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# **REMOVAL OF HEAVY METALS BY SLOW SAND FILTRATION**

**By**

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DEDICATED  
TO  
MY PARENTS  
AND  
PARENTS IN LAW

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## ABSTRACT

Slow sand filters (SSFs) are probably the most effective, simplest and least expensive water treatment process. Micro-organisms and other particulate materials are effectively removed by SSFs. Considerable development has been done on SSFs with respect to particle removal, but only a few works have been reported in the context of the removal of heavy metals which are a severely toxic pollutant of surface waters. No extensive laboratory or pilot studies have been carried out to determine the performance or the mechanisms of removal of heavy metals by SSFs. This research is concerned with an experimental investigation of the removal of heavy metals from surface water by SSFs.

Four laboratory scale SSFs were built and run according to standard design criteria. Removal of four common heavy metals [copper (Cu), chromium (Cr), lead (Pb) and cadmium (Cd)] were monitored. The filters were fed synthetic water made from tap water mixed with settled sewage, and each filter was dosed with one of the heavy metal salts. The concentrations of Cu, Cr, Pb and Cd in the influent were selected as 10 mg/l, 100 µg/l, 60 µg/l, and 100 µg/l respectively considering their relative toxicity and WHO guidelines in drinking water. Settled sewage was added to vary the total organic carbon (TOC) of the feed water. The reduction of heavy metal concentrations were monitored at various TOCs, filtration rates and filter bed depths. The results showed that SSFs succeeded in removing heavy metals from water. The removals of Cu, Cr, Pb and Cd at the conventional flow rate and filter depth are 99.6, 97.2, 100 and 96.6 % respectively. The results also showed that an increase in TOC in the feed water improved metal removal while increases of flow rates caused a decrease of the removal of metals. The removal of heavy metals also decreased with a reduction in sand bed depth.

The optimisation of design parameters for SSFs for the removal of heavy metals depends on the individual heavy metal and on the TOC content of the feed water. Model equations were developed for, and linear correlation was observed between each of the three control parameters and the removal of the selected metal. The removal of heavy metal by SSFs was achieved through the combination of a number of mechanisms. Settlement, adsorption to both sand and organic matter and microbial

uptake were found to be the main mechanisms of removal. Batch tests were carried out to investigate these mechanisms. Speciation of heavy metals in the SSF bed was also carried out to further investigate the mechanisms of removal and to find their relative importance. The results showed that apart from the previously mentioned mechanisms, a small portion of heavy metals was removed through the formation of metal sulphide and it is postulated that these compounds are formed from the presence of sulphur compounds in the feed water.

The relative importance varied with the individual heavy metals and depth of the filter bed. Adsorption of heavy metals at the top of the filter bed onto organic matter was found to be the most significant mechanism. The other mechanisms mentioned above are associated with the removal of heavy metals but are relatively less significant.



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Table 11.1 Optimised parameters of SSF for the removal of selected heavy metals to meet the WHO standards of drinking water.

## LIST OF SYMBOLS AND ABBREVIATIONS

Ag	: Silver
Al	: Aluminium
As	: Arsenic
Ca	: Calcium
Cd	: Cadmium
Co	: Cobalt
Cr	: Chromium
Cu	: Copper
Hg	: Mercury
Mn	: Manganese
Na	: Sodium
Ni	: Nickel
U	: Uranium
V	: Vanadium
Zn	: Zinc
Ca(OH) <sub>2</sub>	: Calcium Hydroxide
CdS	: Cadmium Sulphide
CdSO <sub>4</sub>	: Cadmium Sulphate
CO <sub>2</sub>	: Carbon Dioxide
Cr(NO <sub>3</sub> ) <sub>3</sub>	: Chromium Nitrate
CrO <sub>4</sub>	: Chromate
Cu(OH) <sub>2</sub>	: Copper Hydroxide
Cu(NO <sub>3</sub> ) <sub>2</sub>	: Copper Nitrate
HCl	: Hydrochloric Acid
HCrO <sub>4</sub>	: Bichromate
HNO <sub>3</sub>	: Nitric Acid
KF	: Potassium Fluoride
KNO <sub>3</sub>	: Potassium Nitrate
NaOH	: Sodium Hydroxide
NH <sub>3</sub>	: Ammonia

NH <sub>4</sub> -N	: Ammonical Nitrogen
Pb(NO <sub>3</sub> ) <sub>2</sub>	: Lead Nitrate
C <sub>e</sub>	: Concentration of adsorbent in solution (µg/l)
g	: Gram
K	: Langmiur Constant (l of adsorbent per µg of adsorbate)
K <sub>f</sub>	: Freundlich Constant
l	: Litre
ln	: Natural Logarithm
mg	: Milligram
n	: Freundlich Exponent
Q <sub>e</sub>	: Adsorption density at the equilibrium solute concentration (µg/g of adsorbent)
µg	: Microgram
AOC	: Assimilable Organic Carbon
ATP	: Adenosine Triphosphate
AWWA	: American Water Works Association
APHA	: American Public Health Association
CIRIA	: Construction Industries Research Information Association
COD	: Chemical Oxygen Demand
ES	: Effective Size
FC	: Faecal Coliform
GAC	: Granular Activated Carbon
ICP	: Inductively Coupled Plasma
IRC	: International Reference Centre
NEERI	: National Environmental Engineering Research Institute (India)
NTU	: Naphelometric Turbidity Unit
SSFs	: Slow Sand Filters
TOC	: Total Organic Carbon
WHO	: World Health Organisation

# CHAPTER 1

## INTRODUCTION

### 1.1 BACKGROUND TO THE STUDY

Water is essential to life, and as some water pollution can have serious health effects (particularly if the pollution contains pathogenic materials) considerable effort is put into wastewater treatment. There are a number of possible sources of wastewaters. These include domestic sewage, industrial wastewaters, agricultural run-off, and storm water run-off. However, the most complex pollution is from industrial wastewaters which include many chemical contaminants and heavy metals. Heavy metals are present in abundance naturally and enter the water cycle through a variety of geochemical processes. Many metals are also added to water by man-induced activities such as manufacturing, construction, agriculture and transportation. High concentrations of heavy metals in water supplies are undesirable because of the potential adverse effects on health, environmental toxicity, corrosion of pipeworks and the aesthetic quality of the water environment.

The most toxic metals are arsenic (As), copper (Cu), cadmium (Cd), lead (Pb) and mercury (Hg). They are used in many industrial processing and manufacturing processes. Significant concentrations of these metals are present in solid wastes, municipal sewage sludges and landfill leachate (Pradhan and Levine, 1992 and Marquis *et al*, 1976). Disposal of untreated wastes, surface run off and highway run off can cause extreme pollution of surface water. Percolation of leachate through the ground also causes pollution of ground water. These heavy metals are very toxic to human beings. Muscular and cardiovascular disorders, brain, liver and kidney damage are all caused by heavy metals in water (Sawyer and McCarty, 1987). The research reported in this volume concentrates on four of the more serious metal pollutants, which occur particularly often; namely copper, chromium, lead and cadmium.



Various processes can be employed to remove heavy metals from waste streams. There are two points which always concern water pollution control experts, the first one is the cost of any treatment system and the second one considers environmental problems including operation and disposal. Research work is going on in different countries in various situations to find the probable mechanisms of toxicity as well as suitable technology for the removal of heavy metals from water. Metal uptake by microorganisms, development of biomass, adsorption by activated carbon, coal and peat, the use of chemical pretreatment and sand filtration have been proved effective to some extent in removing heavy metals from water. Details of the work done in this context are included in a detailed literature review (Chapter 2). However, although much effort has been given to finding suitable technologies for removing heavy metals from water, very little has been done in this context on the extent of removal by conventional water treatment. There is a need to develop low-cost treatment technologies for the removal of heavy metals in developing countries. The application of low-cost natural materials for the removal of heavy metals have been tried by many researchers. Some of the natural materials are effective but expensive. Some of them are cheap but not effective. Adsorption by activated carbon is one of the methods that can be used for the removal of heavy metals, especially when the metals are in low concentration. But the regeneration of the activated carbon is very expensive. A considerable amount of development has recently been done on slow sand filtration with respect to particle removal, but only a few works have been reported in the context of heavy metals removal. The published results are taken from the experience of different water works where there is little control of other variables. Virtually no extensive pilot study has been carried out to find the mechanisms and efficiency of slow sand filtration in removing heavy metals and the influence of process variables has not been evaluated. This study investigates the removal of heavy metals by slow sand filtration and evaluates the influence of process variables and the mechanisms of removal.

## **1.2 OBJECTIVES OF THE STUDY**

### **a) To investigate whether heavy metals are removed by SSFs**

Filters were initially run at conventional flow rate, bed depth and typical river water TOC to investigate whether SSF could remove heavy metals.

### **b) To investigate the effect of heavy metals on the removal of other pollutants**

As SSF is largely biological process, the presence of heavy metals may affect the activity of microorganisms which would consequently affect the performance of SSF in removing particulate materials. Hence the performance of SSF fed with heavy metals were monitored and compared with the usual performance of SSF in removing turbidity, faecal coliform and TOC to identify any adverse effects.

### **c) To investigate the optimum filter configuration and composition for enhancing heavy metals removal by SSFs.**

The organic content of the influent water, filter bed depth and flow rate were varied to monitor the effects of those parameters on the removal of heavy metals by SSF. The removal efficiency at various TOC flow rates and filter depths was critically evaluated to optimise those parameters. Model equations were developed relating to the removal efficiency and process variables.

### **d) To evaluate the mechanisms of heavy metal removal by SSF**

The results of the different process variables tests provided the prediction of the probable mechanisms of heavy metal removal. Different batch tests were carried out to confirm these mechanisms. Batch adsorption tests were performed to find the role of adsorption in removing heavy metals. Metal accumulation in the schmutzdecke was monitored and compared with the biomass to identify the effects of microbial uptake of heavy metals. Batch tests for precipitation were also carried out to identify the role of this mechanism.



#### **e) To evaluate the speciation of heavy metals in SSF**

Speciations of heavy metals in the SSF bed were carried out at the end of the research period for further investigation of the mechanisms of removal and also to identify the relative importance of the mechanisms.

The overall aim is to identify the optimum parameters loadings on the SSF for the efficient removal of heavy metals and to evaluate the mechanisms of removal. The work has special importance in developing countries where metal pollution is a major problem for surface water. The work also has relevance to industrial countries where micropollutants from highway runoff are of increasing concern. The work has also importance in treating wastewater containing heavy metals at the tertiary stage of the conventional wastewater treatment processes.

### **1.3 STRUCTURE OF THE THESIS**

Chapter 2 and 3 describe the literature review on various aspects of heavy metals and slow sand filtration respectively. Development of the laboratory scale filter plant and experimental programs are summarised in chapter 4. Chapter 5 describes the experimental results regarding the influences of various process variables on the performance of slow sand filters in removing heavy metals. Chapter 6 summarises the results of the batch adsorption test which has been carried out for the confirmation of the adsorption of heavy metals onto sand. Chapter 7 describes the test results regarding the settlement of heavy metals whereas test results regarding the microbial uptake of heavy metals are summarised in chapter 8. Test results on the speciation of heavy metals in slow sand filter bed are summarised in chapter 9. The overall discussion on the standard design parameters and maintenance are described in chapter 10. Chapter 11 contains the conclusion of the study and recommendations for further study.

#### **1.4 SCIENTIFIC PUBLICATIONS RELATED TO THIS STUDY.**

As a result of this research, two papers are published, one paper is to be published and one is submitted for publication. The papers are described in this section.

1. Muhammad, N., Parr, J., Smith, M. D. and Wheatley, A. D. (1998), Microbial Uptake of Heavy Metals in Slow Sand Filters, *Environmental Technology*, **19(6)**, 633-638.
2. Muhammad, N., Parr, J., Smith, M. D. and Wheatley, A. D. (1997), Removal of Heavy Metals by Slow Sand Filtration, Proceedings of the 23rd WEDC international Conference, Durban, South Africa, 167-170.
3. Muhammad, N., Parr, J., Smith, M. D. and Wheatley, A. D. (1998), Adsorption of Heavy Metals in Slow Sand Filters, Contained in the Preprint of the 24th WEDC international Conference, Islamabad, Pakistan. (this will be published in conference proceedings in due time)
4. Muhammad, N., Parr, J., Smith, M. D. and Wheatley, A. D. (1998), Optimisation of Slow Sand Filters for the Removal of Heavy Metals, submitted to '*Environmental Technology*' for publication.



## **CHAPTER 2**

### **LITERATURE REVIEW ON HEAVY METALS**

#### **2.1 INTRODUCTION**

Heavy metals are one of the most important pollutants in surface and ground water. Heavy metals are also known as trace metals because of their very low concentration (few ppm or less) in natural water (De,1986). They are of special concern because they are nondegradable and therefore persistent (Namasivayam and Ranganathan,1995). The most common and harmful heavy metals are copper (Cu), lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg), arsenic (As), aluminum (Al), silver (Ag) and zinc (Zn). The first four heavy metals are considered for the proposed project because of their abundance in the surface water in Bangladesh which is the country of origin of the author and hence provides much of the motivation for the research.

#### **2.2 TOXICITY OF HEAVY METALS**

Toxicity of heavy metals may be classified as acute, chronic, synergistic and mutagenic/teratogenic

##### **2.2.1 Acute Toxicity**

Heavy metals in surface water may create acute or chronic poisoning in fish and other aquatic animals and also to human beings. It is usually the ionic forms which produce the immediate fish kills, while component metal compounds tend to act by accumulation in the body tissues over a considerably longer period (Ellis, 1988). Once the sediment of a stream is contaminated by mercury, even without further additions, it might take two or three decades for the stream to recover as the heavy metals are continually recycled through different trophic levels and back into the sediment (WPCF, 1981).



Acute toxic effects show up quickly upon ingestion of, or contact with, metal compounds at certain dosages. Soluble copper causes symptoms of gastroenteritis with nausea. Effects produced by chromium include lung tumors, skin sensitisation and inflammation of the kidneys (WPCF, 1981).

### **2.2.2 Chronic Toxicity**

Chronic poisoning develops as ingestion or contact occurs over a period of time. Some metals, such as cadmium and lead accumulate in body tissues and are not excreted and eventually chronic poisoning is the result (WPCF, 1981)

### **2.2.3 Synergistic Toxicity**

Certain metals are more toxic in combination with other metals or under specific environmental conditions. This effect is described as synergistic. Cadmium toxicity increases in the presence of copper or zinc. Copper and zinc may be more or less toxic depending on other water quality conditions such as pH, temperature, hardness, turbidity and CO<sub>2</sub> content (WPCF, 1981).

### **2.2.4 Mutagenic and Teratogenic Toxicity**

Mutagenic and teratogenic toxicity may result when certain metals combine with other physiologically important messenger organic compounds. The nucleic acids are particularly vulnerable to metal binding. If these substances produce changes in genetic make up, metagenic effects are produced. Changes or development of abnormal tissue development in embryos are called teratogenic effects. Similarly messenger compounds in embryonic development are also vulnerable because of their complexity and low concentrations. At certain dosage levels of heavy metals, carcinogenic (cancer causing) effects have been observed (WPCF, 1981; Manahan, 1990).

### **2.2.5 Other Effects**

Heavy metals may interfere with industrial processes: for example, copper may cause adverse colour reactions in the food industry or may pit aluminium and galvanized steel

(WPCF, 1981; Manahan, 1990). Certain metals, if present in irrigation water, may damage the crops.

Heavy metals are also harmful to the biological degradation process utilised at most municipal wastewater treatment plants. The effect is to decrease the activity of the biological system by the increased concentration of heavy metals. The toxic effects increase at lower pH because of the higher solubility of heavy metals (WPCF, 1981).

## **2.3 GENERAL SOURCES OF HEAVY METALS IN WATER**

The sources of heavy metals in water may be diverse but are commonly considered as being generally associated with industrial discharges (Ellis, 1988). The other sources of heavy metals in surface water are road runoff, aerial deposition, agriculture runoff, acid rain and leachate from dumped sewage sludges (Ellis, 1988; Pradhan and Levine, 1992; Marquis *et al*, 1976; Namasivayam and Ranganathan, 1995)

### **2.3.1 Industrial Sources**

The disposal of industrial wastes is often conducted without critical appraisal of the losses incurred. Usually no consideration is taken with regard to the deleterious environmental impact upon the receiving water body. There are numerous sources of industrial effluents leading to heavy metal enrichment of the aquatic environment. A classic example is the discharge of the catalyst methylated mercury chloride into Minimota Bay (Japan) from a factory manufacturing plastics (Forstner and Wittman, 1983). Contrary to expectations, microorganisms converted the sedimented compound to monomethyl-mercury, which led to an enrichment of this most toxic compound in fish consumed by the human population. The result was an outbreak of an unknown and mysterious, non-infectious illness. This illness was, in effect, mercury poisoning. The major industrial uses of various economically important heavy metals have been compiled in table 2.1



TABLE 2.1:Heavy metals employed in major industries (after Dean *et al*, 1972)

	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Ni	Sn	Zn
Pulp, papermills, paperboard, building paper, board mills		X	X		X		X	X		X
Organic chemicals, petrochemicals	X	X		X	X		X		X	X
Alkalis, chlorine, inorganic chemicals	X	X		X	X		X		X	X
Fertilizers	X	X	X	X	X	X	X	X		X
Petroleum refining	X	X	X	X			X	X		X
Basic steel works foundries	X	X	X	X	X		X	X	X	X
Basic nonferrous metalworks, foundries	X	X	X				X	X		X
Motor vehicles, aircraft-plating, finishing	X	X	X							
Flat glass, cement, asbestos products etc		X								
Textile mill products		X								
Leather tanning, finishing		X								
Steam generation power plants		X								X

A comprehensive investigation was carried out by the New York City Wastewater authorities (Klein *et al*, 1974). Disregarding metal-containing discharges by electroplaters, 13 industrial activities were examined as listed in Table 2.2.

TABLE 2.2: Average metals in industrial wastewaters (after Klein *et al*, 1974)

( All the units are in µg/l )

	Cu	Cr	Ni	Zn	Cd
Meat processing	150	150	70	460	11
Fat rendering	220	210	280	3,890	6
Fish processing	240	230	140	1,590	14
Bakery	150	330	430	280	2
Miscellaneous foods	350	150	110	1,100	6
Brewery	410	60	40	470	5
Soft drinks and flavorings	2,040	180	220	2,990	3
Ice cream	2,700	50	110	780	31
Textile dyeing	37	820	250	500	30
Fur dressing and dyeing	7,040	20,140	740	1,730	115
Miscellaneous chemicals	160	280	100	800	27
Laundry	1,700	1,220	100	1,750	134
Car Wash	180	140	190	920	18



2.3.2 Highway Runoff

Apart from industrial discharge, highway runoff is another major source of heavy metals. Metals contained in highway runoff can be generated from a wide variety of sources. The sources have been divided into four main groups as follows (CIRIA report 142) :

- from the operation and passage of motor vehicles including those arising from abrasion, corrosion and attrition from both vehicles and highway surfaces
- from maintenance operations carried out on roads (e.g. de-icing, defoliation)
- accidental discharges from accidents and spillages
- others from miscellaneous sources e.g. atmospheric deposition, maintenance of vehicles, illegal disposal etc.

Table 2.3 describes the sources of metal pollution in highway runoff and Table 2.4 describes the typical metal contents in de-icing salt.

Table 2.3 describes the sources of metal pollution in highway runoff (CIRIA report 142)

	Traffic	Maintenance	Accidents and spillages	Others
Metals	Pb Zn Ni Cr Cd Cu V	Fe Cu Cr Ni Cd As	Pb Zn Cu Cr Fe	Fe Mn

De-icing salt is another significant source of different heavy metals in highway runoff. Iron is the main contributor of heavy metals in the de-icing salt whereas concentration of other heavy metals like, Zn, Ni, Pb, Cr and Cd are also significant.

Table 2.4 describes the typical metal content in de-icing salt (CIRIA report 142)

Metal	Amount
Iron	1550 µg/g
Nickel	12 µg/g
Lead	8.7 µg/g
Zinc	6 µg/g
Chromium	4.7 µg/g
Cyanide	5.7 µg/g

Considering the wide sources of heavy metals, the typical average concentration of various heavy metals in highway runoff is summarised in Table 5.

Table 2.5 describes the typical total (average) concentration of metals in highway runoff (CIRIA report 142)

Metal	Concentration in runoff
Lead	0.59 µg/l
Zinc	1.2 µg/l
Copper	68 µg/l
Chromium	5-85 µg/l
Cadmium	3 µg/l
Iron	440 µg/l

**2.4 SOURCES AND HARMFUL EFFECTS OF SELECTED HEAVY METALS**

The metals discussed in this section are the ones which have been selected for the test programme, the reason for choosing these metals is given in section 2.1.

**2.4.1 Cadmium**

The sources and harmful effects of Cadmium as summarised by WHO (1993) are described below :

Cadmium is generally associated with the industrial processes of fabrication of alloys and



solder, metal plating as pigment, as stabilisers in plastic materials and in batteries. All zinc ores contain small amounts of cadmium. Cadmium sulphide is often associated with the deposition of sphalerite (zinc sulphite ).The levels of cadmium in public water supplies are normally very low. Drinking water normally contains cadmium concentrations of the order of 1 µg/l or less. Occasionally, levels up to 5 µg/l have been reported and on rare occasions levels up to 10 µg/l have been detected. Surface water that contains more than a few micrograms of cadmium per litre have probably been contaminated by discharge of industrial waste or by leaching from areas of landfill or from soil to which sewage sludge has been added. Higher levels of cadmium in drinking water are associated with plated plumbing fittings, silver-based solders and galvanized iron piping materials. Cadmium could be higher in areas supplied with soft water of low pH, since this would tend to be more corrosive to any plumbing systems containing cadmium.

Cadmium causes an illness called “Itai Itai” disease, characterised by brittle bones and intense pain . It causes high blood pressure, sterility among males, kidney damage and flu-like disorder.

Bronchitis, emphysema, anemia and renal stones have been reported due to cadmium. There is evidence of teratogenic, mutagenic and carcinogenic effects after injection of high doses. The evidence of cadmium being carcinogenic to man is rather weak, although prolonged and heavy industrial exposure may constitute an increased risk of prostate cancer. A guideline value established by WHO is 3 µg/l for drinking water.

#### **2.4.2 Chromium**

The sources and the harmful effects of Chromium as summarised by WHO (1993) are mentioned in the following text :

The major sources of chromium are chrome alloys, chrome plating, oxidizing agents, corrosion inhibitors, manufacture of chromium compounds such as pigments, and in the textile, ceramic, glass and photographic industries.



Total chromium concentrations in drinking water are usually less than 2 µg/l although concentrations as high as 120 µg/l have been reported. Trivalent forms are hydrolysed completely in natural waters and the chromium precipitates as the hydroxide leaving very minor amounts in solution. There is no evidence that the trivalent form is detrimental to human health.

Hexavalent chromium is mainly the result of contamination by industrial emissions. Some contamination arises from the use of sewage sludge added to land. Trivalent and hexavalent chromium occur in biological media, but only the trivalent form is stable, since hexavalent chromium is reduced by a variety of organic species.

There is a tendency for naturally occurring high levels of chromium to be associated with waters of the greatest hardness. The harmful effects of water-borne chromium in man are associated with hexavalent chromium. Trivalent chromium is a chromium regarded as essential for man for the prevention of mild diabetes and atherosclerosis .

Hexavalent chromium at 10 mg/kg of body weight will result in liver neurosis, nephritis and death in man; lower doses will cause gastrointestinal mucosa. Hexavalent chromium in high doses has been implicated as the cause of digestive tract cancers in man. Chromate poisoning causes skin disorders and liver damage. There is firm evidence that there is an increased risk of lung cancer for workers who are exposed to high levels of chromium. Prostate cancer have been reported in workers in chromium-using industries . The WHO guideline for chromium in drinking water is 0.05 mg/l.

### **2.4.3 Copper (Cu)**

Discharges of mine takings and fly-ash are the major sources of solid copper. Other sources of copper include fertiliser production and municipal and industrial sewage (Moore and Ramawoorthy, 1984).

The other major sources of copper are metal cleaning and plating baths and rinses as

brass, boiler pipes, cooking utensils, fertilizer and from copper metal working, which requires periodic oxide removal by immersing the metal in strong acid baths. The concentration of copper in the plating bath depends upon the bath type and may range from 3000 to 50,000 mg/l (Patterson, 1975). Therefore, copper is frequently found in water and wastewater in significant quantities.

Copper is an essential metal in a number of enzymes for all forms of life. Problems arise when it is deficient or in excess. Excess copper accumulates in the liver. Its toxicity is highly pH dependent and it has been reported to be more toxic in fish at lower pH values (Sharma *et al*, 1992).

Epidemiological evidence, such as a high incidence of cancer among coppersmiths, suggests a primary carcinogenic role for copper (Lucky and Vanugopal, 1977). The carcinogenic character of copper is accepted. A higher incidence of stomach cancer in humans has been found in regions where the Zn:Cu ratio in the soil exceeded certain limits (Lucky and Vanugopal, 1977).

There is no evidence to indicate that copper is detrimental to public health at levels which are aesthetically acceptable. Copper is toxic to aquatic plants at concentrations below 1 mg/l. A concentration near 1 mg/l is toxic to fish (Sawyer and McCarty, 1987).

WHO (1993) suggests that the results of mutagenicity for Cu are inconclusive and there is no evidence of Cu being carcinogenic. The WHO guidelines for Cu in drinking water is 2 mg/l.

#### **2.4.4 Lead**

The general sources and the harmful effects of lead as summarised by WHO(1993) are described below :

Lead in the environment exists naturally almost entirely in the inorganic form, but small amounts of organic lead result from the use of leaded gasoline and from natural alkylation



processes that produce methyl lead compounds. The major sources of lead are from the manufacture of acid accumulators, alkyl lead compounds for gasoline, solder, pigments, ammunition, cable sheathing and pipe works. The natural lead content of lake and river water worldwide has been estimated as 1-10 µg/l, although higher values have been recorded where contamination has occurred, particularly from industrial sources. The levels in drinking water, however, can be much higher owing to the use of lead service pipes running from streets to dwellings, from lead plumbing and/or lead lined storage tanks. Particularly high levels can result when the water is aggressive, soft or has a low pH.

Lead has been identified as being a cause of brain and kidney damage. In children it may result in mental retardation. Lead in high doses has been recognised for centuries as a cumulative general metabolic poison. Some of the symptoms of acute poisoning are tiredness, lassitude, slight abdominal discomfort, irritability, anemia and, in the case of children, behavioral changes. Significantly higher lead blood levels have been found in mentally retarded children. Lead has a tendency to bind to mitochondria, leading to interference in the regulation of oxygen transport and energy generation.

Lead resembles the divalent alkaline earth group metals in chemical behavior more than its own group IVA metals. It differs from the group IIA metals in the poor solubility of lead salts such as hydroxides, sulphates, halides and phosphates. Metabolism of Pb and Ca are similar both in their deposition in and mobilisation from bone. Since Pb can remain immobilised for years, metabolic disturbances can remain undetected. The WHO guideline for Pb in drinking water is 0.01 mg/l.

## **2.5 CATASTROPHIC EPISODES OF METAL POISONING**

### **2.5.1 Cadmium Poisoning**

Mercury is regarded as the most toxic metal, followed by cadmium, lead and others although there is no rigid order of toxicity. The most catastrophic poisoning of cadmium



occurred in Japan in 1947 when an unusual and painful disease of a 'rheumatic nature' which caused 44 deaths from a village on the banks of the Jintsu River (Friberg *et al*, 1974). Subsequent investigation found that the disease was due to the cadmium pollution. The disease became known as the 'itai-itai' disease in accordance with the patients shrieks resulting from painful skeletal deformities (Forstner and Wittman, 1983). It was estimated that approximately 100 deaths occurred due to the disease until the end of 1965. The incubation period of cadmium poisoning is usually between 5 and 10 years but in some cases up to 30 years (Forstner and Wittman, 1983).

### **2.5.2 Lead Poisoning**

Causes of acute lead poisoning are not frequently encountered but do occasionally occur as illustrated from the following example in 1969. A British military unit stationed in Hong Kong was overtaken by acute lead poisoning and suffered from acute vomiting, intestinal cramps, and circulatory disorders. The source was traced to lead chromate, which had been used to improve the coloration of curry powder (Forstner and Wittman, 1983).

One of the most common consequences of long-term lead poisoning is chronic kidney infection, known as nephritis. During 1929 a physician in Australia became aware of the high incidence of nephritis and early death in Queensland. Investigation revealed that especially children drank rainwater collected from house roofs protected by a lead pigmented pane. In 1954 it was subsequently established that of 352 adults in Queensland who had had childhood lead poisoning, 15 to 40 years earlier, 164 had died and 94 of chronic nephritis (Chisolom, 1971).

### **2.5.3 Chromium Poisoning**

The most fatal chromium poisoning occurred in Japan in 1960 when an epidemic of lung cancer occurred in chromium factory workers due to Cr(VI) poisoning. Due to this incident 30 people died and over 200 were incurable (Forstner and Wittman, 1983).

## 2.6 MECHANISMS OF HEAVY METALS REMOVAL

A number of specialist processes have been developed for the removal of heavy metals from water and wastewater. These include: chemical precipitation, ion exchange, reverse osmosis, adsorption, biological operation, and filtration. Many of them have not yet been successfully implemented on a full scale basis. Chemical precipitation is a widely used method where product recovery from the waste stream is not sought.

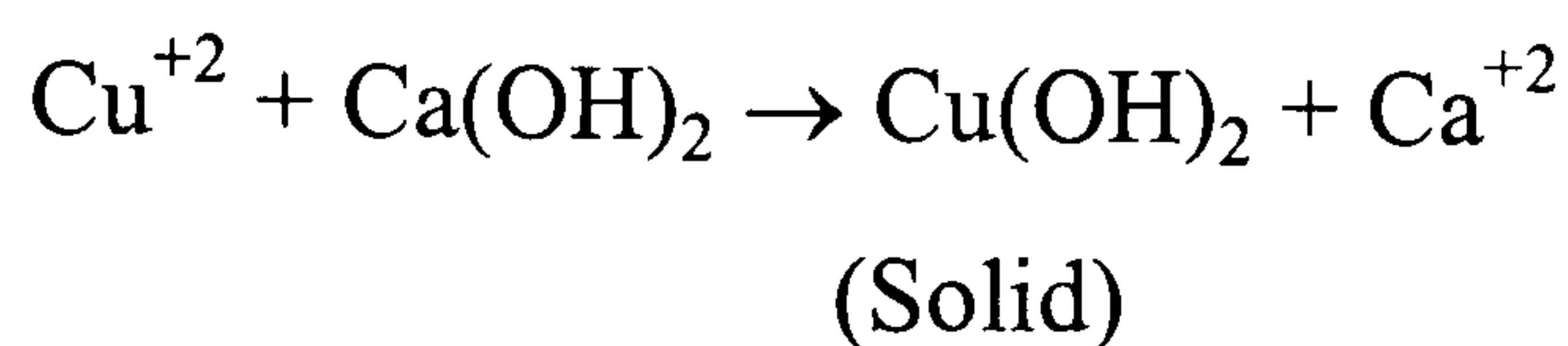
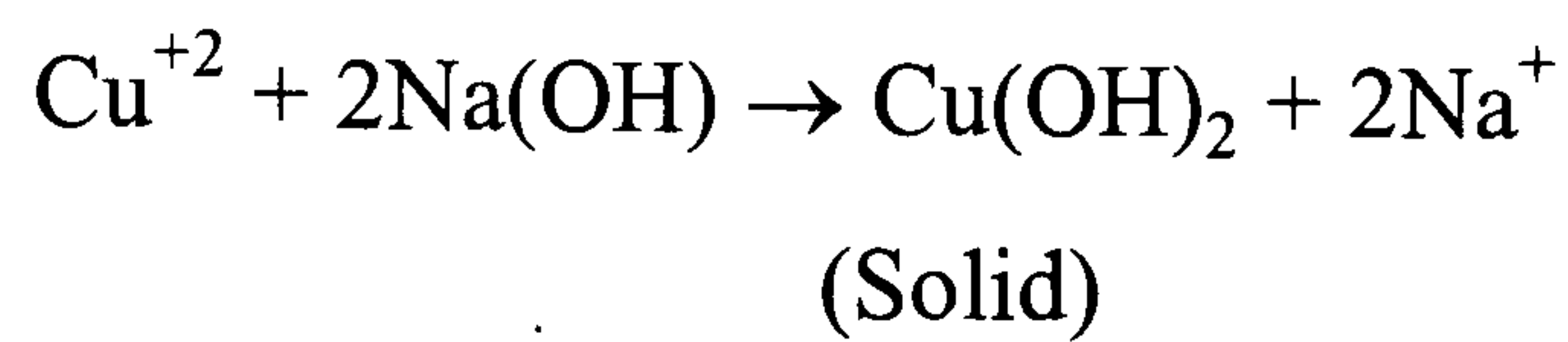
### 2.6.1 Chemical Precipitation

The conventional method of removing heavy metals is chemical precipitation of the metal as a hydroxide, carbonates or sulphides followed by coagulation of the metal particles, which are then separated from water (Metcalf and Eddy, 1991; Benjamin *et al*, 1996). This established method has proved reliable but is very expensive (Namasivayam and Ranganathan, 1995).

Generally hydroxide precipitation involves sodium hydroxide or the significantly cheaper potassium hydroxide. In the presence of high sulphate, considerable calcium sulphate precipitate may form and recovery value of the sludge may dictate use of a more expensive base to obtain purer sludge. Lead has a minimum solubility at about pH 10 with respect to the hydroxide and pH 8-10 with respect to carbonate species. In the precipitation process, lead is normally precipitated as the carbonate,  $\text{PbCO}_3$  or hydroxide,  $\text{Pb(OH)}_2$  (Ho, 1993).



Usually heavy metals are dissolved under acidic conditions and precipitated under alkaline conditions. Thus increasing the pH of a metal containing solution to the alkaline pH range should induce the previously dissolved metal to precipitate. The pH is increased by the addition of a base such as NaOH, Ca(OH)<sub>2</sub> to provide the hydroxide ions to form solid precipitate. For example, with copper:



The pH at which a particular metal is least soluble is a characteristic of that metal. The pH also varies depending on the other components and conditions in the solution. For example, copper is least soluble at pH 8.9 and if mixed with others it becomes least soluble at 9.5. For choosing the right pH, it is better to carry out a jar test. Polymer is sometimes used for the rapid formation of settleable flocs. Addition of polymers is also an expensive and pH dependent method (WPCF, 1981).

Nilson (1971) reported chemical treatment of a waste water by aluminum sulphate and calcium hydroxide to reduce Pb(II), Cu(II), Cr(III), Hg(II), Cd(II) and As(V) to low levels by both precipitants. Zn(II), Ni(II) and Co(II) are precipitated only at pH ≥ 9.5, while Cu(II) and Pb(II) precipitation is greatly inhibited by the presence of nitriotriacetate at pH ≥ 9. Maruyama et al (1975) reported that the removal of Cu(II), Ni(II) and Pb(II) were higher than 90% using a lime system. They also reported sulphide precipitation using calcium sulphide slurry for clean up of Cd, Cu, Pb, Ag and Zn from wastewater.

Lime is the most frequently used base, primarily due to its lower cost relative to sodium hydroxide and sodium carbonate. The problem of using lime is the production of large volumes of sludge. Metals normally removed by hydroxide and carbonate precipitation will remain soluble if strong complexation agents like NH<sub>3</sub>, CN and organics prevent precipitation thus severely reducing the treatment efficiency.

If the lime treatment does not remove all the metals, the removal is aided by the addition of sulphide as most of the heavy metals are sulphide seekers (Manahan, 1990).



According to Benjamin *et al* (1996) the approach of chemical precipitation has several limitations. The limitations are :

- precipitation becomes ineffective if the metals are complexed or if they present as anions (e.g.,  $\text{CrO}_4$ ).
- low efficiency at low concentration of heavy metals
- large settling basin is required to collect the metals, usually followed by a solid thickening operation to concentrate the solids.
- expensive handling and safe disposal of toxic sludges required.

### 2.6.2 Adsorption

Chemical contaminants at low concentrations are difficult to remove from water. Chemical precipitation, reverse osmosis and any other methods become inefficient when contaminants are present in trace concentrations. The process of adsorption is one of the few alternatives available for such situations (Huang *et al*, 1991). Adsorption is the binding of a chemical species at a phase boundary, such as the surface of suspended particles (Benjamin *et al*, 1996). A number of adsorbent materials have been studied for their capacity to remove heavy metals, including activated carbon, activated alumina, ion exchangers, peat moss, crushed coal, fly ash, steel plant granulated slag, rice husk, apple wastes etc. Some of these materials, such as ion exchange resins are effective but expensive. Some of them such as coal and straw are inexpensive but inefficient. Activated alumina is effective in removing heavy metals, but is readily soluble under extreme pH conditions (Huang *et al*, 1991).

Nadar *et al* (1985) reported adsorption as an efficient mechanism of heavy metal removal. They observed bottom ash as a very good adsorbent for Cu and Cd. Aqueous solutions of Cu(II) and Cd(II) were prepared by dissolving definite amounts of copper sulphate and



cadmium sulphate in distilled water, so as to be capable of further dilution in order to give solutions containing the required amount of  $\text{Cu}^+$  and  $\text{Cd}^+$ . Batch type experiments were conducted in which weighed quantities of bottom ash were taken in leak proof bottles. The concentration range of the solutions used for the adsorption study was 425-500 mg/l for copper and 75-500 mg/l for cadmium. The closed bottles were shaken thoroughly in an electric wrist shaker for a specified period and then filtered through a Whatman No 41 filter paper. It was observed that cadmium removal efficiency was 87-95% and copper removal efficiency was 90-95%. An effective removal of  $\text{Cu(II)}$  required a period of 6.5 hours and  $\text{Cd(II)}$  required a period of 5.5 hours of shaking. It was also observed that maximum removal occurred at pH 3 for both the ions.

Activated carbon has been recognised as a highly effective absorbent for the treatment of heavy metals in water and wastewater. Granular carbon is usually preferred to powdered carbon, as the former, although more expensive, can be regenerated and reused. Adsorption capacity increases as the pH decreases. Huang *et al* (1977) described  $\text{Cr(VI)}$  removal, mainly as  $\text{HCrO}_4$  by carbon adsorption using calcinated coke at laboratory level. Decreasing chromium concentration and low pH values improved the removal efficiency. Linstedt *et al* (1971) described that the presence of chelating agents would enhance the removal of mercury by powdered activated carbon, and that neutral pH and small additions of tannic acid increased the effectiveness. Linstedt *et al* (1971) also established removals exceeding 95% for  $\text{Ag(I)}$   $\text{Cd(II)}$  and  $\text{Cr(VI)}$  after treatment. The cations  $\text{Ag(I)}$  and  $\text{Cd(II)}$  were probably retained by a combination of cation exchange as well as adsorption of organic cation complexes. Removal of  $\text{Cr(VI)}$  anions can be attributed to the chemical reduction of insoluble  $\text{Cr(III)}$  hydroxide. Benjamin *et al* (1996) suggested iron-oxide coated sand as an effective and stable sorptive material. They carried out experimental investigation on the removal of Cu, Pb and Cd by using a column of iron-oxide coated sand and found a typical overall removal efficiencies of 99 % or greater for all three metals. They observed that relatively small amounts of iron were lost over time during treatment regeneration, and backwashing steps. However, they have suggested that additional long-term testing is required to confirm their findings and to quantify the effective life time of the media. Satpathi and Chaudhuri (1995) and Ramberg (1995)



have also reported the ability of iron-oxide coated sand to adsorb from electroplating rinsewaters and arsenic from drinking water sources, respectively. Iron-containing minerals such as vermiculite and glauconite as well as iron hydroxide hybrids have demonstrated comparable adsorption capacity for heavy metals (Hao *et al*, 1987; Das and Bandyopadhyay, 1992; Ramesh *et al*, 1993). Smith (1996) described iron sorbent favorable for heavy metals (especially Cd, Zn and Pb) in comparison with other commercial adsorbent such as activated carbon.

Lopez *et al* (1998) carried out batch experiments to examine the adsorption capacity of aggregated red mud (mixture of red mud and  $\text{CaSO}_4$  form aggregate) and observed strong affinities of it for Cu, Zn, Ni and Cd. They found the maximum adsorption capacities, evaluated from fits of the Langmuir isotherm to the experimental data for contact period of 24 h, were 19.72 mg/g for Cu, 12.59 mg/g for Zn, 10.85 mg/g for Ni and 10.57 mg/g for Cd.

### **2.6.3 Ion Exchange**

Ion exchange is well known as a method of water softening and is an effective method of removing heavy metals from water and wastewater. During treatment the ion exchange resin exchanges its ions for those in the wastewater. When the resins are saturated, the exhausted resin must be regenerated by another chemical to remove the metal ions from the resin bed. During treatment the ion exchange involves the reversible exchange of ions between a solution and a solid phase that are in direct contact. The solid phase can be a natural zeolite or synthetic resin consisting of a crosslinked polymeric network with charged functional groups which attract oppositely charged ionic species and retain them by electrostatic forces (Blanchard *et al*, 1984). Linstedt *et al* (1971) observed 85.8% removal of Ag(I) and 99% of Cd(II) following the passage of a high quality wastewater through a cation exchange bed. On subsequent anion exchange, the percentage removal of dichromate and selenate was from 95.4% to 96% and from 90.9% to 99% respectively. They used lime coagulation, sedimentation, sand filtration and activated carbon adsorption prior to ion exchange for conditioning the wastewater in order to reduce



interference of organics by complexing cations or competing directly with anionic trace metals, thus fouling the exchange column and interfering with regenerations.

Cullen and Sivior (1982) reported removal of Cu, Ni, Cr, Cd, Pb, Zn, Hg, Co, Ag, Fe, V, Ge, Al and U using ion exchange media produced by compacting brown coal, peat or wood sawdust with a solution of calcium hydroxide. Yeats (1977) reported that ion-exchange selectively removes heavy metals from mixed plating wastes. The concentration Cu, Ni and Pb in the final treated effluents were lower than 0.05 mg/l.

The ion-exchange capacity of natural zeolite Clinoptililite has been investigated by many authors (Blanchard *et al*, 1984; Cerjan-Stefanovic *et al*, 1992; Joshi and Mohan, 1983). Curkovic *et al* (1997) observed a 90-99 % removal of Pb and Cd at a concentration of 1-10 mmol/l. The removal efficiencies were found to decrease as the concentration exceeded 10 mmol/l. They also found that Pb was more selectively removed than Cd. Application of the ion-exchange process is rather expensive due to the cost of synthetic ion-exchange resins (Kratochvil *et al*, 1997).

#### **2.6.4 Reverse Osmosis**

Reverse osmosis is sometimes used to remove heavy meals from wastewater. It has been used effectively in the plating industry for recovery and reuse of nickel in plating bath water (Lanouette, 1977). Reverse osmosis is composed of semipermeable membranes which act as molecular sieves permitting soluble compounds having various molecular size ranges to pass through their pores (Dean *et al*, 1972). The system works at a pressure up to 42 bars.

#### **2.6.5 Biological Removal**

Biological uptake of heavy metals, known as biosorption is a water treatment process whereby toxic heavy metals are sequester from diluted aqueous solutions by sorption into inexpensive biological materials, such as non-living freshwater and marine algae, yeast, fungi and bacteria (Kratochvil *et al*, 1997; Volesky and Holan, 1995). Biological uptake



of metal ions has been studied by many research workers in the past (Darnall *et al*, 1986; Friedman and Dugan, 1968; Gadd, 1988; Nakajima and Sakaguchi, 1986; Prodhan and Levine, 1992). Due to the formation of complexes, treatment of metallic wastes by conventional chemical treatment poses problems (Prodhan and Levine, 1992). Based on economics, biological treatment approaches compare favorable with chemical treatment techniques (Gadd, 1988; Brierly *et al*, 1989). Moreover, microorganisms have been reported to possess ion exchange capacity much higher than some of the commercial resins (Marquies *et al*, 1976). Recently several researchers have independently concluded that the major mechanism of heavy metal removal by algae (Crist *et al*, 1990; Kratochvil *et al*, 1995), fungi (Fourest and Roux, 1994) and peat moss (Spenti *et al*, 1995) is an ion exchange. It has also been demonstrated that algae biosorbents, similar to ion exchange resins, can be prepared in different ionic form as well (Kratochvil *et al*, 1997). The advantages of biosorption includes low cost, regeneration of biosorbent, high efficiency and the possibility of metal recovery (Kratochvil, *et al*, 1997)

Microbial treatment systems consist of cellular mass and extra cellular enzymes released by cells. Adsorption of metal ions on microbial systems has been modeled as a two stage process: (i) instantaneous binding of cellular surfaces and (ii) gradual transportation and accumulation of metal ions with cytoplasm (Norberg and Person, 1984; Norris and Kelly, 1977). Some microorganisms have the capacity to concentrate metal ions. Besides binding metal ion to cell walls, it is also possible that chemical complexing occurs between metal ions and extra cellular enzymes. Extra cellular material possesses a greater capacity for binding metals (Prodhan and Levine, 1992). In addition to assimilation by microbial cells, complexation and binding of metal ion to various exopolymers by cells is expected to contribute greatly to metal removal efficiency of biological treatment schemes (Prodhan and Levine, 1992). He cultured actinomycetes aerobically using glycerine and L-arginine as organic substrates and nutrients. Nearly 90% of the binding took place within the initial 5-6 hours, perhaps due to stronger concentration gradients and a large number of the free binding sites available in that period. Prodhan and Levine (1992) also observed the optimum operation time in the



range of 5-6 hours for the experimental conditions of pH 4, temperature 25°C and concentration of Cu and Pb of 10 ppm.

Chang *et al* (1997) observed an average 80 % removal of Pb, Cd and Cu by *P.aeruginosa* PU21 at an optimum optimal operating pH of 5.5, 5 and 6 respectively. The HCl-induced desorption achieved nearly 98 % recovery of Pb and Cu, and the recovery efficiency was around 80 % for Cd. They have recommended *P.aeruginosa* as an effective biosorbent of heavy metals because of their high metal adsorption capacity, satisfactory recovery efficiency and the persistence to repeated uses.

### 2.6.6 Sand Filtration

Schmidt (1977) reported nearly complete removal of heavy metals from water by slow sand filtration. Sontheimer (1980) reported 33%-94% removal of heavy metals from water by slow sand filtration. Ellis (1985) and Visscher *et al* (1987) suggested 30%-90% removal of heavy metals by slow sand filtration.

Carlo (1992) described a good removal of selenium (a trace non-metal) from water by slow sand filtration. He has suggested a lower hydraulic loading for good removal of heavy metals. He has suggested anaerobic conditions in the filter.

Khan *et al* (1985) carried out an extensive study on the heavy metal content of Husainsagar Lake (India) water and sediment and found the concentration of Cu, Cr, Cd and Hg in lake water were 168 µg/l, 68 µg/l, 4.60 µg/l and 22 µg/l respectively. They also observed that the heavy metals concentration in sediment was higher with finer sediment and higher percentage of organic matter. The metal concentration decreased along with the decrease of clay and organic matter and the least concentration was recorded with coarser texture and lower organic matter content of sediment. This study indicates that the finer filtering media and organic matter content in water may play an important role in removing heavy metals from water.

Hasan *et al* (1985) carried out an investigation on the removal of heavy metals in different water works at Nagpur in India. The water works consisted of coagulation, flocculation, settlement filtration and disinfection unit processes. The heavy metal concentrations in raw water, settled water, filtered water and finished water were determined. It was found that Cd, Cu, Cr and Pb had large variations in their concentration at different times. It was also observed that single attempts to measure the trace metal concentrations would give misleading results and recommended consideration of time variations. The authors found that all the unit processes contributed to some removal of heavy metals. The maximum removal occurred at the settlement stage. Removal of heavy metal was not significant during the filtration stage, but it was significant during the disinfection and storage process probably due to oxidation of metals to the higher insoluble valence state. They also observed that removal of heavy metals differed from metal to metal. Removal of arsenic and manganese was in the range of 85%-100% whereas for other trace metals, it varied from 67% to 94%. CIRIA (1994) quotes 83% and 81% removal of lead and zinc respectively by means of filter drains. Filter drains, also known as French drains, are particularly suited to road drainage in cuttings. They have a dual function of collecting surface water runoff and controlling the groundwater level below the road. Surface runoff passed through the granular media and is collected in the porous pipes. Filter pipe sizes are calculated in a similar way to conventional storm water pipe drainage systems.

CIRIA report142 mentioned 41% and 45% removal of lead and zinc respectively by means of filtration basins. Filtration basins are commonly used in mainland Europe for treatment of runoff. They consist of sand and/or gravel filter beds with an underdrainage system to remove the filtered runoff.



## 2.7 Comments

- The contamination of water by toxic heavy metals is a world-wide environmental problem. Heavy metals can be distinguished from other toxic pollutants, since they are non-biodegradable and can accumulate in living tissues, thus becoming concentrated throughout the food chain.
- A variety of industries are responsible for the release of heavy metals into the environment through their wastewaters.
- The main techniques which have been utilised to reduce the heavy metal ion content of effluents include lime precipitation, adsorption, ion exchange, reverse osmosis and biosorption. These methods have been found to be limited since they often involve high operational costs and may also be associated with the generation of secondary wastes which present treatment problems. Considerable attention has been focused in recent years upon the field of biosorption for the removal of heavy metals from aqueous effluents. Despite much research efforts, few biosorption processes have reached commercial application.
- A very few works have been reported regarding the removal of heavy metals by sand filtration. The published results were taken from various water works where very little control was ensured over different variables.
- Hence further research to investigate the removal of heavy metals by SSFs is justified. The mechanisms of the removal of heavy metals reviewed here will be helpful to enhance the removal by SSFs
- The basic principle of SSFs, infrastructures, operational procedures, performance and the associated problems will be reviewed in next chapter.

## CHAPTER 3

### LITERATURE REVIEW ON SLOW SAND FILTRATION

#### 3.1 HISTORICAL BACKGROUND OF SLOW SAND FILTRATION

Modern slow sand filtration was first developed in 1804 by John Gibb at Paisley in Scotland to produce water for his bleachery. His design was improved by Robert Thorn working at Greenock in 1827 (Baker, 1949; Ellis, 1985). The technology was first adapted for a public water supply by James Simpson in 1829 for the Chelsea Water Company and since then it has been in continuous use as a reliable means of preparing potable water from polluted water sources (Ellis, 1985). Slow sand filters were working at Gorbals Sanitation and Water Company in 1846 and 1852 respectively (Baker, 1949; Lloyd *et al*, 1983; Ellis, 1985). 20% of all London's water passes through a slow sand filter (Bowels *et al*, 1983; Ellis, 1985). The most convincing proof of the efficacy of this process was first demonstrated in 1892 when the river Elbe from which two the neighbouring cities of Hamburg and Altona were drawing their water supply, was polluted resulting in a cholera epidemic. Altona which filtered its supply, completely escaped from the epidemic, while Hamburg with no filtration suffered more than 7500 deaths (NEERI, 1982).

Slow sand filtration became nearly universally employed for water treatment during the nineteenth century until difficulties associated with high turbidities in surface waters - particularly with some surface waters in the US - led to the development of the rapid gravity sand filter with all its necessary complexities of chemical pre-treatment, backwashing and auxiliary scour systems (Ellis, 1985). During the later half of the 19th century widespread introduction of slow sand filtration in Europe occurred (Rachwal *et al*, 1996). Still slow sand filters are widely used in countries like the UK, Holland, Switzerland, Sweden and Japan. The use of slow sand filters has been strongly encouraged over recent years in the developing world (Huisman and Wood, 1974; Visscher *et al*, 1987; Jain, 1975). Brink and Parks (1996) suggests that within the last decade slow sand filtration becomes a treatment alternative regularly considered by utilities, designers and regulators in the USA as well. A preliminary



report done for the American slow sand filters association identified 225 SSF plants in America. This is an increase of more than 100 SSF plants since 1940. Slow sand filtration is capable of removing almost all the turbidity, much of the organic materials and some of the colour in one simple operation (Kawata, 1982). Slow sand filtration is capable of removing most of the coliform bacteria and almost all pathogenic bacteria and viruses from the raw water (Kawata, 1982). Slow sand filters are capable of removing all the *cercariae* of schistosomiasis from raw water (Kawata, 1982). Slow sand filters are the most effective, simplest and least expensive water treatment process for developing countries. However, slow sand filtration, though practised for over 150 years, is still one of the least understood processes. The complex mechanisms that bring about the purification have yet to be explained fully.

### **3.2 SLOW SAND FILTERS AS AN APPROPRIATE TECHNOLOGY FOR DEVELOPING COUNTRIES.**

Modern technology provides a choice of treatment methods that can produce any desired quality of water from any given sources, the limiting factor being economic rather than technical. The provision of any form of treatment will require a capital cost. Most importantly, it requires operation and maintenance. Some water treatment processes are easier to operate and maintain than others. When designing a water treatment process capital cost, as well as the operational and maintenance cost, are the key factors that must be considered carefully. However, the following are some of the required criteria for deciding a water treatment process for rural situations in developing countries:

- a) Design, construction, operation and maintenance costs should be reduced to a minimum without sacrificing the water quality.
- b) Locally available material should be used for construction and filter media; limited or no use should be made of imported materials.
- c) Construction, operation, maintenance and preferably repair should be within the competence of local technical staff or the users.
- d) Use of mechanical equipment should be kept to a minimum.

