frugal, and usage -based pricing should enforce. d. the more the usage the higher the price rule should be enforced	• To keep track of all agricultural activities and increasing the use fertilizers, insecticides, pesticides etc. • To set up separate unit for household hold based or small agricultural activities and their use of chemicals. • To set up another unit for professional agricultural activities and their use of chemicals. • To ban the use of chemicals that may harm water quality and safety levels if they seep into underground water-tables or if they run off into the rivers.	• To set up toll free hotline to receive any complaints from duty-conscious citizens about potential dangers to the water sources of the nation. • To setup a unit to pass on the information to the Enforcement Unit for immediate action.

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