- e) Chemicals and power requirements should be minimised.
- f) The system should satisfy the local needs, preferences and socio-economic conditions.
- g) The system should provide easy monitoring of its performance.
- h) Treated water quality should not deteriorate with time.
- i) The plant should be very effective in removing pathogenic bacteria and other microorganisms.

Biological filtration, known as slow sand filtration, satisfies all the above mentioned criteria. It is therefore a highly appropriate technology for developing countries and it is for this reason that it is the process under study in this research project (which is based on actual problem of heavy metal contamination in the developing country scenario of Bangladesh. Its simple technology and high purification efficiency in the treatment of surface waters with a moderate level of inorganic and organic pollution has made it one of the most suitable water treatment technology for the developed countries as well (Luxton and Graham, 1998).

### **3.3 BASIC ELEMENTS OF SLOW SAND FILTERS**

The essential elements of a typical slow sand filter are:

1. the supernatant water reservoir
2. the filter media
3. the gravel media
4. the underdrainage system
5. the filter box containing 1, 2, 3 and 4
6. the filter control system.

These elements are shown in Figure 3.1 and are described in the subsequent subsections.



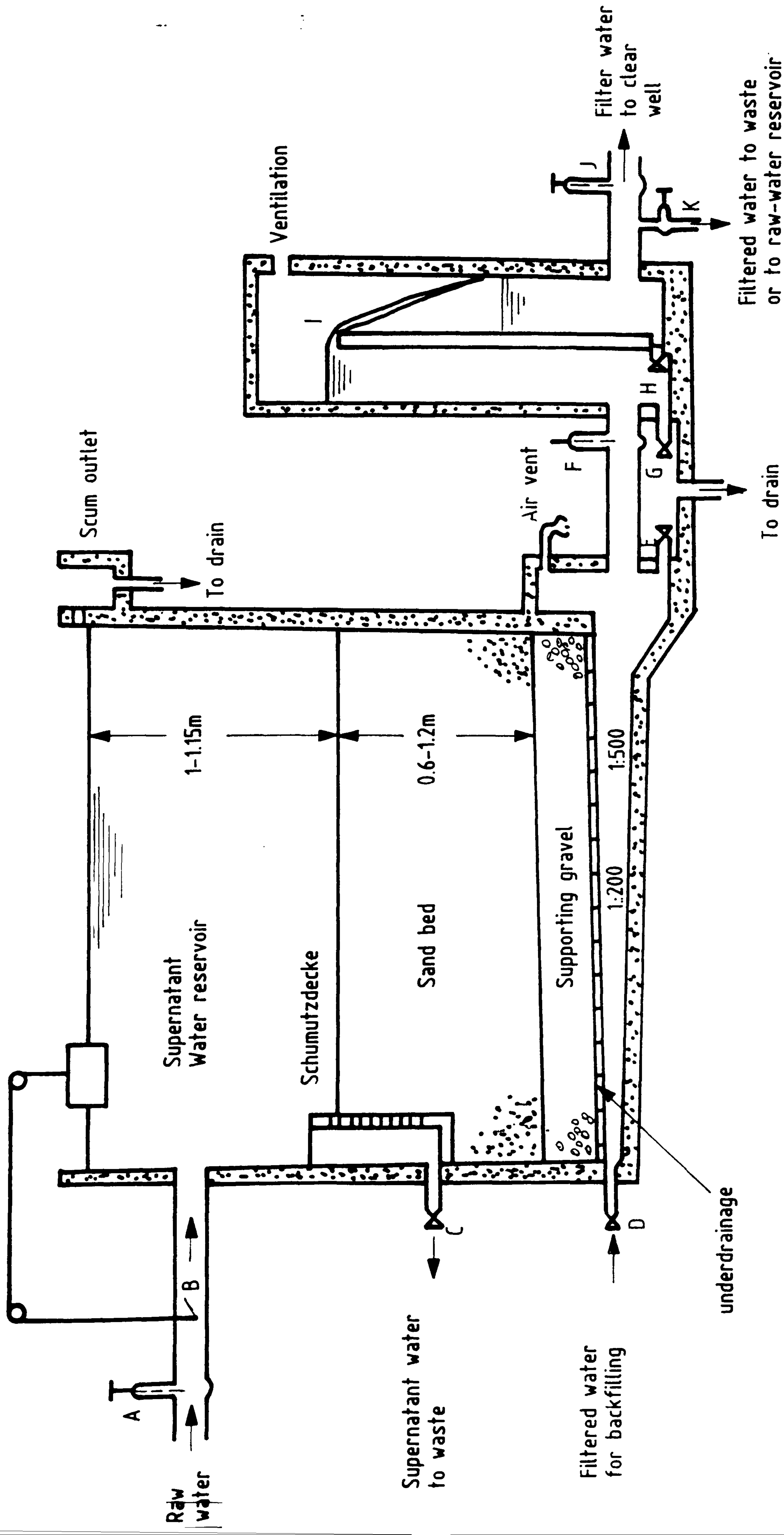


FIGURE 3.1 Elements of slow sand filter  
(Huisman and Wood, 1974)

### 3.3.1 The Supernatant Water Reservoir

The supernatant water reservoir above the sand bed provides sufficient head to overcome the resistance of the filter bed, thereby inducing downward flow through the filter. This depth is normally 1-1.5m. The supernatant water reservoir is actively involved in the improvement of water quality. It provides a waiting period of 5-15 hours for the raw water, during which sedimentation, natural flocculation, oxidation of organic materials, and die-off of bacteria occur (Ellis, 1985). It prevents the deep penetration of sunlight to discourage the growth of rooted aquatic plants in the filter surface. An outlet has to be provided to serve as an overflow for the supernatant water and to enable removal of scum which may form on the surface of the water (Visscher, *et al* 1987).

### 3.3.2 The Filter Media

#### a) Materials

The filtering media is invariably sand although other materials such as crushed coral, burnt rice husks and volcanic ash have been used. Crushed coral and volcanic ash have been used in Ethiopia and burnt rice husks were used in south-east Asia (Huisman and Wood, 1974). Bauer (1994) suggested a granular activated carbon layer termed as GAC sandwich as a partial replacement on the top to reduce the headloss. The use of fabric protected slow sand filtration has been shown to reduce the rate of filter blocking, resulting in a longer period of filter operation between periods of filter start-up and cleaning (Graham and Mbwette, 1991). Luxton and Graham (1998) suggests that the development of schumtzdecke on the jute fabric is faster than that of sand filter only because of the cellulose nature of the jute fabrics which encourage the development of bacterial community.

#### b) Size distribution

The sand is characterised by its Effective Size (ES) and Uniformity Coefficient (UC), concepts introduced by Hazen in 1892 (Ellis, 1985). The effective size is the mesh diameter in millimetres of a sieve, which retains 90% by weight of the material and allows 10% to pass through. The effective size is represented by  $D_{10}$ . The uniformity coefficient is the ratio of the mesh diameter of the sieve, which passes 60% by weight



of the material to the effective size (ES). The uniformity coefficient UC is therefore given by

$$UC = \frac{D_{60}}{D_{10}}$$

Recommendations for the ES for a slow sand filter vary between 0.15 and 0.40 mm (Ellis, 1985; Rachwal *et al*, 1996). Huisman and Wood, (1974) and Thanh *et al* (1983) suggested an ES between 0.15 mm and 0.35 mm. Cox (1969) suggested an ES between 0.20 and 0.40 mm. Fair *et al* (1968) and Van de Vloed (1955) all suggested an ES between 0.25 and 0.35 mm. It has been observed by the author that the treatment efficiency by SSF is not too sensitive to sand size up to an ES of 0.45mm. It is essential that the ES of the sand selected should not be finer than is essential (Bowles *et al*, 1983). Too fine a sand, although improving the quality of the filtrate, will add appreciably to the headloss. The effectiveness of filtration depends not only upon the fineness of the sand, but also on the depth of the sand and on the rate of filtration. If an additional margin of safety is required in any filter, it is better to increase the depth of the sand bed rather than to reduce the grain size (Ellis, 1984). Muhammad *et al* (1997) also suggest that from the standpoint of removal efficiency the argument of using very fine sand is not strong. They observed that sand sizes upto 0.45 mm produced satisfactory filtrate quality with longer filter run. The filtrate quality of filters having a coarse grain size (ES= 0.45 mm) can not be considered in general inferior to the filtrate quality of filters having a smaller grain size (Ellis and Aydin, 1993). In order to produce a superior final water quality with the lowest AOC-content (Assimilable Organic Carbon), turbidity and colony counts, etc., a small grain size in combination with a low filtration rate may be preferred (Ellis and Aydin, 1995; Haarhoff and Cleasby, 1991; Hendricks and Bellemey, 1991). On the other hand Van der Hoek *et al* (1996) observed no clear effect of grain size on AOC removal and particle reduction in their study.

The recommendations for UC vary between 1.7 and 3 but preferably not greater than 2.7 (Ellis, 1985). Kirkhoven (1979) suggested that builders sand with an ES of 0.25 mm and a UC of 2.9 was nearly as good as a filter media as normal graded sand with an ES of 0.21 mm and UC of 2.1. He observed that a coarser sand of ES of 0.32 mm



and UC of 2.59 was not suitable. Joshi *et al* (1982 ) reported that sand of ES 0.2 mm and UC of 2.1 was capable of removing 74% of applied COD while sand with ES of 0.25 mm and 0.32 mm and UC of 2.9 and 2.6 removed 64% and 63% of applied COD only. As stated in the Manual of Design for Slow Sand Filtration of American Water Works Association (1991), for economic reasons, local sand with ES of 0.15 to 0.35 mm and UC greater than 3 may be used in place of an industrialised sand that matches the strict specifications for the latter parameter. It has shown in the manual that a sand with ES in the range of 0.15 mm-0.45 mm and UC in the range of 2.0-3.3 may cost ten times less than an industrialised sand with UC equal to 1.5, restricting the use of slow sand filtration technology, specially in the rural areas. Bernerdo and Rivera (1996) reported that average effluent quality produced in the two filters with higher UC resulted better with a longer filter run. They also reported that dirt penetration was deeper in the sand and the schumtzdecke was thicker in the filters with higher UC.

Stevenson (1994) described a different way called 'hydraulic size' to specify the sand media. The hydraulic size is related to hydraulic behaviour of the sand media rather than to material composition and appearance. He suggested that the concept of ES and UC should be abandoned. In the UK materials are described by the size range, e.g. 0.5-0.86 mm rather than by ES. The stated sizes are generally understood to be the 5 and 95 percentile. Stevenson (1994) suggested that this concept would also be abandoned, particularly as given designations sometimes mean different things in different countries..

The new standard has received much detailed thought. The draft was passed to all the main water service companies, the Water Research Centre, the institution of Water and Environmental Management, a representative of the consultants, and some suppliers. The author has commented that some minor change will prove advisable after the standard has gained wider use. The author has also commented that the "hydraulic size" is more relevant to the backwashing of the rapid gravity filtration. Hence the conventional method of "effective size and uniformity coefficient" has been used to specify the sand in the present study.



### c) Depth of the media

The initial depth of the sand bed at commissioning or following resanding will frequently be as much as between 1.2m and 1.4 m and reducing to an absolute minimum depth of 0.65m before resanding (Ellis, 1987). The sand layer is periodically reduced by about 25 or 50 mm as a result of cleaning operations (Huisman and Wood, 1974).

The minimum bed depth requirements are a matter of some debate. Cox (1969) suggested a minimum sand depth of 800 mm. Toms *et al* (1988) described the minimum sand depth of 300 mm for London slow sand filters. A minimum depth of 300 mm may be adequate for removing turbidity and may also achieve the removal of most of the coliform bacteria from a moderately good quality of feed water, but to remove all the viruses and perhaps to complete oxidation of ammonia a minimum depth of at least 600 mm is suggested (Windle-Taylor, 1972). Bellemy *et al* (1985) reported that the sand depth could be reduced to 0.48 m without significant impairment of removal efficiency.

Burman (1978) suggested that the poorer the quality of raw water the deeper must be the sand bed. Aydin (1993) suggested a decrease in removal efficiency at lower depths especially at higher velocities. Muhammad *et al* (1997) observed that filters produced satisfactory bacteriological quality of water at 0.4 m depth but turbidity and colour removal efficiency declined more and ammonia was not oxidised completely at this depth.

### 3.3.3 The Gravel Media

The gravel media possesses a dual function both of ensuring uniform abstraction of the filtrate water and of preventing the filter media from entering and blocking the underdrains. It is built up in a number of layers with the coarsest at the bottom and the finest at the top; each layer is composed of carefully graded stones. Usually the bottom layer should have a diameter of at least twice that of the openings in the underdrainage, and the top layer, in contact with the filter media should have a  $D_{10}$  not more than four times greater than the  $D_{10}$  value of the coarsest sand (Huisman and

Wood, 1974; Ellis, 1985). The depth of each layer is usually at least three times the diameter of its largest stone (Huisman and Wood, 1974). The depth of gravel plus that of the underdrainage system will be about 0.5m (Ellis, 1985).

### **3.3.4 Underdrainage System**

The underdrainage plays a dual role. It supports the filter media and provides free drainage from the media. It consists of numerous lateral drains feeding into a main drain. The main drain may be pipe or concrete channel constructed into the floor of the filter box and covered with perforated tiles or jointed bricks. The lateral drains may be:

- a) porous or perforated unglazed pipe
- b) glazed pipe laid with open joints
- c) perforated pipe of asbestos cement
- d) perforated PVC pipe.

Other drainage devices include:

- a) standard bricks, set either on vertical bricks or on precast concrete bricks
- b) standard concrete tiles supported on quarter tiles
- c) a layer of large (40-100 mm) gravel.

The maximum spacing between drains should not normally be greater than 3m. There should be no drains within 0.6m of the side wall of the filter box in order to discourage short circuiting.

### **3.3.5 Filter Box**

The filter box is mainly constructed of reinforced concrete, ferrocement, stone or brick work masonry. It should be water tight to prevent head losses and to avoid contamination by shallow ground water or surface run-off.



### 3.3.6 Filtration Control System

Figure 3.1 shows the essential elements of a typical slow sand filter. The controlling devices are marked on the figure. Their functions are as follows:

- A: Inlet valve, allows water to enter into the supernatant water reservoir
- B: Float controlled valve, regulates the flow of water according to the supernatant water level
- C: Quick drain valve, drains the water quickly to just above schmutzdecke prior to cleaning
- D: Device to fill the filter from the bottom
- E: Valve to lower the water level within the bed
- F: Valve to control the rate of filtration
- G: Valve used to drain water from the upstream chamber of the weir
- H: Bypass valve to drain the downstream chamber of the weir
- I: Outlet weir provided to prevent the negative head or the drying out of the sand bed.
- J: Valve allows filtrate water to pass to the clear well
- K: Valve to allow the filtrate water to waste if necessary.

## 3.4 FILTRATION RATES

The rate of flow through a slow sand filter varies commonly from 0.08 m/h to 0.2 m/h, with perhaps 0.1 m/h being the ‘conventional’ rate (Van Dijk, 1978; Ellis, 1985). However, it is possible to increase the filtration rate considerably if effective pre-treatment is given and if an effective disinfection follows the filtration (Ellis, 1987). Visscher *et al* (1987) suggested filtration rates of 0.1 to 0.2 m/h as satisfactory, but the filtration rate may be increased to 0.3 m/h for a very short period without undue harm. Ridley (1967) suggested a filtration rate of 0.05 to 0.15 m/h for slow sand filters. Filtration rates as low as 0.025 m/h and as high as 0.5 m/h have been reported, although the latter rate was following prefiltration using rapid sand filters (Burman, 1978). Rachwal *et al* (1988) reported the reference of Thames Water Authority using

slow sand filtration rates of 0.12 m/h following the preliminary rapid gravity filtration and 0.25 m/h following rapid upflow filters. NEERI (The National Environmental Engineering Research Institute), Nagpur, India (1977) observed that higher filtration rates than the conventional rate (0.1 m/h) gave no adverse effects on the filtrate quality, but with the advantage of greater output for a good quality raw water (turbidity < 10 NTU). However, they observed that increasing the filtration rates resulted in a reduction of run length. Williams (1988) found that there was virtually no difference in bacteriological quality of the effluent for filters operating at 0.1 and 0.05 m/h.

Huisman and Wood (1974) reported that at the water works in Amsterdam three covered filters at different filtration rates of 0.1, 0.25 and 0.45 m/h had been operating for a full year without any marked difference in effluent quality being detected.

Bellamy, et al, (1985) operated laboratory scale filters with an effective size of 0.28 mm at filtration rates of 0.04, 0.12 and 0.4 m/h and reported no marked deterioration in the filter performance as the flow rates increased. Ellis (1985) suggested that faster filtration rates than the conventional figure of 0.1 m/h are possible without unacceptable filtrate quality deterioration if the feed water is not of low quality. He also suggested that too high rates with some lower quality waters would result in silt being carried deeper into the filter, which would necessitate the removal of a considerably thicker than normal layer of sand at each skim or may result in deeper blocking of the filter. Schuler et al (1991) found no effect of the filtration rate on the removal of cysts by slow sand filters. Van der Hoek et al (1996) observed that the effects of filtration rate (0.3 m/h versus 0.6 m/h) was less pronounced and not conclusive in their study.

Muhammad *et al* (1997) observed that bacteriological treatment efficiency by SSF did not deteriorate much at filtration rates higher than the conventional figure. Turbidity and colour removal efficiency deteriorated at higher filtration rates. Filters at higher filtration rates require more frequent cleaning.



### 3.5 PURIFICATION MECHANISMS OF SLOW SAND FILTRATION

Visscher *et al* (1987) summarises the purification mechanisms of slow sand filtration as described in this section.

In a slow sand filter, purification of water is achieved through a combination of processes such as sedimentation, straining, adsorption and chemical and biological action, together with the other minor mechanisms such as diffusion, mass attraction and electrostatic attraction. Purification begins in the supernatant layer where heavier particles settle on the filter bed and some of the lighter particles coalesce and settle. A degree of aerobic biological activity and die-off of bacteria occurs before filtration starts.

During the first few days, water is purified mainly by mechanical and physical processes. The resulting accumulation of alluvial mud, suspended organic waste, together with the bacterial, algal, planktonic and protozoan matter forms a layer on the top of the sand bed and is intimately mixed with the topmost grains. This layer is known as the 'schmutzdecke' or filter skin which acts as both a very fine filter coat and active biological zone. Most impurities, including bacteria and viruses, are removed from the raw water as it passes through the filter skin and the layer of the filter bed sand just below. Pathogenic bacteria adsorbed on to the sand or trapped in the schmutzdecke are a prey to adverse conditions and to predators ranging from bacteriophages to protozoa. The breakdown of organics is achieved by the microbiological activity. Nitrogenous organic materials are first converted into ammonia which is then oxidised by specific autotrophic bacteria to nitrite and ultimately to nitrate.

From the schmutzdecke, the dissimilation products of the initial biological activity are swept down to act as substrate for further bacteria positioned in the upper levels of the sand bed until complete breakdown is achieved. Biological activity decreases with depth although it will still be evident as deep as 400 mm or more beneath the sand

surface. The finer colloidal substances and biological products which are not strained and adsorbed in the upper layer, are removed at greater depth by further adsorption and sedimentation.

Biological activity on and within the sand bed is aerobic in nature so that any water entering the filter should possess an absolute minimum of 3.0 mg/l dissolved oxygen. Any undesirable anaerobic condition adversely affects the treatment process.

The efficiency of slow sand filtration may also be reduced by low temperatures. The speed at which chemical reactions take place and the rate of metabolism of bacteria and other microorganisms, are both affected at low temperatures. Huisman and Wood (1974) suggest that below 6°C temperature the oxidation of ammonia practically comes to a standstill. At low temperatures the activity of bacteria-consuming protozoa and other predators drops sharply and the metabolism of pathogenic bacteria slows down, increasing the chance of survival of those that are carried through the bed. Hence, *E.coli* removal efficiency is also reduced at low temperatures.

### **3.6 TYPICAL PERFORMANCE/EFFICIENCY OF SLOW SAND FILTRATION**

The performance of slow sand filtration depends on various factors, such as raw water quality, grain size, bed depth, rate of filtration, temperature and raw water dissolved oxygen content. The performance of SSFs in removing various pollutants has been carried out by many researchers. Visscher *et al* (1987) summarises the performance of a matured filter which is shown in Table 3.1, based on the work of Ellis (1985) and the results of IRC slow sand filtration projects.

The results in Table 3.1 are from filters which are being operated under varying conditions and the results therefore show a wide range.



Table 3.1: Typical performance characteristics of slow sand filters

Parameter of water quality	Purification effect of slow sand filtration
Colour	30-100% reduction
Turbidity	Turbidity is generally reduced to 1 NTU
Faecal coliforms	Between 95-100% and often 99-100% reduction in the level of faecal coliforms
Cercariae	Virtual removal of cercariae of schistosoma, cysts and ova
Viruses	Virtually complete removal
Organic matter	60-75% reduction in COD
Iron and manganese	Largely removed
Heavy metals	30-95% reduction

The range of the removals of heavy metals is very wide. The results are taken from the experiences from various water works. It is not based on any controlled laboratory or pilot scale investigations.

The organic content of water can be expressed in term of BOD, COD, TOC etc. Melleby (1990) reported an average 28 % (maximum 47 % and minimum 7 %) removal of TOC. Rachwal et al. (1988) reported a 24 % reduction of TOC by SSFs with a very low ozone dose.

### 3.7 OPERATIONAL PRINCIPLES OF SLOW SAND FILTERS

The most attractive aspect of slow sand filtration is its simplicity of operation and control. The following operational principles, suggested by Ellis (1985) should be followed to achieve a good quality of filtrate water from a slow sand filter.

- The filter should be run at a steady rate. Sudden changes in filtration rate tend to upset the equilibrium of the microbiological activity and result in a deterioration of the effluent quality (Huisman and Wood, 1974). Hence there must not be quick rate alterations.
- The idle bed should not be left full of water to avoid the creation of anoxic or anaerobic conditions.
- The rate of filtration should be adjusted regularly.

- d) The filter needs to be cleaned when the outlet valve is fully open and the maximum head of water is available, but the desired rate of filtration is not being achieved.
- e) The filter should be cleaned and restarted as quickly as possible.
- f) After cleaning, the filter should be filled from the bottom.
- g) The water level in the supernatant reservoir should be kept at its maximum level.
- h) Effective pre-treatment must be employed if the raw water turbidity is in excess of about 30 NTU for prolonged periods.
- i) Growth of algae must be prevented to stop blockage of the sand bed.

### **3.8 COMMISSIONING OF A SLOW SAND FILTER**

With all outlet valves closed, filtered water is admitted from the bottom to flow upward through the drainage system and the gravel and sand bed until it reaches 10-15 cm above the sand bed. This method of charging ensures that air accumulated in the system, especially in the pores of the sand bed, are driven out.

Next the inlet valve is gradually opened and water is allowed to flow on the top of the sand bed. The rate of filling is initially low to prevent flowing of the sand around the inlet. With increasing layers of supernatant water the rate of filling can be increased. When the normal working depth of the supernatant is reached the outlet valve is opened gradually.

### **3.9 MATURATION OF SLOW SAND FILTERS**

When a new slow sand filter is commissioned, the filtration can be started at about one quarter of the design flow rate. The filtration rate may be increased slowly to the design flow rate over the next few weeks while the filter media matures.

The maturation process is the development of the correct balance of electrostatic charges on the individual sand grains, especially for the new sand. However more



importantly for the maturation process, is the slow development of the required balance of bacteria and other microorganisms on the sand grains of the zoological layer. The biologically active zone will extend to a depth of 400 mm in the sand bed (Huisman and Wood, 1974; Jain, 1975). Rachwal *et al* (1996) suggest that maximum biofilm growth and finer particle capture is usually concentrated within the top 20-30 mm of the sand media. The authors considers the top 10 mm sand surface as the most active sand layer. Studies of the top 10 mm surface layer (Duncan, 1988) have shown 0.1 kg of organic carbon,  $10^{13}$  bacteria and  $10^7$  protozoa per square metre of surface area. The development of biological activity will have three principal roles. They are the entrapping and eliminating of unacceptable microorganisms, facilitating the breakdown of organic material from the water and also oxidising the ammonia to nitrate autotrophically.

The maturation period ends when bacteriological analysis indicates that the effluent quality reaches the local water quality standards (Visscher, *et al* 1987). The maturation process may take up to 40 days or even more (Ellis, 1985). Schmidt (1977) suggested a period of 40 days for the maturation of a new filter. The maturation period can be reduced with increasing temperature.

Towards the end of the maturation period, before the filtrate is put into the supply, tests should be carried out on the filtrate in order to make sure that physical, chemical and especially the bacteriological purification is being achieved. There should be no ammonia in the sample taken from the filtrate of a mature filter (Jain, 1975).

Aydin (1993) reported that during the maturation period, the filtrate quality measured in terms of total coliform content, faecal coliform content and suspended solid content, was found be independent of the number of days that the filters had been in operation. However, the turbidity removal improved gradually with the number of days that the filters had been in operation which was the only indication of developing maturation.

### 3.10 FILTER CLEANING

The length of the filter run between one filter cleaning and the next will depend upon a number of factors: on the rate of filtration, the size and uniformity of the sand bed, the quality of the water being filtered, and particularly on climatic conditions which greatly influence the development of algal blooms. A normal run will vary from situation to situation and might be anything from 30, 60 to 100 days or more (Ellis, 1985). Bed cleaning is necessary when, with the maximum water head above the sand and the outlet valve fully open, it is no longer possible to achieve the design flow rate. A significant degree of biological activity and biofilm development is reported throughout the undisturbed media after the surface cleaning process (Duncan, 1988; Eighmy, 1994). This is believed to contribute a rapid re-establishment of filter performance. More recently, on-line particle counters and rapid biological activity measurement using a field test for adenosine triphosphate(ATP) (Smith, 1994) have been used to ensure that SSFs maintain effective pathogens barriers following a surface cleaning procedure.

Van Dijk *et al* (1978) and Huisman and Wood (1974) suggested a sequence of five step filter cleaning procedures. These are as follow:

1. Close the inlet valve and allow the water level to drop by filtration, preferably overnight.
- 2, Drain off the remaining supernatant water by opening the valve situated just above the sand surface
3. Allow the water to drain about 200 mm below the sand surface.
4. Skim off about 25 mm of the accumulated schmutzdecke and associated sand.
5. Return the filter to operation.

Steps 2 and 4 should be carried out as quickly as possible, preferably in one day (Ellis, 1985). Burman (1978) suggested draining off the filter completely in order to prevent anaerobic conditions developing in the filter bed. However, draining the water down about 200 mm below the sand surfaces is commonly accepted practice (Ellis, 1985).



The filter is to be restarted at one quarter filtration rate with the filtrate water going to waste. After 12 hours, the filtration rate is to be increased to the design rate. After 12 more hours, the filtrate will be ready for consumption.

### **3.11 SAND WASHING**

The washing of the sand removed during the filter-skimming operation is commonly carried out immediately in order to prevent trouble associated with putrefaction and with bird scavenging and rodent feeding. However, at the Bristol Water Works Company in England the material which has been removed is allowed to stand for two months to allow the *schmutzdecke* to rot away, otherwise blocking difficulties are encountered in the sand washer (Ellis, 1985).

Sand washing is carried out employing a variety of techniques. The simplest of these is to use a sand washing platform consisting of a platform surrounded by a low brick wall and with a drainage facility over a low wooden weir. The operator applies a high pressure water jet on the sand in order to remove the dirt from the sand grains. The wash water containing a high suspension of removed dirt then flows away over the low weir while the clean sand remains on the platform.

### **3.12 RESANDING OF A FILTER**

Resanding becomes necessary when successive scrapings have reduced the thickness of the sand bed to 0.5m-0.6m. Huisman and Wood (1974) suggested a technique known as 'throwing over' for resanding of the filter bed. The initial step of this technique is to remove the top biologically active layer of the sand (*schmutzdecke* bed) down to a depth of 400 mm. This is then stored on one side while the required depth of new or cleaned sand is placed in position. Finally the biologically active initial sand is replaced as the top layer. In this way much of the biological activity is retained which results in a reduction of the rematuration period. The accumulation of fouling material at a deeper level of the sand bed is avoided by this technique.

Burman (1978) has pointed out that resanding should be carried out as quickly as possible and during the coldest season of the year. These he suggested as being necessary because when the water is drained from the sand bed the microorganisms attached to the sand grains find nutrient material to be in short supply and hence these microorganisms become more oxidative in nature and begin to use the bacterial gums by which the bacteria are attached to the sand. As a result many bacteria will be freed from the grains to be washed through with the filtrate when the filter is restarted. This effect will be increased with lengthier interruptions and higher temperatures.

### **3.13 HIGH TURBIDITY PROBLEM**

The major limitation of slow sand filters is that they are not suitable for high turbid water. High turbidity causes a reduction in the length of the filter run resulting in an increase of maintenance costs. The maximum acceptable turbidities of raw water for slow sand filters have been suggested as being between 10-30 NTU (Cox, 1969; Huisman and Wood, 1974; Thanh *et al*, 1982 and Paramasium *et al*, 1982). Huisman and Wood, (1974) has pointed out that higher turbidities of up to 120 NTU can be tolerated for 1 or 2 days without major effect.

Turbidity as a parameter for assessing the acceptability of water for slow sand filters has been questioned as water turbidity may be caused by colloids and dissolved material as well as by suspended solids. However, it is only the suspended solids content which has any effect on the development of headloss in slow sand filters. Hence it was suggested that the suspended solids concentration is a more useful parameter by which to judge the quality of the raw water applied to slow sand filters than is turbidity.



A number of techniques can be employed for reducing high turbidities in the source of water down to a level acceptable to slow sand filters. The available techniques for pre-treatment are as follows:

- Infiltration wells and galleries
- Storage
- Plain sedimentation
- Upflow roughing filters
- Horizontal flow gravel filters
- Chemical pre-treatment
- Rapid sand filters
- Coarse filtration at the river bed
- Roughing filtration by pebble matrix.

### **3.14 EFFECTS OF ALGAE ON SLOW SAND FILTERS**

The effects of algae on the operation and efficiency of a slow sand filter are various. According to Ellis (1985) these effects are as follows:

- Over-early blocking of the filter
- Production of taste and odour
- Increase in the concentration of soluble and biodegradable products of metabolism i.e. increasing the biological oxygen demand
- increased difficulties associated with filter cleaning
- Difficulties and benefits associated with the precipitation of calcium carbonate or increased pH
- The development of anoxic conditions.

### **3.15 INTERMITTENT OPERATION OF SLOW SAND FILTRATION**

It is often undesirable to run the slow sand filter through 24 hours, principally because of the lack of trained operators. In that case it is normal to close down the filtration process overnight for a period of several hours. If both inlet and outlet valves are closed overnight, the water in the supernatant reservoir becomes stagnant. The lower

level of the water is in contact with a highly biological active sand surface for an appreciable period which causes the total removal of dissolved oxygen at this level and subsequent development of anaerobic activity occurs. Anaerobic activity creates unpleasant tastes and odours in the filtrate water, but most importantly, Paramasivam *et al* (1980) suggest that a substantial deterioration in the bacterial removal efficiency occurs, following the start-up of the filter. The disadvantages of an overnight shutdown can be minimised if only the inlet valve is closed while the outlet valve is left open. For this case water will be continuously flowing at a declining rate during the shutdown period which avoids the creation of anoxic conditions. The outlet weir should be raised to 200 mm above the sand surface to prevent drying out of the sand surface.

### **3.16 COMMENTS**

This chapter has summarised the various aspects of SSFs including the fundamental theory, design, installation, operation and maintenance. The effects of various process variables have also been summarised. The contents of this chapter will be of particular use for the development and operation of the laboratory scale SSF for the experimental investigation. It will also be useful for the necessary alteration/improvement of the filter plant to enhance the removal performance.

The development of the filter plant and experimental programme will be covered in the following chapter of the thesis.



## **CHAPTER 4**

### **EXPERIMENTAL SET-UP**

#### **4.1 INTRODUCTION**

The present research was carried out in two stages: initially the development of the apparatus and then the experimental investigation. The development of the apparatus involved the preparation of the model slow sand filter infrastructure, sand and gravel media, underdrainage system, flow control arrangement, selection of variables and arrangements for feed water. The experimental investigation comprised of two phases. The first phase was the maturation period of the filters. The second phase of the investigation involved the operation of the filters for various variables, batch experiments, analysis and evaluation of test results. This chapter is mainly concerned with the experimental development of the research.

#### **4.2 DEVELOPMENT OF THE EQUIPMENT**

##### **4.2.1 The Slow Sand Filter Infrastructure**

To carry out the experimental investigation, four separate laboratory scale slow sand filters were constructed. The filters are of 60 mm diameter and are divided into two sections and flange jointed in the middle to make scraping the sand possible. The filters are fed from individual overhead tanks containing different heavy metals salts. Four influent tanks are fixed at the top to maintain gravity flow. Salts of Cd, Cr, Pb and Cu are mixed in each of the tanks. The overhead tanks are fed from a single common tank at the bottom. Sewage was added to this tank content to maintain various levels of organic load (TOC) to represent various grades of water quality. The schematic layout of the filter set-up is shown in fig 4.1.

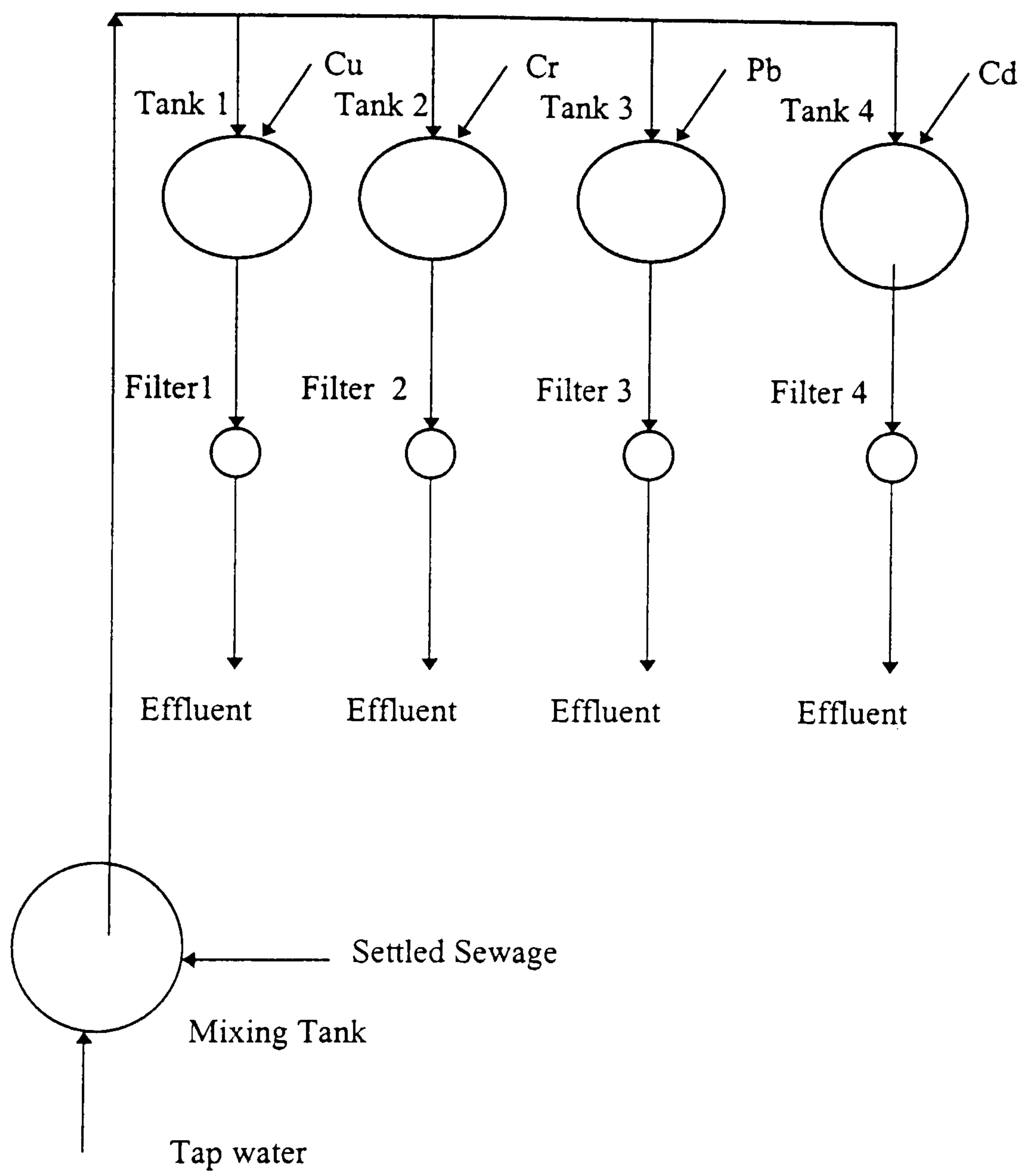


Figure 4.1 Schematic layout of the laboratory filter plant



Plate 1 shows the four filters. Details of one of the filter columns and tank arrangements are shown in Figure 4.2. The various features of the arrangement are described below.

1. Influent pipe for the tank. The pipe is fitted with a ball valve to avoid overflow.
2. Stirrer is fitted with a motor. Arrangements are made to keep the motor above the tank and vibrations from the motor should not reach the filter column.
3. 6 mm inside diameter tapping fitted at the side of the tank. The tapping will be used to feed the individual tank. The tapping is attached to a flexible tube (4) to feed the filter.
4. Flexible tube to feed the filter.
5. A float valve to provide constant head in the supernatant water.
6. 1200 mm high supernatant transparent water column.
7. 1500 mm high filter column containing sand and gravel.
8. Overflow tube of 6 mm internal diameter
9. Quick drain tube of 6 mm internal diameter.
10. Flanges of the supernatant water column and the filter column are bolted together.
11. Outlet tube of 3 mm internal diameter. A flexible tube (12) is fitted to this tube. No valve is required to control the flow.
12. Flexible tube attached to (11).
13. A small square wooden board holding the tube (12).
14. A threaded rod holding the board (13).
15. Handle to rotate the rod to move tube (12) up and down.
16. Sampling point.
17. Funnel to collect the effluent. Arrangements should be made to vary the height of the funnel to catch flow from (16).
18. Effluent tube.
19. Funnel to collect water from (8) and (9).
20. Temperature probe of the thermostat to keep the temperature fixed at 20°C.
21. Sampling tap fitted at 0.4 m of filter depth.
22. Sampling tap fitted at 0.8 m of filter depth.



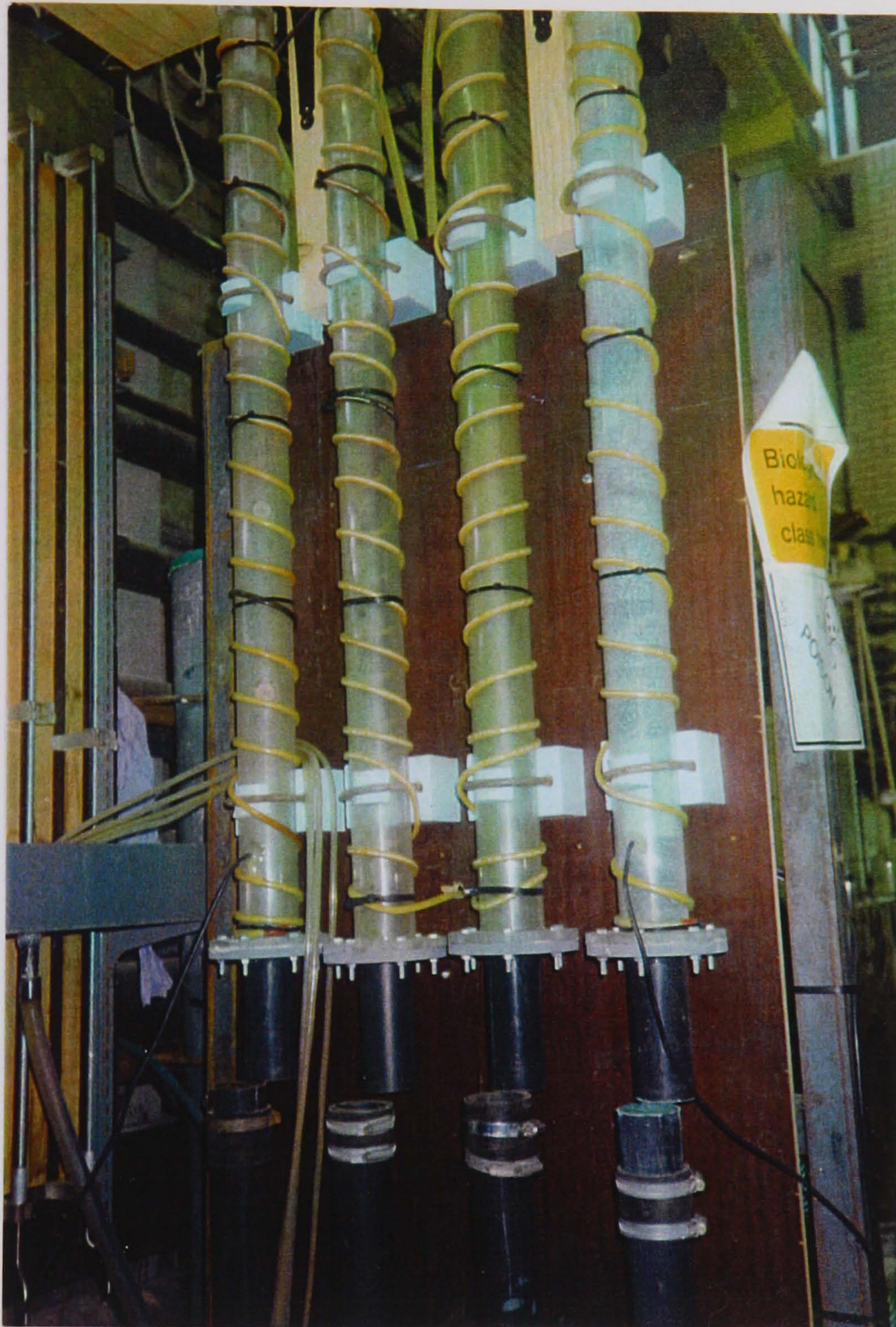


Plate 1: Arrangement of four filters



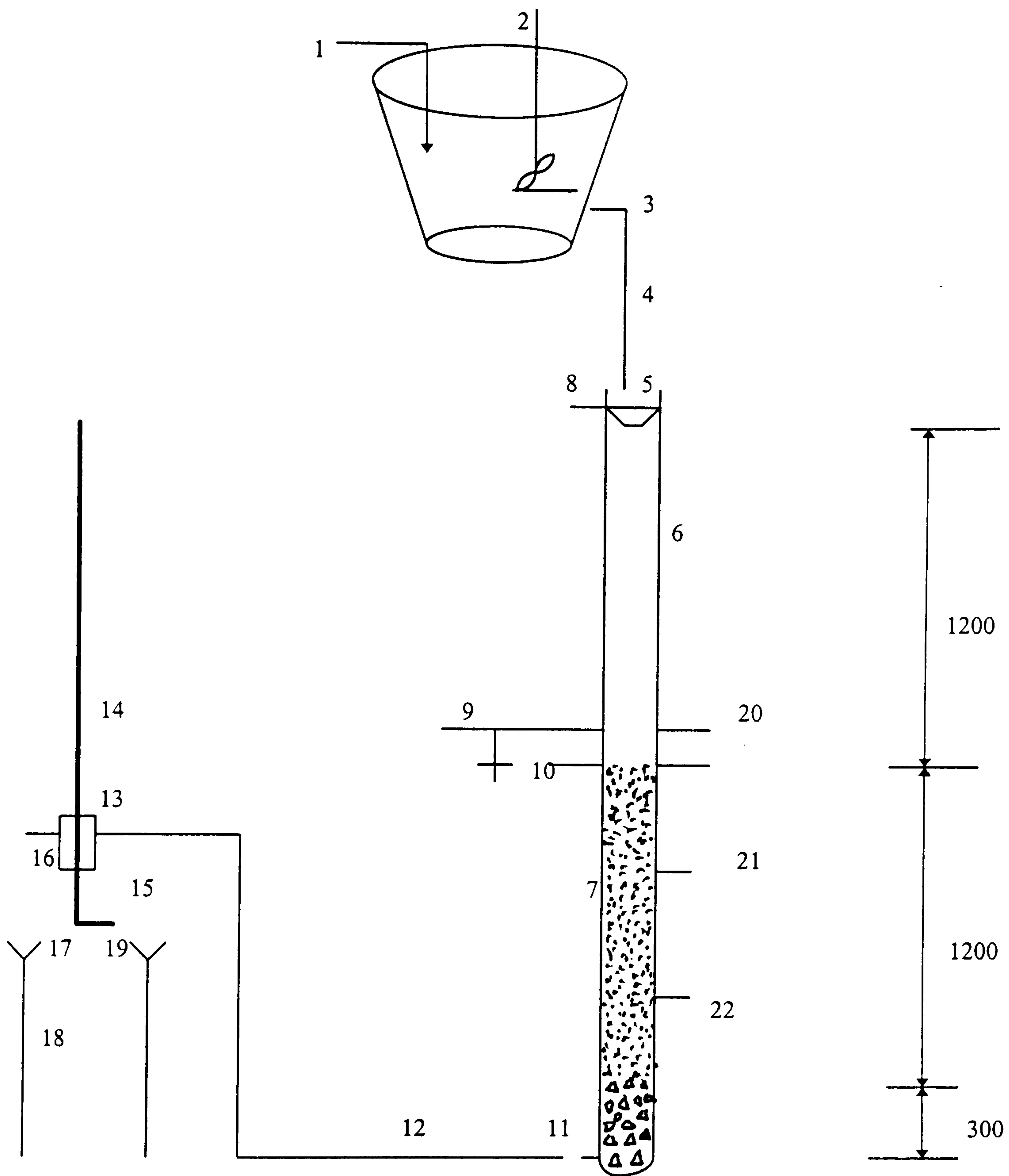


Figure 4.2 Details of a filter (numbers refer to descriptions in the text)

## **4.2.2 Inlet and Outlet Control**

Critical thought was given to selecting the inlet and outlet arrangements. Several options were considered for selection.

### **4.2.2.1 Inlet Arrangement**

#### **1) By means of a manually operated tap attached to the influent pipe.**

This is a very simple arrangement. The main problem associated with this arrangement however is that the water level in the tank falls down causing a decrease in the head for the flow. The flow rate will decrease gradually which needs to be adjusted daily.

#### **2) By means of siphon:**

Siphons can be used to feed the filter at uniform rate. By varying the position of the siphon end, flow can be adjusted. This is a more precise method of feeding the filters.

The problems associated with this method are as follows:

- air bubbles in the siphon may affect the flow rate
- small variations in the position of the siphon head cause considerably higher variations in the flow rate
- temperature variations cause the variation of viscosity of water which affects the flow rate.

#### **3) By means of peristaltic pumps:**

Peristaltic pumps are normally used for constant feeding of the filter at lower rates. The problem associated with this method is the damage of the pump tube. Silicon rubber tubes are very vulnerable to damage especially for very long term experimental studies. A stand by pump must be arranged if peristaltic pumps are used for constant feeding.

#### **4) By means of float valves:**

A simple float valve can be used for maintaining a constant head in the filter column. In this case the flow should be adjusted at the outlet only. The float should be able to stop the flow completely and to slide easily in the filter column.



Among all these four operations, a float valve was selected for the project because of its simplicity and capacity for maintaining a constant head automatically. In this method the added advantage is that the flow needs to be adjusted at the outlet only.

#### **4.2.2.2 Outlet Arrangement**

##### **1) Adjustable tap**

Flow can be adjusted by means of a manually operated tap. The outlet weir is generally fixed at a depth 100 mm above the sand bed. The rate of flow is adjusted every day by means of opening the tap gradually. This is a very simple arrangement, but the main problem associated with this method is that every day adjustment of the tap causes vibration of the filter column and fluctuation of flow which affects the filtrate quality.

##### **2) Adjustable head outlet weir**

In this method, the outlet weir is fitted with a rod which can be lowered or raised by rotating a handle. The variation in the height of the outlet weir causes a variation in head causing flow. The outlet weir position is adjusted depending upon the required rate of flow. The advantages of this method are as follow:

It is not necessary to keep a tap at the outlet tube which avoids the fluctuation of flow

The whole outlet arrangement can be fixed on another board away from the filter which avoids vibration of the filter column.

Considering the mentioned advantages of the adjustable head outlet weir, it was selected for the project. The outlet arrangements by adjustable head outlet weir are shown in plate 2.





Plate 2 : Adjustable head outlet weir.



### **4.2.3 Addition of Heavy Metal Salts**

The following approaches of feeding the filters by metal salts were considered.

#### **1) Adding certain amount of metal salts for a specific period**

In this approach a central feeder tank is used in which suspensions are added and individual tank is installed to feed the filter. A certain amount of metal salts is added to each tank for a certain period. The advantage of this approach is that in practical situations, pollution occurs in this way.

#### **2) Drip feeding by Marriott jar**

Another way of adding metal salts is by drip feeding by a Marriott jar. A Marriott jar can deliver the liquid at a very low rate. In this approach, a considerable amount of time must be provided for the equilibrium condition to be reached. If a float valve is used for the inlet arrangement, a considerable amount of heavy metals are absorbed by the float valve.

#### **3) By using a peristaltic pump**

A peristaltic pump may be used for adding metal salts. The dose considered for the proposed project was too low for peristaltic pumps and also there is a chance of frequent damaging of the silicone tube.

Considering the relative advantages and disadvantages of the methods approach 1, with the addition of metal salts directly into the tank was selected for the project.

### **4.2.4 Filter Media**

Leighton Buzzard sand of ES (described in chapter 3) of 0.32 and UC (described in chapter 3) of 1.56 has been used for this project. The specifications of the sand obtained from the supplier were as follows:

Grade → 0.71 – 0.25 mm (No 21)

Nominal effective size range → 0.25 – 0.39 mm

Mean uniformity coefficient → less than 1.7

The sieve analysis of the sand was performed in the laboratory and a particle size distribution curve was plotted. Table 4.1 and Figure 4.3 show the sieve analysis and particle size distribution of the sand.. The sand bed depth for all the filters is 1.2m.

TABLE 4.1: Showing data for sieve analysis of the sand

Weight of sand = 1000 gm

Sieve Size	Weight of sand retained (gm)	% Retained	Cumulative % retained	% Passing
1.18 mm	0	21.18	0	100.00
600 µm	31.8	62.05	3.18	96.82
425 µm	620.5	26.08	65.23	34.77
300 µm	258.8	5.64	92.11	7.89
212 µm	546.4	1.89	97.75	2.25
150 µm	18.9	0.36	99.64	0.36
63 µm	3.6	0	100.00	0
Pan	0		100.00	0
	1000			

From figure 4.3,

$$d_{10} = \text{Effective Size (ES)} = 0.32 \text{ mm}$$

$$d_{60} = 0.50 \text{ mm}$$

$$\text{Hence Uniformity Coefficient (UC)} = d_{60}/d_{10} = 1.56$$

#### 4.2.5 Gravel Media and Underdrainage System

The purpose of providing gravel media and underdrainage system is described in chapter 3. A layer of 300 mm gravel of different sizes was used for the model filter (figure 4.2). The finest and coarsest gravel are placed on the top and bottom of the layer respectively. The range of different sizes of gravel is shown in Table 4.2.



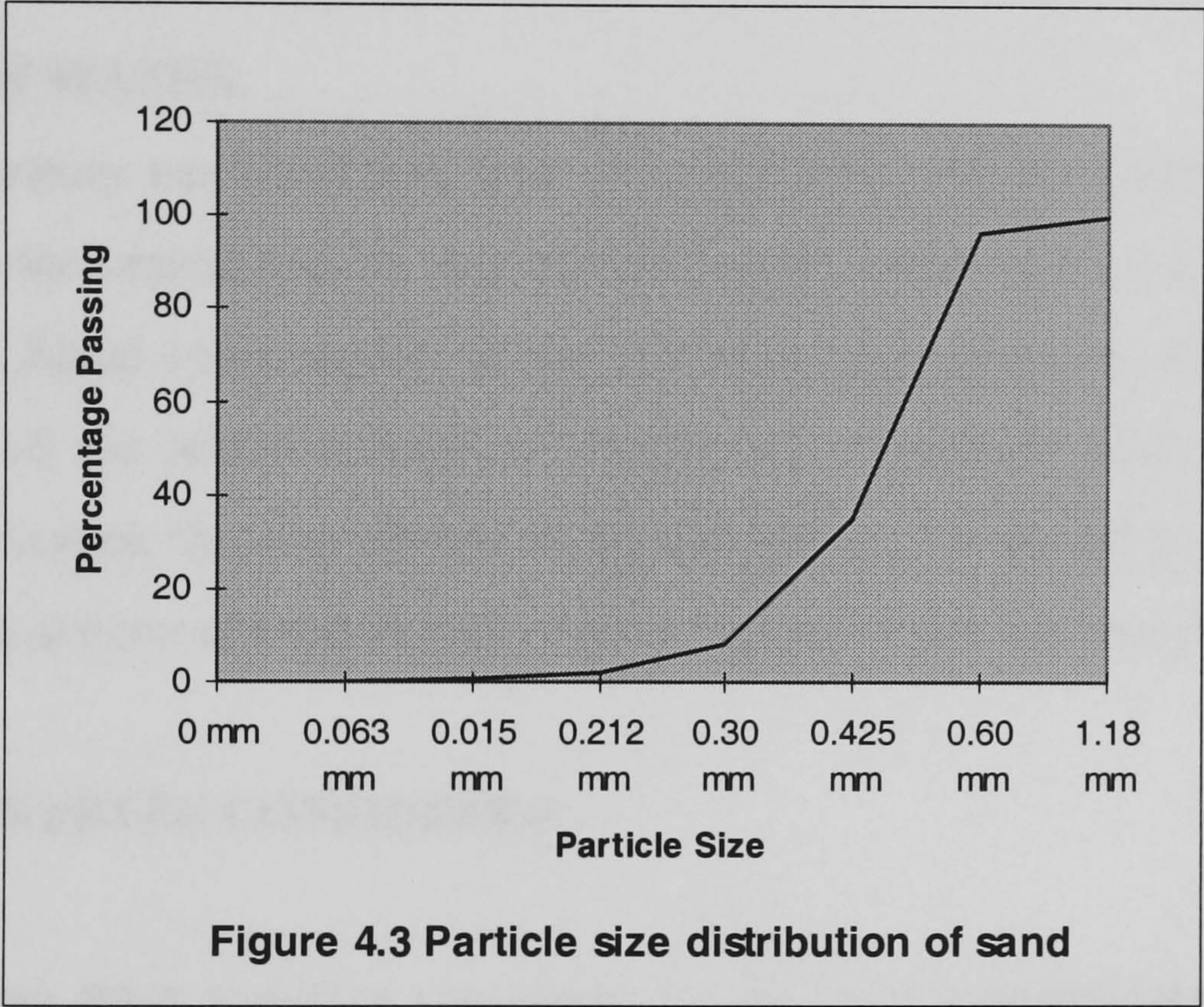




TABLE 4.2: Gravel size distribution

Size of Gravel (mm)	Depth (mm)
1.18	40
3.35	50
5.00	70
10.00	70
14.00	70
	300 mm

4.3 RAW WATER

The laboratory tap water was used as a feed water for the filters. Settled sewage was added to the central tank to vary the TOC of the water and to add turbidity to the tank contents. Metal concentration of the raw water was regularly monitored just after the addition of the settled sewage to identify any accidental metal pollution (during the experimentation this was always found negligible). The turbidity, TOC and FC content were also monitored for every set of experiments (results are described in chapter 5).

4.4 VARIABLES CONSIDERED

There were three variables considered for the main experimental investigations. They were as follows :

- Flow rates
- Organic loading (in terms of TOC)
- Filter bed depth.

Four different flow rates of 0.1m/hr, 0.2 m/hr, 0.3 m/hr and 0.4 m/hr were considered. As the initial experimental results showed very good removal of all four heavy metals at a conventional flow rate of 0.1 m/hr, a further decrease in flow rate was not considered. Flow rates exceeding 0.4 m/hr are not normally considered for conventional slow sand



filters.

Three different TOC of 4 mg/l, 8 mg/l and 12 mg/l were considered as a measure of organic loading. Although the organic loading of the surface water mainly depends on the degree of pollution, the highest level of TOC was considered as 12 mg/l to avoid excessive turbidity for slow sand filtrations. Filters were run at all four flow rates for each level of TOC.

To investigate the influences of filter bed depths on the removal of heavy metals by slow sand filters, samples from the depth of 0.4m, 0.8m and 1.2m (only sand bed depth is considered) were taken and monitored. Simple taps were inserted to the filter bed at 0.4 m and 0.8 m depth.

#### **4.5 STOCK SOLUTIONS AND DOSE CONSIDERED**

The salts of four metals Cu, Cr, Pb and Cd used were as follows :

Copper Nitrate	$\text{Cu}(\text{NO}_3)_2$
Chromium Nitrate	$\text{Cr}(\text{NO}_3)_3$
Lead Nitrate	$\text{Pb}(\text{NO}_3)_2$
Cadmium Sulphate	$\text{CdSO}_4$

The metal salts were selected considering their highest solubility in water. The stock solutions of all these four metal salts were prepared at a concentration of 500 mg/l.

The doses of Cu, Cr, Pb and Cd were selected as 10 mg/l, 100 µg/l, 60 µg/l and 100 µg/l respectively. The doses are selected considering the WHO guidelines for acceptable limits of all those metals in drinking water. The WHO limit of Cu, Cr, Pb and Cd are 2 mg/l, 50 µg/l, 10 µg/l and 3 µg/l respectively.

## **4.6 COMMISSIONING AND MATURATION OF THE FILTERS**

### **4.6.1 Commissioning of the Filters**

The filters were commissioned by filling them from the bottom by means of a peristaltic pump. When the water level was 200 mm above the sand level, the inlet valve was opened to fill the supernatant water column. The filters were at first run at 0.05 m/hr for four days, then the rate of flow was increased to 0.1 m/hr and was maintained at this rate for the whole maturation period.

### **4.6.2 Maturation of the Filters**

After commissioning of the filters a period of one week was allowed for the filter beds to settle down. Metal salts were not added during the maturation period. Settled sewage was added to the influent to maintain a TOC level of 8-10 mg/l to provide a reasonable organic and turbidity level. It also provided a certain level of faecal coliform in the influent TOC. Faecal coliform count, turbidity and  $\text{NH}_4\text{-N}$  (ammoniacal nitrogen) content were selected as the parameters for testing the maturation of the filters. In selecting the maturation period, the following criteria were considered:

- a consistent removal of TOC, turbidity, faecal coliform and  $\text{NH}_4\text{-N}$
- the removal of  $\text{NH}_4\text{-N}$  was expected to be 100%
- the effluent turbidity should be  $<1$  NTU

Table 4.3 describes the experimental results during the maturation period. Table 4.4 describes the summary of the average removal of turbidity, TOC, faecal coliform and  $\text{NH}_4\text{-N}$  content. As the filters were identical, influent was the same and metals were not added, the average removal was considered. In this report  $F_1$ ,  $F_2$ ,  $F_3$  and  $F_4$  indicate filters containing heavy metals, Cu, Cr, Pb and Cd respectively.

The removal of faecal coliform and  $\text{NH}_4\text{-N}$  compound was very high from the beginning of the maturation period. Although the removal efficiency of faecal coliform was very high, the effluent contained a considerably high number of faecal coliform for the first



Date	Filter	Turbidity (NTU)			TOC (mg/l)			Faecal Coliform (No/100 ml)			NH <sub>3</sub> Content (mg/l)			Remarks
		Influent	Effluent	% Removal	Influent	Effluent	% Removal	Influent	Effluent	% Removal	Influent	Effluent	% Removal	
28.11.95	F1	8	2	75	10.51	4	61.9	-	-	-	-	-	-	
	F2	8	2	75	11.3	5	55.8	-	-	-	-	-	-	
	F3	7	2	71.4	9.95	4.365	6.1	-	-	-	-	-	-	
	F4	8	2	75	10.63	4.96	53.4	-	-	-	-	-	-	
5.12.95	F1	4.5	1	77.8	9.32	4.6	50.6	2x10 <sup>3</sup>	150	99.93	1.08	0.055	99.5	
	F2	4	0.92	76.8	8.5	4.25	50	2x10 <sup>3</sup>	170	99.92	1.08	0.005	99.5	
	F3	4.5	1.5	66.7	8.12	4.31	46.9	2x10 <sup>3</sup>	146	99.93	1.08	0.005	99.5	
	F4	4	1	75	8.75	4.152	52.5	2x10 <sup>3</sup>	160	99.92	1.08	0.005	99.5	
11.12.95/ 14.12.95	F1	8.3	0.67	91.9	8.6	3.51	58.3	2.34x10 <sup>3</sup>	160	99.94	1.08	0	100	
	F2	8.3	0.69	91.7	8.73	3.67	57.9	2.34x10 <sup>3</sup>	150	99.94	1.08	0	100	
	F3	8.4	0.83	90.2	8	3.47	56.7	2.34x10 <sup>3</sup>	150	99.94	1.08	0	100	
	F3	8.1	0.58	92.8	8.46	4.02	52.5	2.34x10 <sup>3</sup>	160	99.94	1.08	0.005	99.5	
19.12.95/ 20.12.95	F1	12	0.62	94.8	-	-	-	1.95x10 <sup>3</sup>	20	99.99	1.08	0	100	TOC machine out of order.
	F2	12	0.57	95.3	-	-	-	1.95x10 <sup>3</sup>	0	100	1.08	0	100	
	F3	12	0.43	96.4	-	-	-	1.95x10 <sup>3</sup>	0	100	1.08	0	100	
	F4	12	0.65	94.6	-	-	-	1.95x10 <sup>3</sup>	0	100	1.08	0.005	99.5	
28.12.95	F1	10.62	0.62	94.2	-	-	-	1.2x10 <sup>3</sup>	2	100	0.36	0	100	TOC machine out of order
	F2	10.62	0.95	91.1	-	-	-	1.2x10 <sup>3</sup>	0	100	0.36	0	100	
	F3	10.62	0.53	95	-	-	-	1.2x10 <sup>3</sup>	0	100	0.36	0	100	
	F4	10.62	0.73	93.1	-	-	-	1.2x10 <sup>3</sup>	10	99.99	0.36	0	100	
15.1.96	F1	11	0.6	94.5	12	4.129	65.6	1.4x10 <sup>3</sup>	10	99.99	0.36	0	100	End of maturation
	F2	11	0.83	92.5	12	4.42	63.7	1.4x10 <sup>2</sup>	4	100	0.36	0	100	
	F3	11	0.64	94.2	12	5	58.3	1.4x10 <sup>3</sup>	0	100	0.36	0	100	
	F4	11	0.71	93.5	12	5	58.3	1.4x10 <sup>3</sup>	0	100	0.36	0	100	

two weeks. After three weeks, the removal of faecal coliform improved to almost 100% and the effluent contained a negligible number of faecal coliform and the removal was consistent for the rest of the three week maturation period.

TABLE 4.4    Summary of the percentage removal efficiency of SSF in treating different parameters of water during the maturation period (Figures in the bracket indicates days)

Date	Turbidity	TOC	Faecal Coliform	NH <sub>4</sub> -NContent
28.11.95(1)	74.0	56.8	-	-
05.12.95(7)	74.0	50.0	99.93	99.5
11.12.95(14)	91.7	56.4	99.94	99.9
19.12.95*(22)	95.3	-	100.00	99.9
29.12.95(32)	93.4	-	100.00	100.0
15.01.96(49)	93.8	61.5	100.00	100.0

The removal of NH<sub>4</sub>\_N compounds was very high for the first two weeks but some of the filters contained minor amounts of NH<sub>4</sub>\_N. The removal was 100% from the fourth week of maturation and it remained consistent for the rest of the maturation period.

The removal of turbidity improved gradually from the third week of the maturation period and remained consistent for the remaining period of maturation. The turbidity of effluent for all the filters was less than 1 NTU from the third week of maturation.

The removal of TOC was 50-56% for the first three weeks. At the end of seven weeks, the removal efficiency improved to 61%.

After four weeks, the removal efficiency of turbidity, faecal coliform and NH<sub>4</sub>-N compound was very high and the NH<sub>4</sub>-N removal was 100%. Only TOC removal was comparably low but consistent. So the maturation period may be considered as four



weeks. However as the TOC machine was out of order, there was a further three week delay to investigate the improvement in removing TOC. At the end of seven weeks, the TOC removal improved to 61%. So the maturation period is considered as seven weeks. This agrees with the recommendations of previous researchers, such as Ellis (1985) and Schmidt (1977).

#### **4.7 OVERVIEW OF THE EXPERIMENTAL INVESTIGATIONS**

The experimental investigations consisted of three different stages: (i) maturation period of the filters (already discussed in section 4.6.2), (ii) testing of the process variables and (iii) exploration of the mechanisms of removal.

After a certain maturation period, the filters were run to evaluate the efficiency of the SSF in removing heavy metals. Different process variables were tested to identify the effects of these variables with a view to optimising the parameters and also to predict the mechanisms of removal. Chapter 5 of this report describes the detailed test results, analyses the data and discusses the influence of the process variables.

The third and final stage of the investigation consisted of the evaluation of the mechanisms of heavy metal removal by SSF. A critical explanation of the test results regarding the process variables was carried out to predict the mechanisms of removal. It was observed that heavy metal removal was achieved through the combination of a number of mechanisms. Adsorption of heavy metals onto sand and organic matter, microbial uptake and settlement were predicted as the probable mechanisms of removal.

Batch adsorption tests of heavy metals on to sand were carried out with a view to identify whether it satisfies the Langmuir and Freundlich isotherms and also to explore the maximum adsorption capacity of sand with respect to different heavy metals. Chapter 6 describes the results of batch adsorption tests.

Experimental investigations regarding the settlement of heavy metals were carried out by

means of keeping the certain amount of influent water without stirring and measuring the concentration at different time and at various pH. The results are summarised in chapter 7.

Investigation into the microbial uptake of heavy metals was carried out by means of a comparison of the accumulation of heavy metals in the schumtzdecke and the associated amount of biomass. The details of the investigation are summarized in Chapter 8.

Speciations of the accumulated metals in SSF beds were carried out for further investigation into the mechanisms of removal and also to find out the relative importance of the associated mechanisms. Chemical speciations of the heavy metals in the SSF bed were carried out by using Stover method (Stover *et al*, 1977 ). Chapter 9 describes the details of this method of speciation and the results.

#### **4.8 EQUIPMENTS USED FOR MONITORING THE WATER QUALITY.**

All the water quality parameters were measured by the standard methods (AWWA, 1986). The instruments used for the measurements are mentioned briefly in this section.

##### **4.8.1 Measuring Metal Concentrations.**

Inductively coupled plasma method of spectrophotometry (ICP) was selected to monitor the metal concentrations of the influent and effluent. ICP model “Atom Scan 16” manufactured by an US company “Thermo Jarrell Ash” was used for the present research.

##### **4.8.2 Measurement of TOC**

The TOC of the influent and effluent was monitored by using the total organic carbon analyzer model “Rosemount Dohrman DC-190”, an instrument of the “Sartec Analytical System” UK ltd.



#### **4.8.3 Measurement of Turbidity**

The turbidity was monitored by using a HACH turbidity meter of CAMLAB model-43900.

#### **4.8.4 Miscellaneous Instruments**

A pH stick of model no pHep2 was used to measure the pH of the influent and effluent. Faecal coliform count was carried out by means of membrane filtration method. Flask shaker of model “GALLENKAMP” was used to shake the flask for batch adsorption tests. Kjeldahl system of distillation unit was used for the measurement of total nitrogen.  $\text{NH}_4\text{-N}$  was measured by using “Palintest Photometer-5000”.

# **CHAPTER 5**

## **EXPERIMENTAL INVESTIGATION: INFLUENCES OF PROCESS VARIABLES**

### **5.1 INTRODUCTION**

The results of the main experimental investigations regarding the heavy metal removal by SSF and the influences of process variables are presented in this chapter. The filters were run for all the four flow rates (0.1, 0.2, 0.3 and 0.4 m/hr) at each TOC level (4, 8 and 12 mg/l). Samples were monitored for all three depths (4, 8 and 12 mg/l) at each TOC and each flow rate. The inductively coupled plasma (ICP) of spectrophotometry was used to measure the metal concentration. The performance of the filters was evaluated using the percentage removal criteria as a measure of efficiency. The average performance was calculated using the results from three sets of results. Each set of tests continued for one week. The percentage removal of heavy metals was the main item under investigation. Percentage removal of faecal coliform (FC), TOC, turbidity and the variation of pH were also monitored for further information to evaluate the filtration efficiency and filter response at different test conditions with heavy metals in water. The results were compared with WHO guidelines of the selected parameters. Optimisation of the process variables was carried out by considering the highest removal and TOC of the influent water. The correlation equations were developed relating the percentage removal of the selected heavy metals and SSF process variables. The statistical analysis of the test data was carried out using the package Excel-5 in Windows 3.11.

### **5.2 EXPERIMENTAL RESULTS**

Annex 1 describes the test results regarding the effects of the process variables (flow rates, filter depths and TOC). The standard deviations and comparison of test data at 95% confidence range are also shown along with the test results. A summary of the test results is shown in the following text.



### **Heavy Metal Test Results**

Tables 5.1, through to 5.12 describe the summary of the percentage removal of heavy metals by different filters at various TOCs, flow rates and filter depths. Figures 5.1, through to 5.12 describe the comparison of the percentage removal of different heavy metals at various test conditions. The general trend of the results shows that the removals of Cu and Cr were always higher than that of Pb and Cd. The removal of all four metals increases with increase of TOC. Removals of Pb and Cd were shown to be more vulnerable to process variables.

### **TOC Test Results**

Tables 5.13 through to 5.16 describe the summary of the removal of TOC by different filters at various influent TOC levels at flow rates of 0.1 m/hr, 0.2 m/hr, 0.3 m/hr and 0.4 m/hr respectively. Figures 5.13 through to 5.16 show the comparison of the removal of TOC by different metal containing filters.

### **Turbidity Test Results**

Tables 5.17 through to 5.20 describe the summary of the removal of turbidity by different filters at various TOCs and flow rates. Figures 5.17 through to 5.20 describe the comparison of the removal of turbidity by different metal containing filters.

### **FC Test Results**

Tables 5.21 through to 5.24 describe the summary of the removal of faecal coliform by different filters at various TOCs and flow rates. Figures 5.21 through to 5.24 describe comparison of the number of faecal coliform/100 ml in the effluent of various metal containing filters. The percentage removals were almost same for all the filters at various test conditions. Hence the numbers of the faecal coliforms per 100 ml were considered for comparison.

### **pH Test Results**

Tables 5.25, 5.26, 5.27 and 5.28 describe the drop in pH in the effluent of different metal containing filters.

Table 5.1: Variation of % removal efficiencies of heavy metals at various TOC levels at the flow rate of 0.1 m/hr and at 1.2m of depth (Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	98.2 (0.07)	98.6 (0.20)	99.6 (0.58)
F <sub>2</sub> /Cr	96.7 (0.46)	97.0 (0.25)	97.2 (0.64)
F <sub>3</sub> /Pb	90.6 (1.04)	94.2 (1.27)	100.0 (00)
F <sub>4</sub> /Cd	94.0 (2.23)	96.2 (0.17)	96.6 (0.35)

Table 5.2: Variation of % removal efficiencies of heavy metals at various TOC levels at the flow rate of 0.2 m/hr and at 1.2m of depth.(Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	97.6 (0.17)	97.8 (0.17)	98.3 (0.45)
F <sub>2</sub> /Cr	96.5 (0.42)	97.0 (0.71)	97.2 (0.67)
F <sub>3</sub> /Pb	84.9 (0.78)	88.7 (1.41)	92.7 (2.27)
F <sub>4</sub> /Cd	88.3 (1.08)	91.0 (1.32)	92.4 (3.12)

Table5.3: Variation of % removal efficiencies of heavy metals at various TOC levels at the flow rate of 0.3 m/hr and at 1.2m of depth.(Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	97.2 (0.16)	97.5 (0.17)	97.8 (0.17)
F <sub>2</sub> /Cr	95.7 (0.59)	96.1 (1.18)	95.8 (0.72)
F <sub>3</sub> /Pb	81.6 (1.14)	83.0 (1.56)	91.6 (1.35)
F <sub>4</sub> /Cd	82.9 (0.42)	85.9 (2.21)	88.4 (0.93)

Table 5.4: Variation of % removal efficiencies of heavy metals at various TOC levels at the flow rate of 0.4 m/hr and at 1.2m of depth. (Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	96.9 (0.45)	97.1 (0.36)	97.3 (0.17)
F <sub>2</sub> /Cr	94.0 (0.40)	94.6 (0.00)	95.1 (0.12)
F <sub>3</sub> /Pb	62.9 (1.29)	66.6 (0.10)	70.4 (1.32)
F <sub>4</sub> /Cd	53.4 (1.52)	64.9 (3.86)	68.1 (0.70)



Table 5.5: Variation of % removal efficiencies of heavy metals at various TOC levels at the flow rate of 0.1 m/hr and at 0.8m of depth.(Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	98.1(0.25)	98.6(0.12)	99.4(0.33)
F <sub>2</sub> /Cr	95.5(1.40)	96.3(0.17)	97.0(0.485
F <sub>3</sub> /Pb	89.4(1.83)	91.3(1.68)	95.9 (3.20)
F <sub>4</sub> /Cd	87.5(1.12)	88.5(0.14)	89.3(1.30)

Table 5.6: Variation of % removal efficiencies of heavy metals at various TOC levels at the flow rate of 0.2 m/hr and at 0.8m of depth. (Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	97.6(0.16)	97.9(0.10)	98.4(0.44)
F <sub>2</sub> /Cr	95.4(0.36)	95.7(0.60)	96.4(0.54)
F <sub>3</sub> /Pb	62.9(1.25)	78.7(2.15)	86.9 (4.40)
F <sub>4</sub> /Cd	73.7(1.74)	76.6(2.67)	78.3(5.00)

Table 5.7: Variation of % removal efficiencies of heavy metals at various TOC levels at the flow rate of 0.3 m/hr and at 0.8m of depth. (Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	97.3(0.32)	97.7(0.20)	97.7(0.44)
F <sub>2</sub> /Cr	95.2(0.81)	95.2(0.17)	95.0(1.62)
F <sub>3</sub> /Pb	55.1(1.95)	66.8(3.50)	87.3(1.40)
F <sub>4</sub> /Cd	54.5(3.82)	67.4(1.70)	65.0(2.00)

Table 5.8: Variation of % removal efficiencies of heavy metals at various TOC levels at the flow rate of 0.4 m/hr and at 0.8m of depth (Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	96.8(0.36)	97.1(0.20)	97.3(0.47)
F <sub>2</sub> /Cr	93.4(0.31)	93.6(0.49)	93.9(0.78)
F <sub>3</sub> /Pb	54.3(1.38)	58.3(3.92)	62.4 (0.64)
F <sub>4</sub> /Cd	39.2(3.63)	52.0(2.76)	59.0(0.44)

Table 5.9: Variation of % removal efficiencies of heavy metals at various TOC levels at the flow rate of 0.1 m/hr and at 0.4m of depth. (Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	97.2(0.72)	97.9(0.10)	98.5(0.63)
F <sub>2</sub> /Cr	94.7(1.93)	95.9(0.15)	96.3(0.77)
F <sub>3</sub> /Pb	82.2(1.64)	85.9(0.53)	78.2(2.30)
F <sub>4</sub> /Cd	68.0(4.40)	71.6(1.00)	73.1(3.10)

Table 5.10: Variation of % removal efficiencies of heavy metals at various TOC levels at the flow rate of 0.2 m/hr and at 0.4m of depth. (Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	96.8(0.16)	97.0(0.10)	97.5(0.66)
F <sub>2</sub> /Cr	94.2(0.26)	94.8(0.48)	95.8(0.50)
F <sub>3</sub> /Pb	47.0(1.00)	65.4(5.84)	65.0 (3.02)
F <sub>4</sub> /Cd	66.4(0.95)	72.3(3.33)	73.6(0.90)

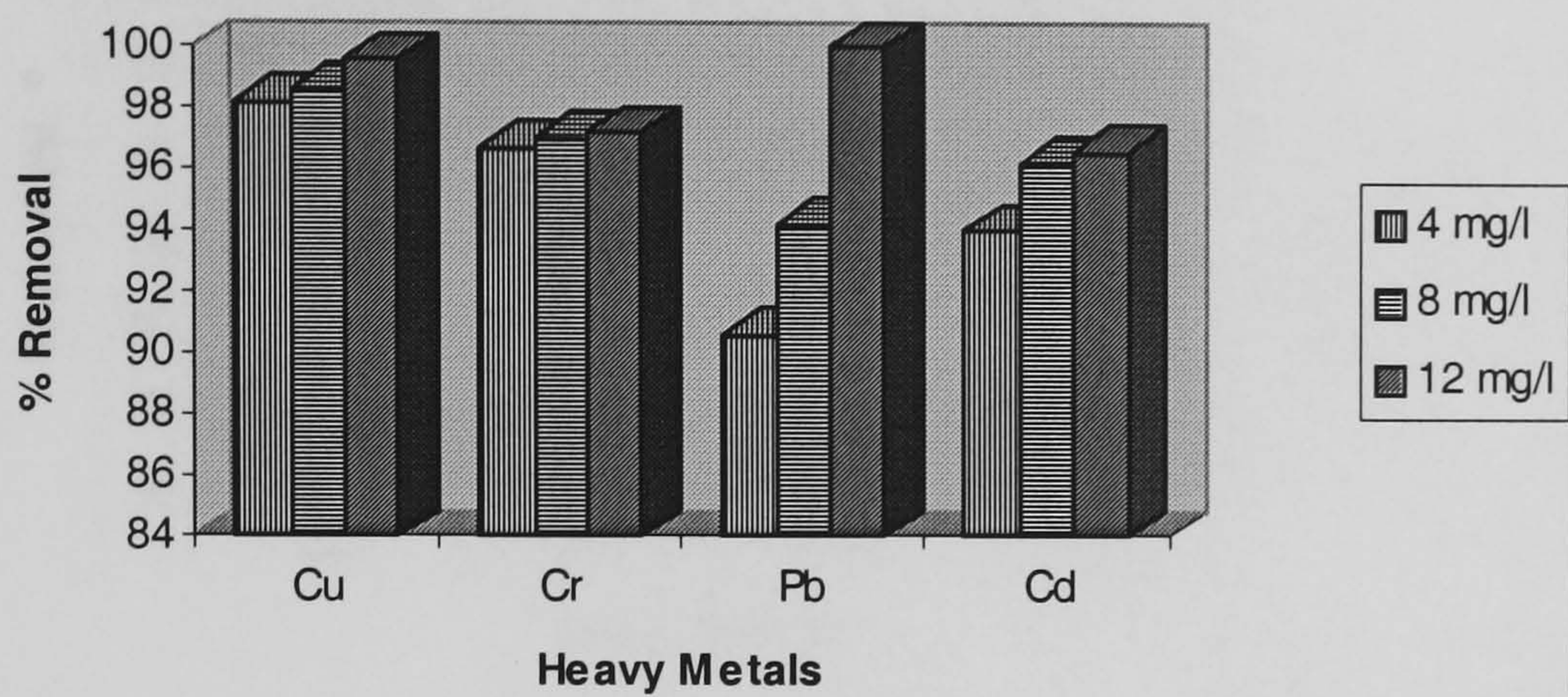
Table 5.11: Variation of % removal efficiencies of heavy metals at various TOC levels at the flow rate of 0.3 m/hr and at 0.4m of depth. (Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	96.4(0.64)	96.8(0.20)	96.2(0.93)
F <sub>2</sub> /Cr	93.7(0.70)	94.2(0.41)	93.4(3.60)
F <sub>3</sub> /Pb	38.3(4.20)	55.3(2.36)	66.8 (4.10)
F <sub>4</sub> /Cd	49.3(0.73)	50.3(0.58)	50.9(4.30)

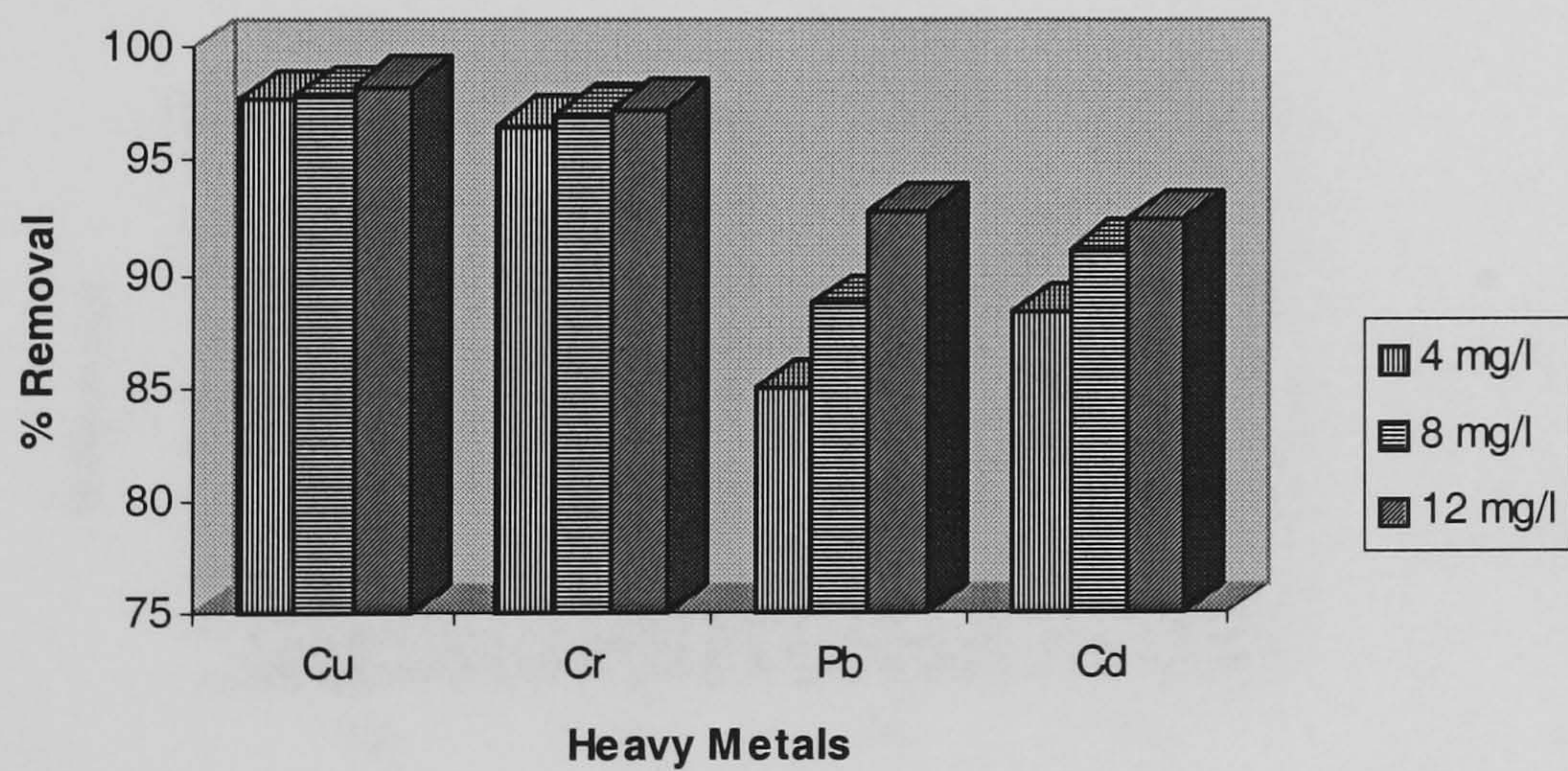
Table 5.12: Variation of % removal efficiencies of heavy metals at various TOC levels at the flow rate of 0.4 m/hr and at 0.4m of depth. (Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	96.6(0.20)	96.8(0.10)	97.0(0.07)
F <sub>2</sub> /Cr	92.0(0.26)	92.3(0.81)	93.0(0.11)
F <sub>3</sub> /Pb	32.1(4.60)	40.7(1.03)	46.7(0.84)
F <sub>4</sub> /Cd	25.0(1.96)	40.2(3.40)	50.0(0.64)



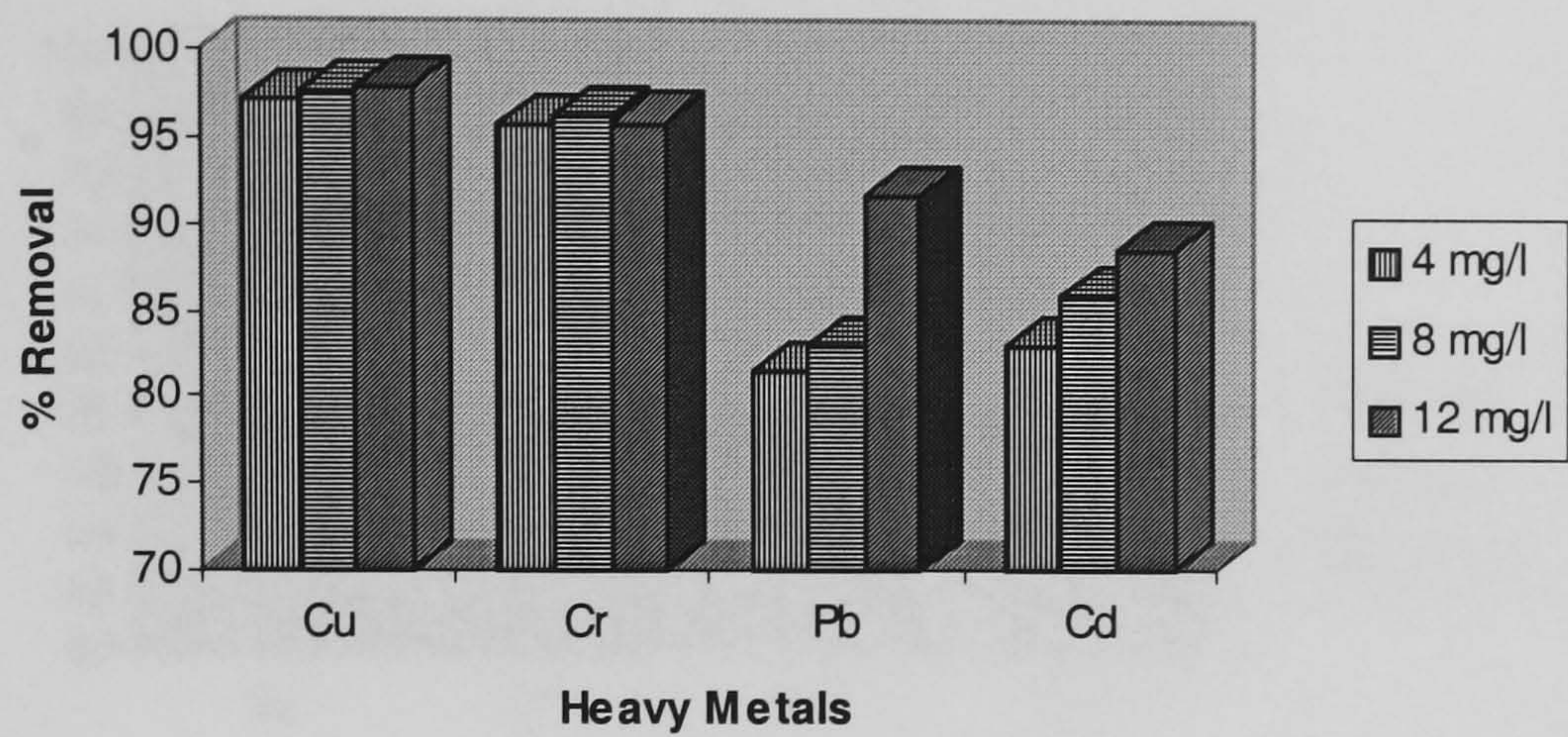


**Figure 5.1 Comparison of % removal of different heavy metals at various TOCs at flow rate of 0.1 m/hr and at a filter depth of 1.2 m.**

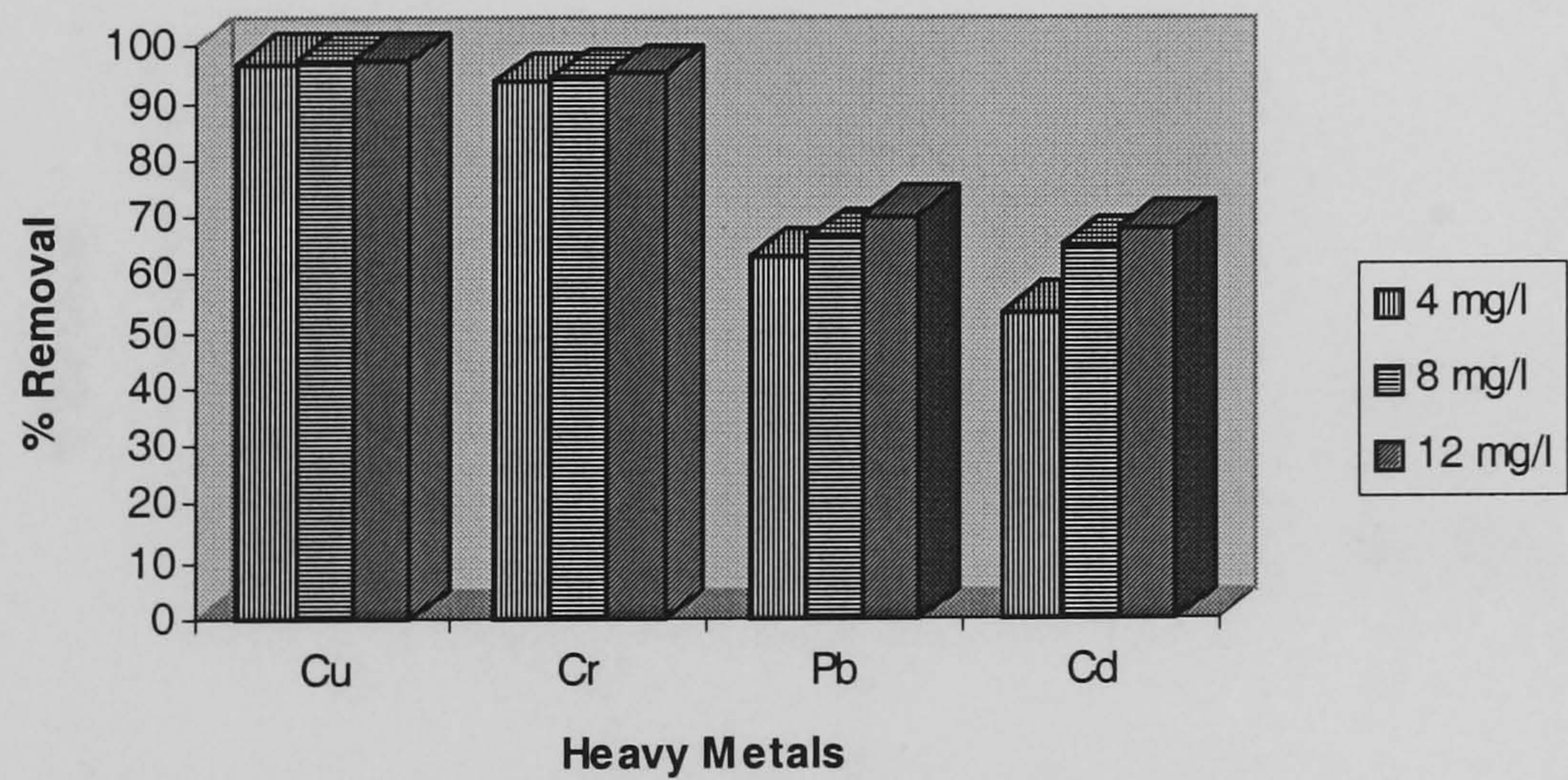


**Figure 5.2 Comparison of % removal of different heavy metals at various TOCs at a flow rate of 0.2 m/hr and at a filter depth of 1.2 m.**



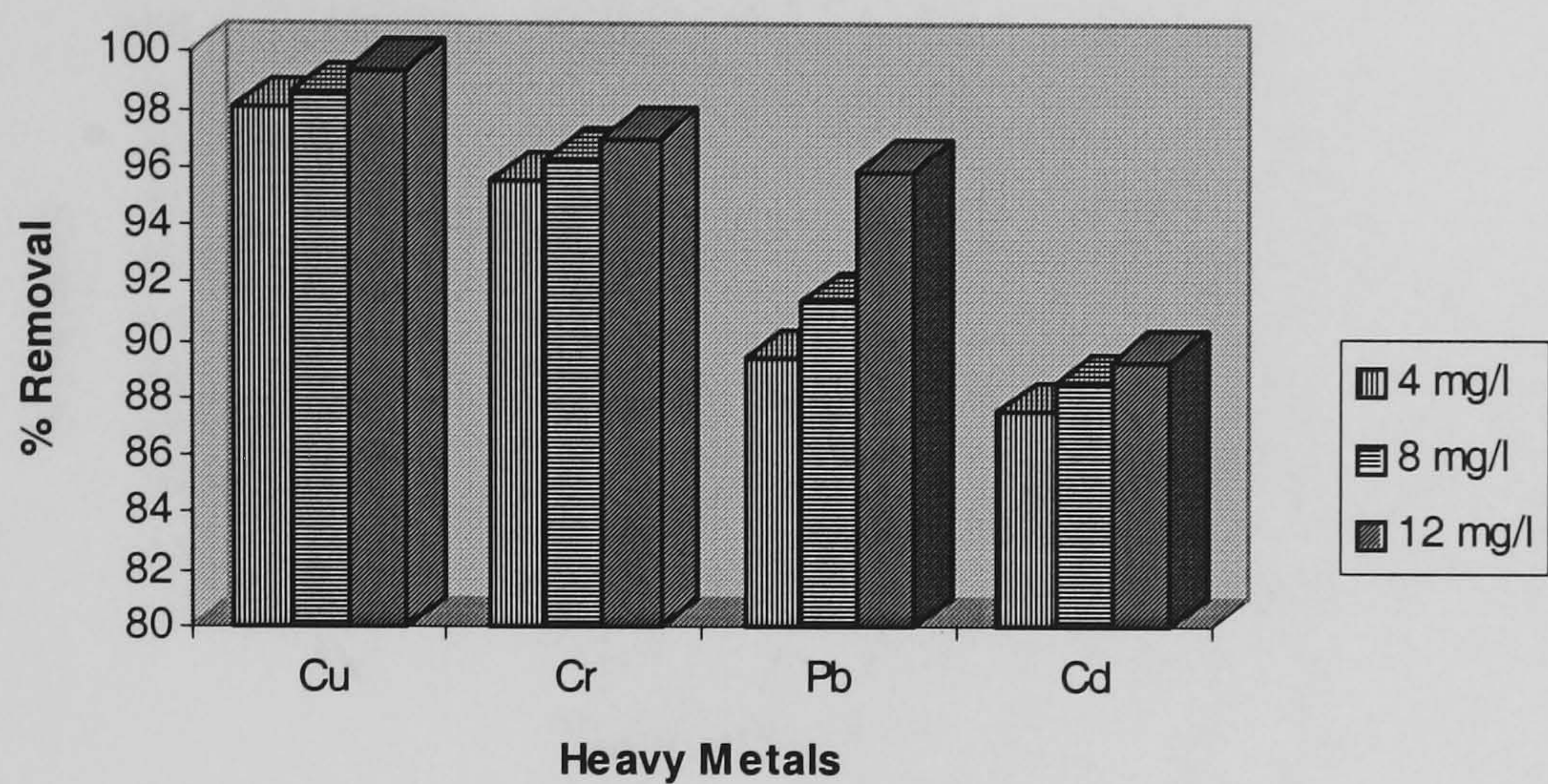


**Figure 5.3 Comparison of % removal of different heavy metals at various TOCs at a flow rate of 0.3 m/hr and at a filter depth of 1.2 m.**

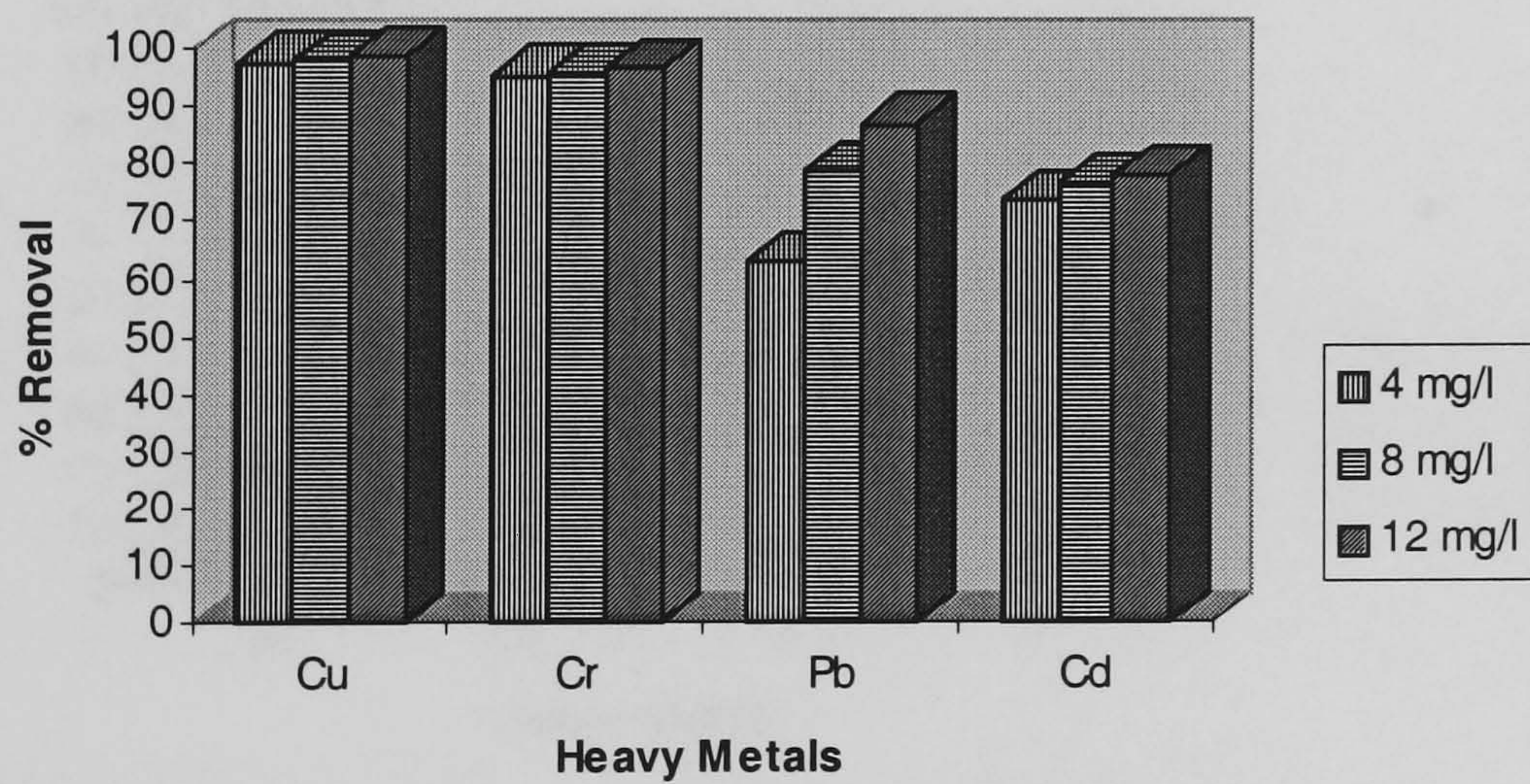


**Figure 5.4 Comparison of % removal of different heavy metals at various TOCs at a flow rate of 0.4 m/hr and at a filter depth of 1.2 m.**



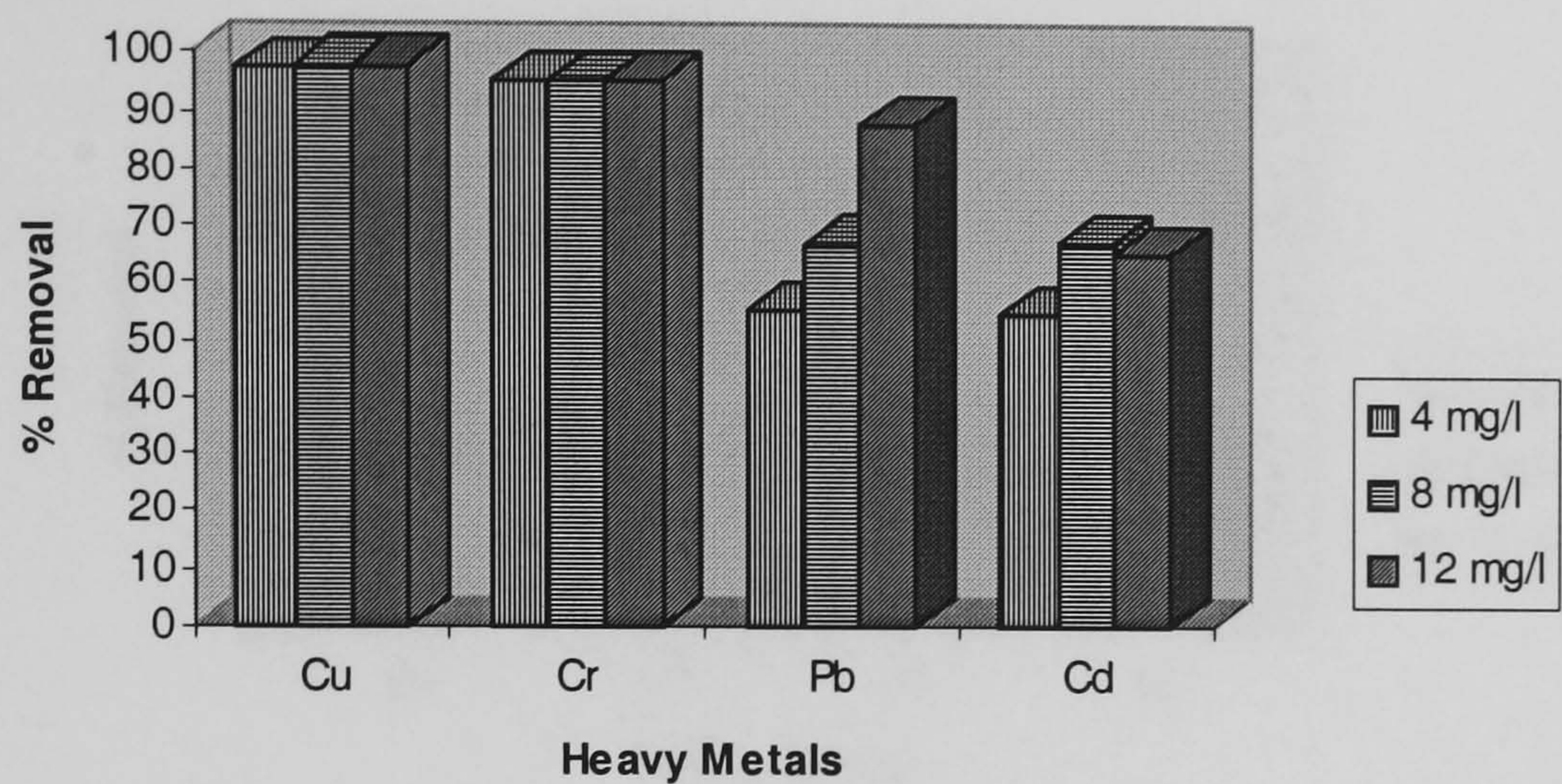


**Figure 5.5 Comparison of % removal of different heavy metals at various TOCs at flow rate of 0.1 m/hr and at a filter depth of 0.8 m.**

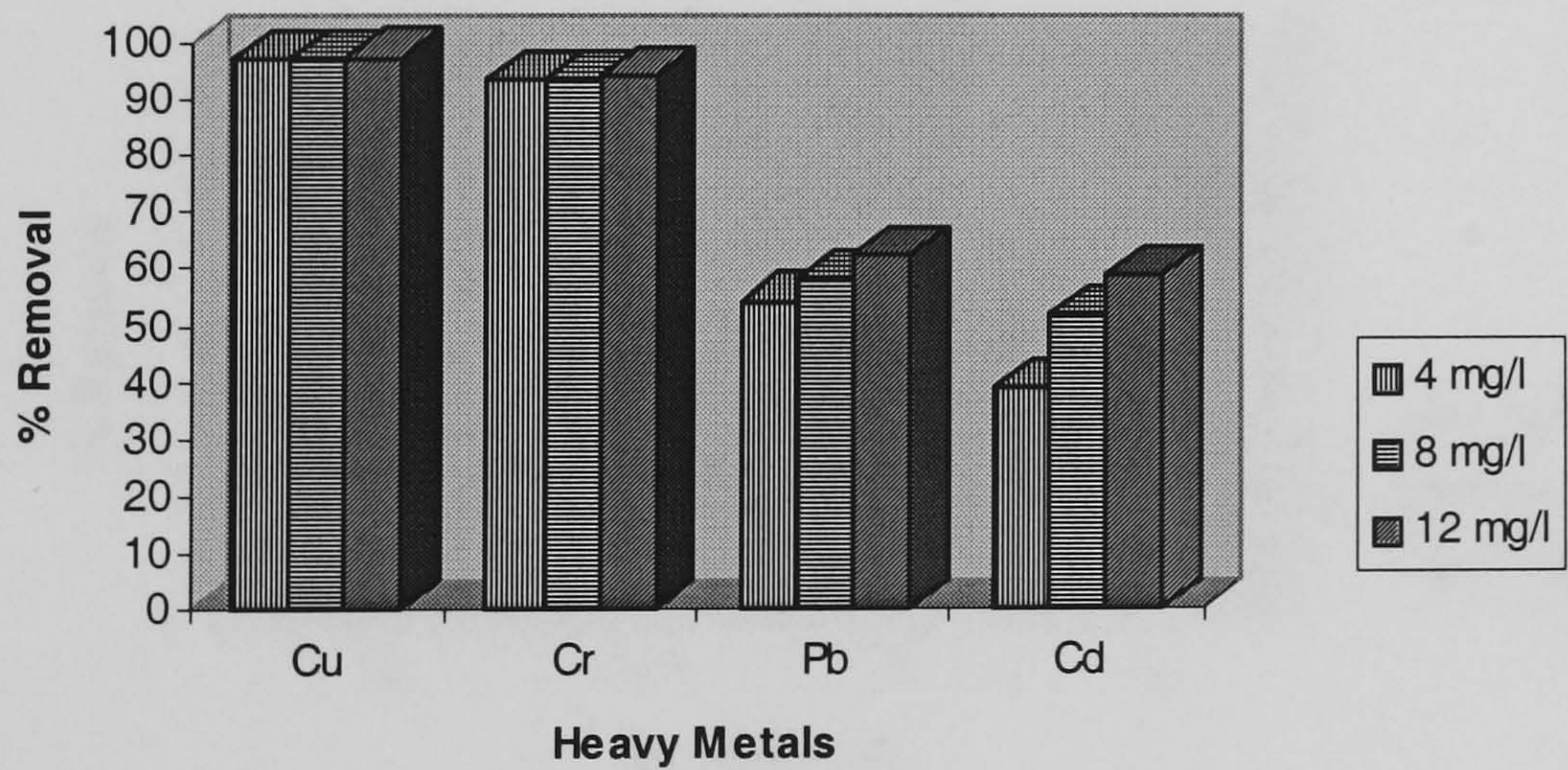


**Figure 5.6 Comparison of % removal of different heavy metals at various TOCs at a flow rate of 0.2 m/hr and at a filter depth 0.8 m.**



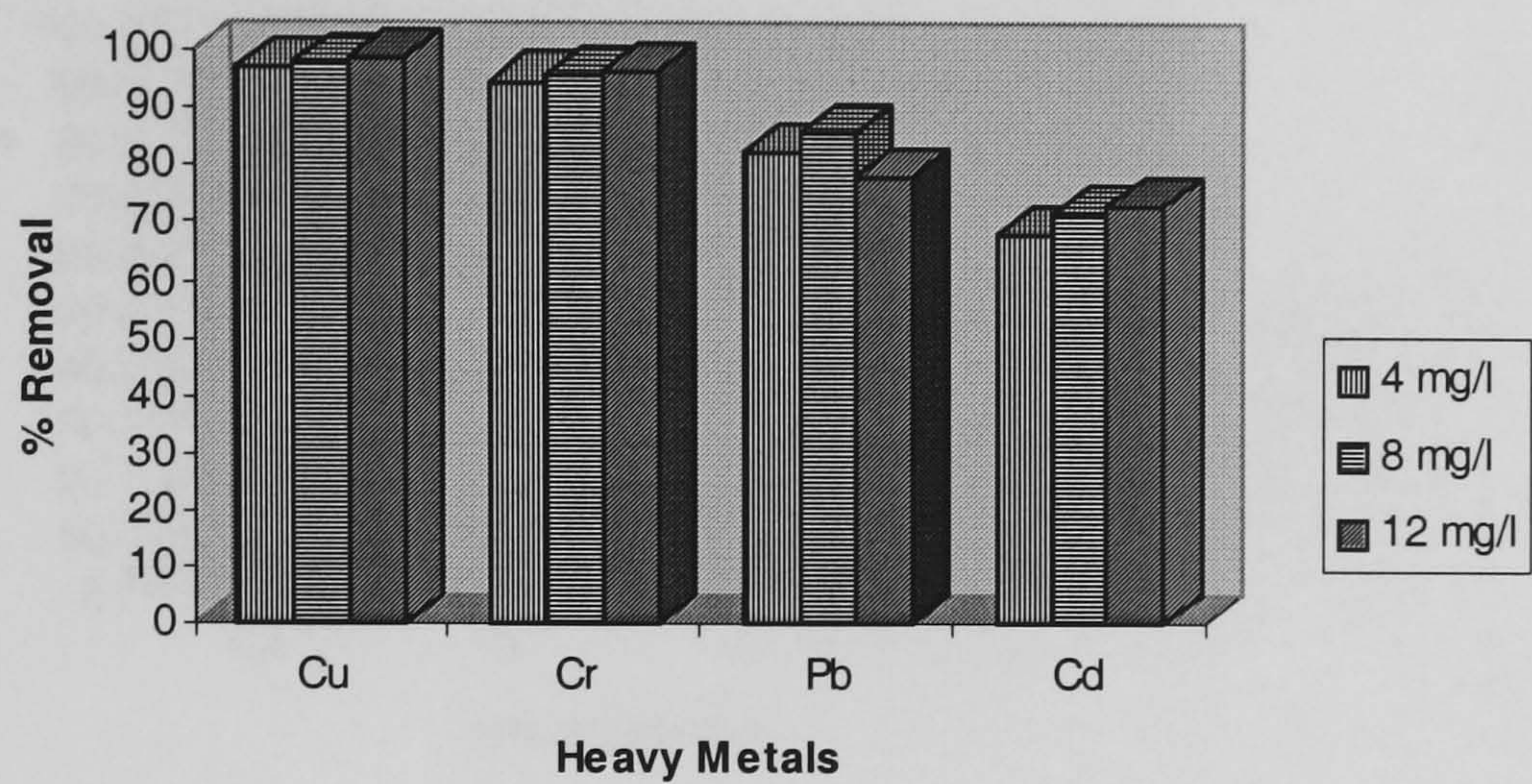


**Figure 5.7 Comparison of % removal of different heavy metals at various TOCs at a flow rate of 0.3 m/hr and at a filter depth of 0.8 m.**

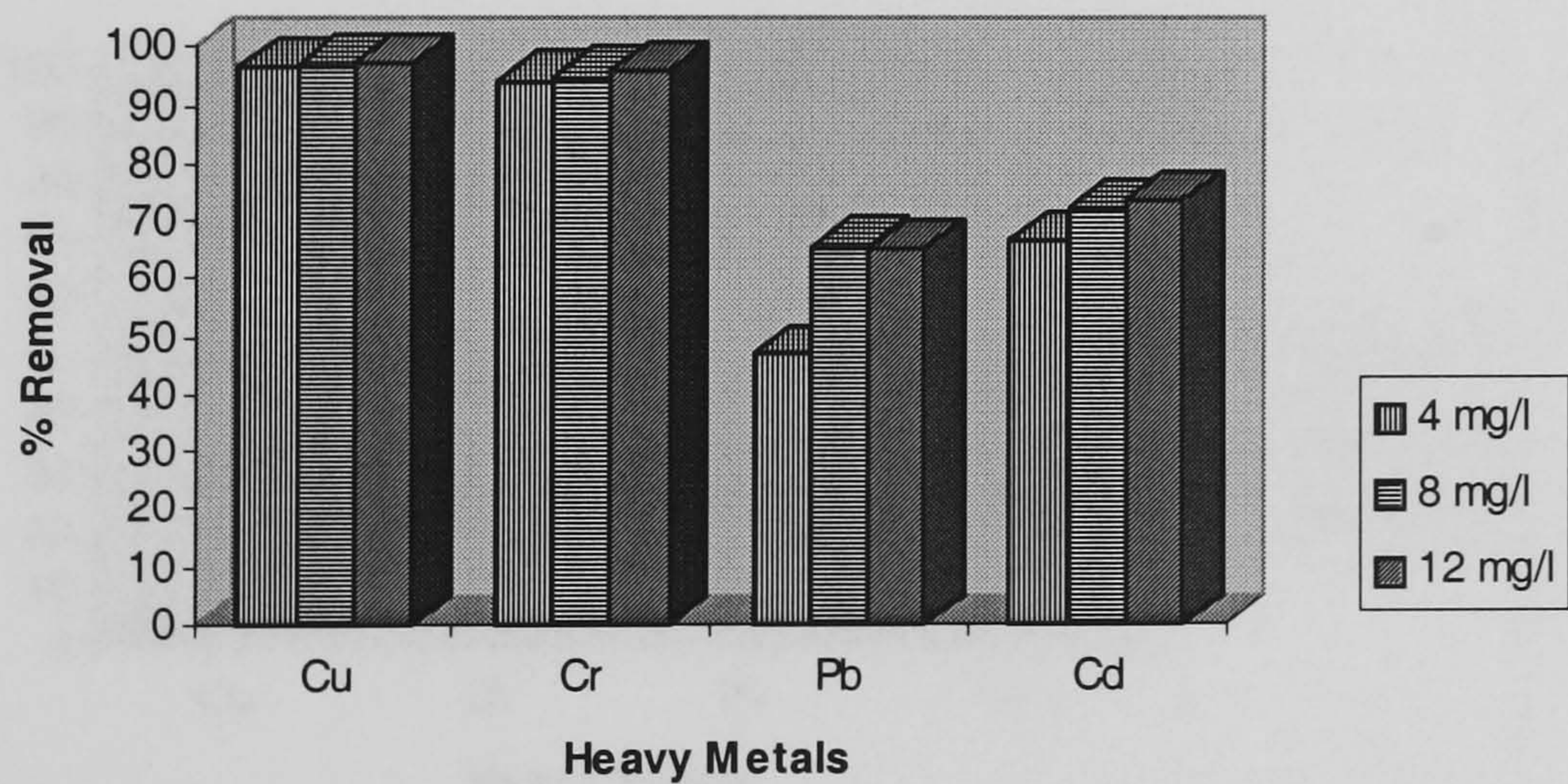


**Figure 5.8 Comparison of % removal of different heavy metals at various TOCs at a flow rate of 0.4 m/hr and at a filter depth of 0.8 m.**



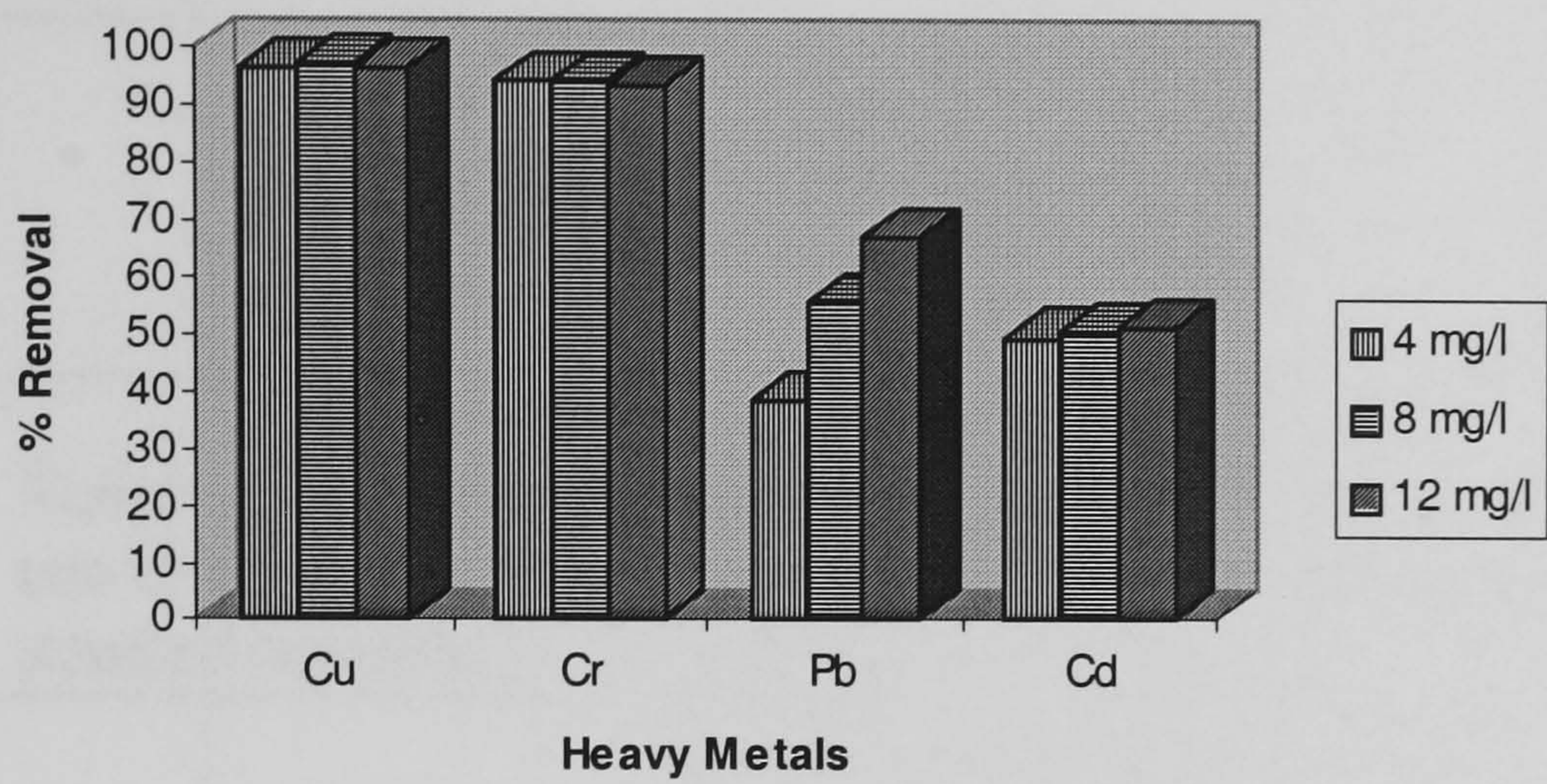


**Figure 5.9 Comparison of % removal of different heavy metals at various TOCs at a flow rate of 0.1 m/hr and at a filter depth of 0.4 m.**

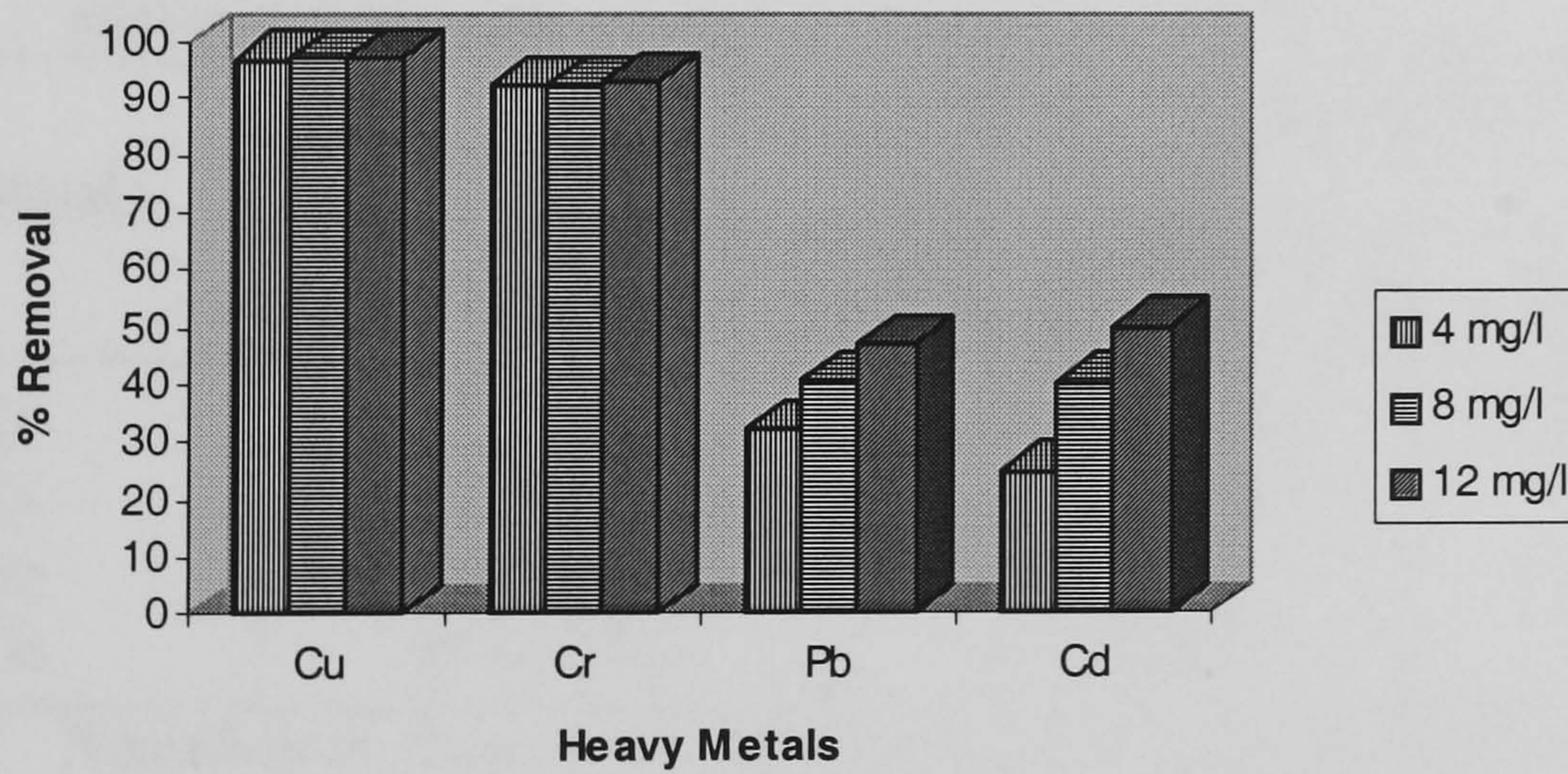


**Figure 5.10 Comparison of % removal of different heavy metals at various TOCs at a flow rate of 0.2 m/hr and at a filter depth of 0.4 m.**





**Figure 5.11 Comparison of % removal of different heavy metals at various TOCs at a flow rate of 0.3 m/hr and at a filter depth of 0.4 m.**



**Figure 5.12 Comparison of % removal of different heavy metals at various TOCs at a flow rate of 0.4 m/hr and at a filter depth of 0.4 m.**



Table 5.13: Variation of % removal efficiencies of TOC by different filters at the flow rate of 0.1 m/hr and at 1.2 m of depth.(Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	49.9 (1.16)	51.9 (0.72)	58.8 (2.65)
F <sub>2</sub> /Cr	48.0 (0.83)	50.4 (0.90)	58.3 (1.44)
F <sub>3</sub> /Pb	46.3 (0.36)	41.8 (0.45)	57.8 (1.73)
F <sub>4</sub> /Cd	46.9 (0.82)	49.0 (0.78)	58.3 (1.51)

Table 5.14: Variation of % removal efficiencies of TOC by different filters at the flow rate of 0.2 m/hr and at 1.2 m of depth.(Figures in the bracket indicate the standard deviation )

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	48.6 (0.72)	53.3 (1.67)	58.5 (0.36)
F <sub>2</sub> /Cr	47.8 (0.10)	52.8 (1.40)	59.3 (1.33)
F <sub>3</sub> /Pb	46.1 (0.30)	52.1 (1.15)	58.9 (0.35)
F <sub>4</sub> /Cd	46.8 (0.17)	53.0 (1.40)	58.5 (0.35)

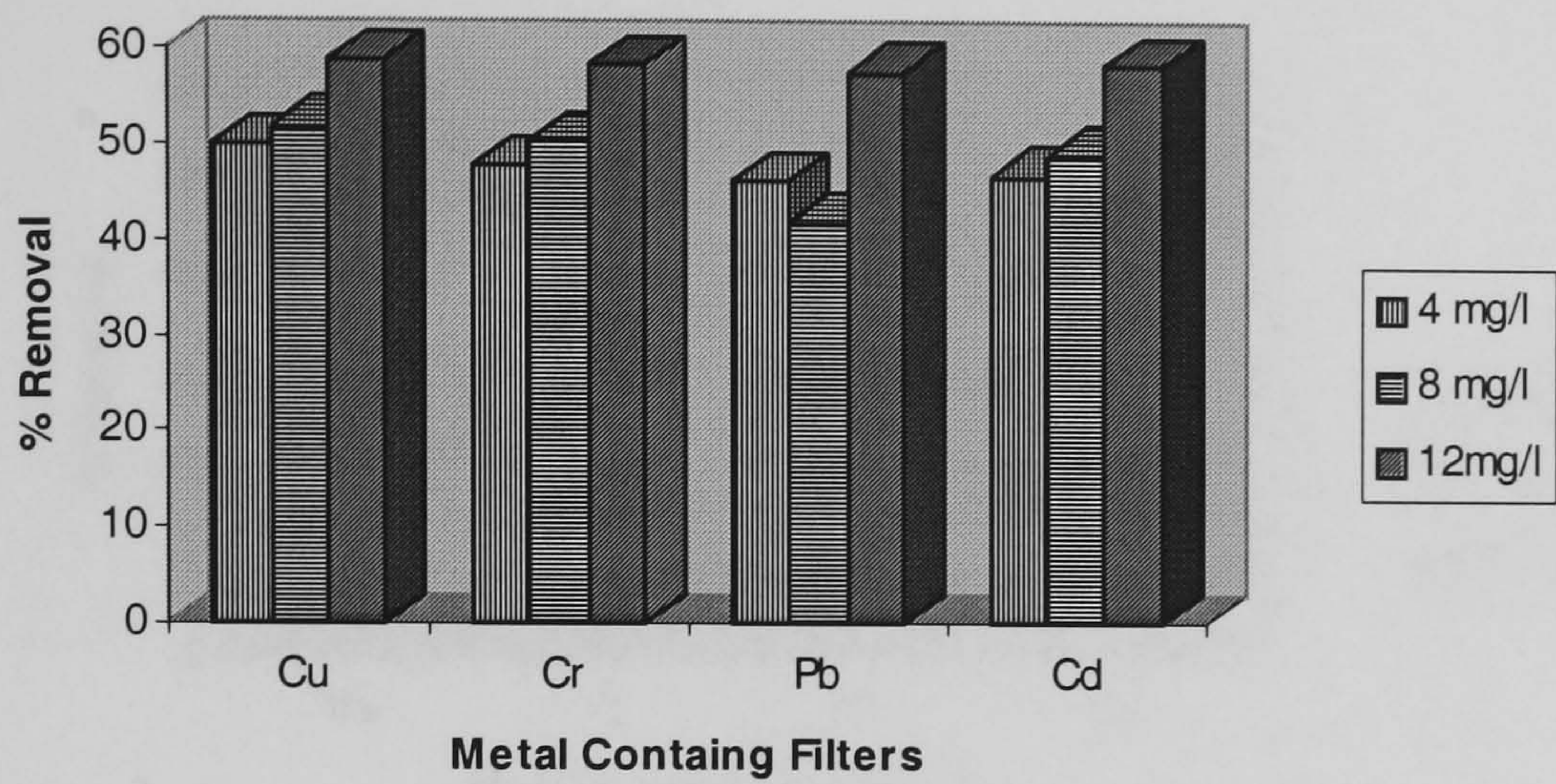
Table 5.15: Variation of % removal efficiencies of TOC by different filters at the flow rate of 0.3 m/hr and at 1.2 m of depth.(Figures in the bracket indicate standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	48.6 (1.35)	54.2 (1.76)	57.0 (1.34)
F <sub>2</sub> /Cr	48.2 (0.70)	55.4 (1.00)	56.4 (1.46)
F <sub>3</sub> /Pb	46.7 (1.02)	54.8 (0.71)	55.4(0.57)
F <sub>4</sub> /Cd	46.3 (1.12)	51.2 (1.82)	56.0 (0.47)

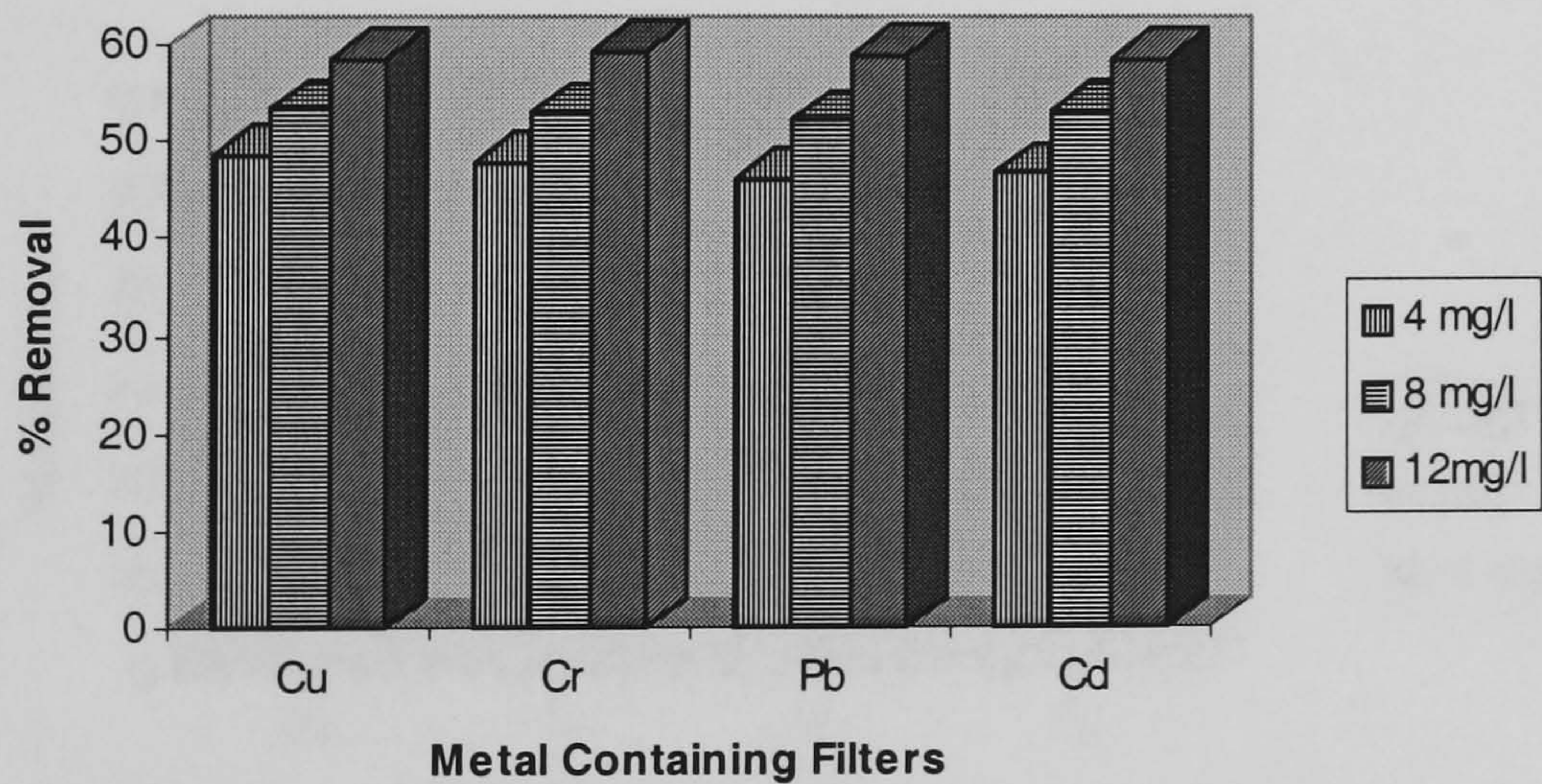
Table 5.16: Variation of % removal efficiencies of TOC by different filters at the flow rate of 0.4 m/hr and at 1.2 m of depth. (Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	48.0 (1.90)	53.5 (2.65)	57.5 (0.95)
F <sub>2</sub> /Cr	46.5 (2.20)	54.7 (1.96)	56.2 (1.32)
F <sub>3</sub> /Pb	45.8 (1.66)	56.1 (1.54)	55.6 (0.23)
F <sub>4</sub> /Cd	45.4 (1.08)	52.9 (1.50)	56.0 (0.45)



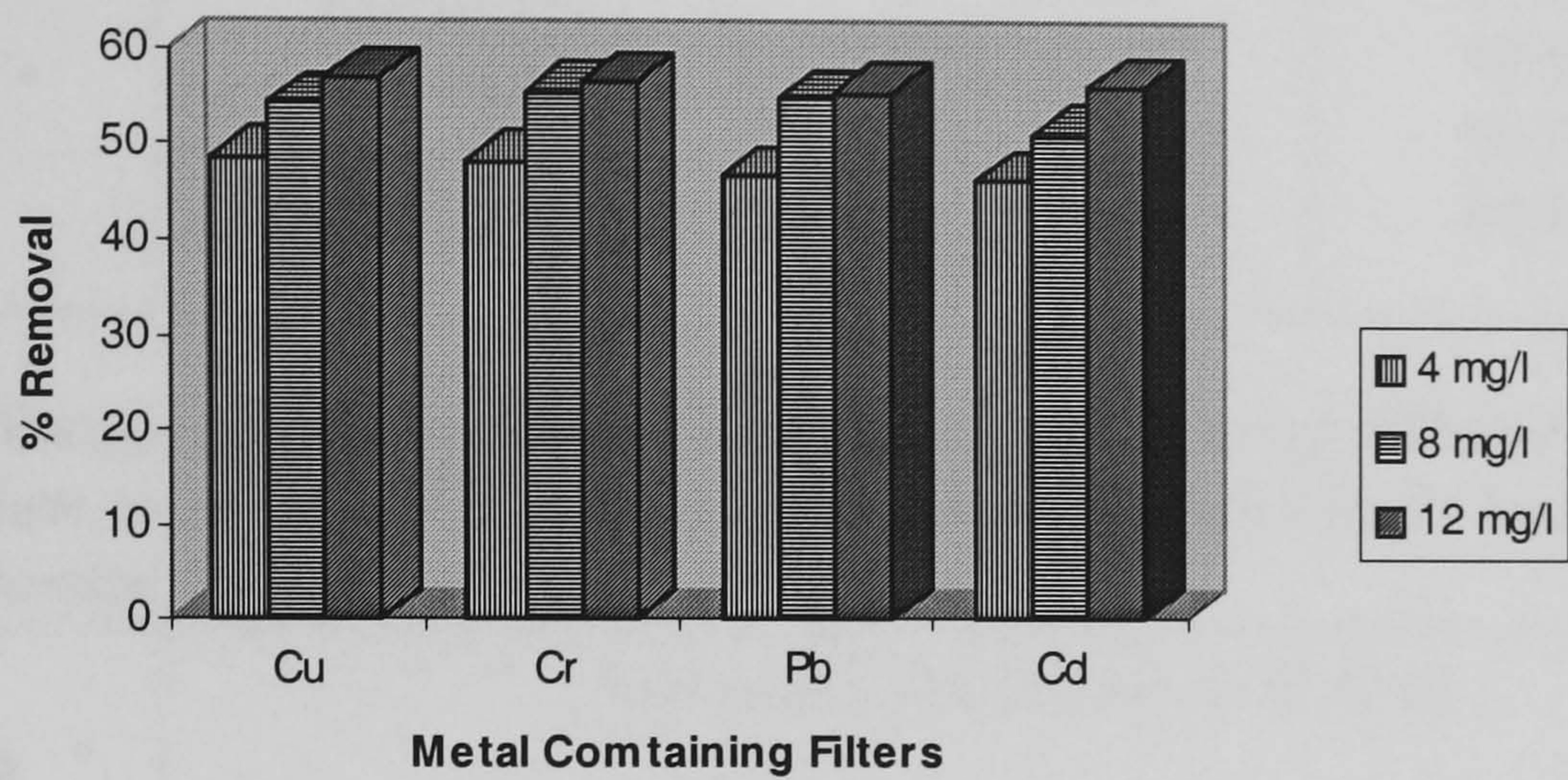


**Figure 5.13** Comparison of % removal of TOC by different metal containing filters at a flow rate of 0.1 m/hr and at a filter depth of 1.2 m.

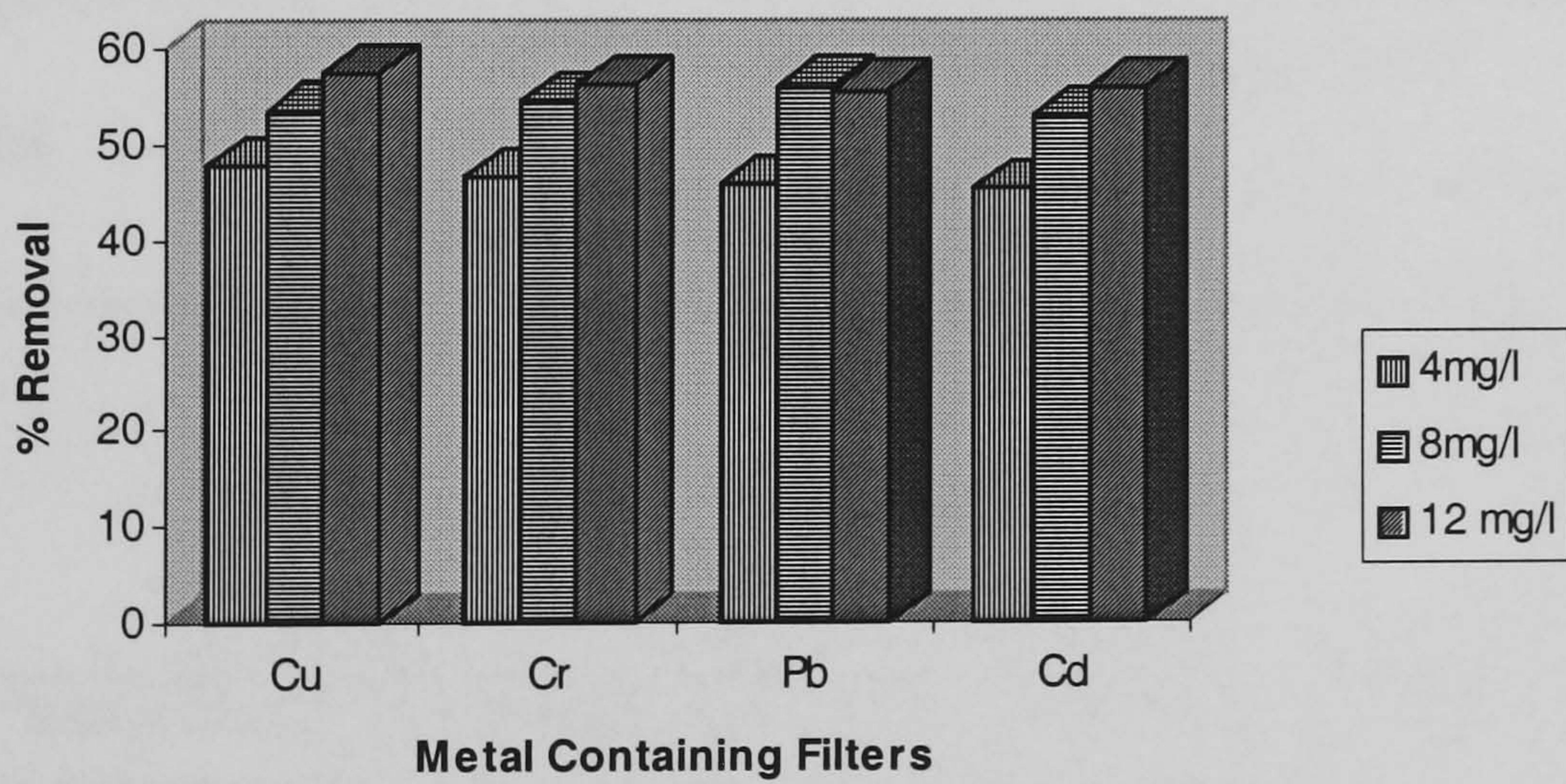


**Figure 5.14** Comparison of % removal of TOC by different metal containing filters at a flow rate of 0.2 m/hr and at a filter depth of 1.2 m.





**Figure 5.15 Comparison of % removal of TOC by different metal containing filters at a flow rate of 0.3 m/hr and at a filter depth of 1.2 m.**



**Figure 5.16 Comparison of % removal of TOC by different metal containing filters at a flow rate of 0.4 m/hr and at a filter depth of 1.2 m.**



Table 5.17: Variation of % removal efficiencies of turbidity by different filters at the flow rate of 0.1 m/hr and at 1.2 m of depth. (Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	90.0 (0.35)	90.3 (0.50)	90.7 (0.47)
F <sub>2</sub> /Cr	89.7 (0.00)	90.2 (0.61)	90.6 (0.52)
F <sub>3</sub> /Pb	89.4 (0.35)	90.2 (0.00)	90.7 (0.39)
F <sub>4</sub> /Cd	89.4 (0.35)	90.3 (0.70)	90.7 (0.00)

Table 5.18: Variation of % removal efficiencies of turbidity by different filters at the flow rate of 0.2 m/hr and at 1.2 m of depth. (Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	82.9 (0.59)	85.1 (0.26)	87.8 (0.00)
F <sub>2</sub> /Cr	82.9 (0.58)	84.7 (0.59)	87.8 (0.00)
F <sub>3</sub> /Pb	82.2 (0.38)	84.7 (0.42)	87.5 (0.16)
F <sub>4</sub> /Cd	82.1 (0.33)	85.1 (0.37)	87.7 (0.00)

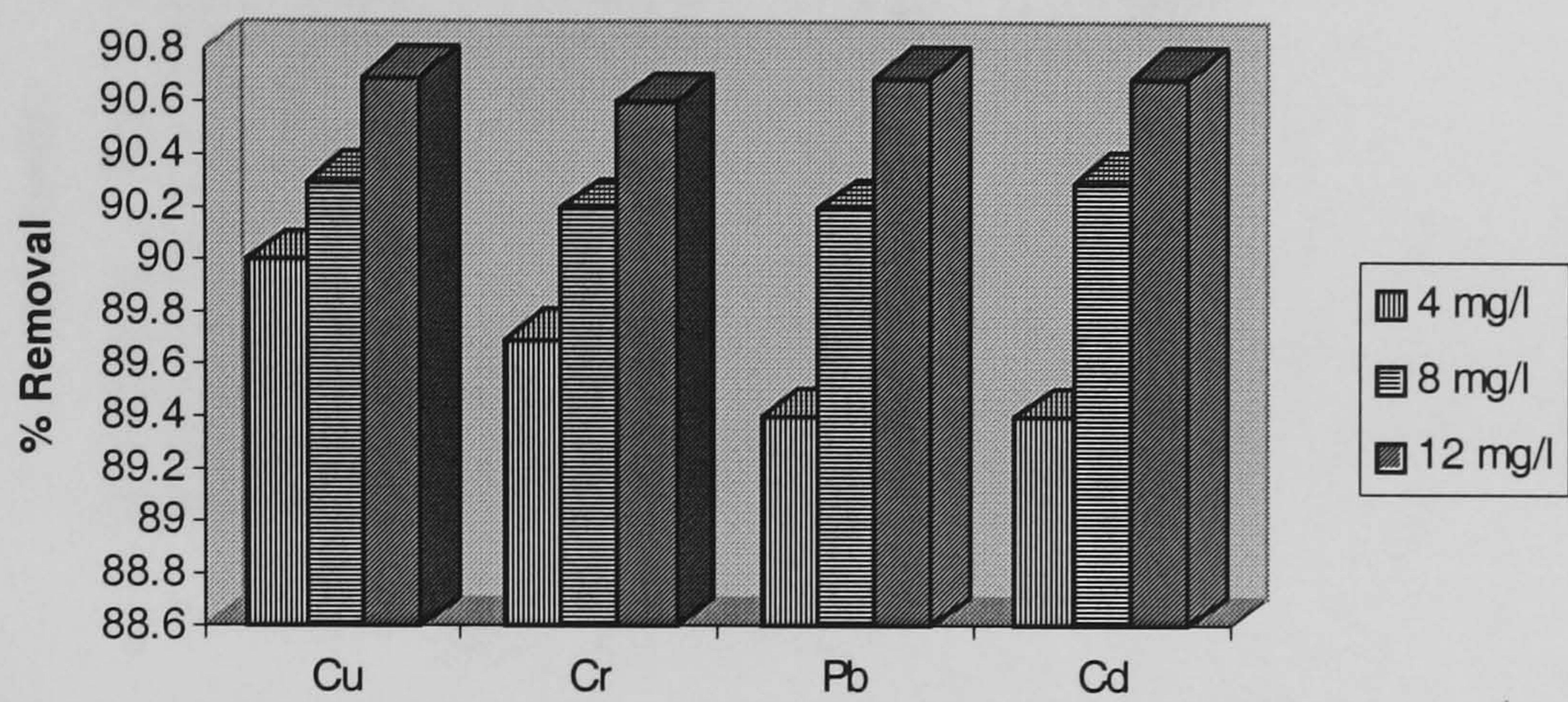
Table 5.19: Variation of % removal efficiencies of turbidity by different filters at the flow rate of 0.3 m/hr and at 1.2 m of depth. (Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	75.6 (0.50)	82.9 (0.78)	85.7 (0.17)
F <sub>2</sub> /Cr	75.3 (0.23)	82.9 (0.53)	86.2 (0.06)
F <sub>3</sub> /Pb	74.8 (0.21)	83.0 (0.17)	85.8 (0.46)
F <sub>4</sub> /Cd	74.8 (0.21)	83.1 (0.26)	85.6 (0.35)

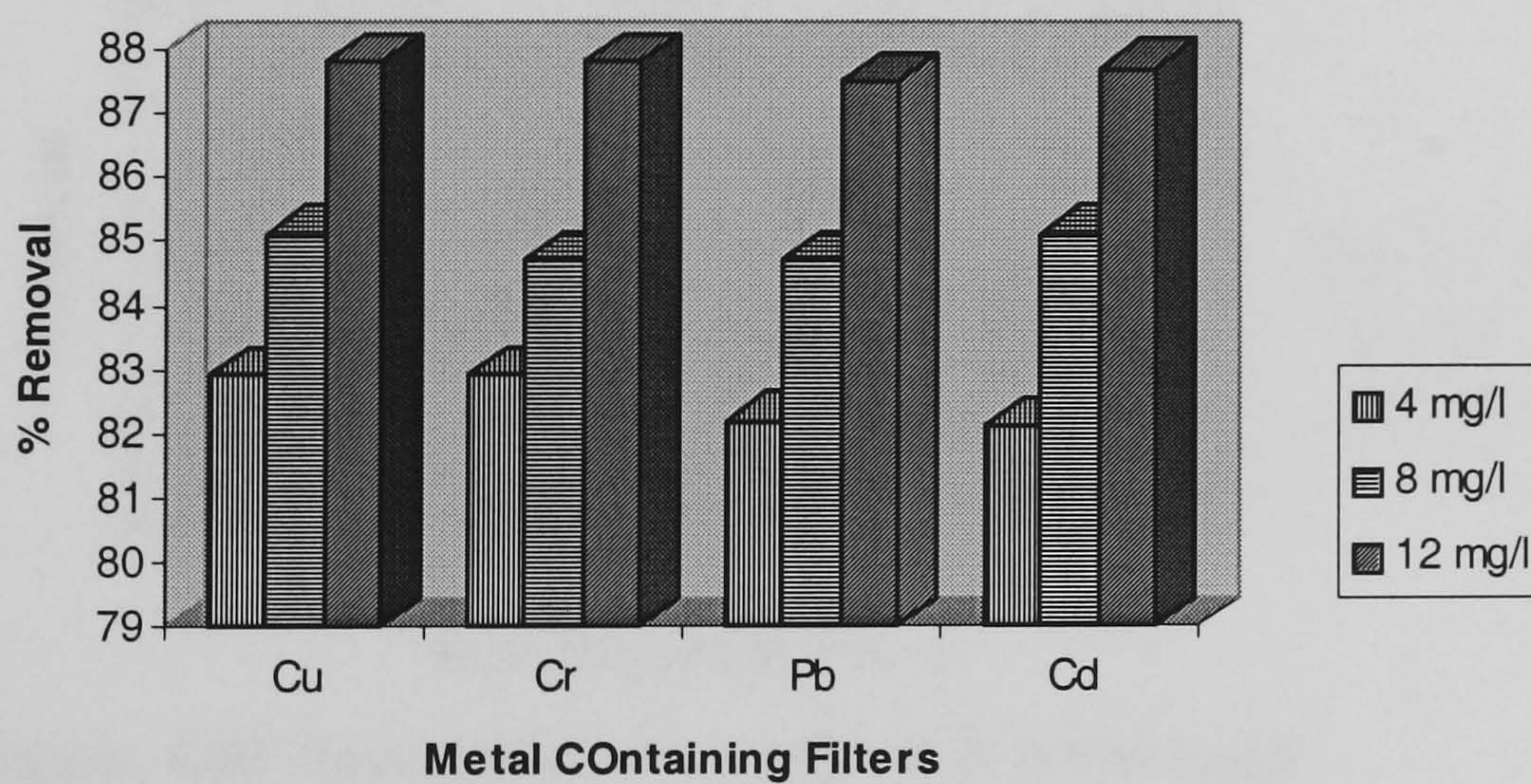
Table 5.20: Variation of % removal efficiencies of turbidity by different filters at the flow rate of 0.4 m/hr and at 1.2 m of depth. (Figures in the bracket indicate the standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	71.4 (1.00)	78.6 (0.71)	84.5 (0.15)
F <sub>2</sub> /Cr	71.9 (0.40)	78.1 (0.26)	84.5 (0.06)
F <sub>3</sub> /Pb	71.9 (0.50)	77.8 (0.29)	84.3 (0.27)
F <sub>4</sub> /Cd	71.4 (1.27)	77.7 (0.35)	84.0 (0.15)



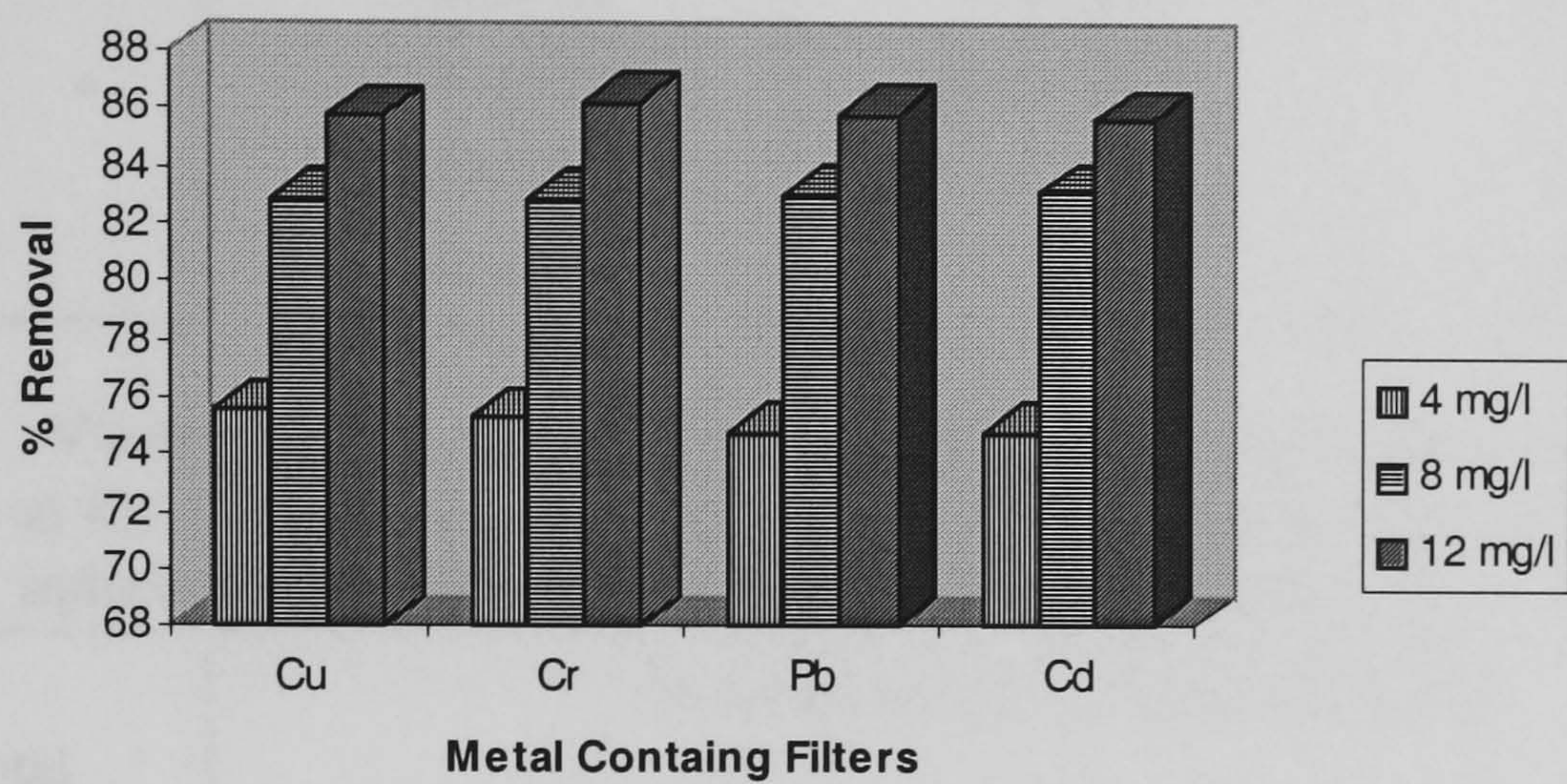


**Figure 5.17 Comparison of % removal of turbidity by different metal containing filters at a flow rate of 0.1 m/hr and at a filter depth of 1.2 m.**

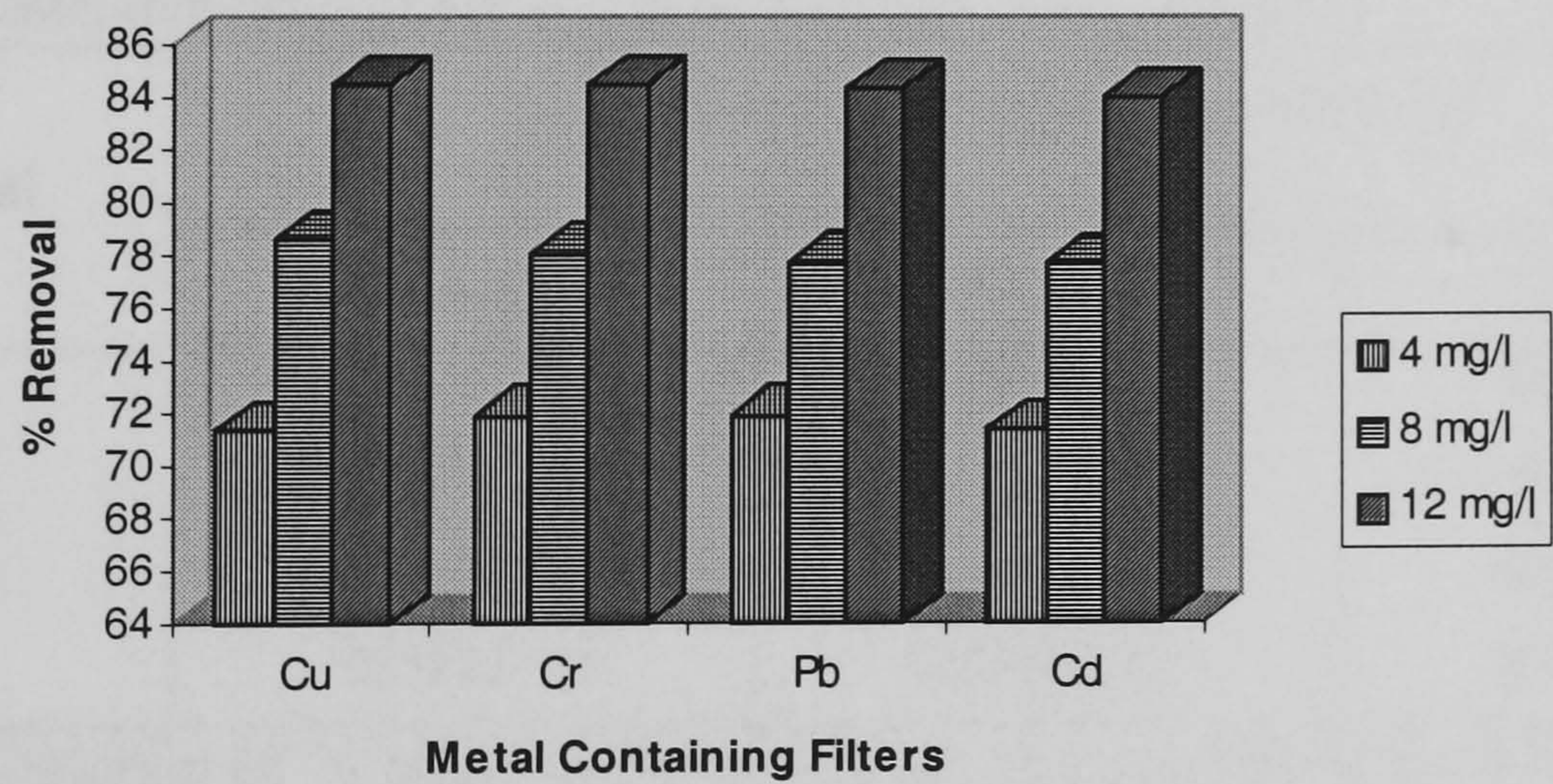


**Figure 5.18 Comparison of % removal of turbidity by different metal containing filters at a flow rate of 0.2 m/hr and at a filter depth of 1.2 m.**





**Figure 5.19 Comparison of % removal of turbidity by different metal containing filters at a flow rate of 0.3 m/hr and at a filter depth of 1.2 m.**



**Figure 5.20 Comparison of % removal of turbidity by different metal containing filters at a flow rate of 0.4 m/hr and at a filter depth of 1.2 m.**



Table 5.21: Variation of % removal efficiencies of faecal coliform by different filters at the flow rate of 0.1 m/hr and at 1.2 m of depth.(Figures in the bracket indicates the number of faecal coliform in the effluent)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	100 (00)	100 (01)	100 (03)
F <sub>2</sub> /Cr	100 (00)	100 (01)	100 (03)
F <sub>3</sub> /Pb	100 (00)	100 (00)	100 (04)
F <sub>4</sub> /Cd	100 (00)	100 (00)	100 (04)

Table 5.22: Variation of % removal efficiencies of faecal coliform by different filters at the flow rate of 0.2 m/hr and at 1.2 m of depth. (Figures in the bracket indicates the number of faecal coliform in the effluent)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	100 (02)	99.99 (08)	99.99 (12)
F <sub>2</sub> /Cr	100 (00)	99.99 (06)	99.99 (10)
F <sub>3</sub> /Pb	100 (01)	99.99 (09)	99.99 (18)
F <sub>4</sub> /Cd	100 (00)	99.99 (10)	99.99 (16)

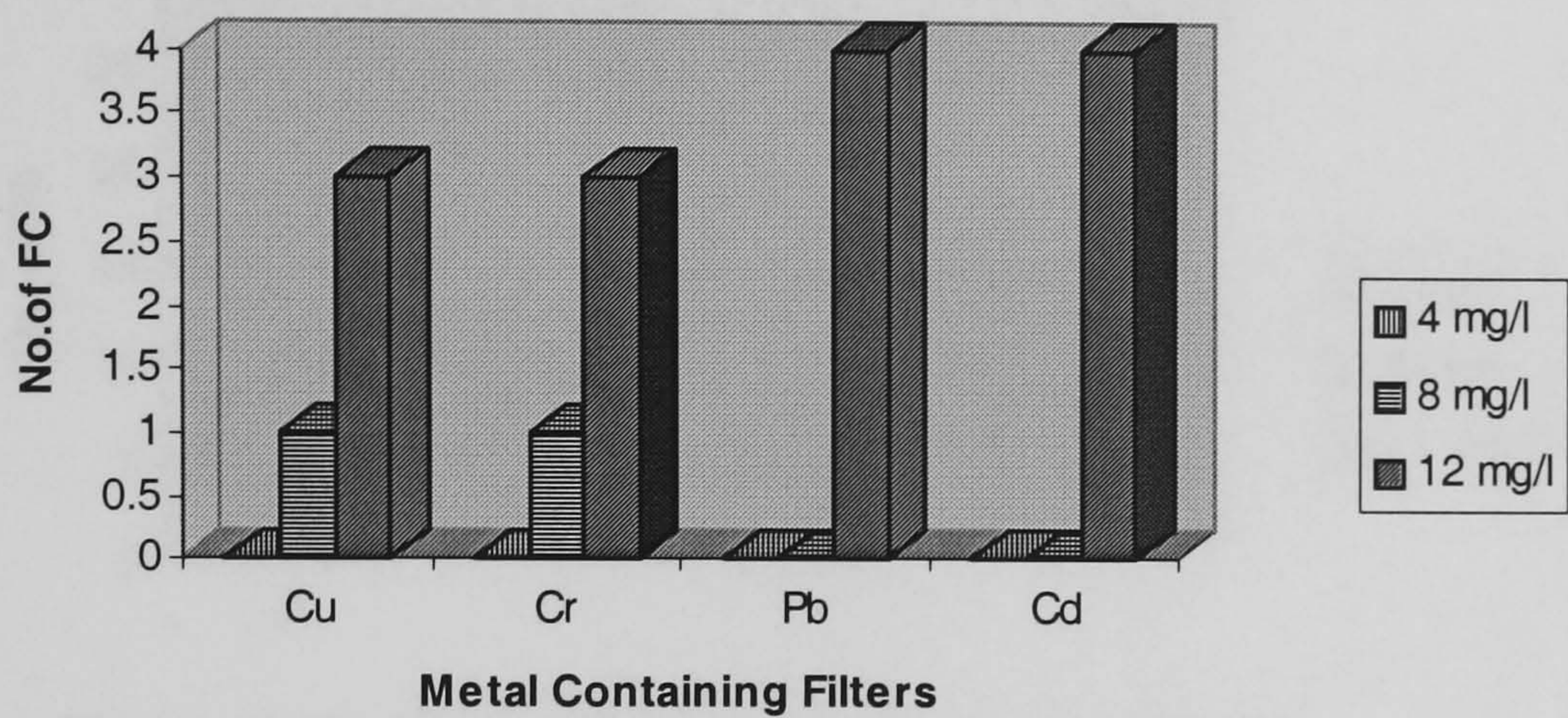
Table 5.23: Variation of % removal efficiencies of faecal coliform by different filters at the flow rate of 0.3 m/hr and at 1.2 m of depth.(Figures in the bracket indicates the number of faecal coliform in the effluent)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	99.99 (12)	99.99 (12)	99.99 (20)
F <sub>2</sub> /Cr	99.99 (10)	99.99 (12)	99.99 (25)
F <sub>3</sub> /Pb	99.99 (12)	99.99 (16)	99.99 (25)
F <sub>4</sub> /Cd	99.99 (10)	99.99 (16)	99.99 (30)

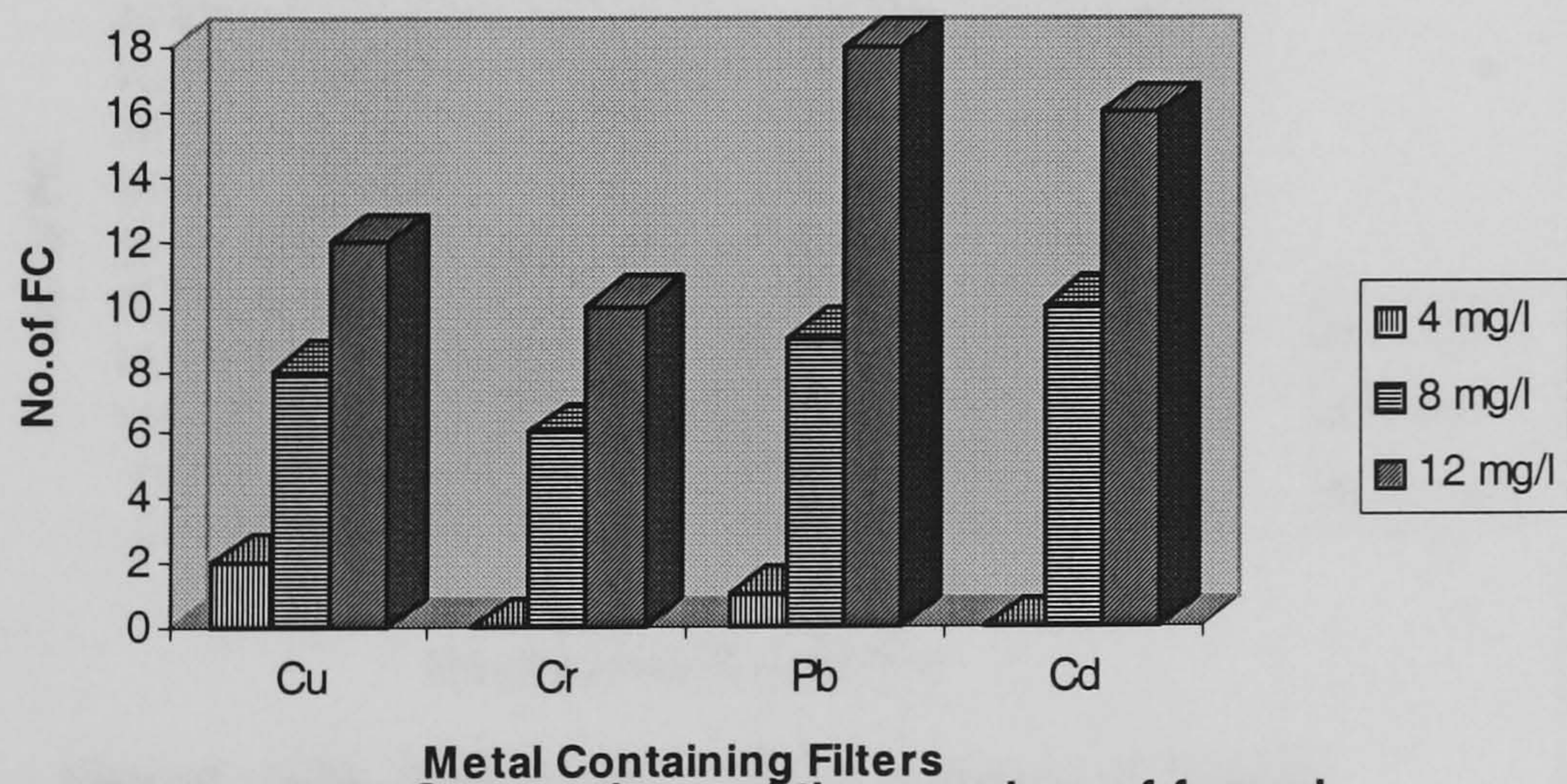
Table 5.24: Variation of % removal efficiencies of faecal coliform by different filters at the flow rate of 0.4 m/hr and at 1.2 m of depth.(Figures in the bracket indicates the number of faecal coliform in the effluent)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	99.99 (24)	99.99 (32)	99.99 (34)
F <sub>2</sub> /Cr	99.99 (26)	99.99 (30)	99.99 (36)
F <sub>3</sub> /Pb	99.99 (28)	99.99 (36)	99.99 (42)
F <sub>4</sub> /Cd	99.99 (28)	99.99 (38)	99.99 (46)



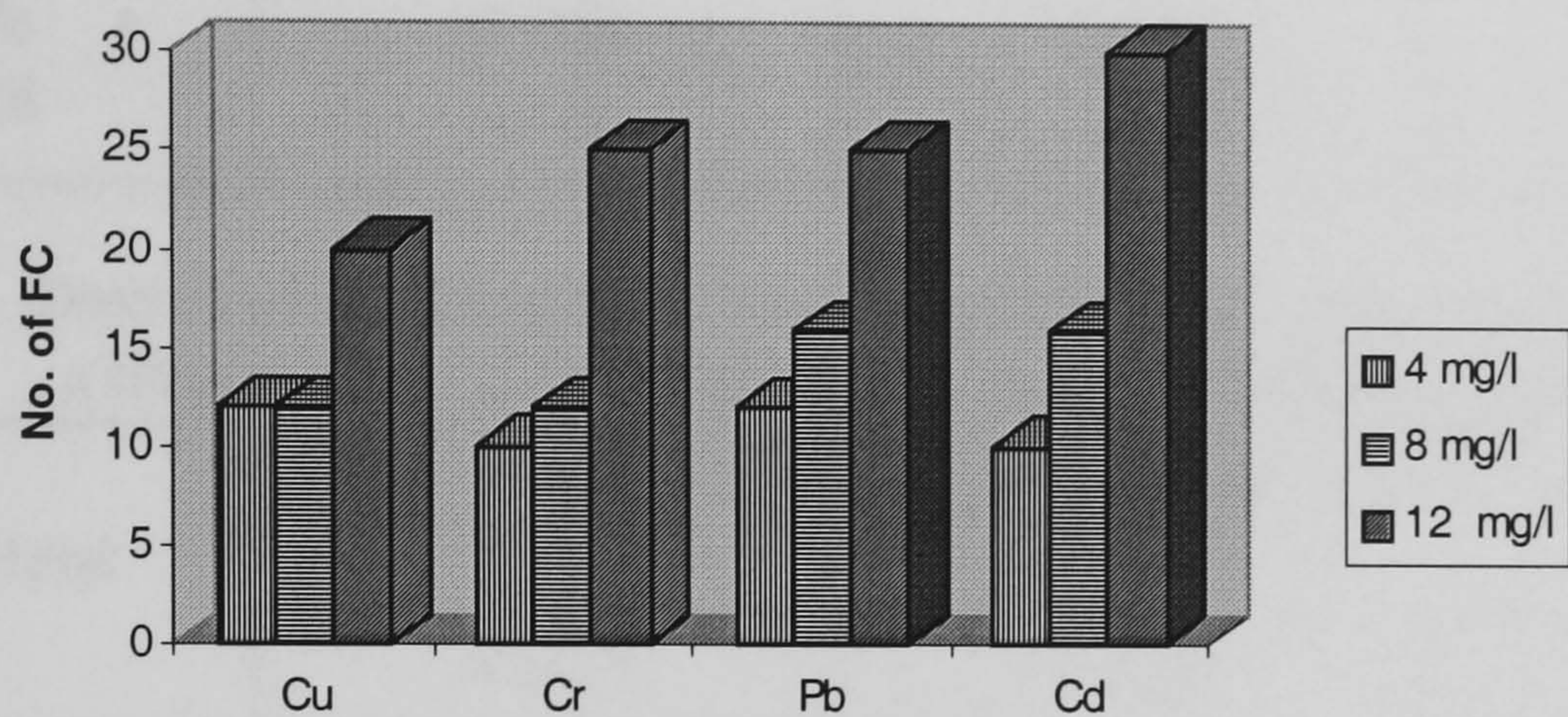


**Figure 5.21** Comparison of the number of faecal coliform/100 ml in the effluent of different metal containing filters at various TOCs at flow rate of 0.1 m/hr and at a filter depth of 1.2 m.

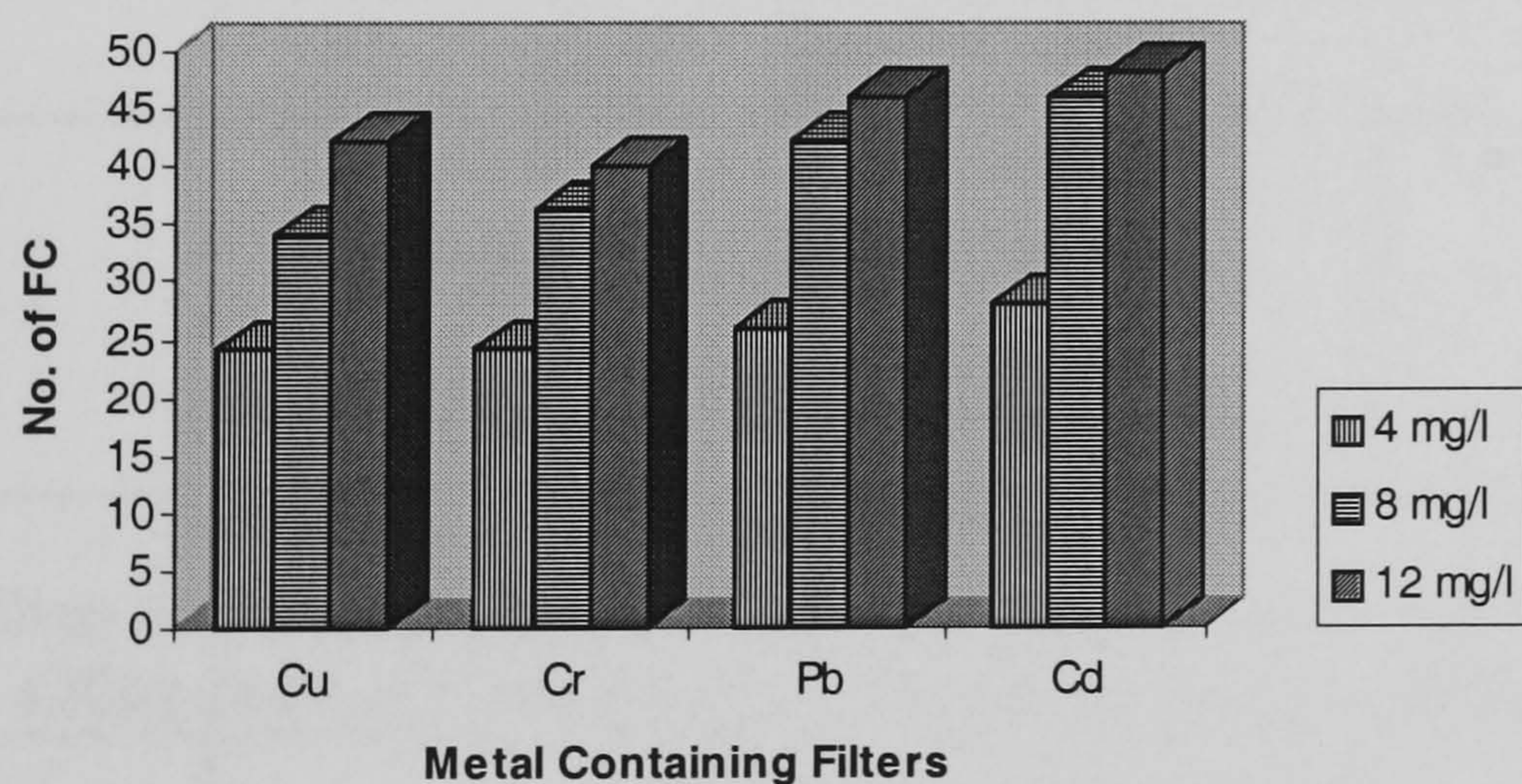


**Figure 5.22** Comparison of the number of faecal coliform/100 ml in the effluent of different metal containing filters at various TOCs at a flow rate of 0.2 m/hr and at a filter depth of 1.2 m.





**Figure 5.23 Comparison of the number of faecal coliform/100 ml in the effluent of different metal containing filters at various TOCs at a flow rate of 0.3 m.hr and at a filter depth of 1.2 m.**



**Figure 5.24 Comparison of the number of faecal coliform/100 ml in the effluent of different metal containing filters at various TOCs at a flow rate of 0.4 m/hr and at a filter depth of 1.2 m.**



Table 5.25: Drop of pH in the effluent of different filters at a flow rate of 0.1 m/hr and at a filter depth of 1.2m.(Figures in the bracket indicate standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	0.4(0)	0.5(0)	0.5(0)
F <sub>2</sub> /Cr	0.3(0)	0.5(0)	0.5(0)
F <sub>3</sub> /Pb	0.3(0)	0.4(0)	0.5(0)
F <sub>4</sub> /Cd	0.3(0)	0.4(0)	0.5(0)

Table 5.26: Drop of pH in the effluent of different filters at a flow rate of 0.2 m/hr and at a filter depth of 1.2m.(Figures in the bracket indicate standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	0.4(0)	0.5(0)	0.5(0)
F <sub>2</sub> /Cr	0.4(0)	0.5(0)	0.5(0)
F <sub>3</sub> /Pb	0.4(0)	0.4(0)	0.5(0)
F <sub>4</sub> /Cd	0.4(0)	0.4(0)	0.5(0)

Table 5.27: Drop of pH in the effluent of different filters at a flow rate of 0.3 m/hr and at a filter depth of 1.2m.(Figures in the bracket indicate standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	0.4(0)	0.4(0)	0.5(0)
F <sub>2</sub> /Cr	0.4(0)	0.4(0)	0.5(0)
F <sub>3</sub> /Pb	0.4(0)	0.5(0)	0.5(0)
F <sub>4</sub> /Cd	0.4(0)	0.4(0)	0.5(0)

Table 5.28: Drop of pH in the effluent of different filters at a flow rate of 0.4 m/hr and at a filter depth of 1.2m.(Figures in the bracket indicate standard deviation)

Filter/Metal	% removal efficiencies at TOC of		
	4 mg/l	8 mg/l	12 mg/l
F <sub>1</sub> /Cu	0.4(0)	0.4(0)	0.5(0)
F <sub>2</sub> /Cr	0.4(0)	0.4(0)	0.5(0)
F <sub>3</sub> /Pb	0.4(0)	0.5(0)	0.5(0)
F <sub>4</sub> /Cd	0.4(0)	0.4(0)	0.5(0)



### **5.3 REMOVAL OF HEAVY METALS AT CONVENTIONAL FLOW RATES AND FILTER BED DEPTHS**

The percentage removal of Cu, Cr, Pb and Cd at the conventional flow rate of 0.1 m/hr and filter bed depth of 1.2m at various TOCs are summarised in Table 5.1. It shows that :

- The highest removals of Cu, Cr, Pb and Cr were achieved as 99.6, 97.2, 100 and 96.6% respectively at a TOC of 12 mg/l. The concentration of Cu, Cr, Pb and Cd in the influent was 9.3 mg/l, 92 µg/l, 49.1 µg./l and 99 µg/l respectively. The concentrations of Cu, Cr, Pb and Cd in the effluent were 34 µg/l, 2.60 µg/l, 0 µg/l and 3.40 µg/l respectively (Table A7.9.1). The effluent standard of Cu, Cr and Pb satisfied the WHO guidelines whereas the effluent standards of Cd were very close to the WHO limit. The WHO guidelines for Cu, Cr, Pb and Cd are 2 mg/l, 50 µg/l, 10 µg/l and 3 µg/l respectively for drinking purposes.
- The removals of Cu, Cr, Pb and Cd at TOC 8 mg/l were 98.6, 97, 94.2 and 96.2 % and at 4 mg/l were 98.2, 96.7, 90.4 and 94 % respectively. The removals of all four metals were slightly lower at TOC 8 and 4 mg/l but still the removal was very high. The concentrations of Cu, Cr, Pb and Cd in the effluent at TOC 8 mg/l were 140 µg/l, 2.90 µg/l, 3.0 µg/l and 3.6 µg/l respectively and that at TOC 4 mg/l were 154 µg/l, 3.40 µg/l, 4.70 µg/l and 5.6 µg/l respectively (Tables A1.5.1 and A1.1.1). The effluent quality of Cu, Cr and Pb satisfied the WHO guidelines and that of Cd was close to the WHO limit.

### **5.4 REMOVAL OF OTHER POLLUTANTS**

#### **5.4.1 Removal of TOC**

The removal of TOC by the Cu containing filter varied between 49.9% and 58.8% depending on the TOC level in the influent water (Tables 5.13, 5.14, 5.15 and 5.16). The highest removal was achieved at the influent TOC level of 12 mg/l. A similar trend has been observed for the filters containing Cr, Pb and Cd. A general trend was observed as



the increase of percentage removal of TOC with the increase in TOC. Although at higher TOC the removal is relatively higher, relatively more organic matter passed with the filtrate at higher TOC. The percentage removal of TOC was more or less the same by filters containing different metals. Visscher *et al* (1988) suggests that the removal of organic matter by SSFs varies between 35% and 50% as COD which is equivalent to 12%-20% as TOC. Raechel (1985) suggests the removal of TOC by SSFs is as minimum as 20 %. Hence the removal of TOC by SSF is not affected due to the presence of heavy metals in water. The results also show that the removal of TOC is not affected by the flow rates up to 0.4 m/hr.

#### **5.4.2 Removal of Turbidity**

The percentage removal of turbidity by the Cu containing filter was found to vary between 90% and 90.7%. The highest removal was achieved at 12 mg/l of TOC. A similar trend was observed for the filters containing Cr, Pb and Cd (Table 5.17, 5.18, 5.19 and 5.20). Muhammad *et al* (1997) suggested the removal of turbidity by SSF varied between 88.5% and 90.6% depending on the sand size and flow rates. Ellis(1985) suggested a removal of more than 90% turbidity by SSFs. Visscher *et al* (1988) describes that turbidity is generally reduced to 1 NTU. The investigations show that the effluent turbidity was reduced to  $1 \leq \text{NTU}$  in almost all test conditions. The effluent turbidity was slightly more than 1 NTU at the flow rate of 0.4 m/hr ( TablesA1.1.4, A1.2.4, A1.3.4, A1.4.4, A1.5.4, A1.6.4, A1.7.4, A1.8.4, A1.9.4, A1.10.4, A1.11.4 and A1.12.4). Hence the removal of turbidity is not affected due to the presence of heavy metals in water. The turbidity removal efficiency decreased with the increase in flow rate.

#### **5.4.3 Removal of Faecal Coliform**

The removal of FC by all four filters was almost 100% at a conventional flow rate of 0.1 m/hr and filter depth of 1.2m. The effluent contained a negligible number of FC at TOC 12 mg/l because of very high bacterial count in the influent at this TOC (Table A1.9.6). The removal of FC by all four filters was 99.99% at all four flow rates. Although the removal efficiency was very high for the filters, the effluent contained a considerable



number of FC because of very high bacterial content in the influent (Tables A1.1.6, A1.2.6, A.1.3.6, A.1.4.6, A1.5.6, A1.6.6, A1.7.6, A1.8.6, A1.9.6, A1.10.6, A1.11.6 and A1.12.6).

The typical performance of SSF in removing FC is  $> 99.99\%$  (Visscher *et al*, 1988; Ellis, 1985; Muhammad *et al*, 1997; Aydin, 1993 and Huisman, 1974). The results of the tests at the end of maturation period are considered as the performance of the control filters (without any heavy metals). The removal of FC was found almost 100 % at the end of the maturation of the filters of the present study. So the FC removal efficiency of SSF has not been affected due to the presence of heavy metals.

#### **5.4.4 Drop of pH**

The pHs of influent and effluent were monitored at various flow conditions. A drop of pH with a range of 0.3-0.4 had always been observed (Tables 5.25, 5.26, 5.27 and 5.28). This may be the reason for microbial activity in SSF. Microbial activity produces  $\text{CO}_2$  which might have reduced the pH in the effluent.

### **5.5 EFFECTS OF TOC ON THE PERFORMANCE OF SSF IN REMOVING HEAVY METALS AT THE CONVENTIONAL FLOW RATE OF 0.1 m/hr**

- It is obvious from the test results that the organic content (TOC) of the influent has a significant influence on the removal of heavy metals by SSF. The results demonstrate the general trend of increasing heavy metal removal efficiency with the increase in TOC. The positive effects of increased organic load are more significant in the case of Pb and Cd than for Cu and Cr.

- Linear correlations have been found between the percentage removal of heavy metals and TOC of the influent water. Figure 5.25 describes the variation of the percentage removal of Cu, Cr, Pb and Cd with TOC at a flow rate of 0.1 m/hr and filter depth of 1.2m. Table 5.29 summarises the mathematical models and correlation coefficients



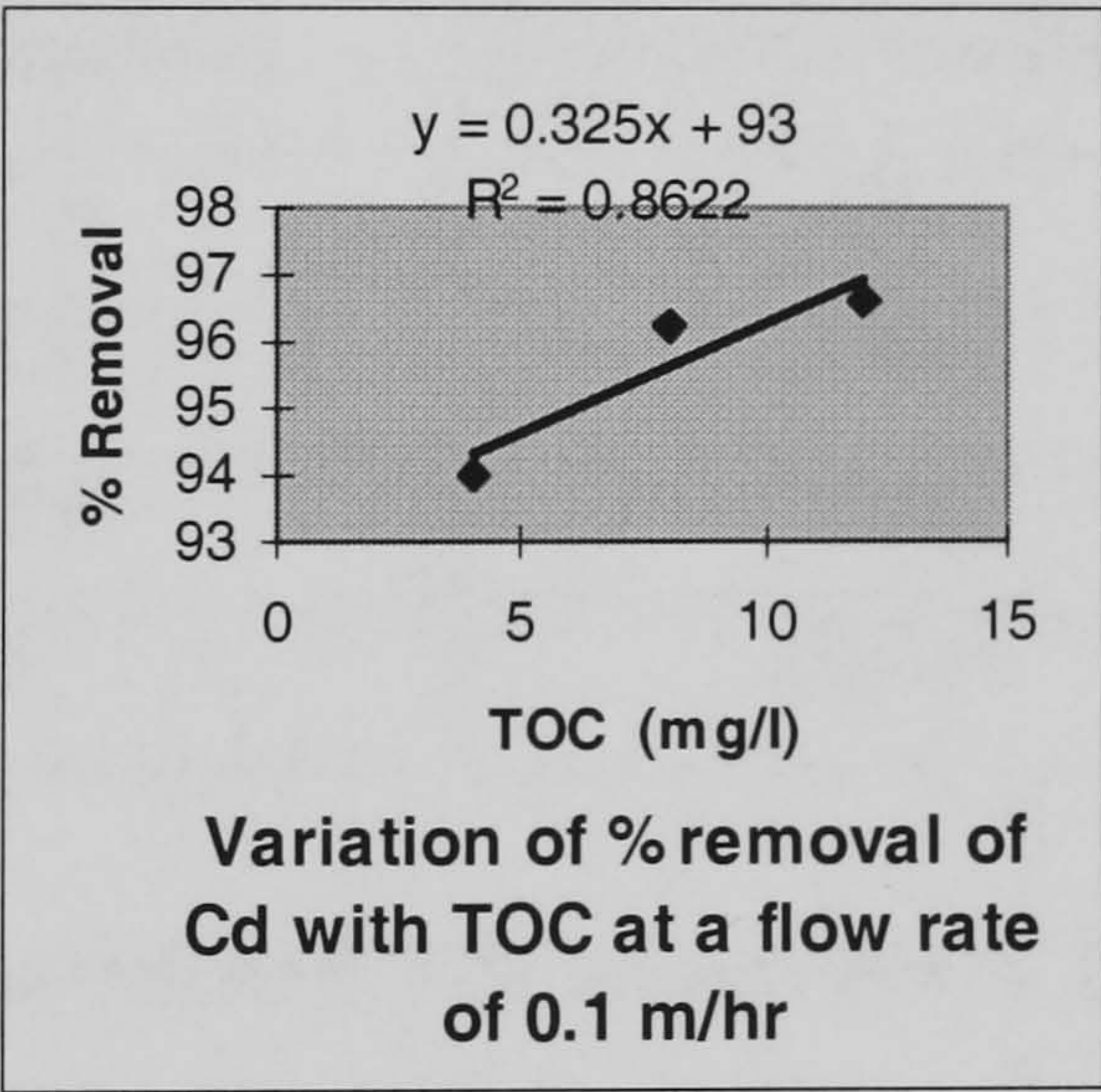
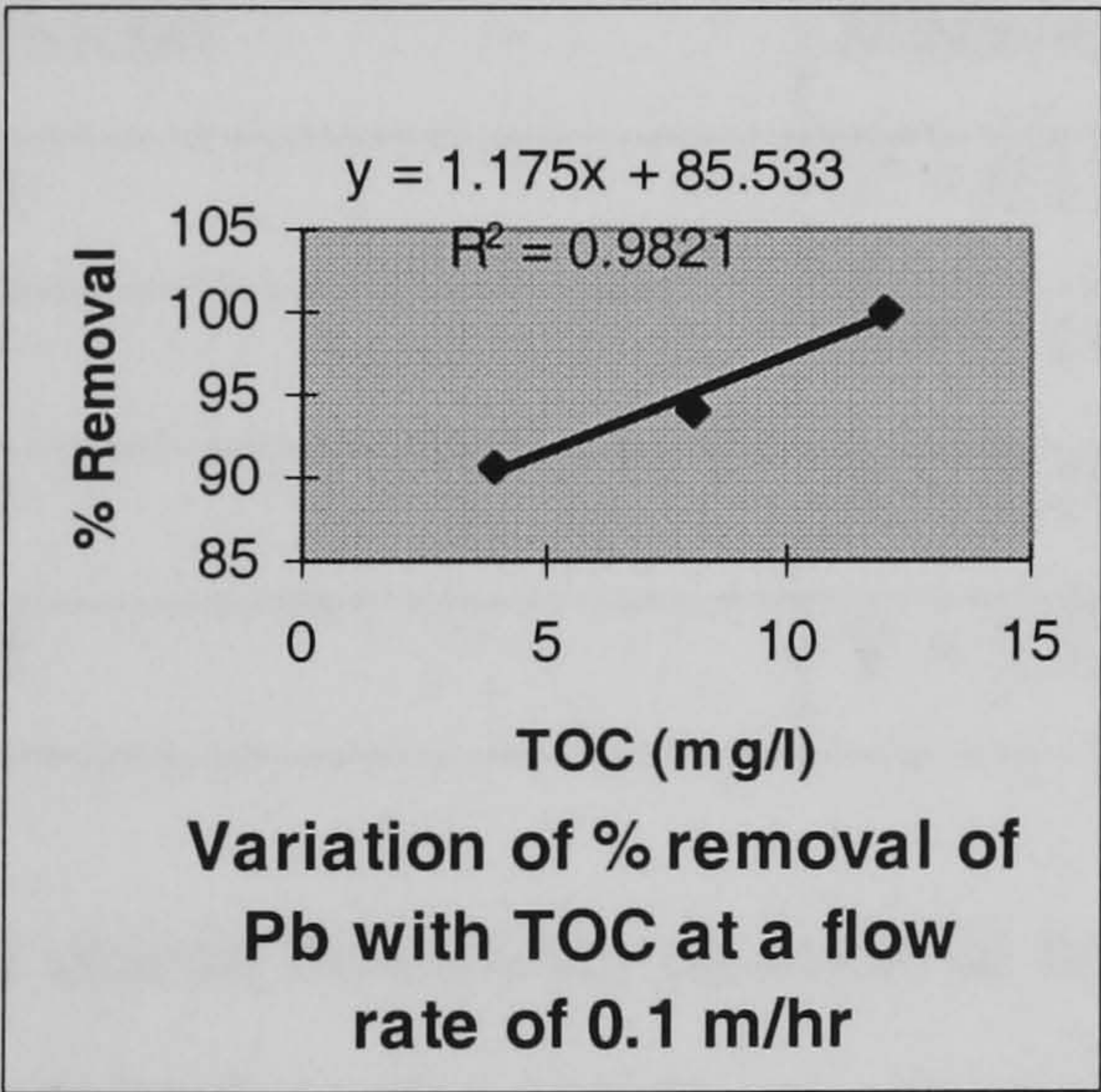
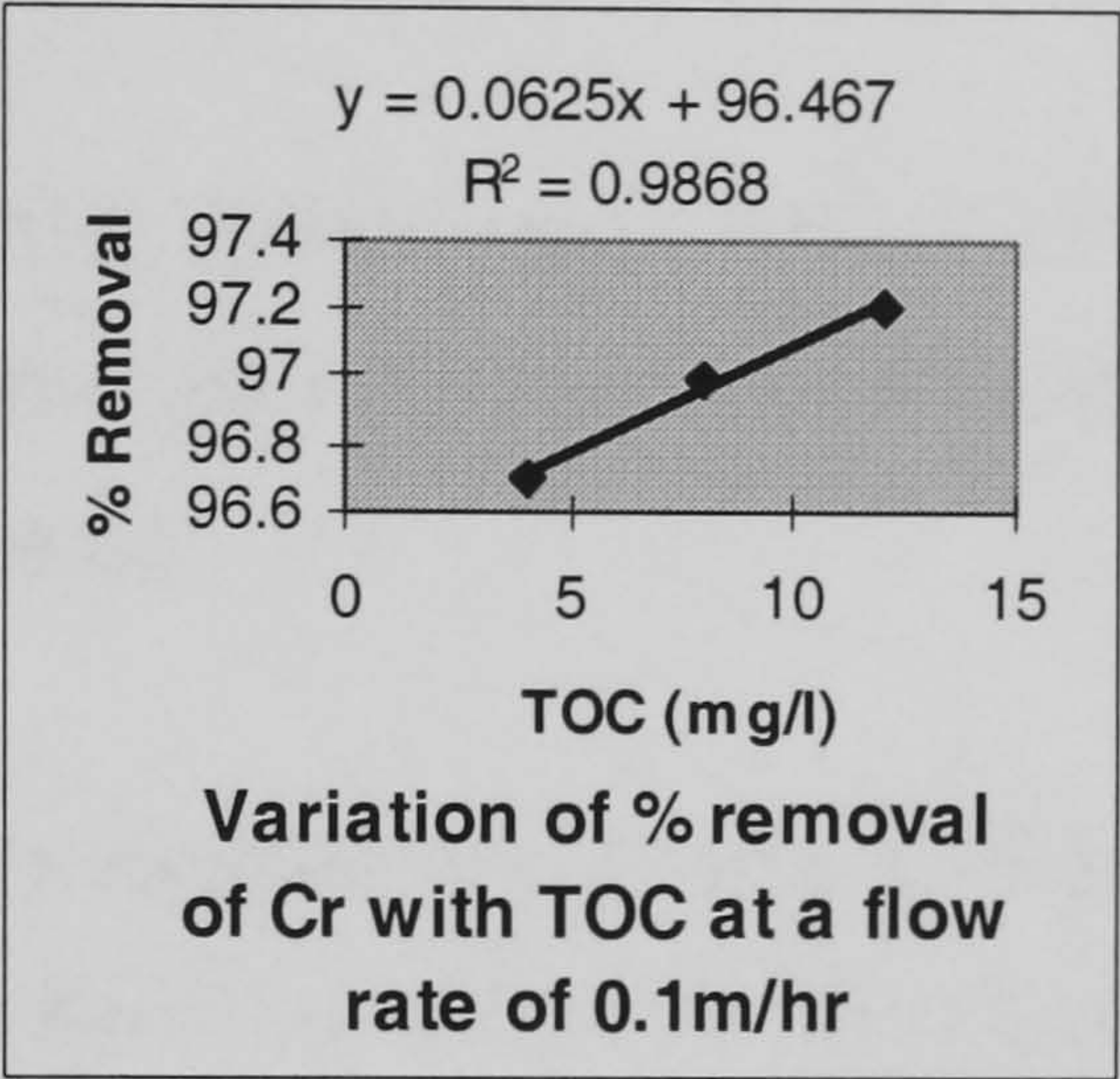
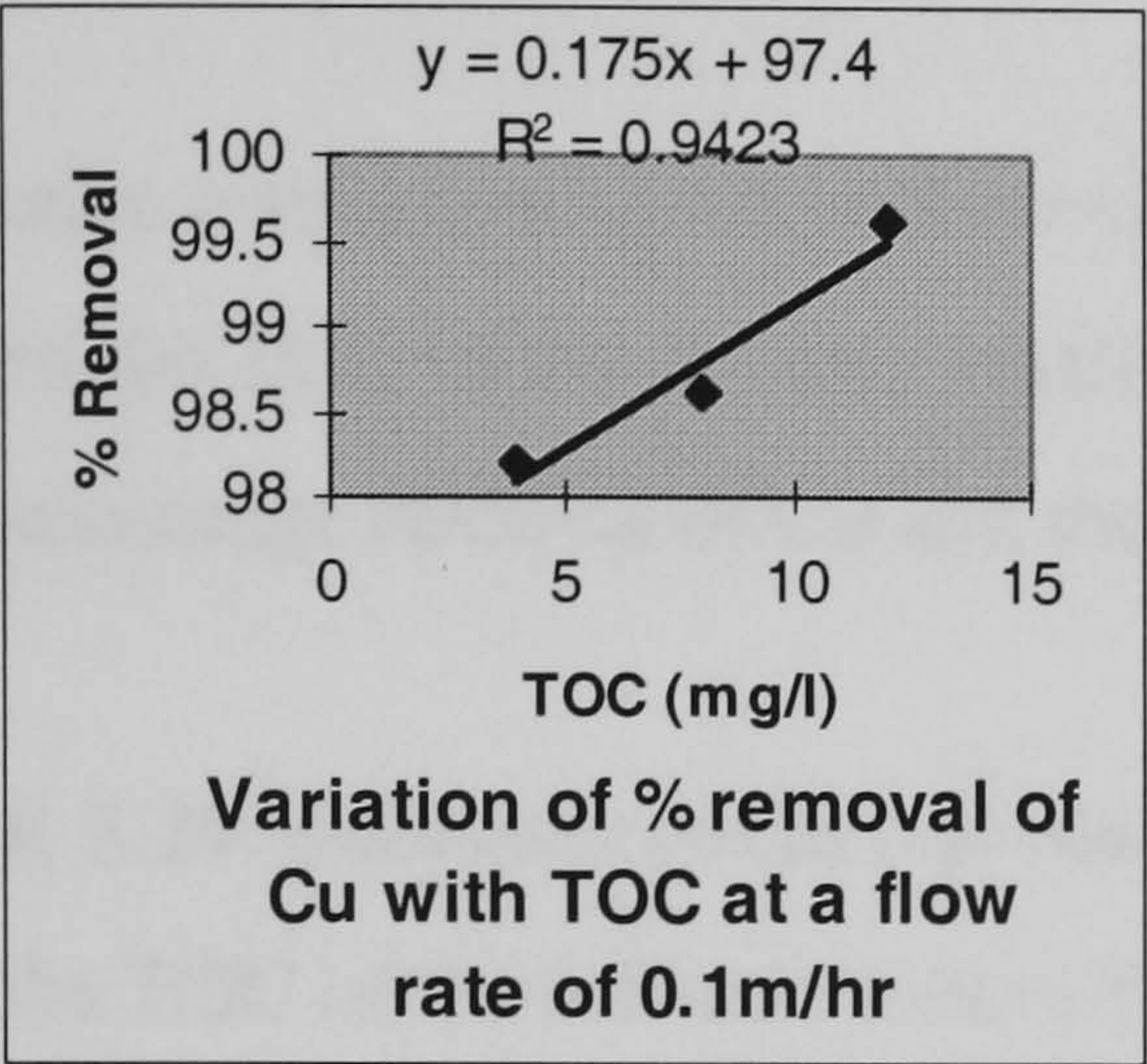


Figure 5.25 Variation of % removal of different heavy metals with TOCs at a flow rate of 0.1 m/hr and at a filter depth of 1.2 m.



relating the percentage removal and TOC for various metals.

- The critical linear regression coefficients ( $R^2$ ) for a d.f (degree of freedom) of 1 is 0.9938 (Blend, 1985). In case of Cu, Cr and Pb, the linear regression coefficients are very close the value of the critical regression coefficient. But in the case of Cd, the linear regression coefficient value is relatively lower but close to the critical value.
- Hence a very strong correlation exists between the percentage removal of Cu, Cr and Pb and the TOC of the influent water. And a reasonably strong correlation exists between the percentage removal of Cd and the influent water.

Table 5.29 Summary of the regression analysis regarding the % removal of heavy metals and the TOC of the influent water (Y indicates the % removal of the specific heavy metal and X indicates the TOC content of the influent)

Filter/Metal	Mathematical Equations	Regression Coefficient ( $R^2$ )
F1/Cu	$Y = 0.175X + 97.4$	0.9423
F2/Cr	$Y = 0.063X + 96.5$	0.9868
F3/Pb	$Y = 1.175X + 85.6$	0.9821
F4/Cd	$Y = 0.325X + 93$	0.8622

- The reason behind the increase in heavy metal removal with the increase of TOC could be explained as the result of adsorption of heavy metals onto organic matter (this has been further demonstrated by the speciation test results described in chapter 9)

**5.6 EFFECTS OF FILTRATION RATES ON THE REMOVAL OF HEAVY METALS BY SSFs.**

Figures 5.26, 5.27 and 5.28 describe the variation of the percentage removal of heavy metals with flows rates at the TOCs of 4, 8 and 12 mg/l respectively.



- It is evident from the results that an increase in flow rate caused the decrease in removal efficiency of heavy metals by SSF. But the decline in efficiency with flow rates depended on the individual metals and TOC of the influent water.
- The removal efficiency of Cu and Cr declined slightly with flow rates even up to 0.4 m/hr at all TOC levels. The removal efficiencies of these two metals were very high at a flow rate of 0.4 m/hr and the effluent concentrations were much below WHO limits (Tables A1.4.1, A1.8.1 and A1.12.1). Hence in the case of Cu and Cr, a flow rate of 0.4 m/hr can be recommended.
- The removal efficiency of Pb declined slightly with flow rates up to a flow rate of 0.3 m/hr and then declined sharply at a flow rate of 0.4 m/hr at all TOCs. If the TOC of the influent water is 8 mg/l or more, a flow rate up to a maximum of 0.3 m/hr can be adopted without sacrificing the effluent quality of Pb. If the TOC of the influent water is less than 8 mg/l, the conventional flow rate 0.1 m/hr is recommended for Pb.
- The removal efficiency of Cd declined gradually with the increase in flow rates at all TOCs. It is evident from the results that only a conventional flow rate of 0.1 m/hr can produce effluent quality of Cd close to WHO limits at a TOC of 8 and 12 mg/l (Tables A1.5.1 and A1.9.1). Hence a conventional flow rate of 0.1 m/hr is recommended for the efficient removal of Cd at a TOC of 12 mg/l.
- The regression analysis shows that linear correlation exists between the removal of heavy metals and the filtration rates. Table 5.30 describes the summary of the mathematical equations relating to the flow rates and the heavy metal removal efficiency by SSFs.



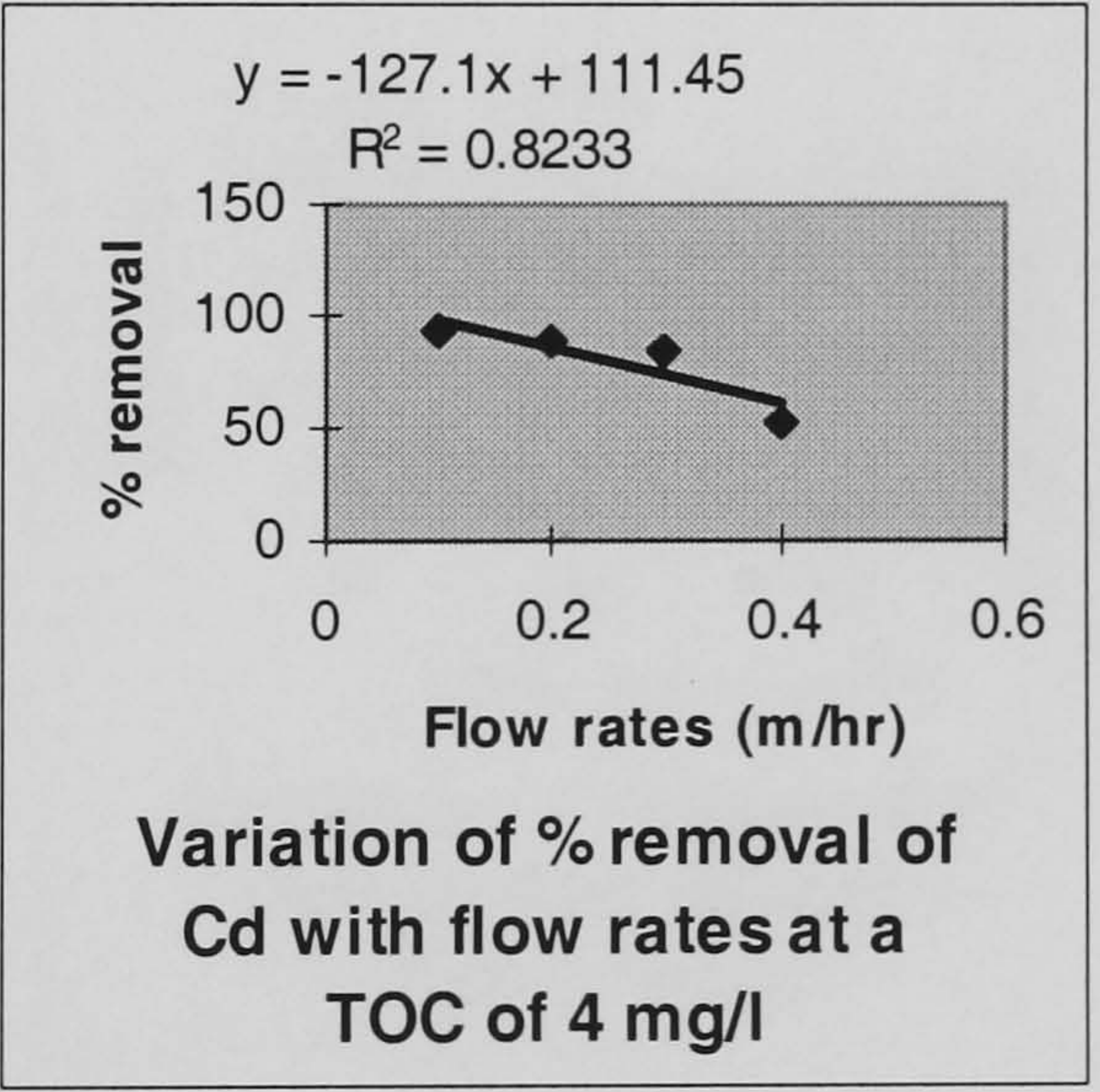
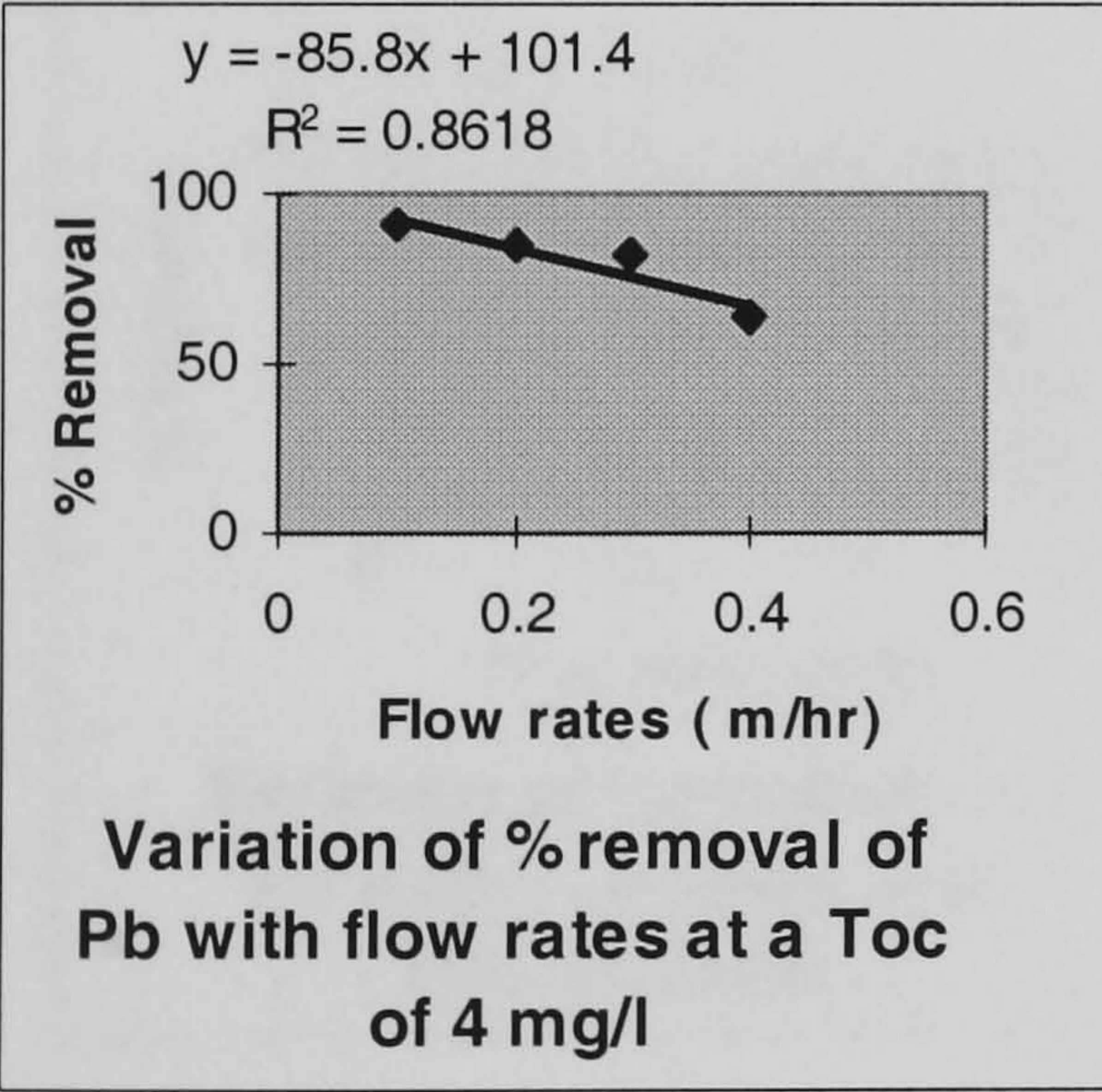
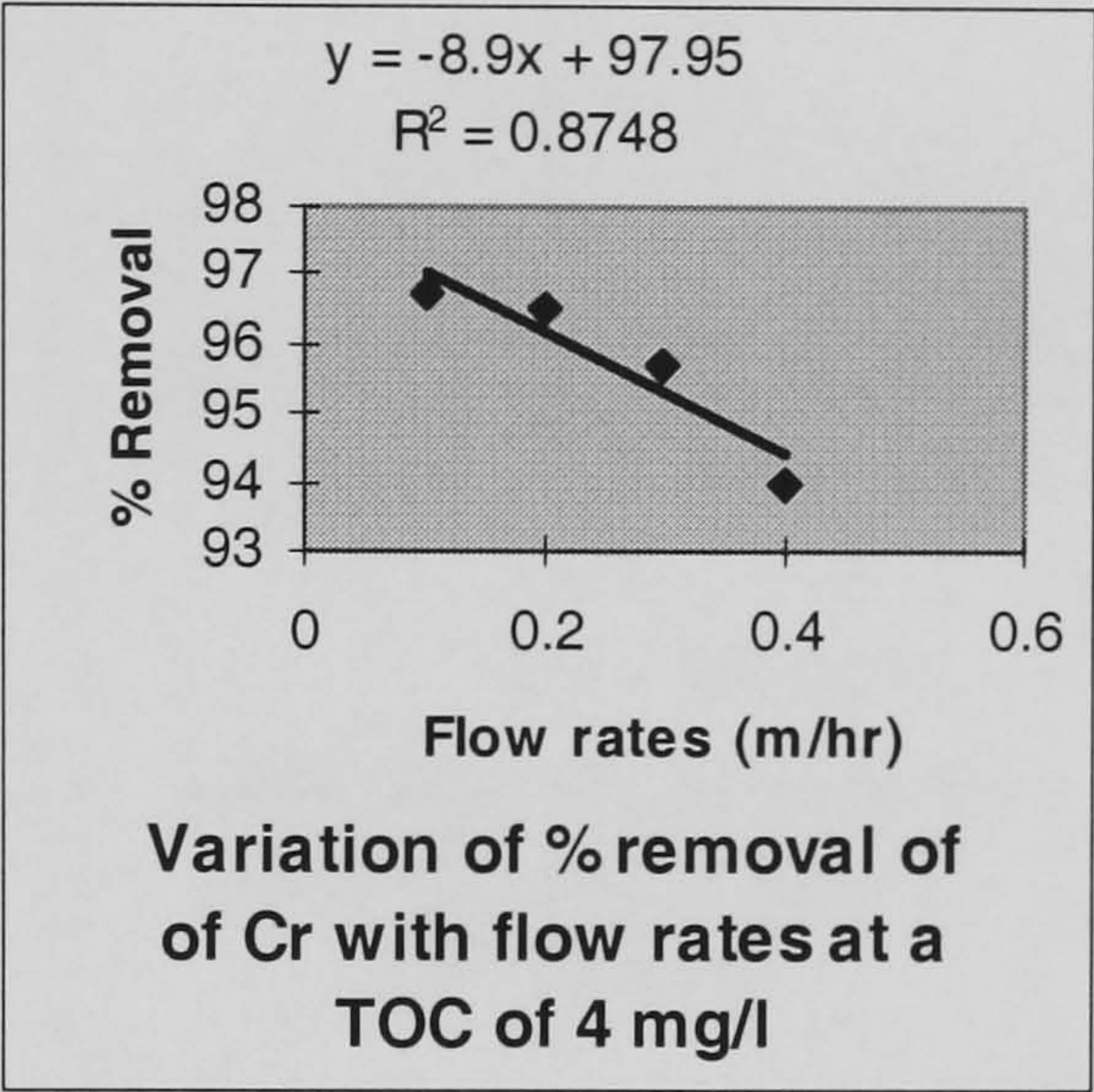
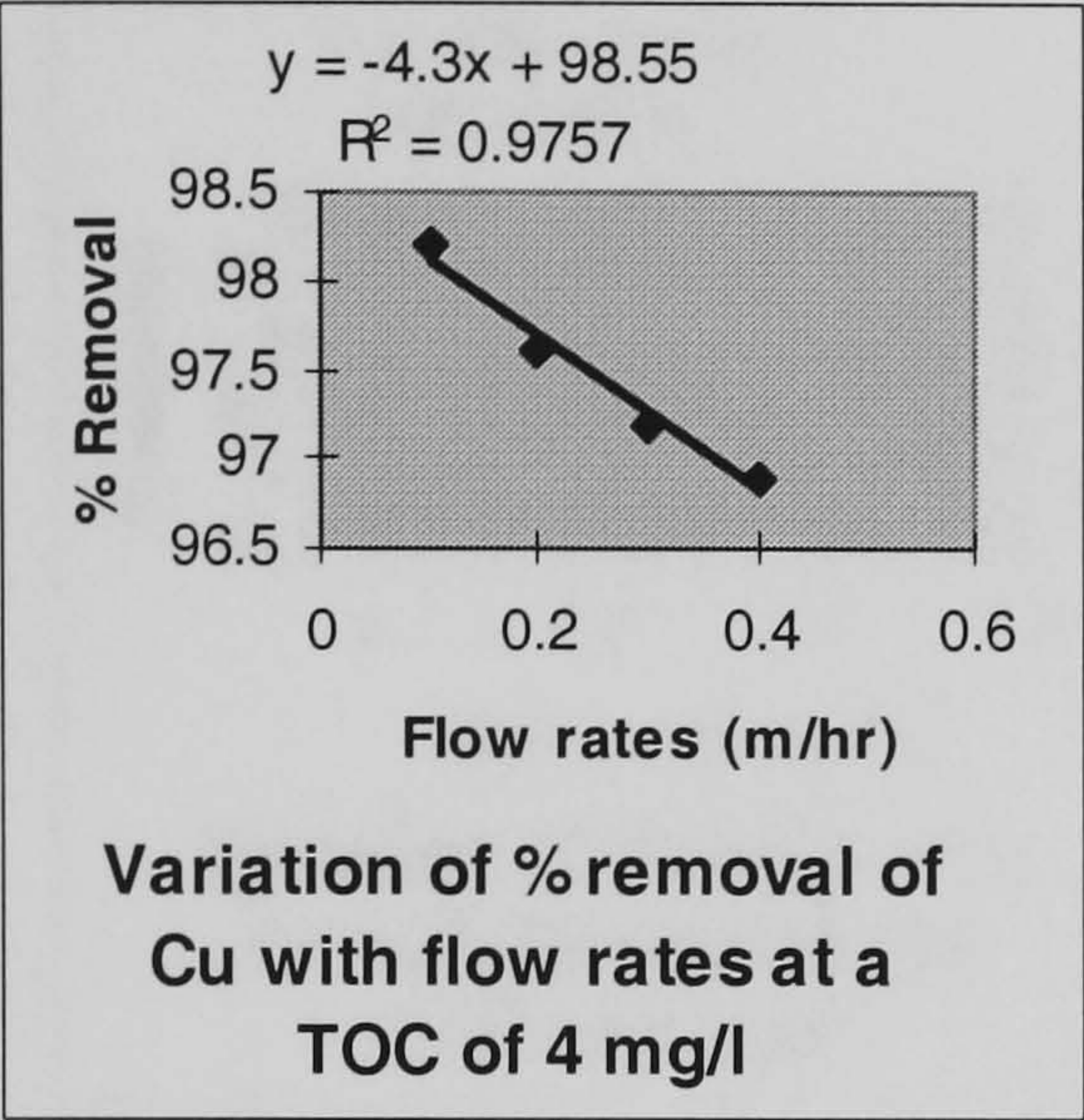


Figure 5.26 Variation of % removal of different heavy metals with flow rates at a TOC of 4 mg/l and at a filter depth of 1.2 m.



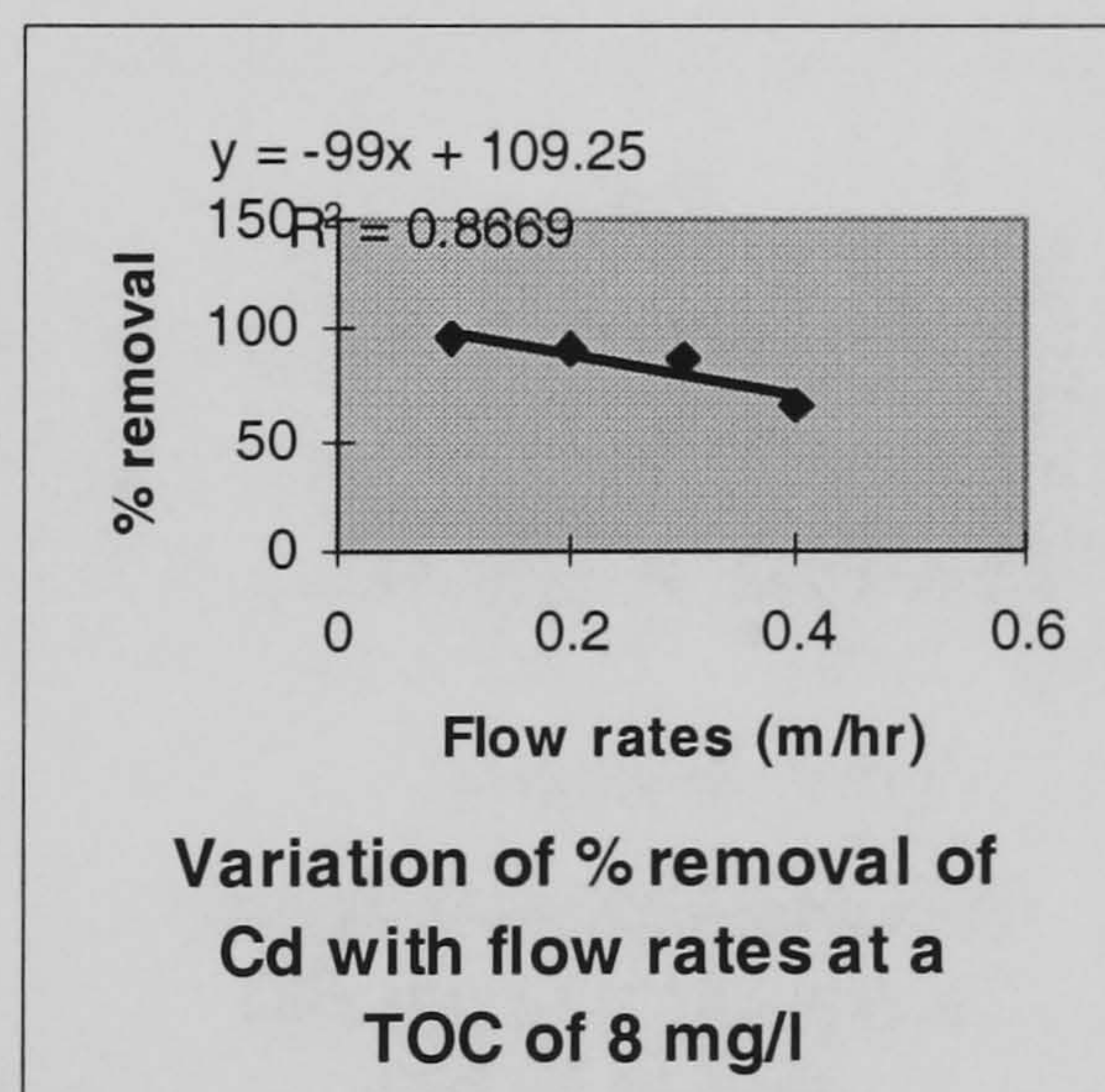
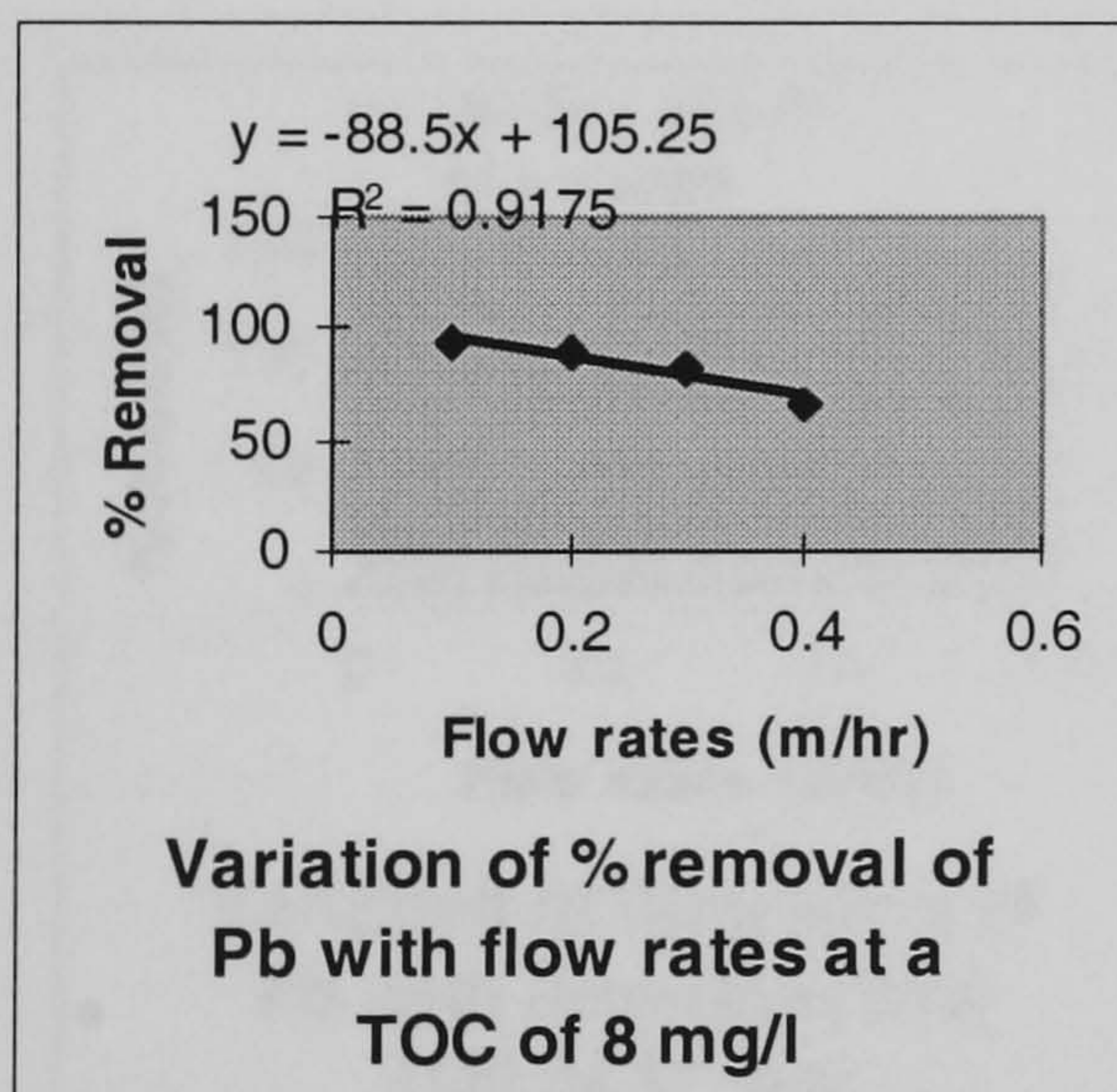
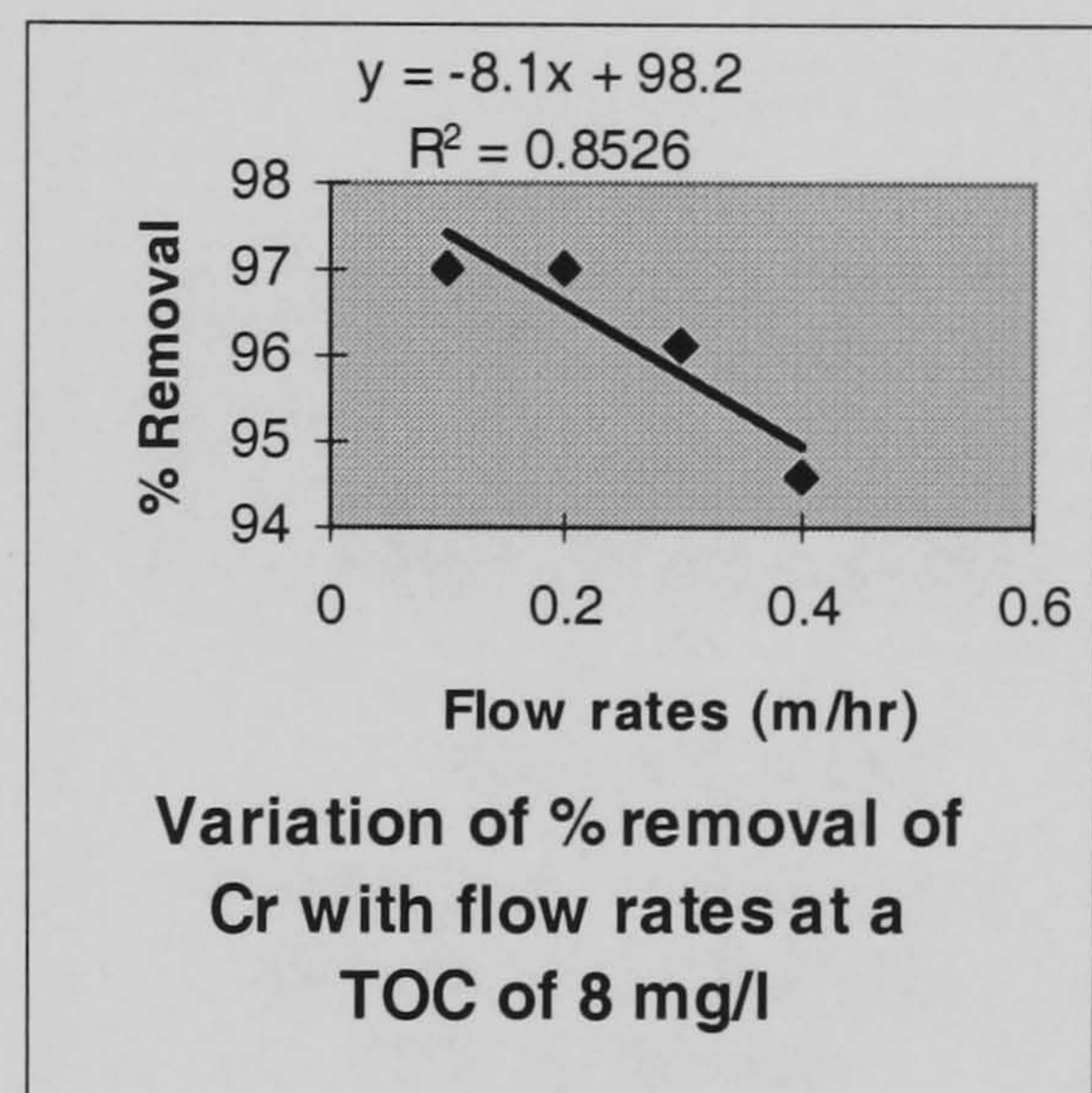
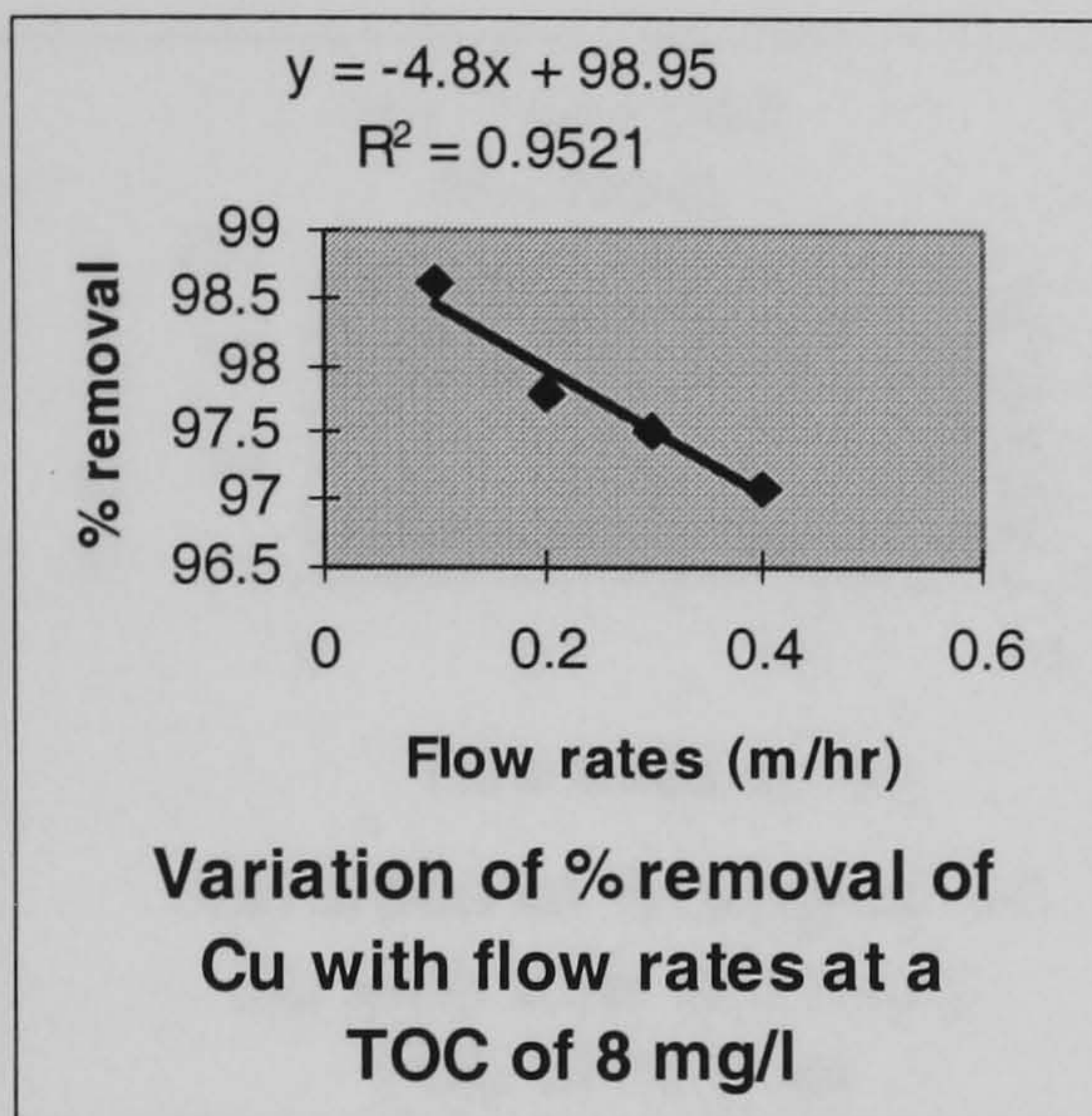


Figure 5.27 Variation of % removal of different heavy metals with flow rates at a TOC of 8 mg/l and at a filter depth of 1.2 m.



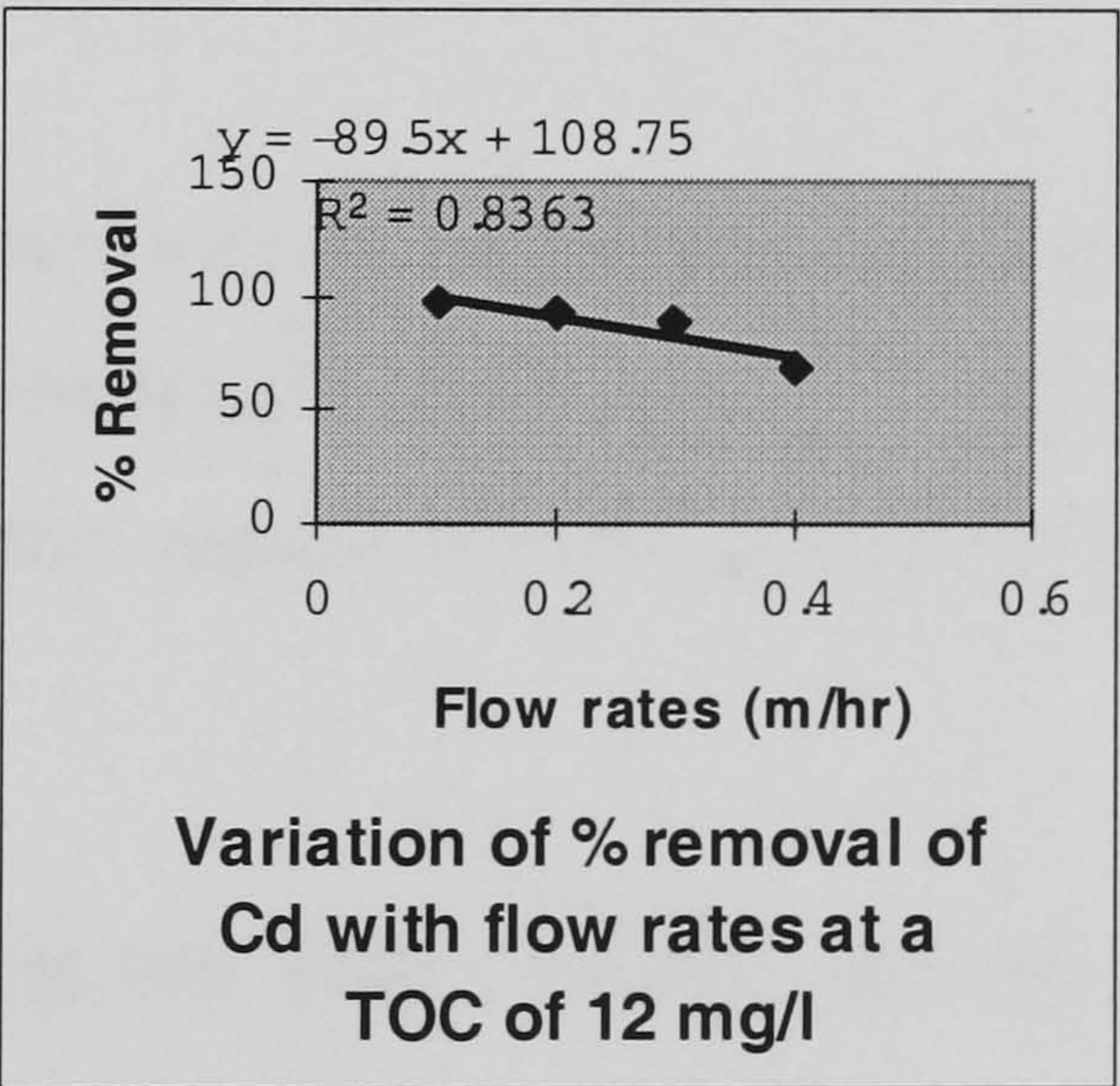
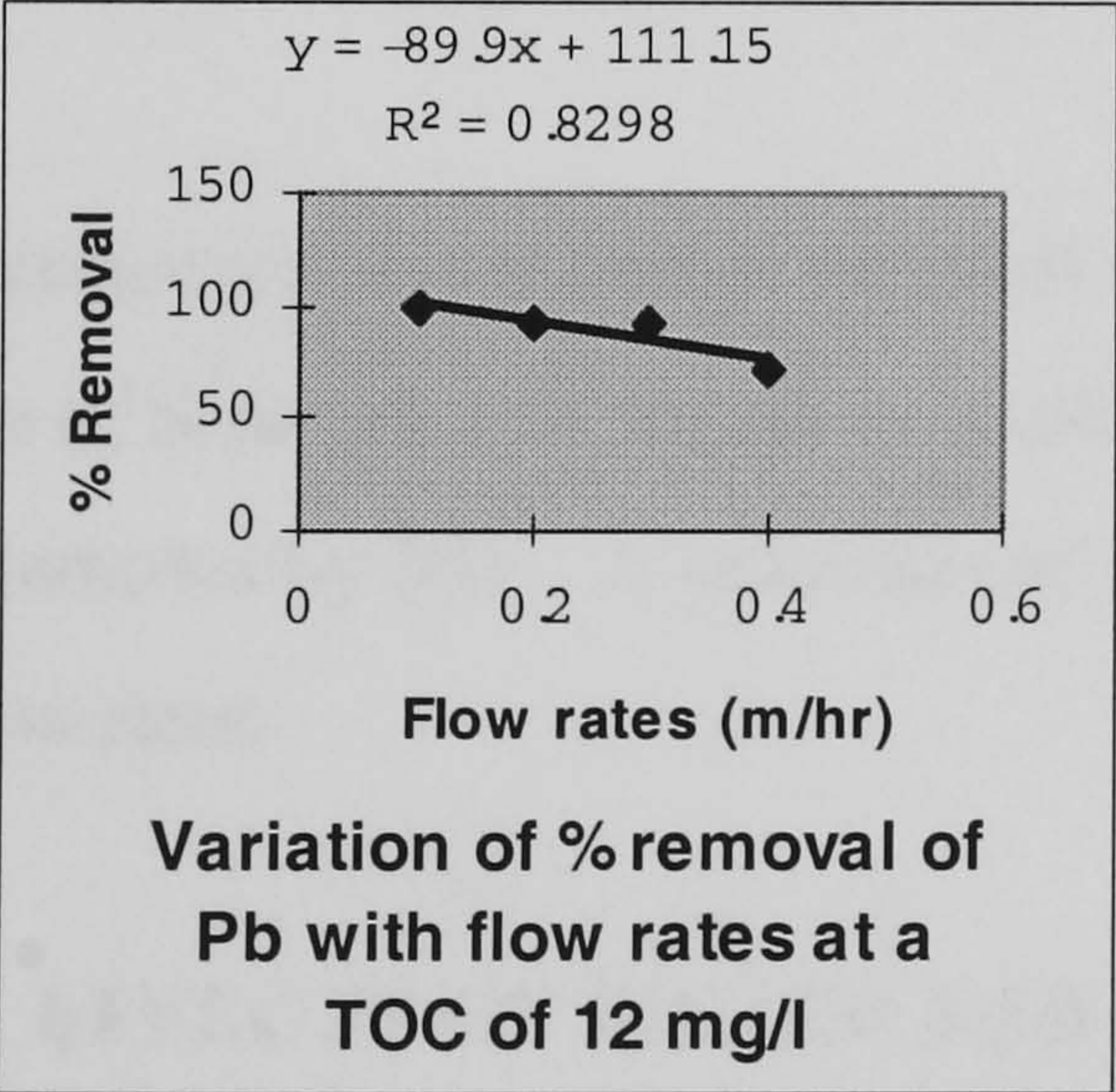
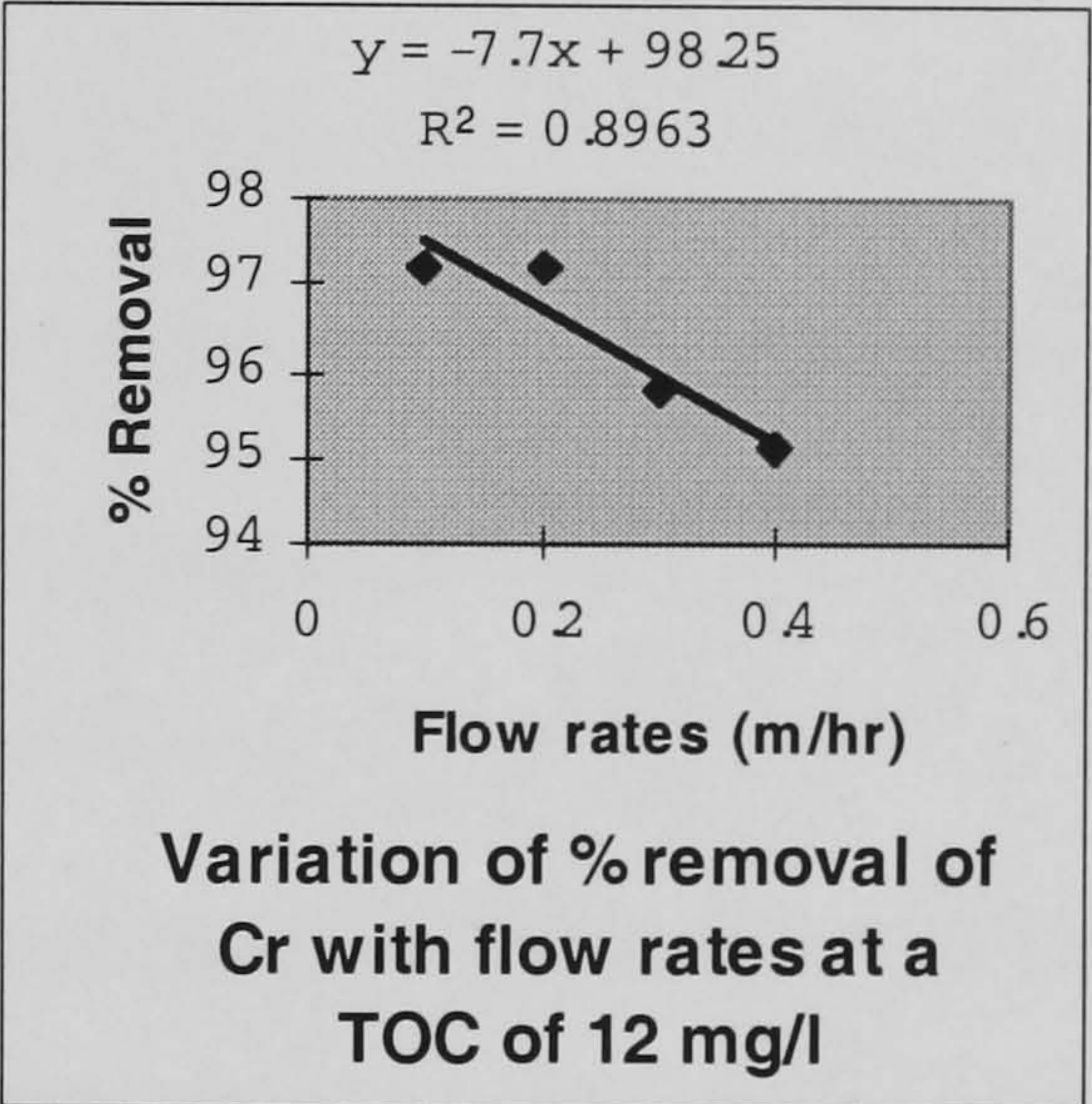
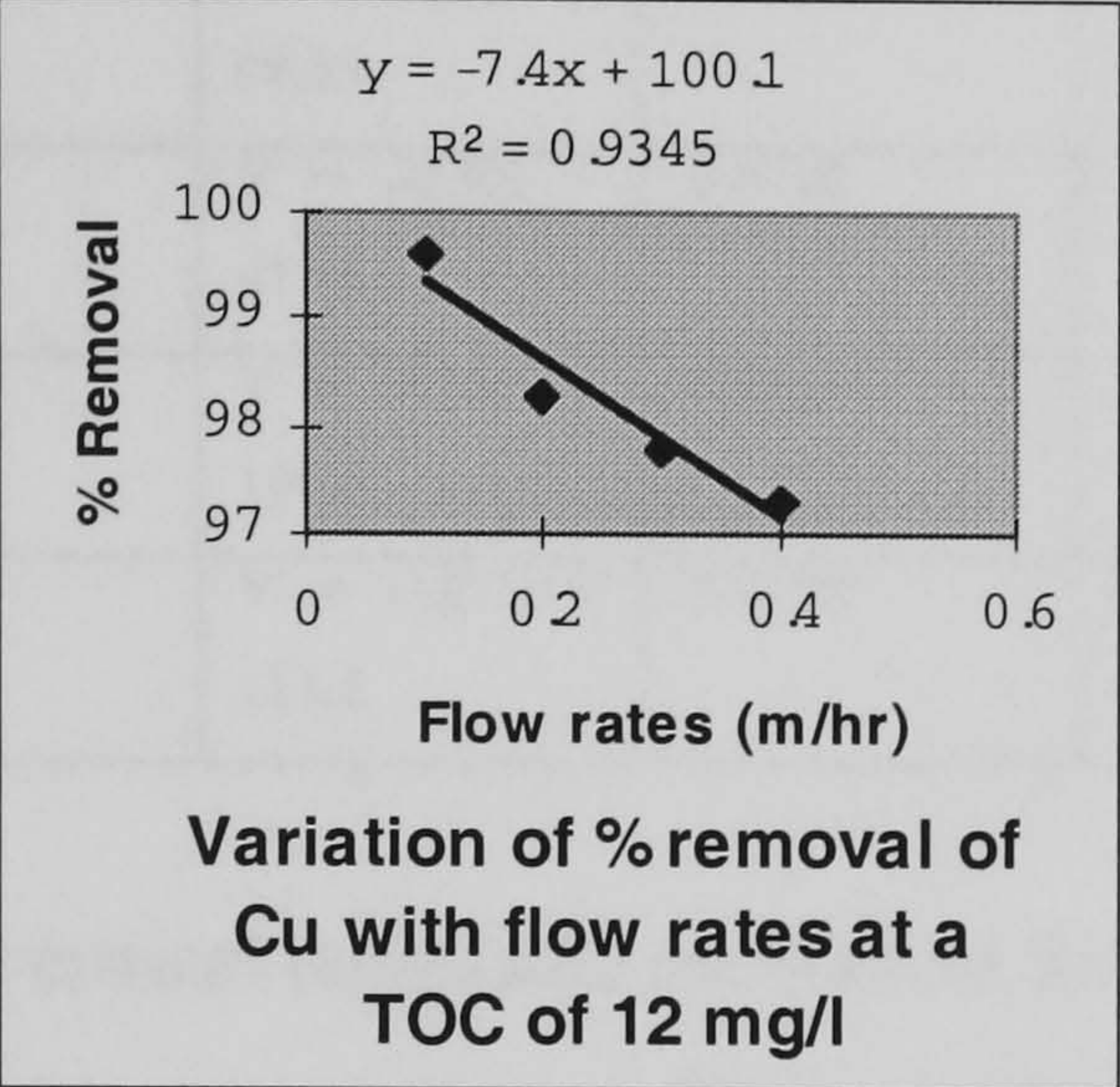


Figure 5.28 Variation of % removal of different heavy metals with flow rates at a TOC of 12 mg/l and at a filter depth of 1.2 m.



Table 5.30 Summary of regression analysis regarding flow rates and the % removal of heavy metals at the filter depth of 1.2 m (Y indicates the percentage removal of heavy metals and X indicates the flow rate).

Filter/Metal	TOC 4 mg/l		TOC 8 mg/l		TOC 12 mg/l	
	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )
F1/Cu	Y = -4.3X + 98.55	0.9757	Y = -4.8X + 98.95	0.9521	Y = -7.4X + 100.1	0.9345
F2/Cr	Y = -8.9X + 97.95	0.8748	Y = -8.1X + 98.20	0.8526	Y = -7.7X + 98.25	0.8983
F3/Pb	Y = -85.8X + 101.4	0.8818	Y = -88.5X + 105.3	0.9175	Y = -89.9X + 111.5	0.8293
F4/Cd	Y = -127X + 111.1	0.8223	Y = -99X + 109.25	0.8669	Y = -89.5X + 108.75	0.8363

- The critical regression coefficient for a degree of freedom of 2 is 0.9025 (Blend, 1985). The linear regression coefficients relating the percentage removal of Cu, Cr, Pb and Cd and flow rates are very close to the critical value. Hence a strong correlation exists between the percentage removal of the selected heavy metals and flow rates.
- Decrease of heavy metals removal efficiency with the increase of flow rates implies the role of adsorption of metals on sand and onto organic matter as a mechanism of heavy metal removal by SSF. A reduction of adsorption capacity of sand is expected at a higher filtration rates.

### 5.7. EFFECTS OF FILTER BED DEPTH ON THE PERFORMANCE OF SSF IN REMOVING HEAVY MEALS

Figures 5.29 through to 5.40 show the variation of the % removal of different heavy metals with filter depth at different flow rates and TOCs.

- It is evident from the results that the removal efficiencies of heavy metals increased with the increase of filter bed depth.



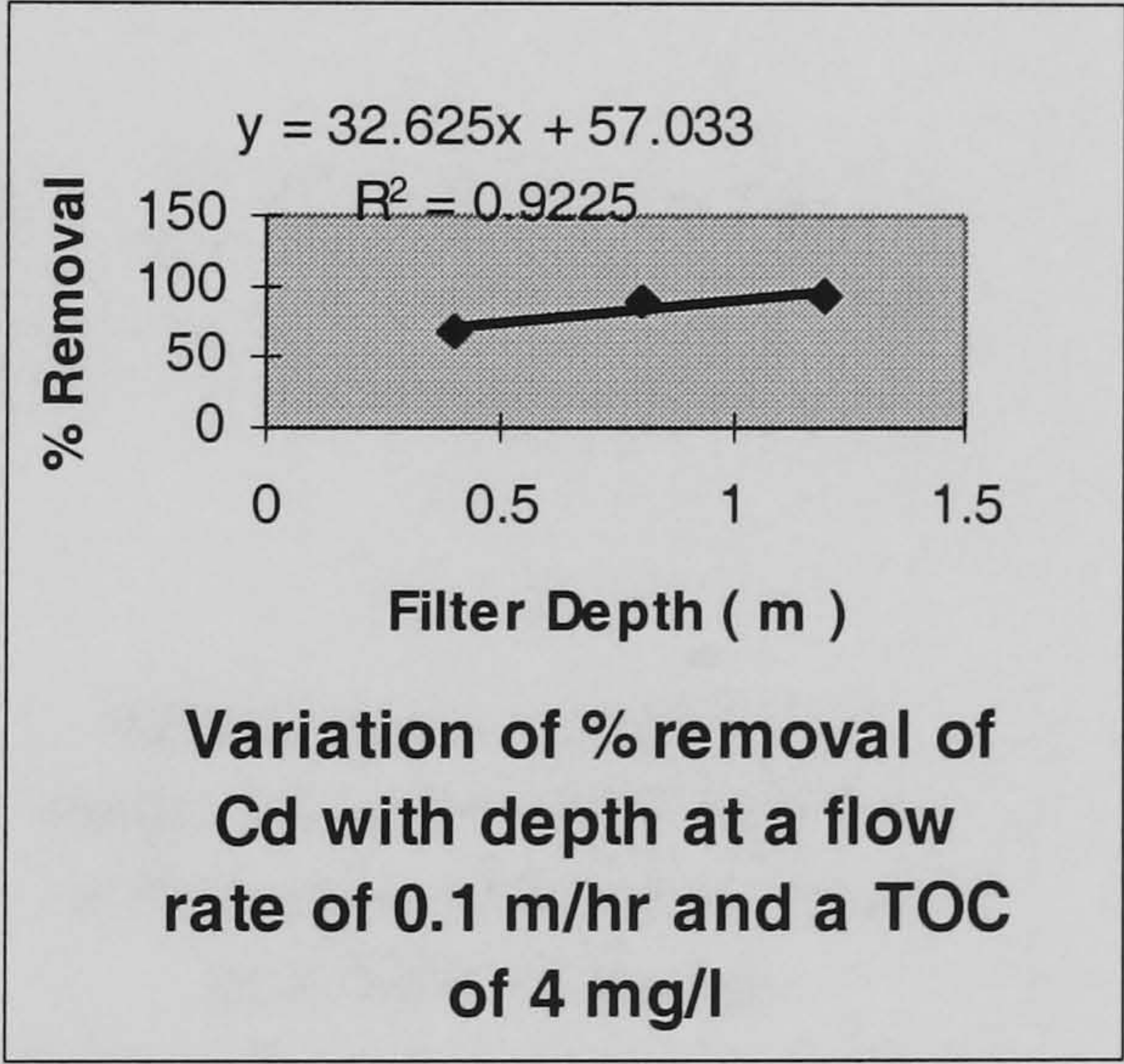
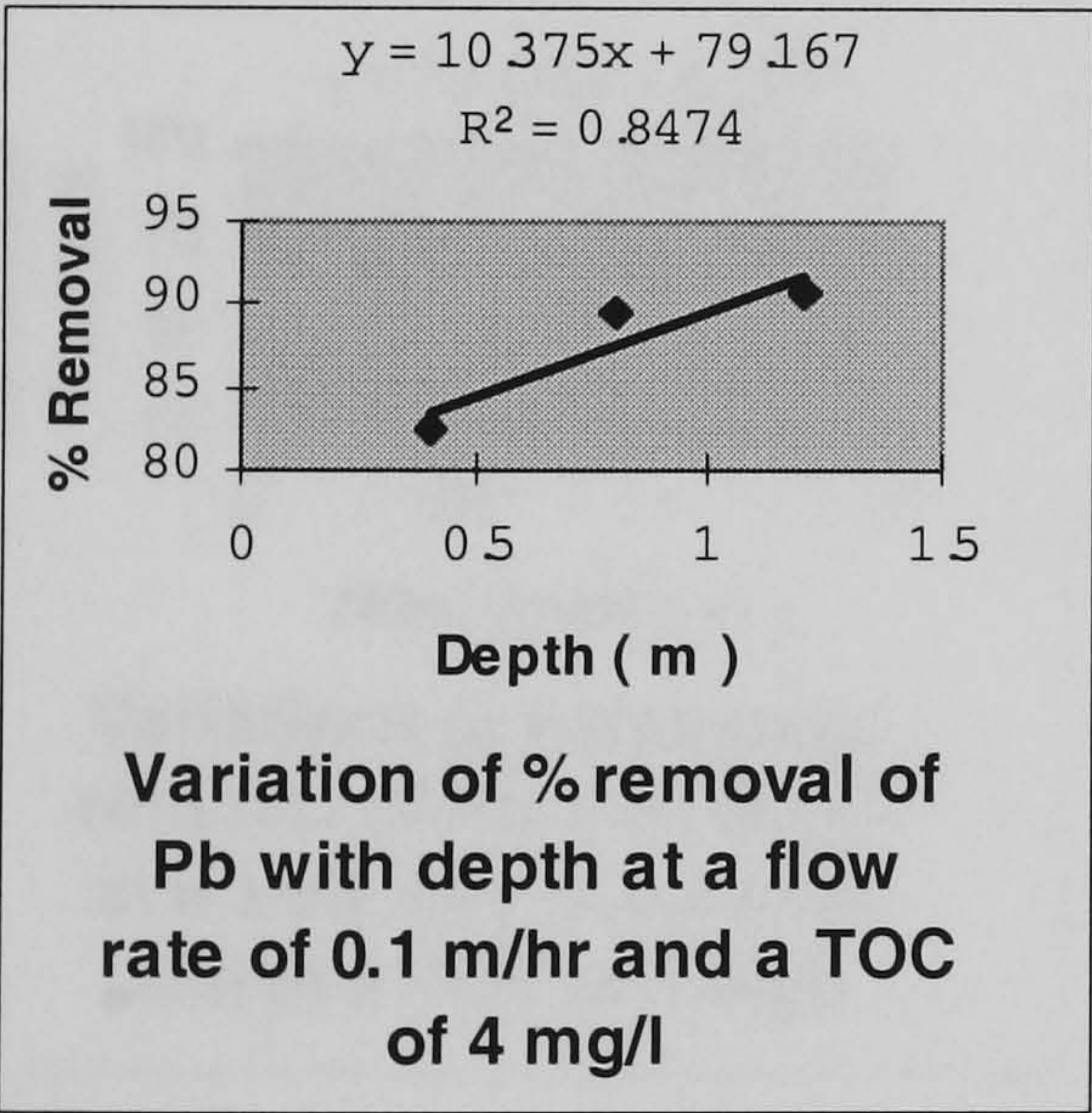
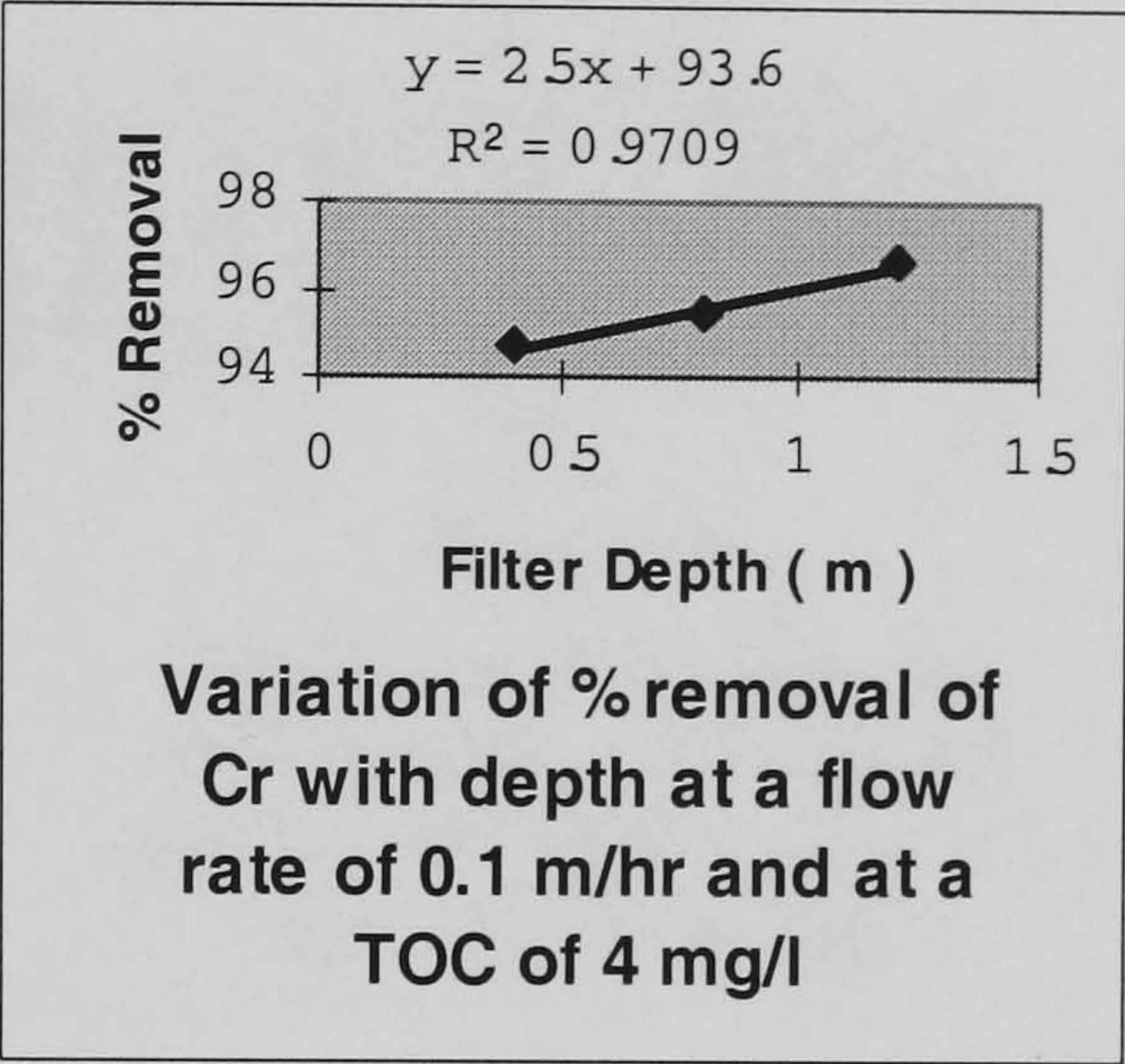
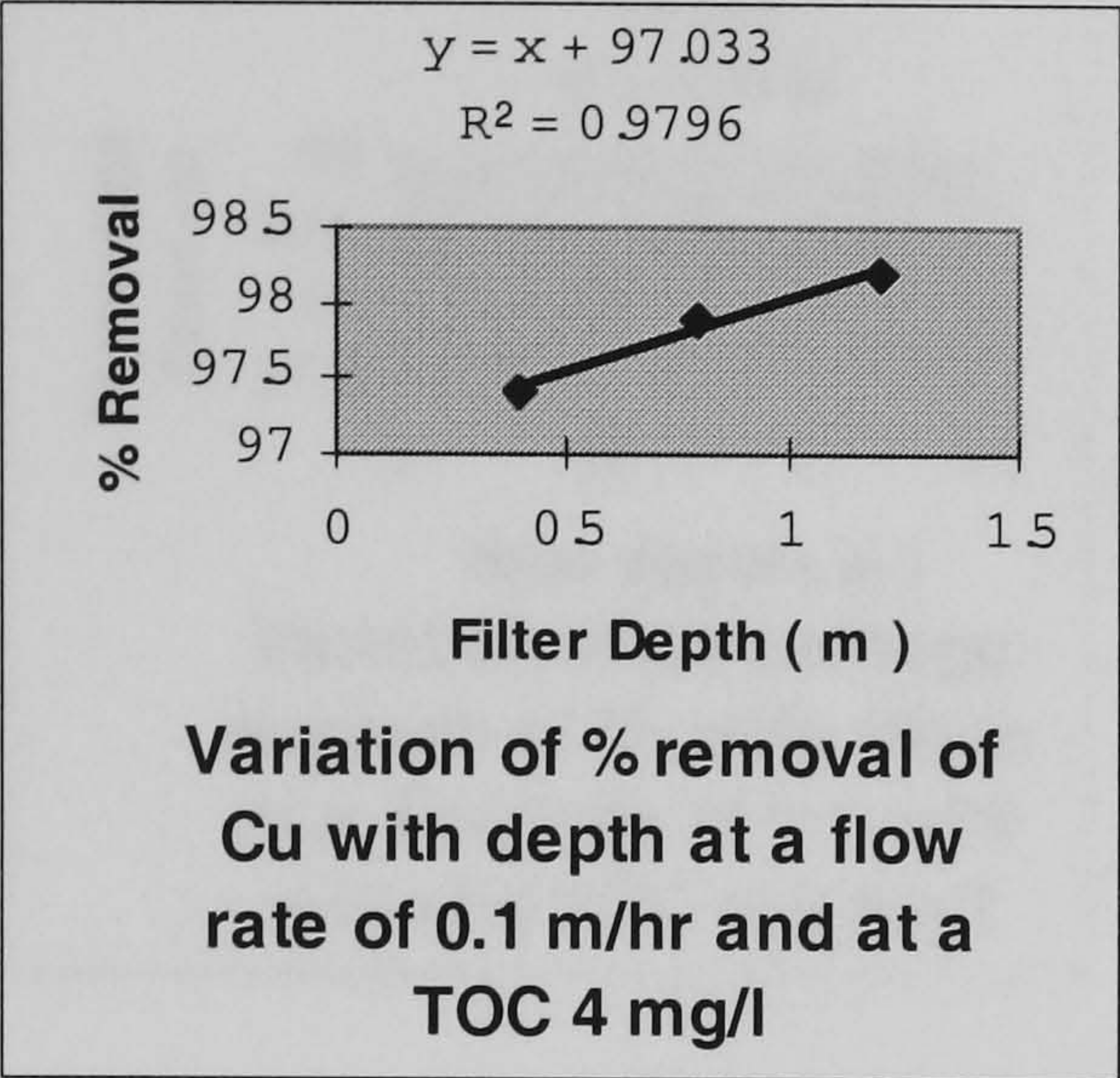


Figure 5.29 Variation of % removal of different heavy metals with filter depth at a flow rate of 0.1 m/hr and at a TOC of 4 mg/l



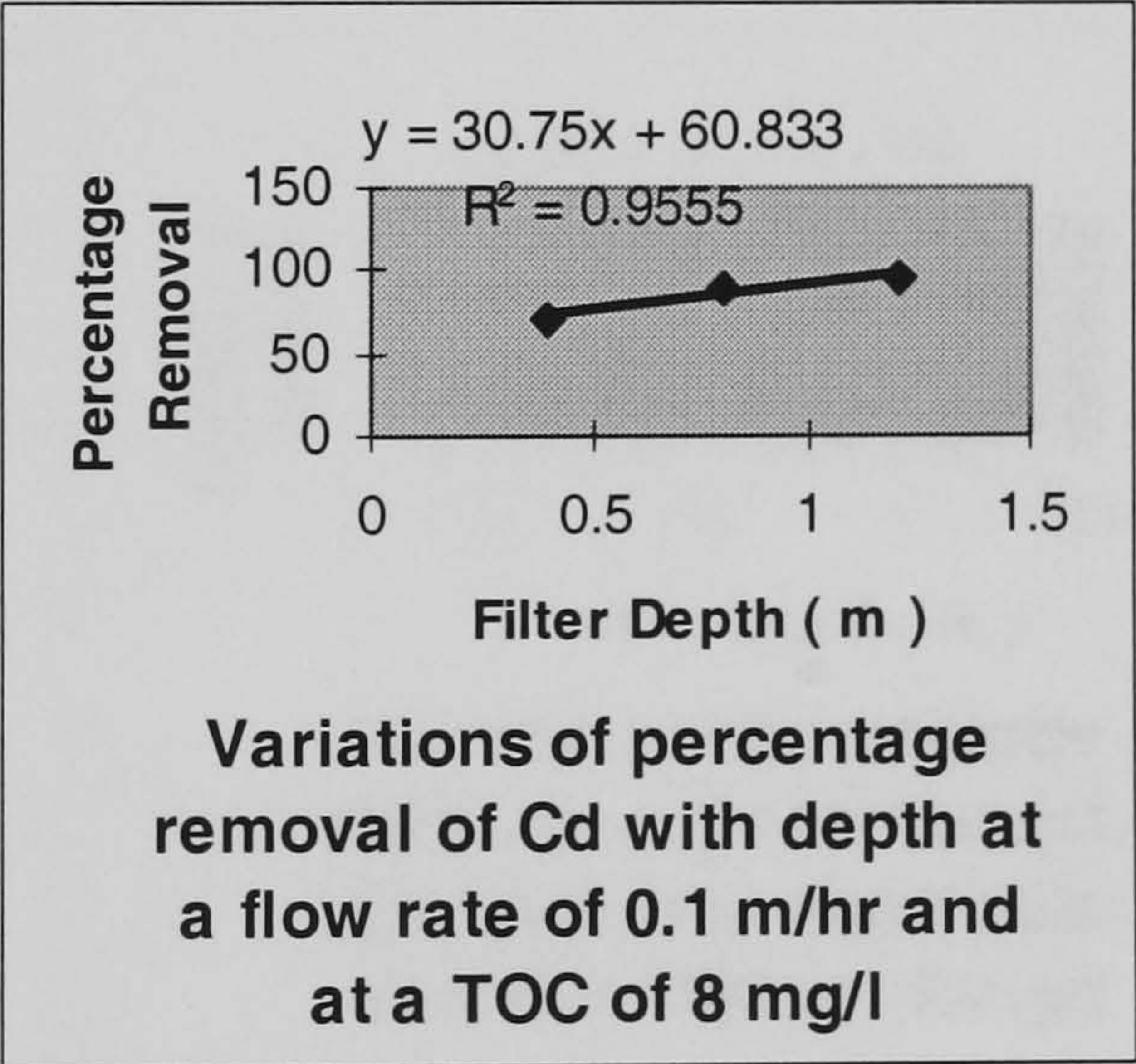
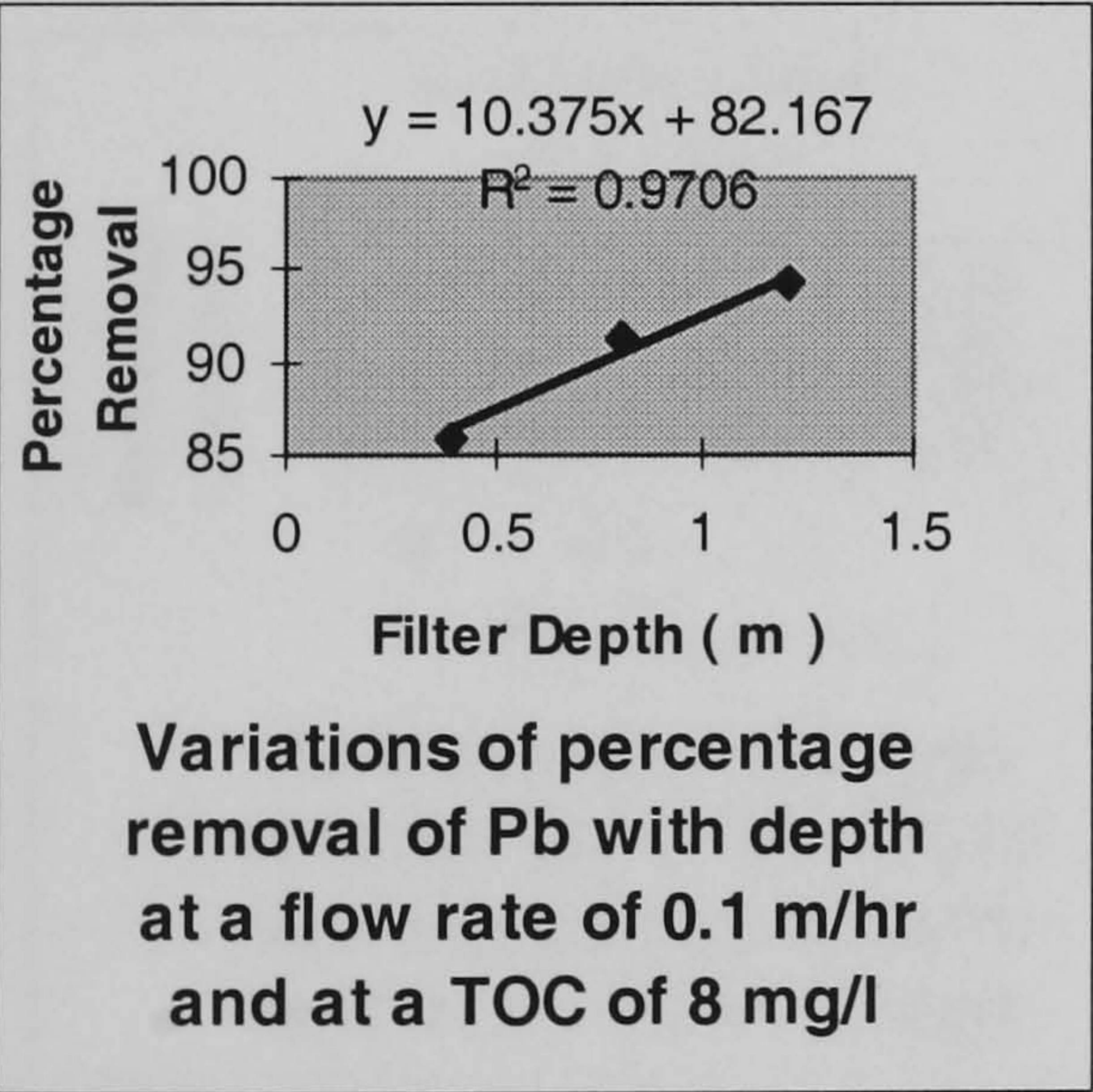
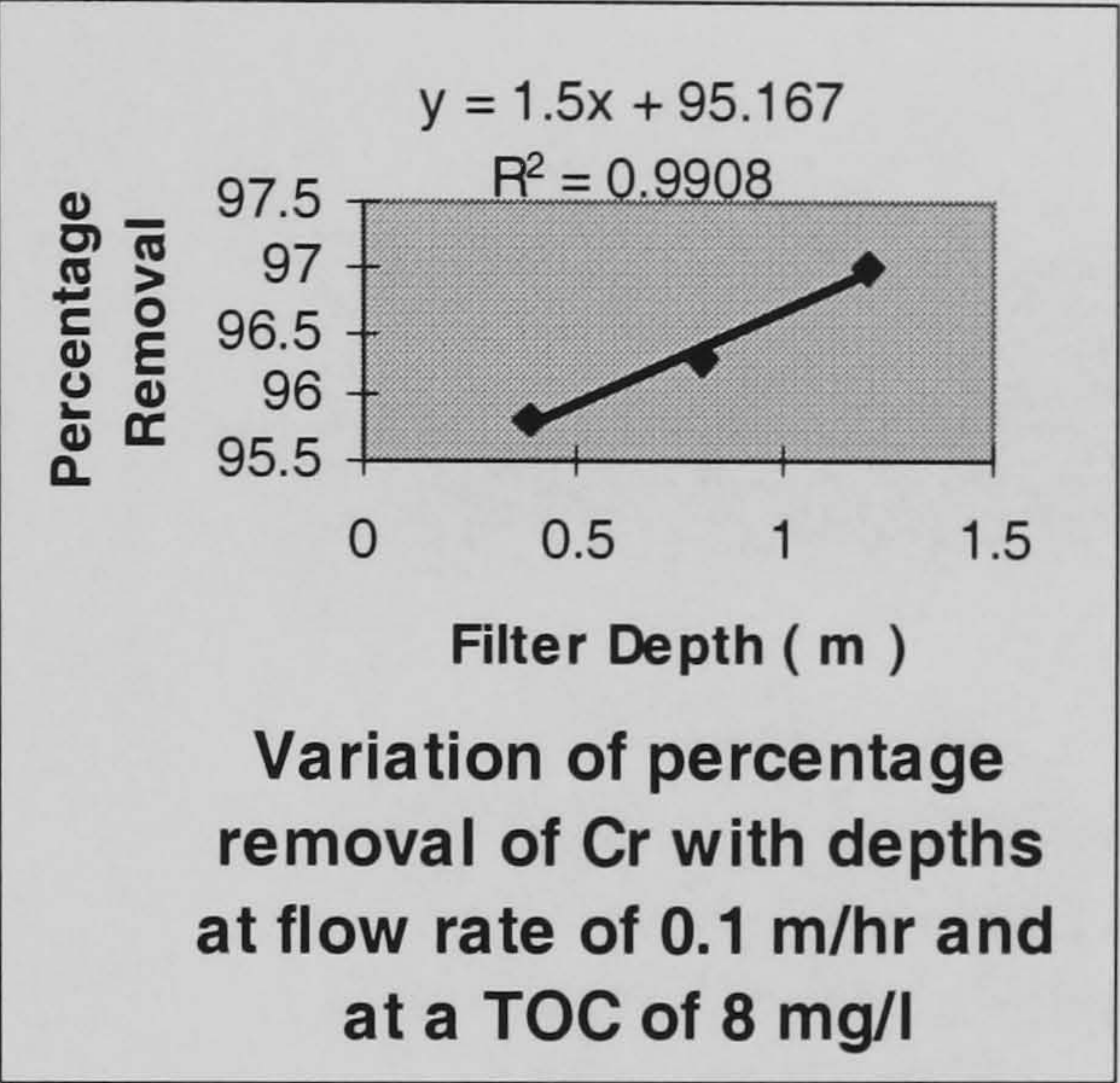
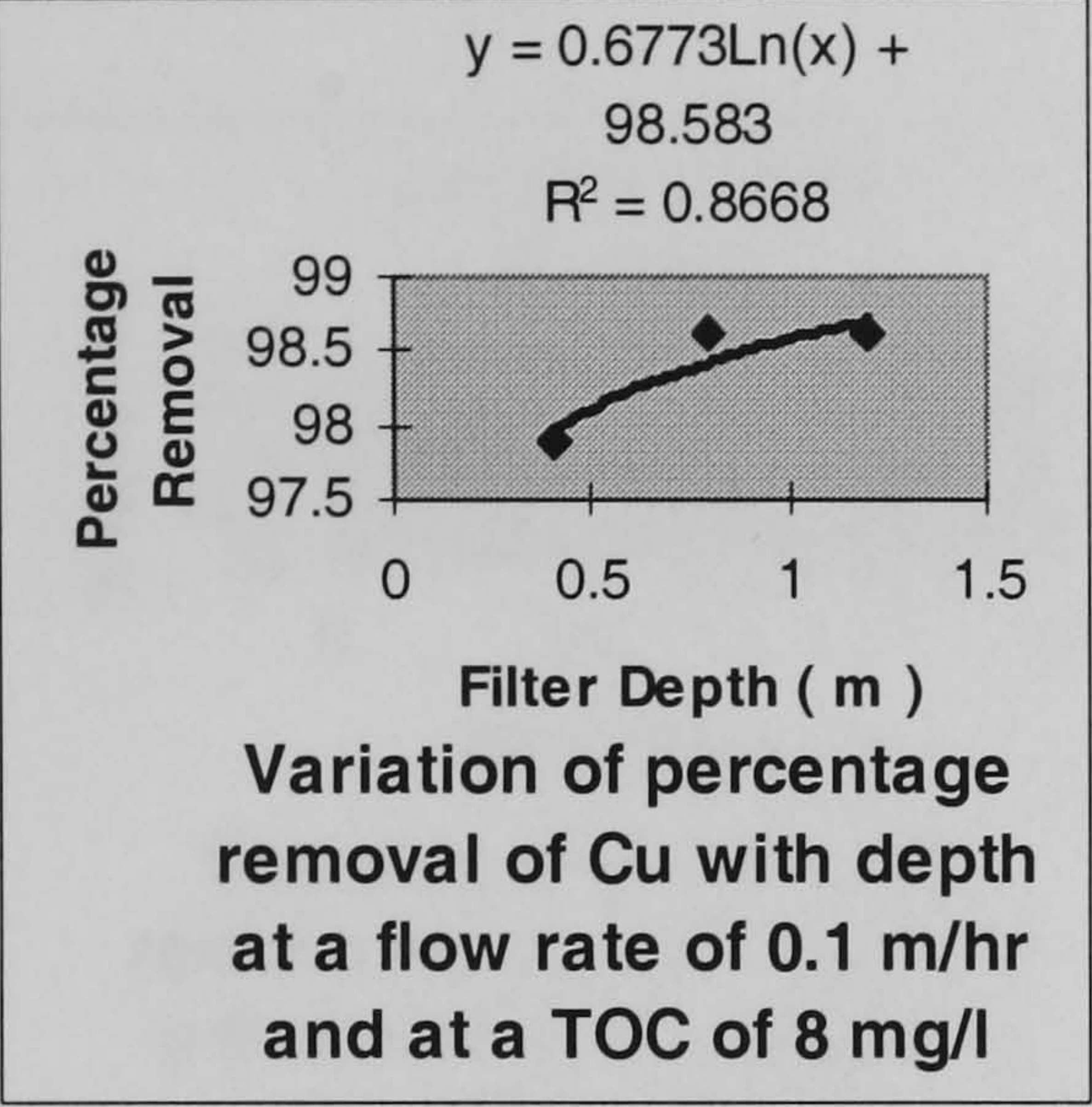


Figure 5.30 Variation of % removal of different heavy metals with filter depth at a flow rate of 0.1 m/hr and at a TOC of 8 mg/l.



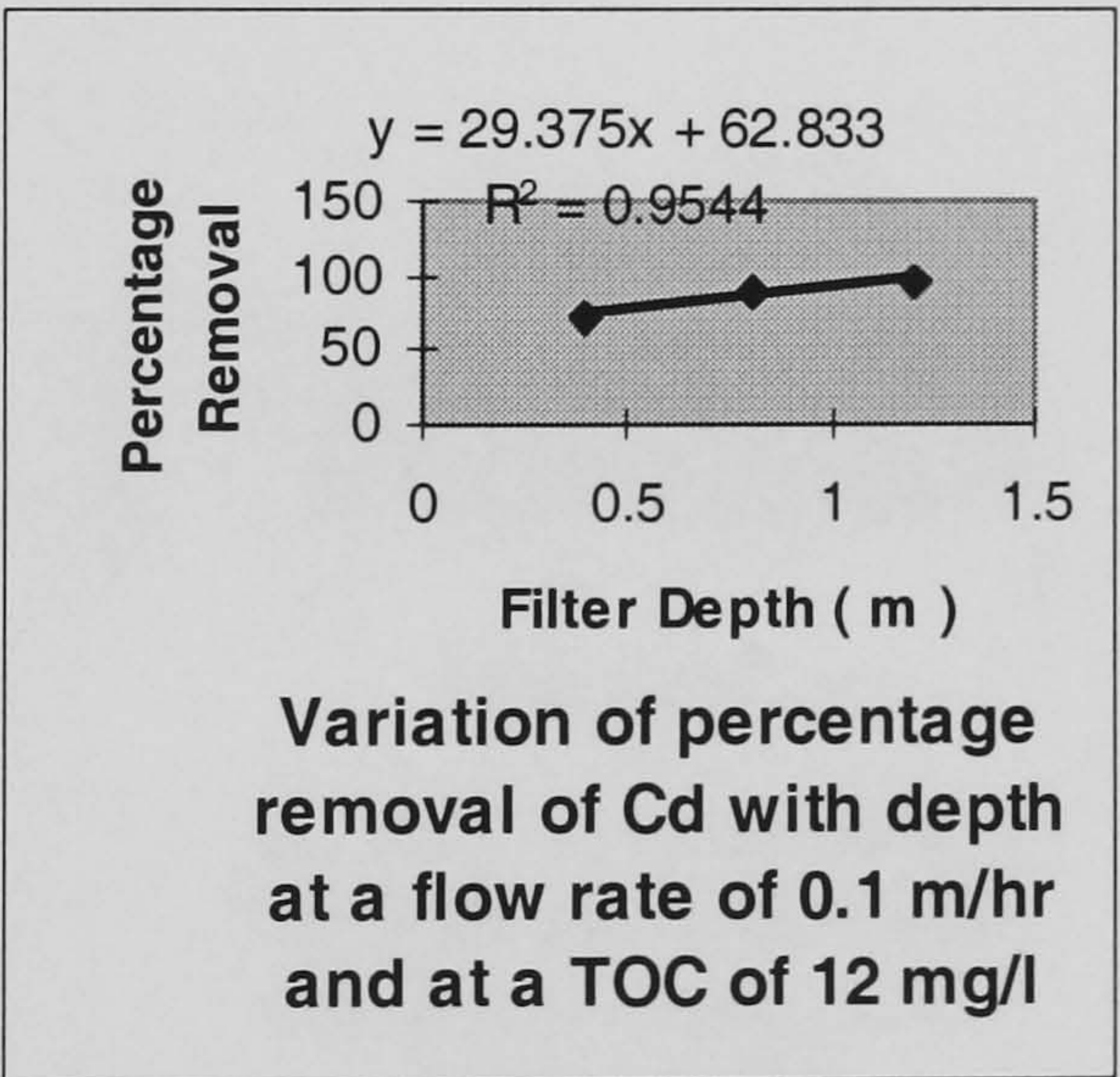
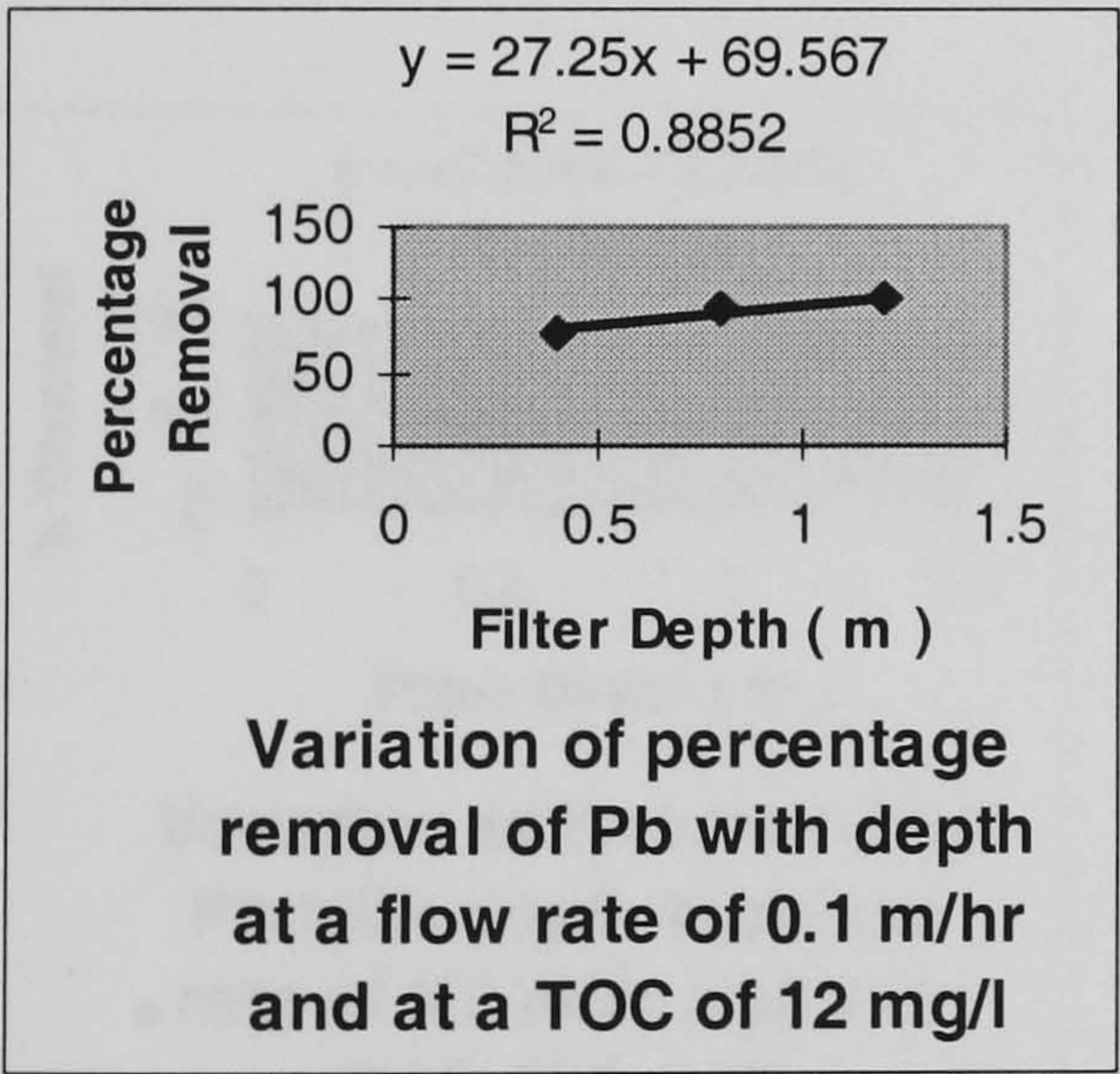
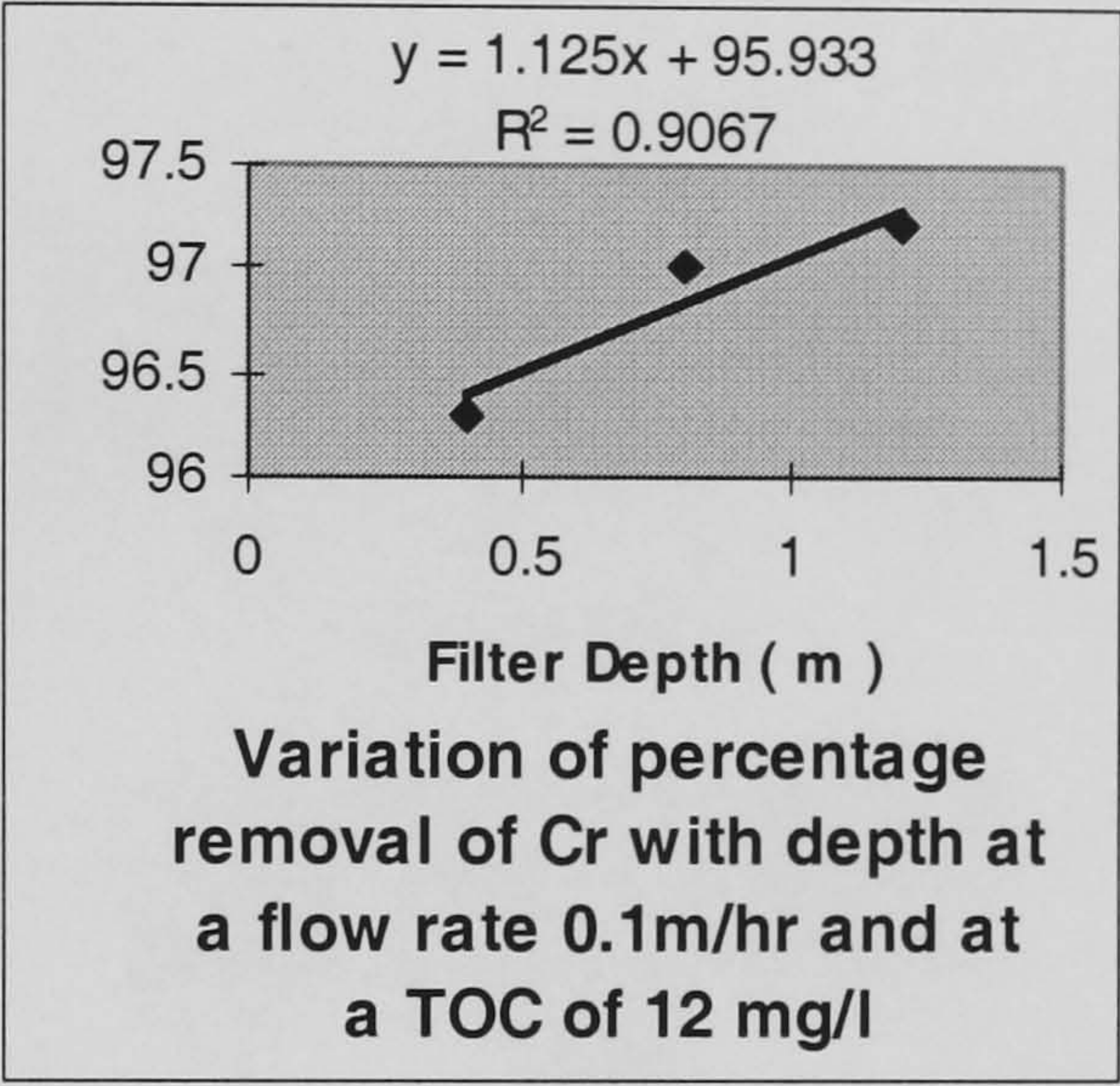
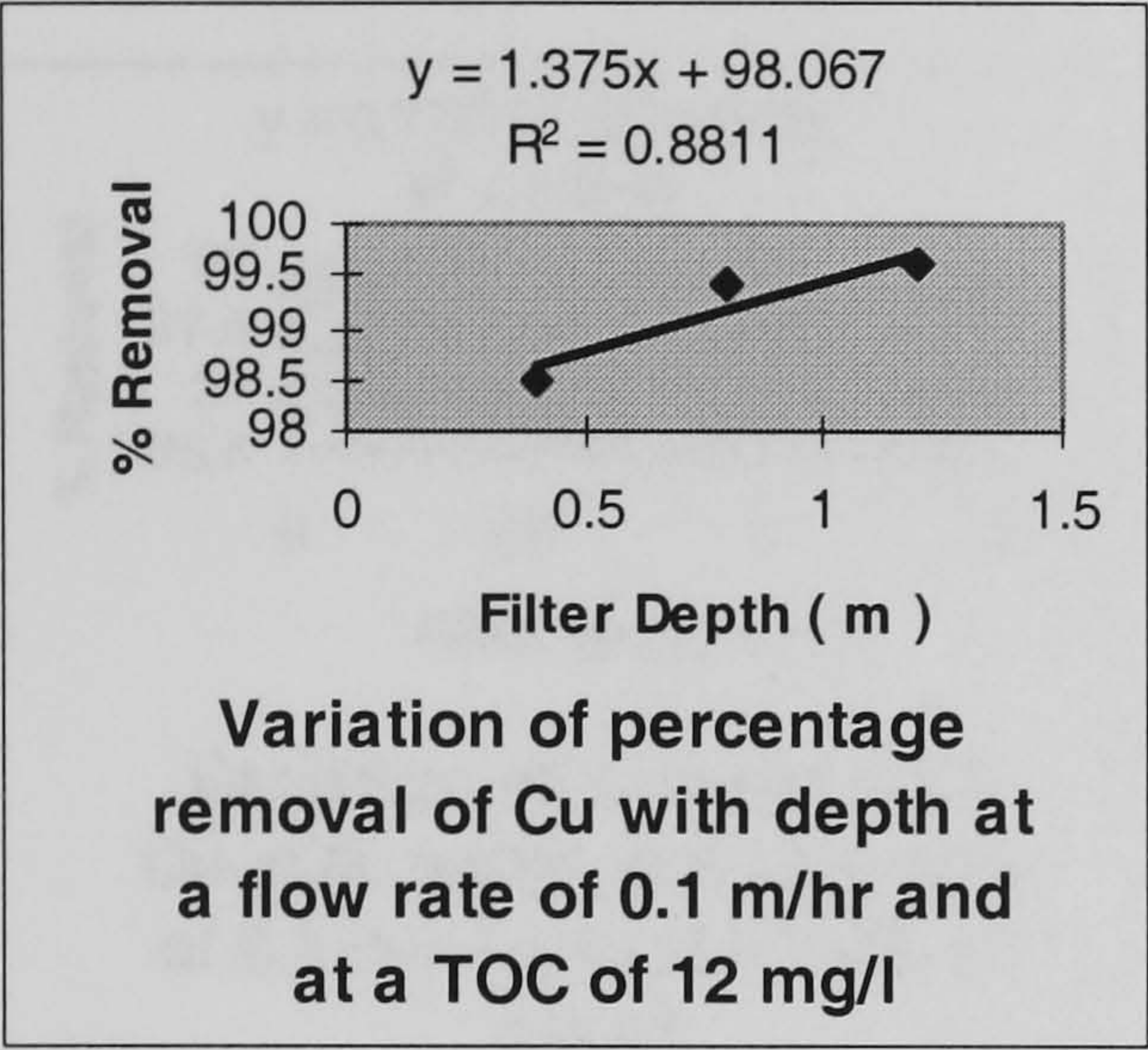


Figure 5.31 Variation of % removal of different heavy metals with filter depth at a flow rate of 0.1 m/hr and at a TOC of 12 mg/l.



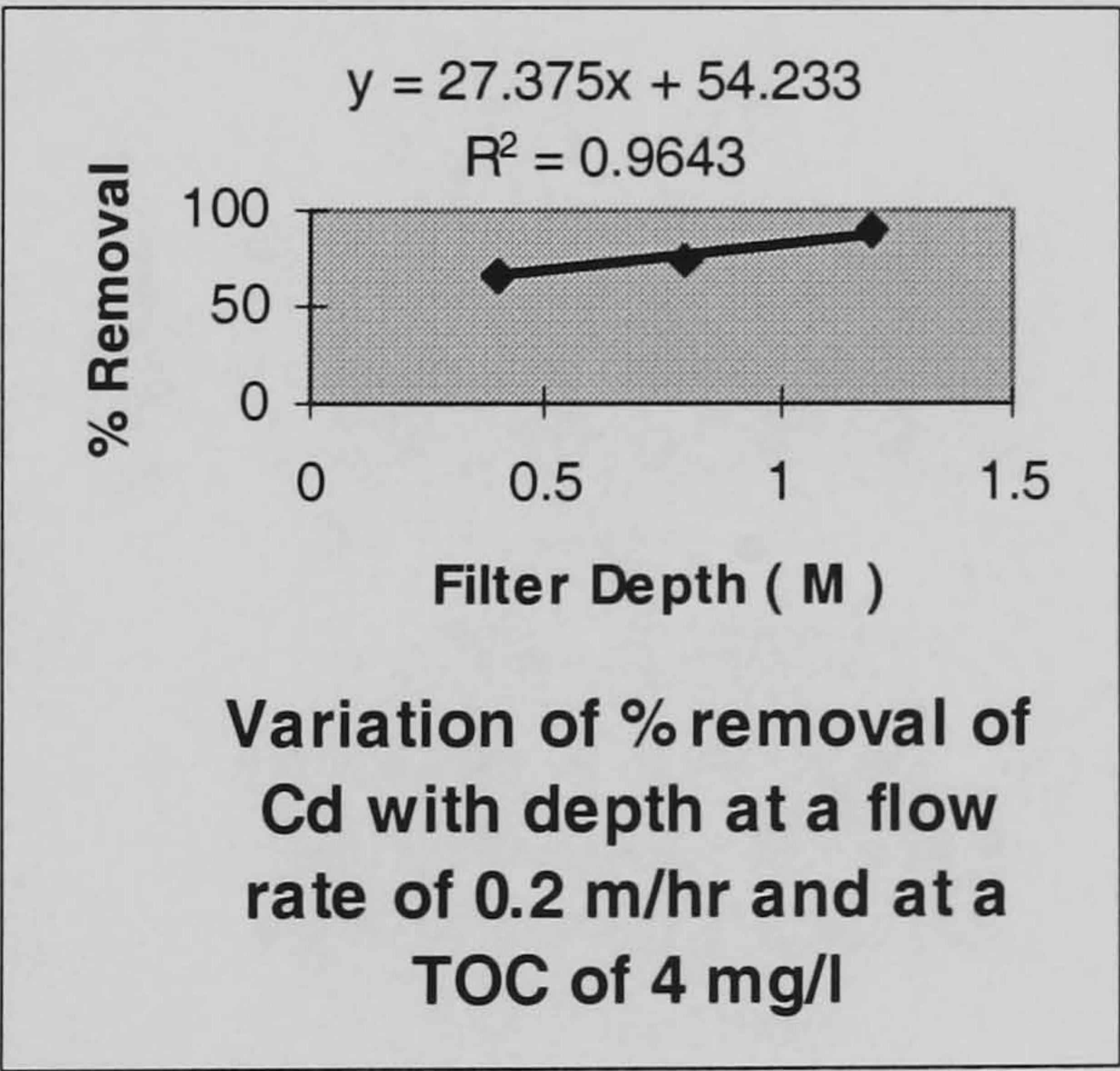
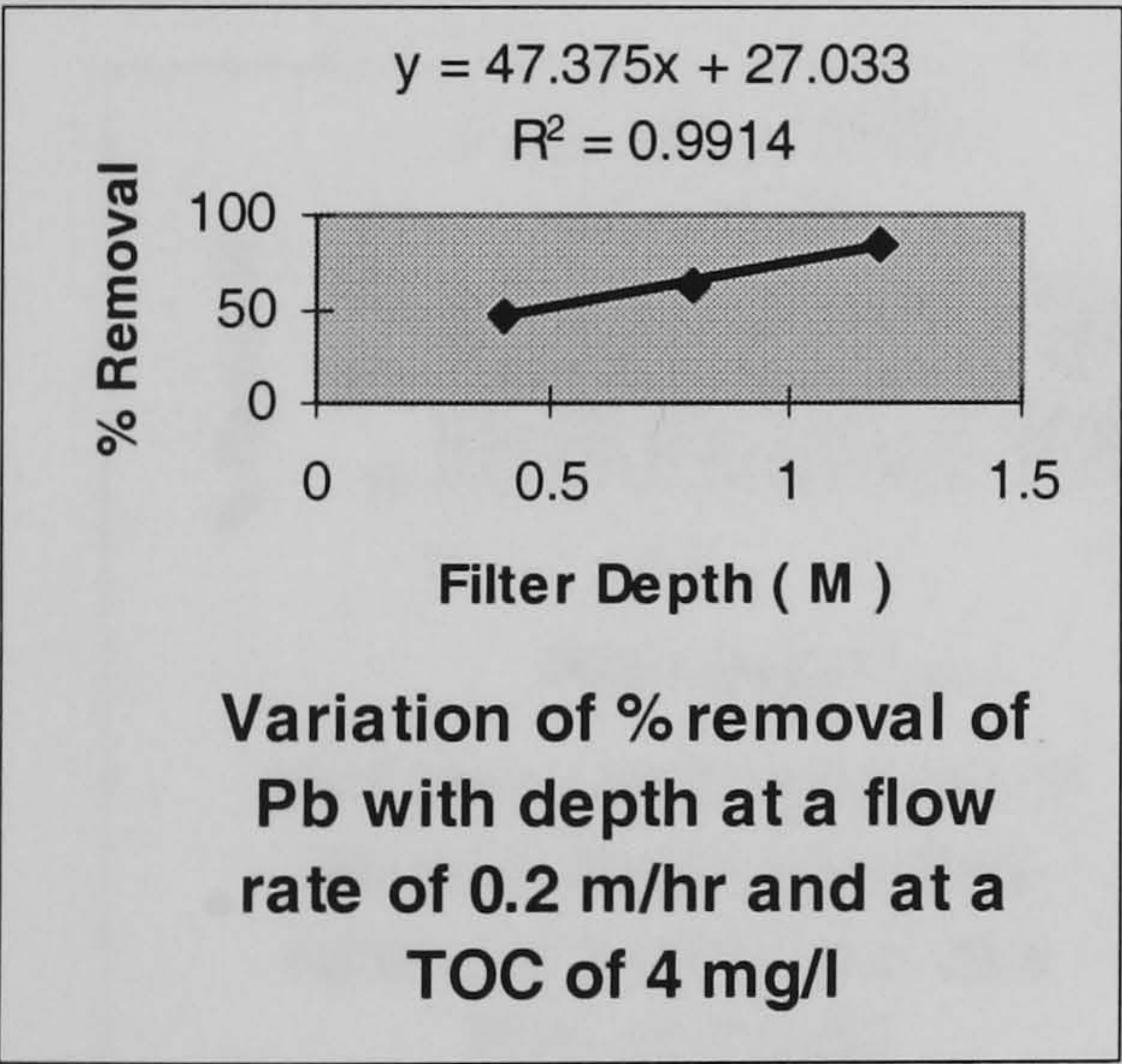
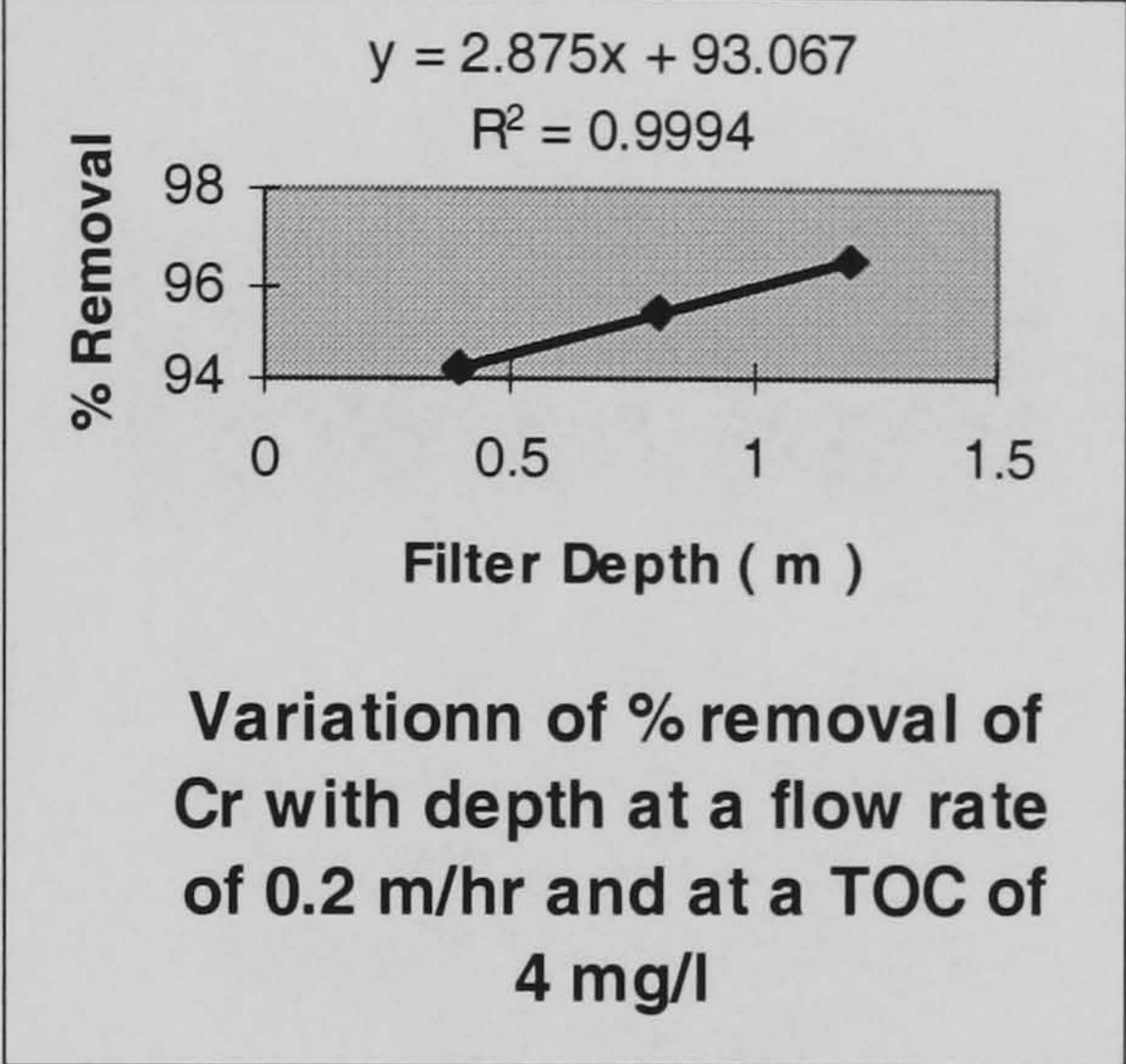
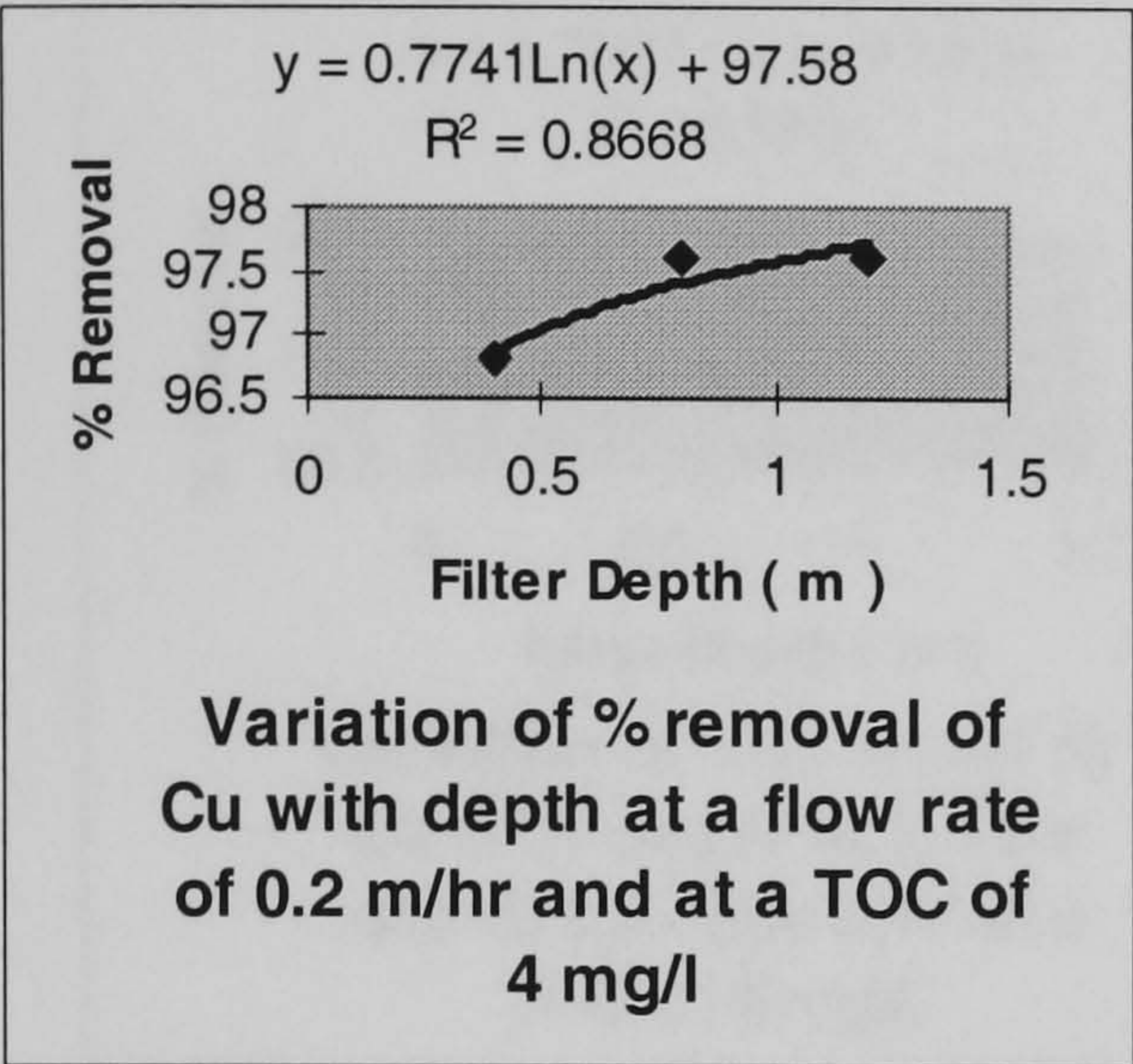


Figure 5.32 Variation of % removal of different heavy metals with filter depth at a flow rate of 0.2 m/hr and at a TOC of 4 mg/l.



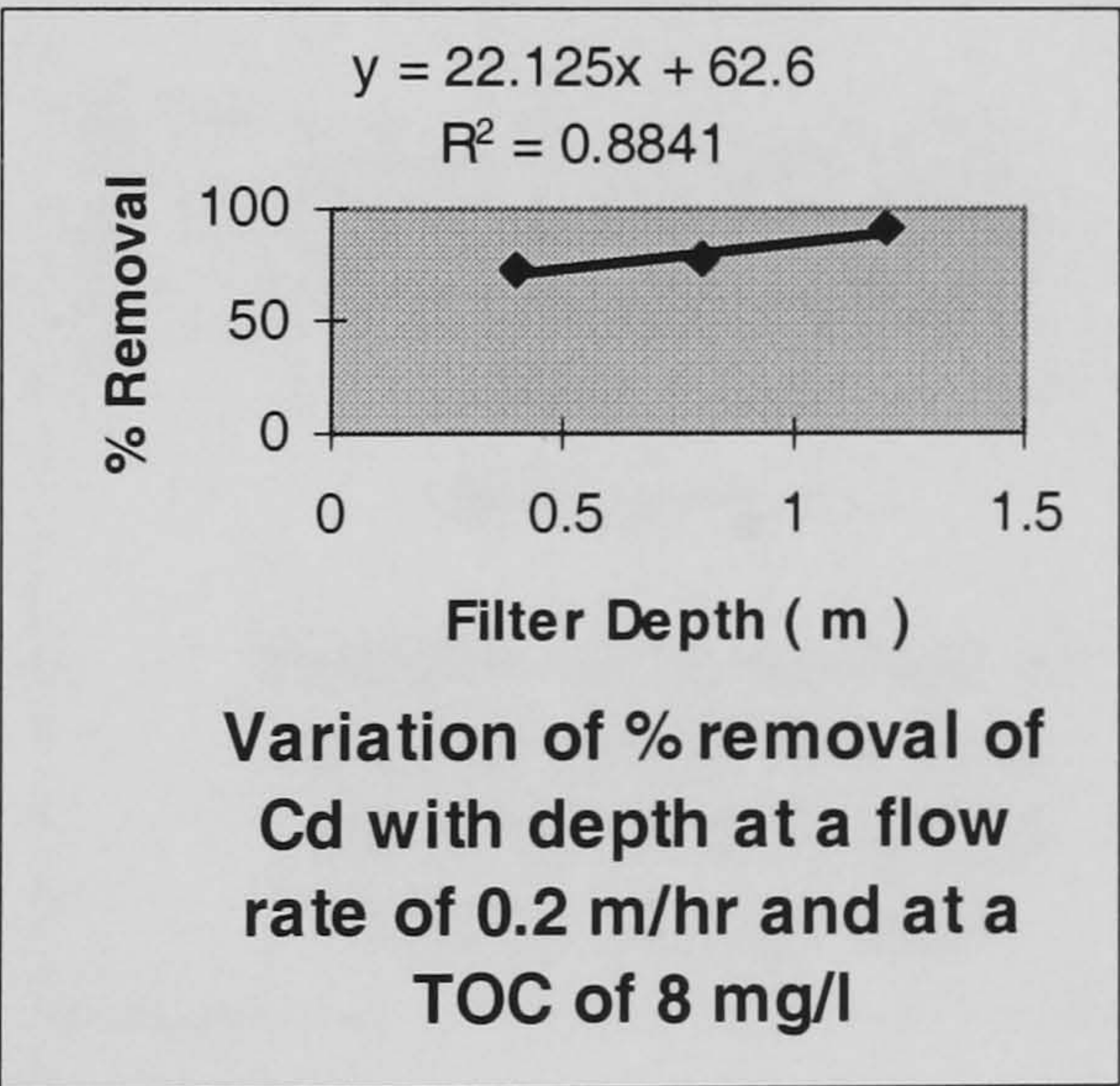
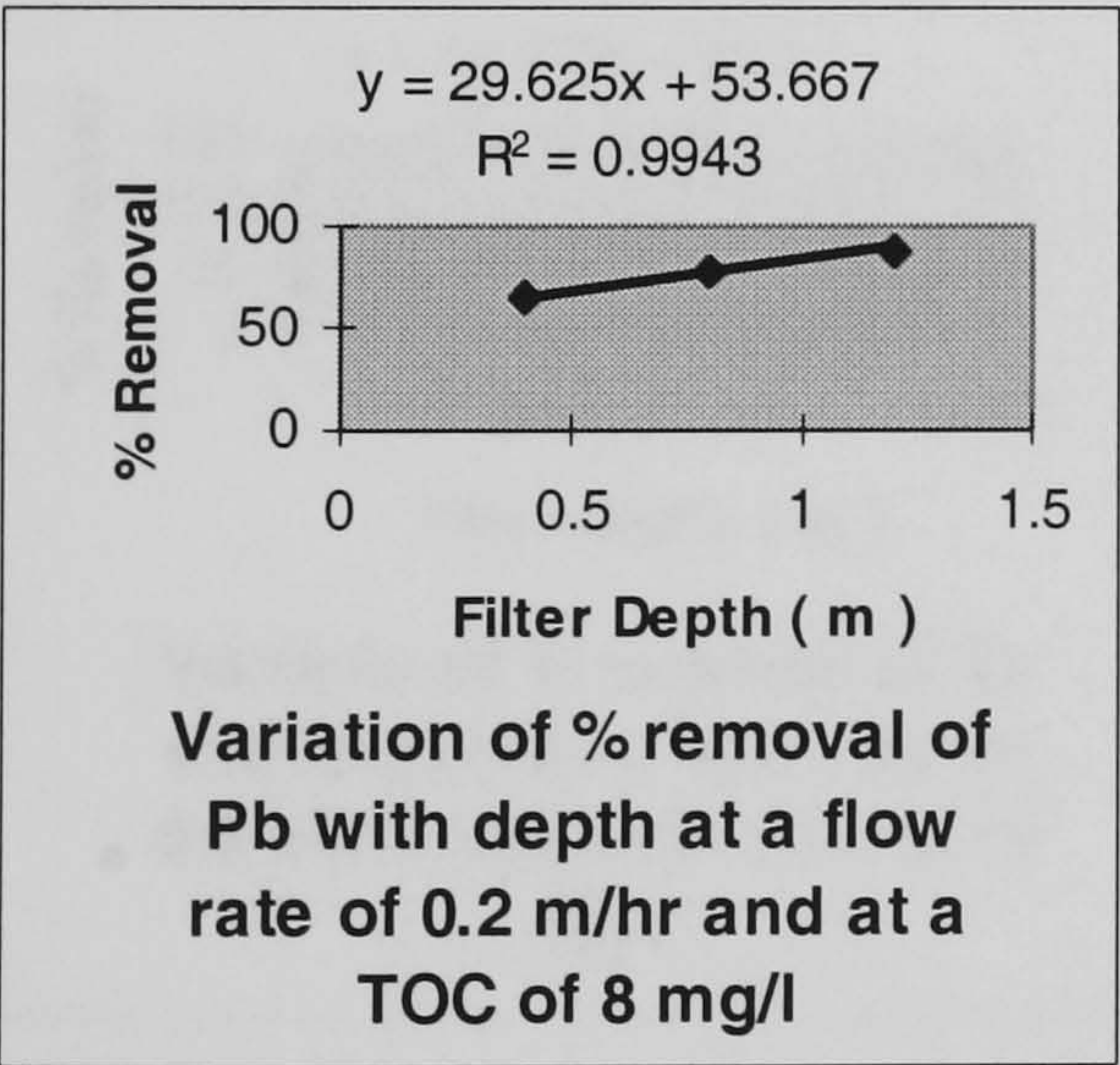
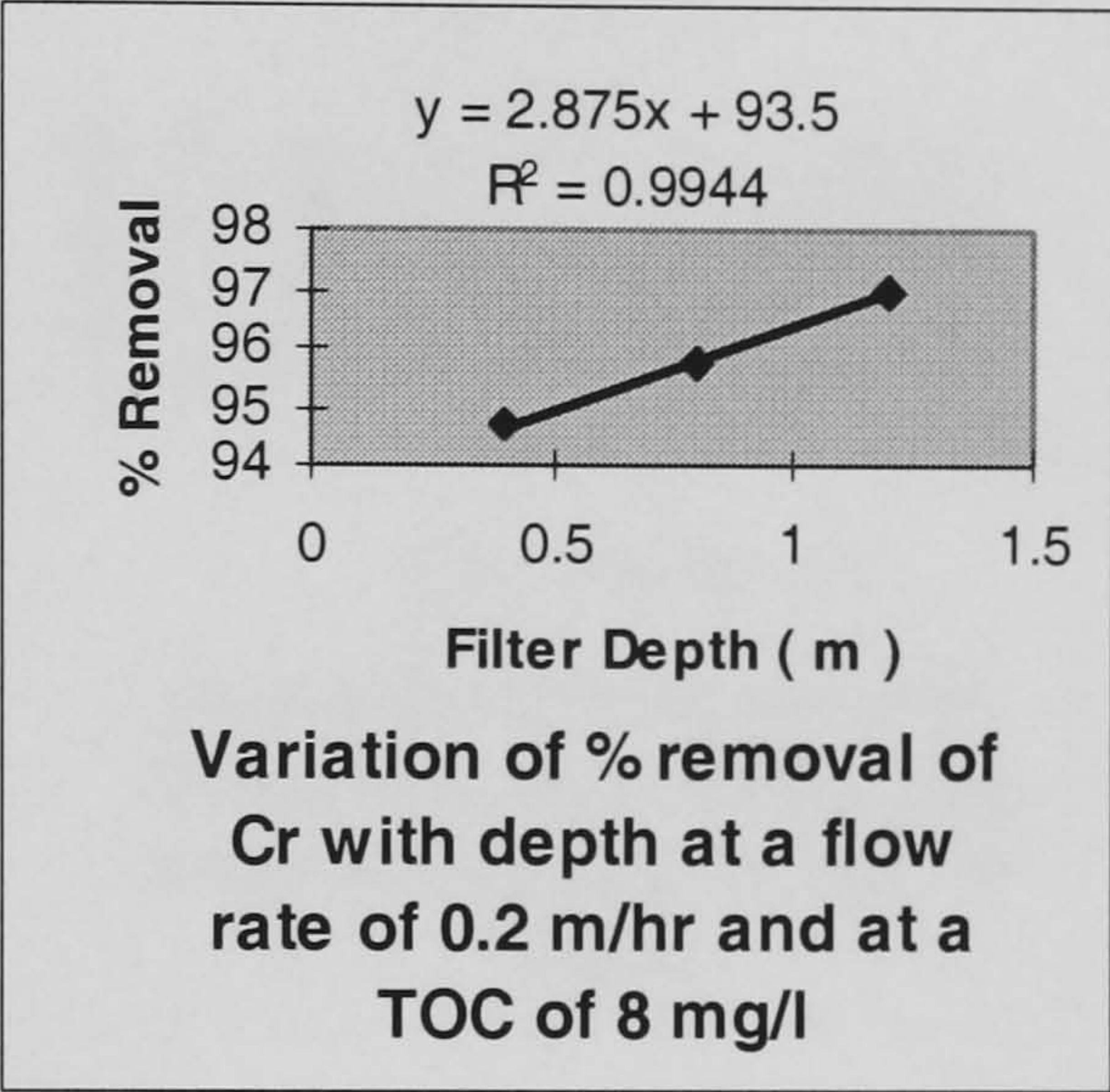
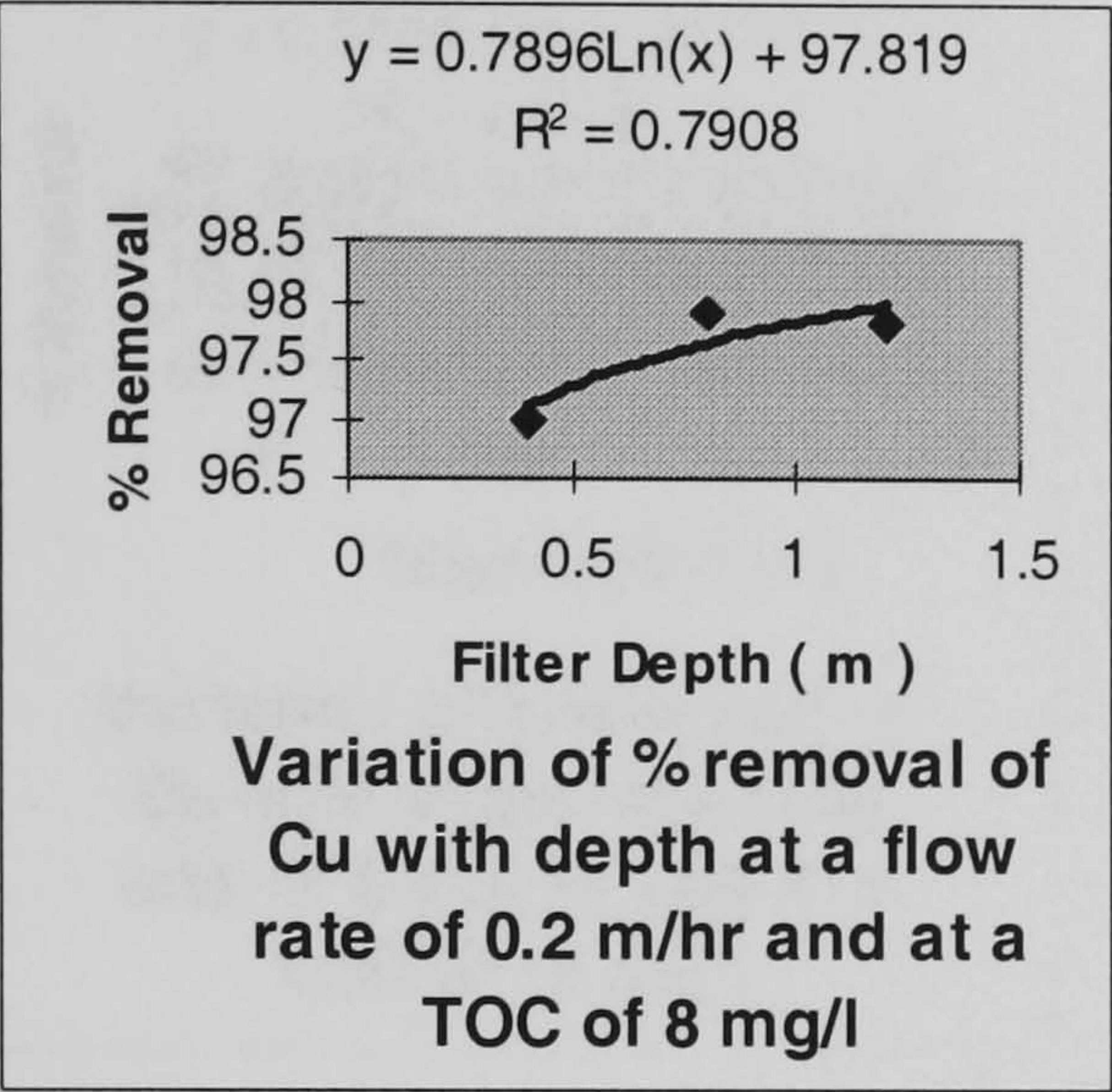


Figure 5.33 Variation of % removal of different heavy metals with filter depth at a flow rate of 0.2 m/hr and at a TOC of 8 mg/l.



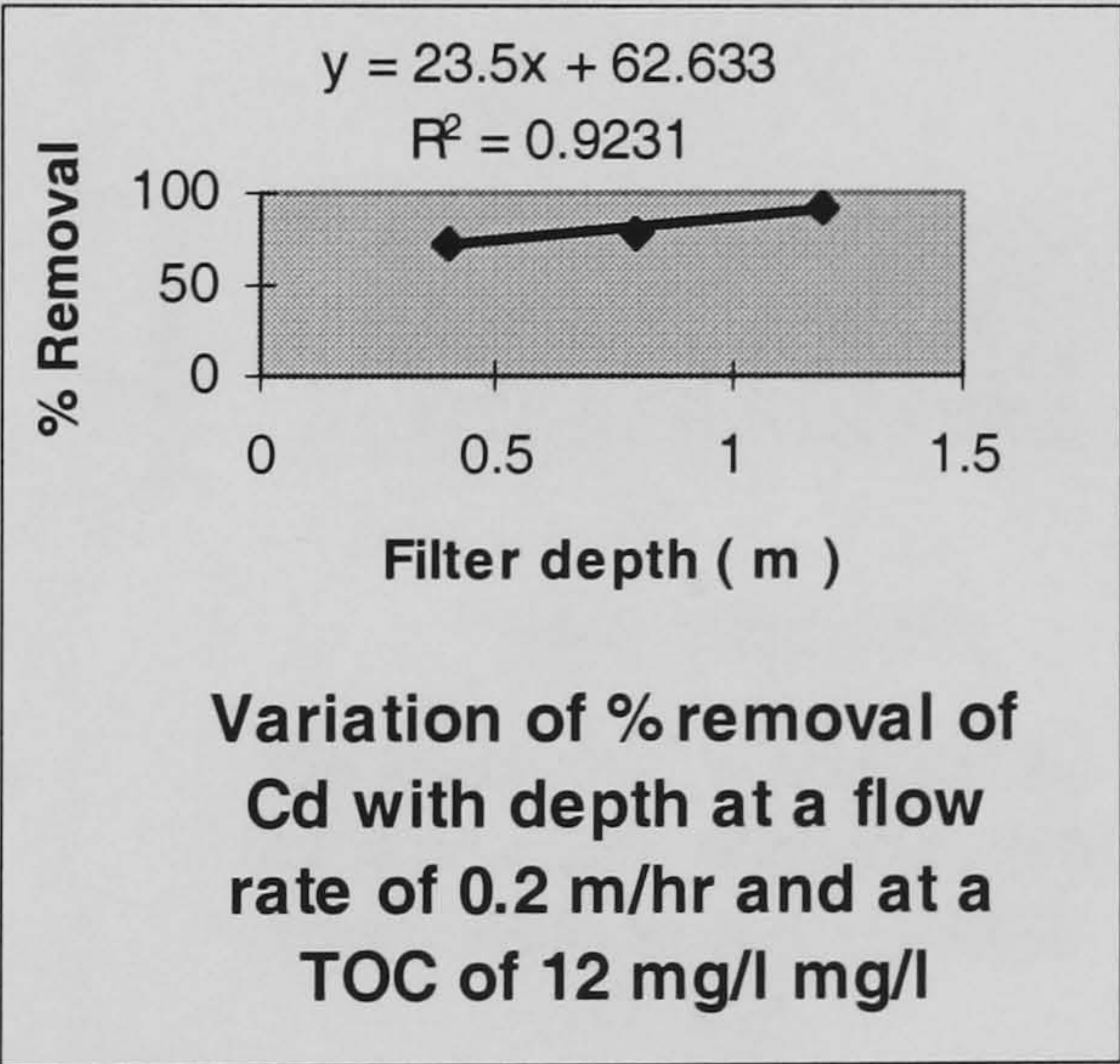
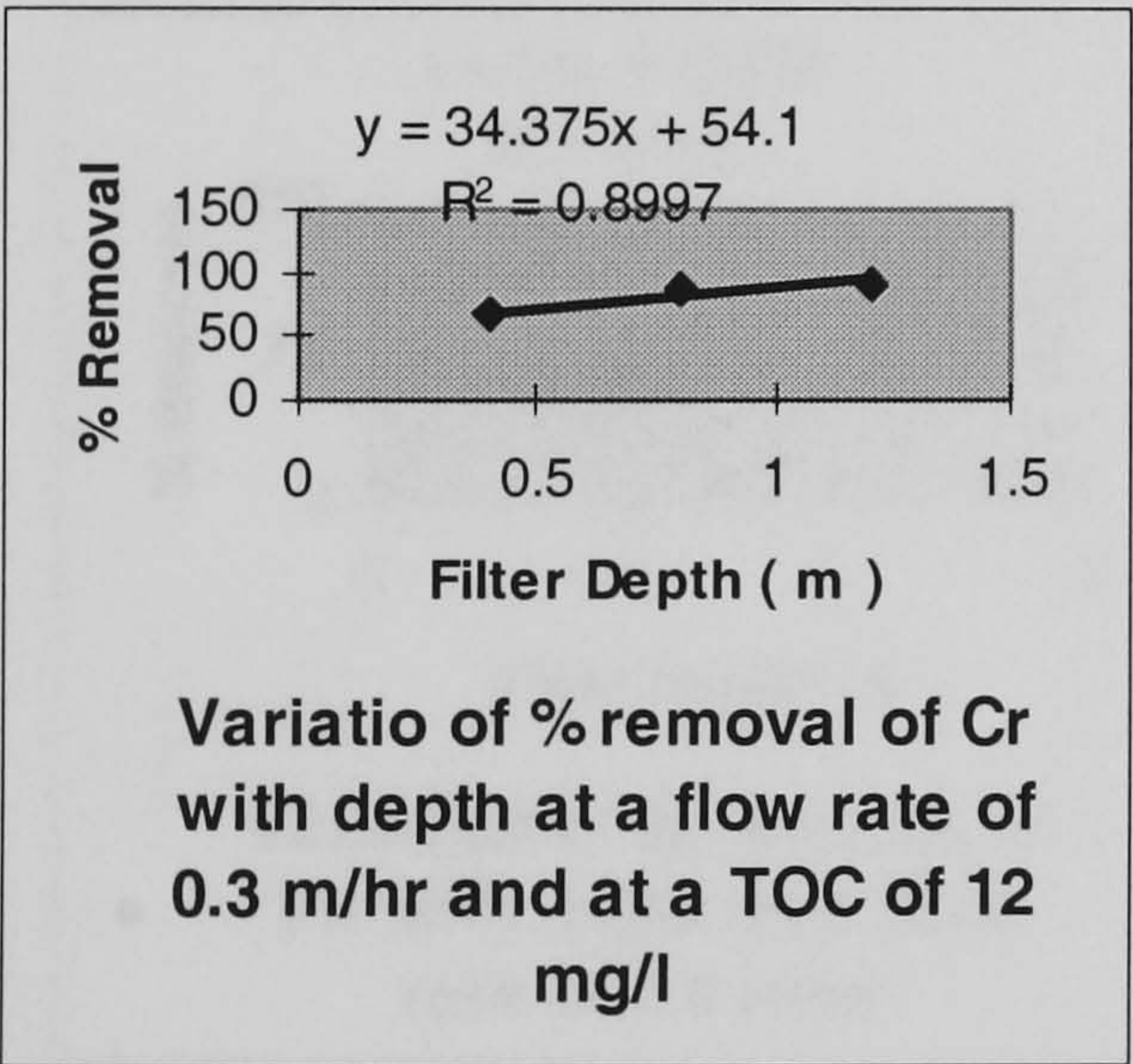
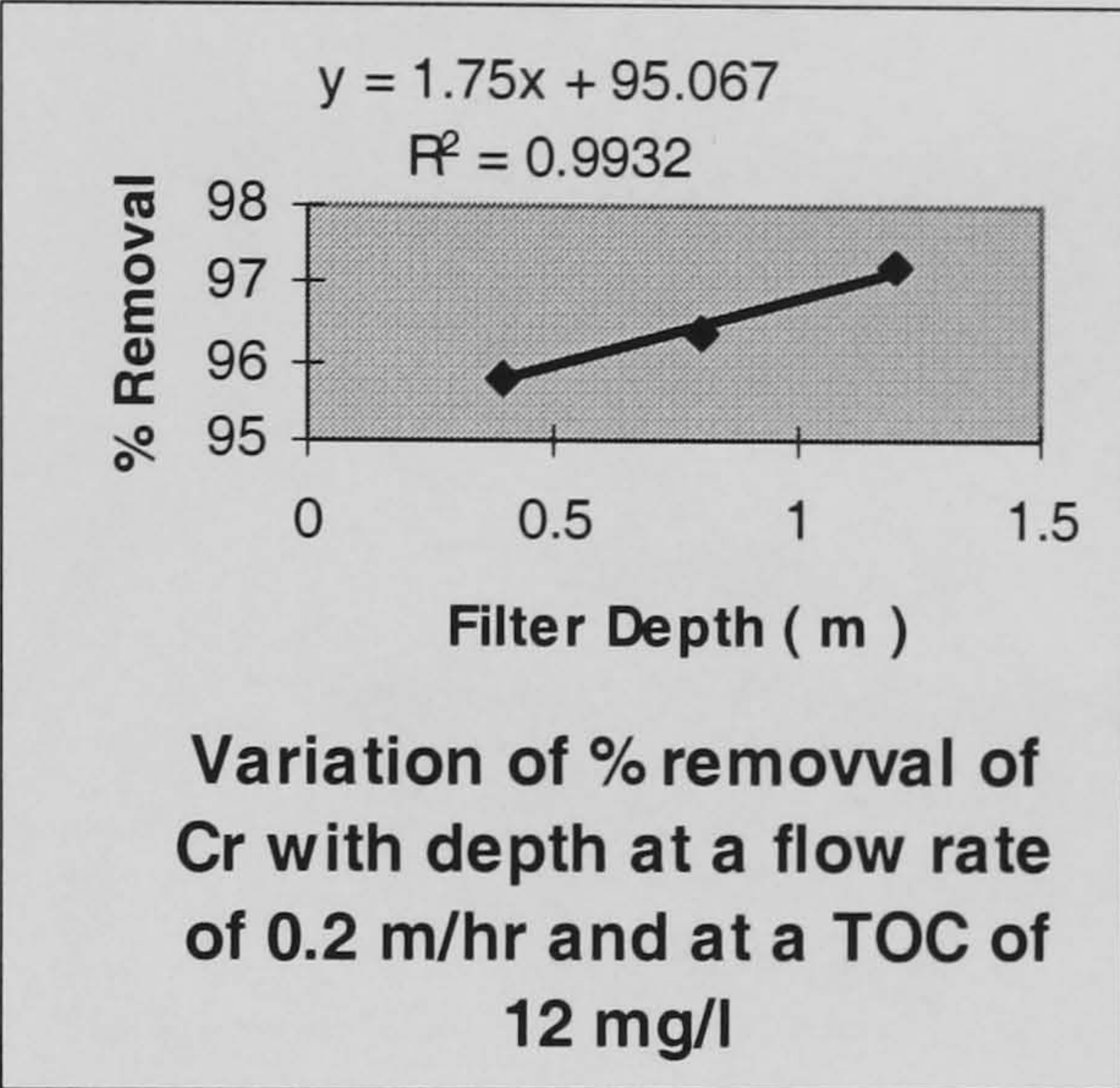
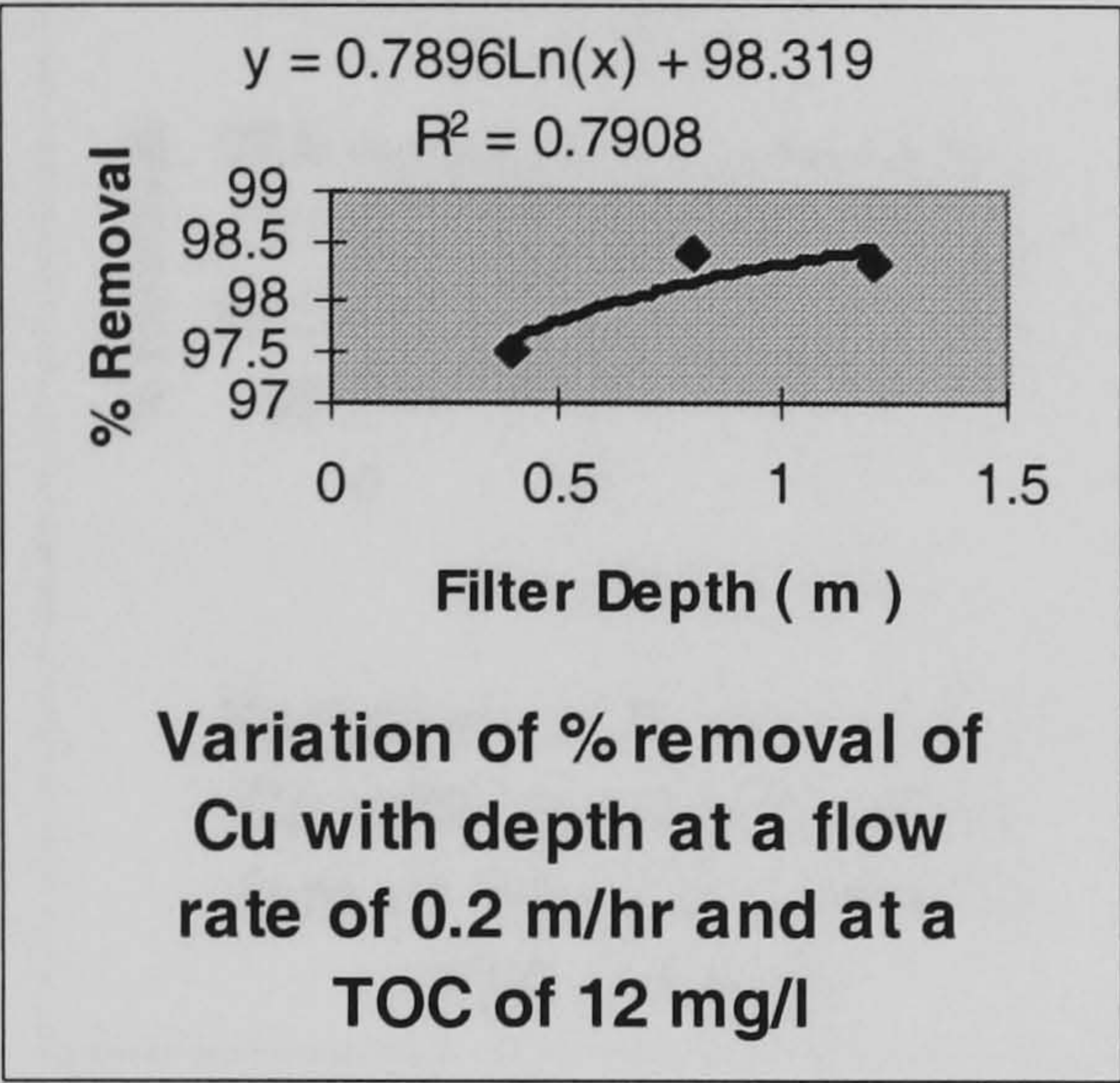


Figure 5.34 Variation of % removal of different heavy metals with filter depth at a flow rate of 0.2 m/hr and at a TOC of 12 mg/l.



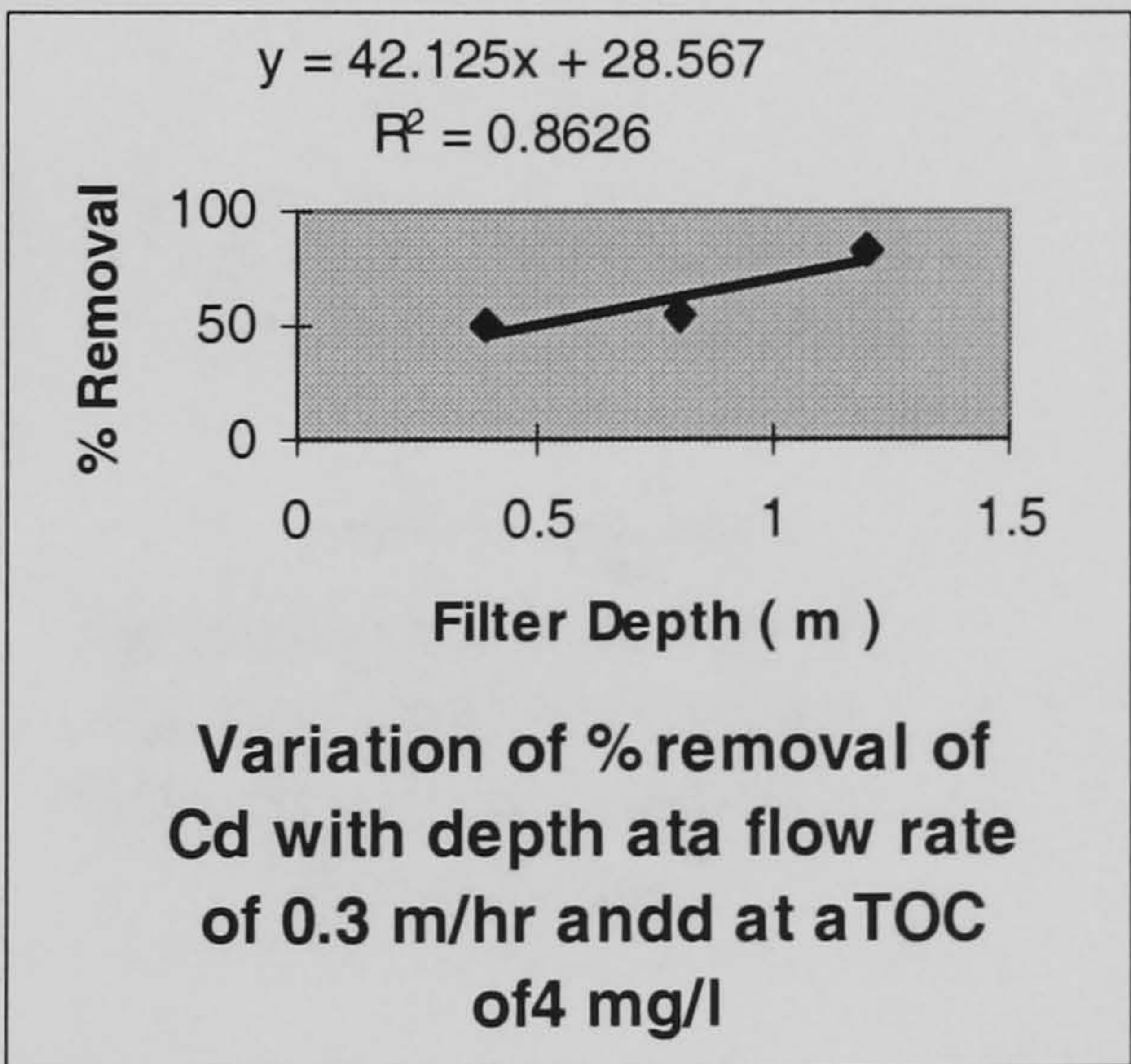
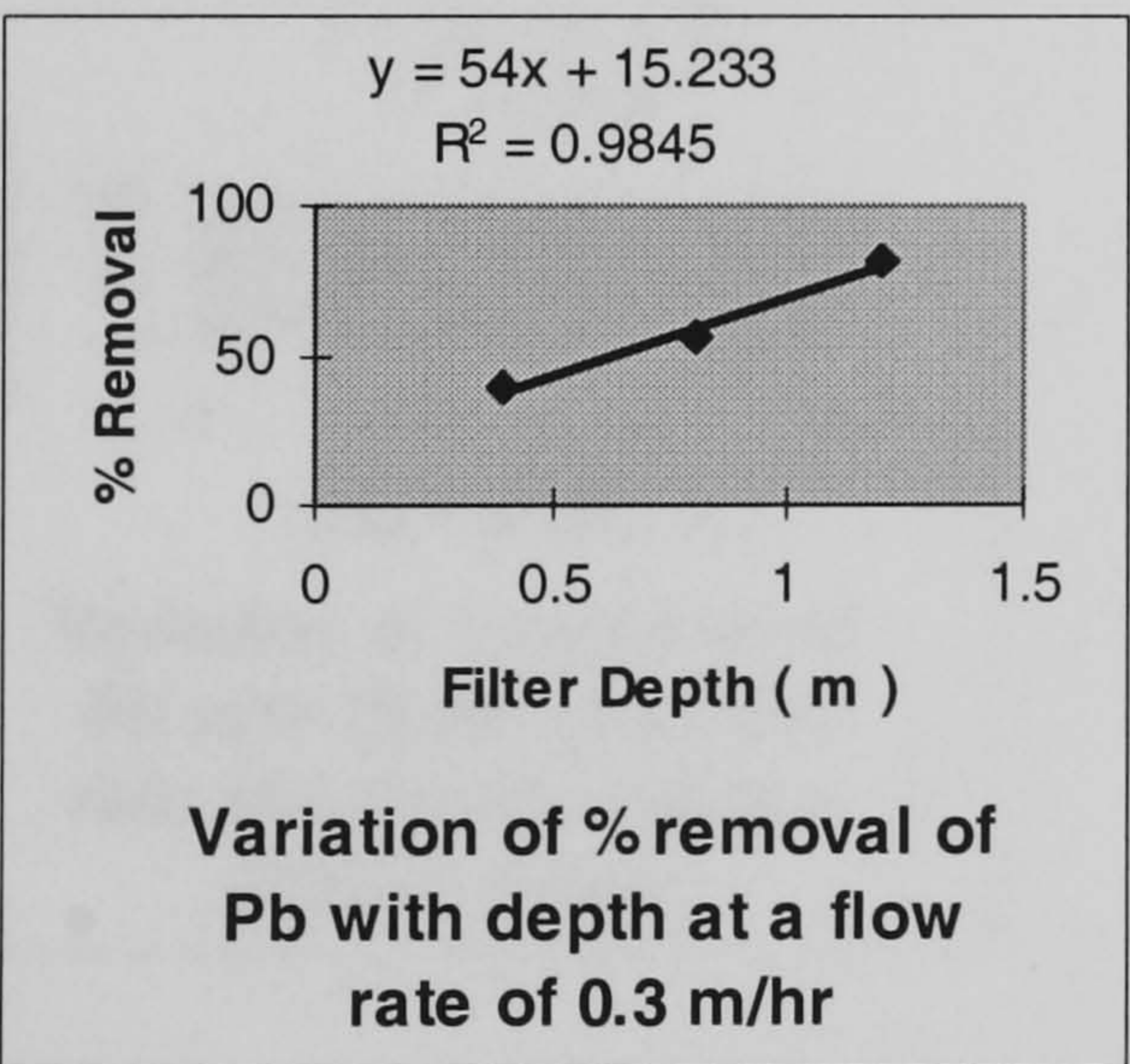
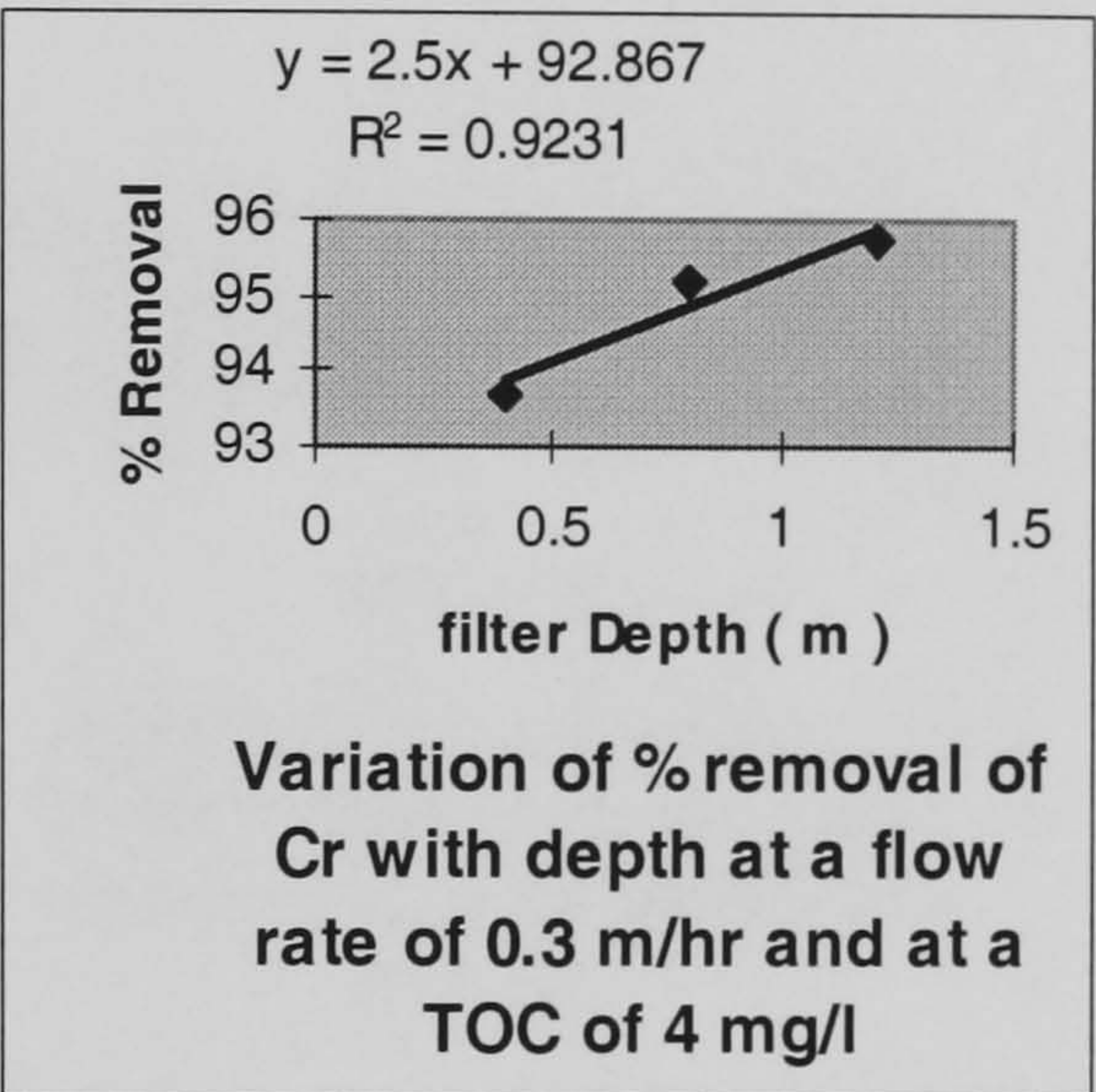
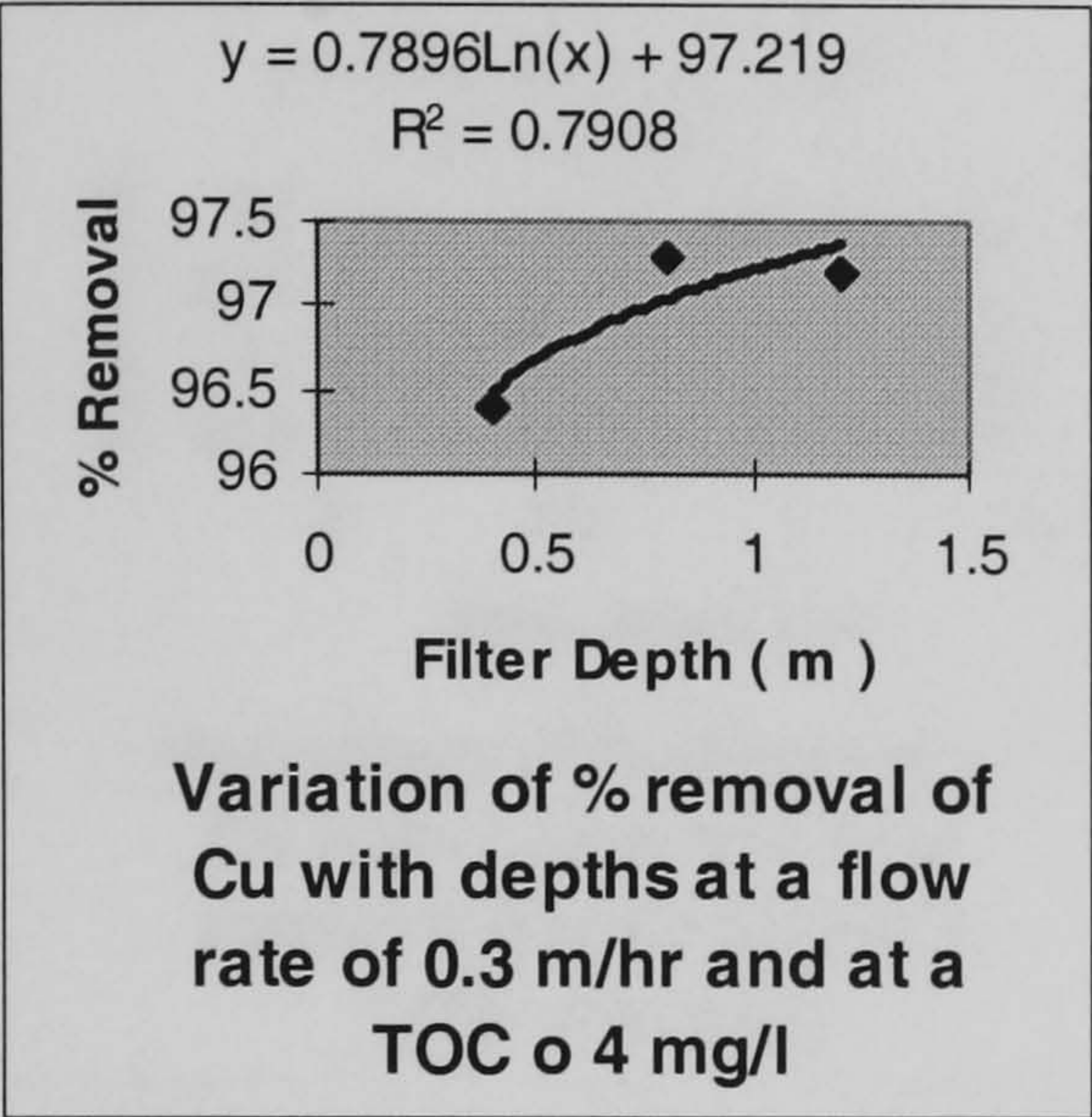


Figure 5.35 Variation of % removal of different heavy metals with depth at a flow rate of 0.3 m/hr and at a TOC of 4 mg/l.



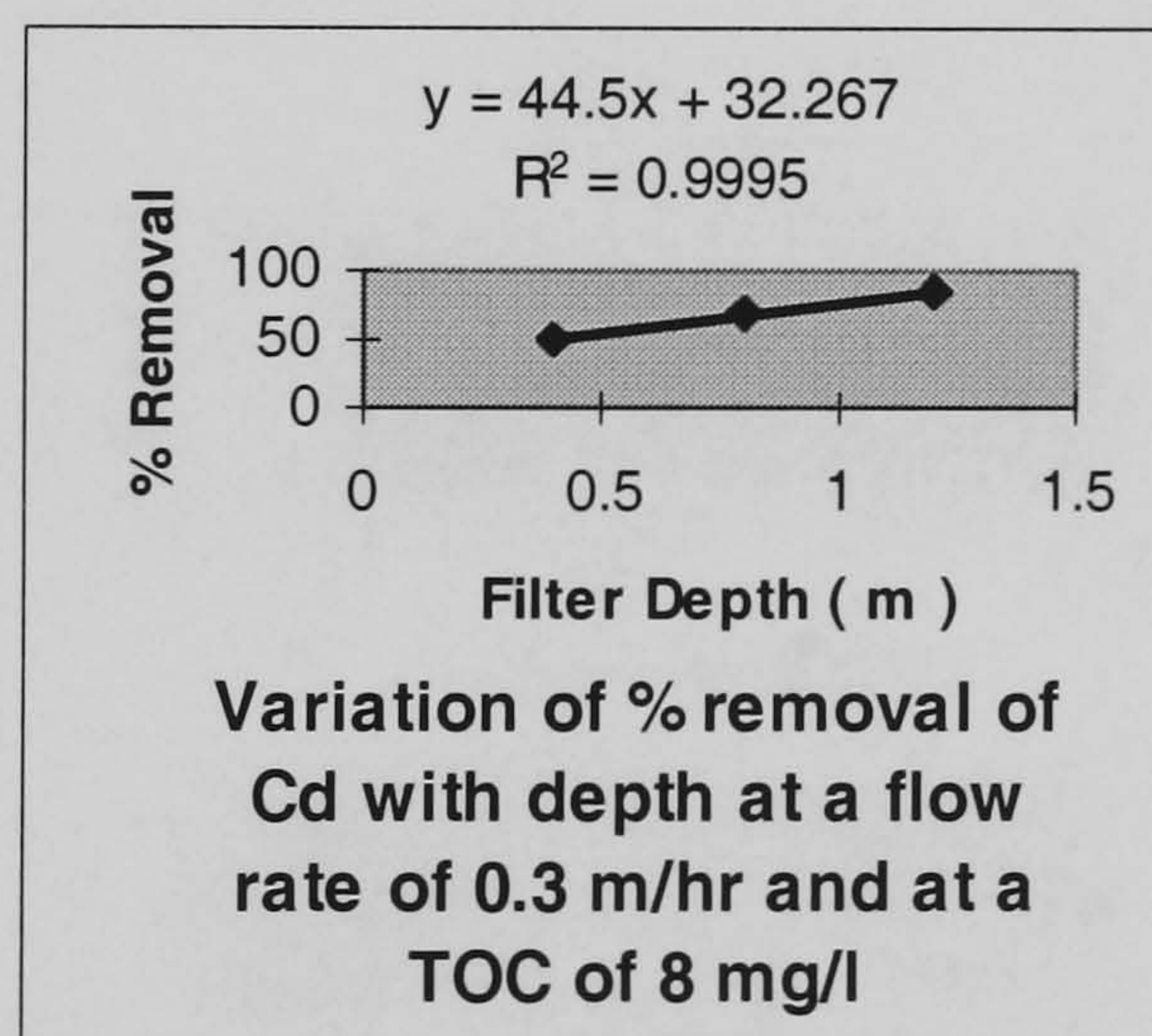
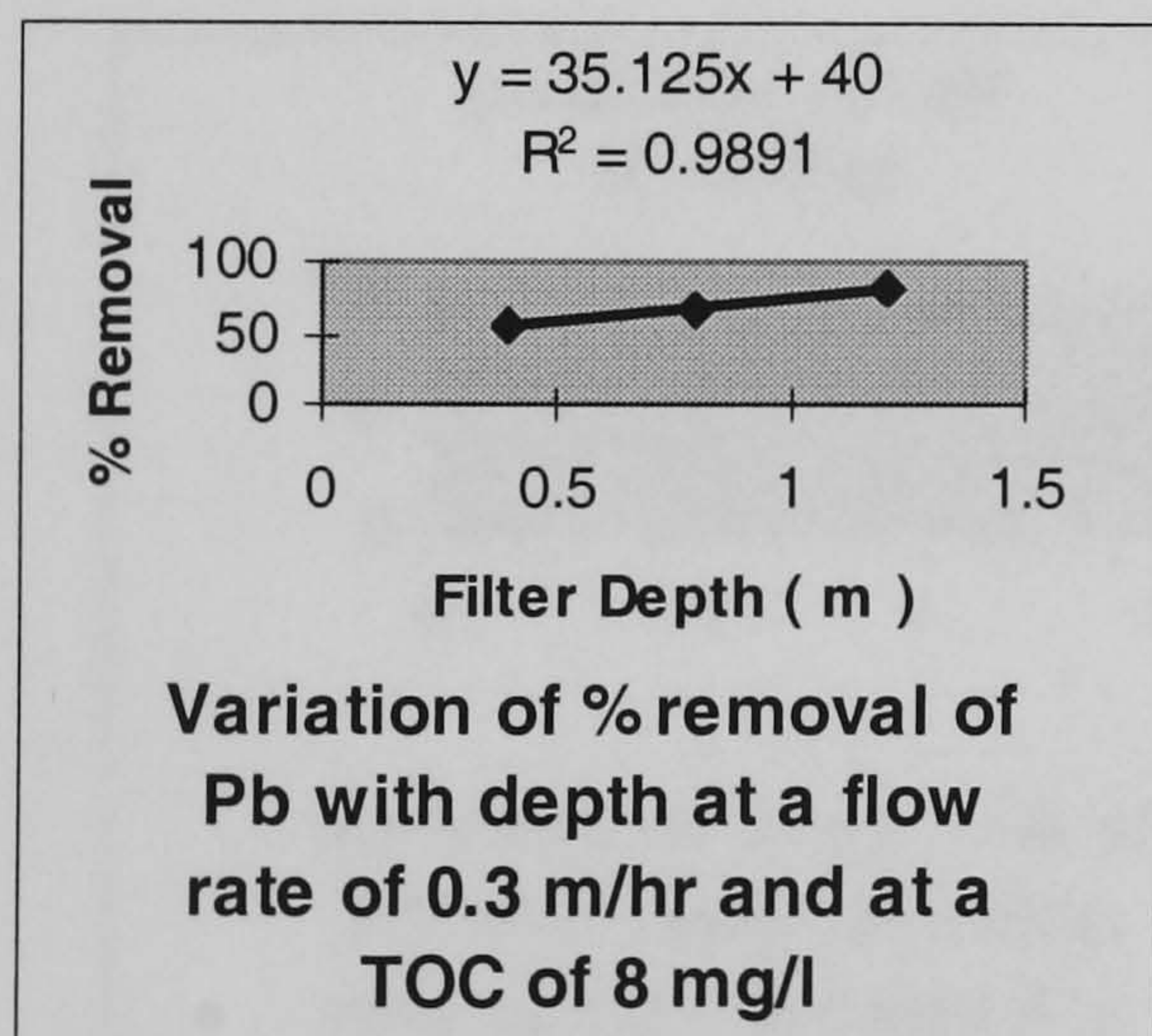
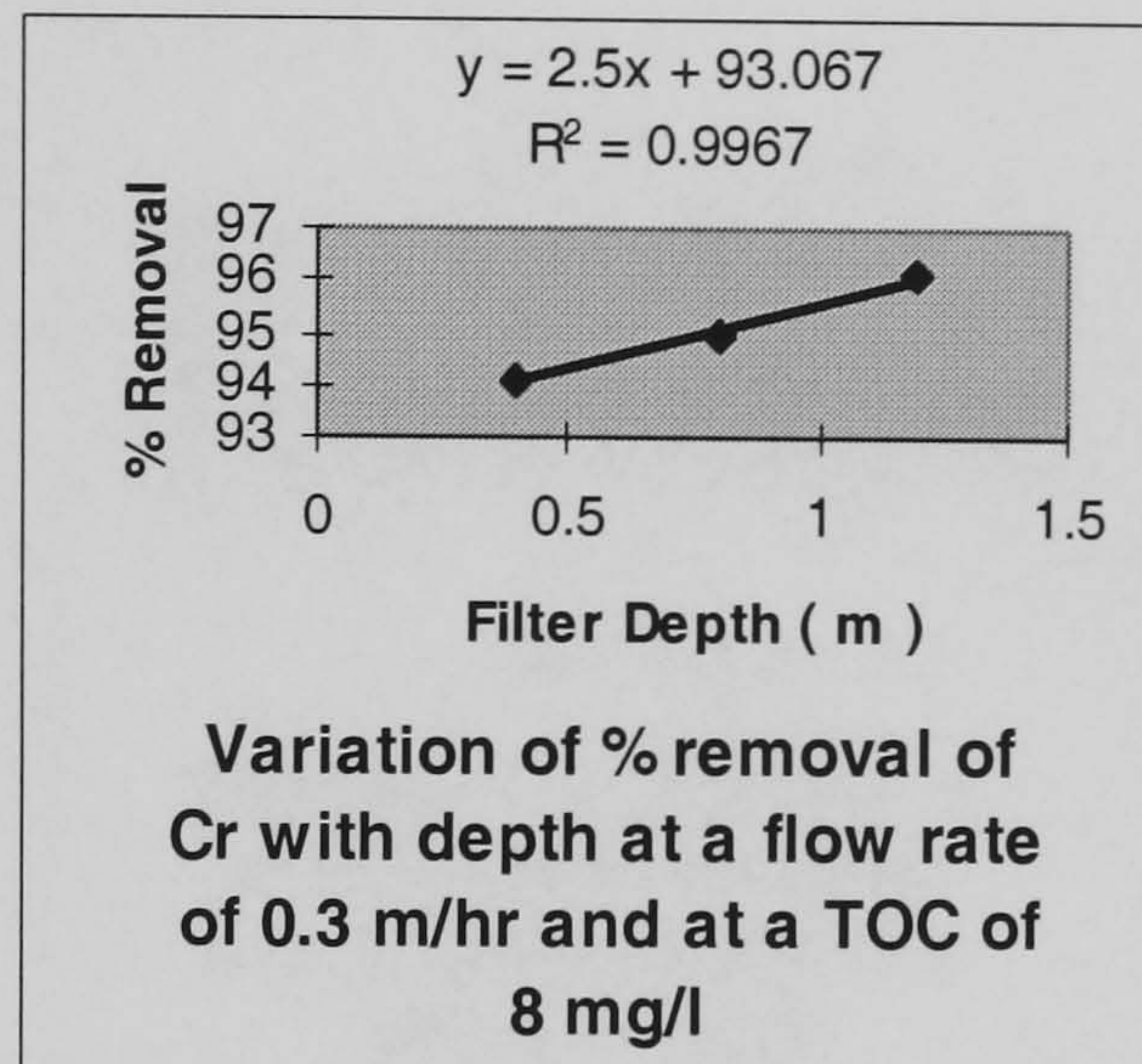
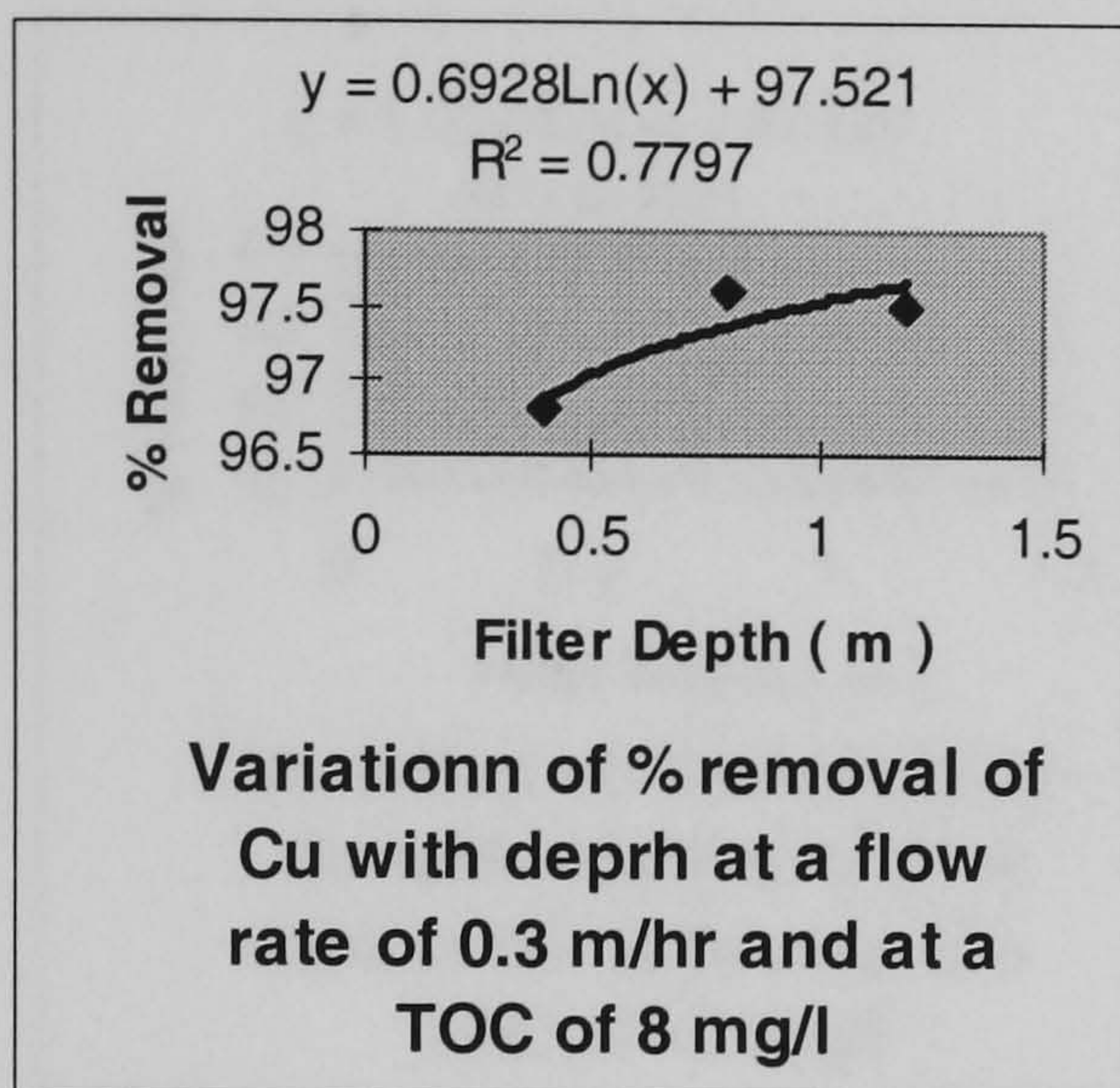


Figure 5.36 Variation of % removal of different of heavy metals with filter depth at a flow rate of 0.3 m/hr and at a TOC of 8 mg/l.



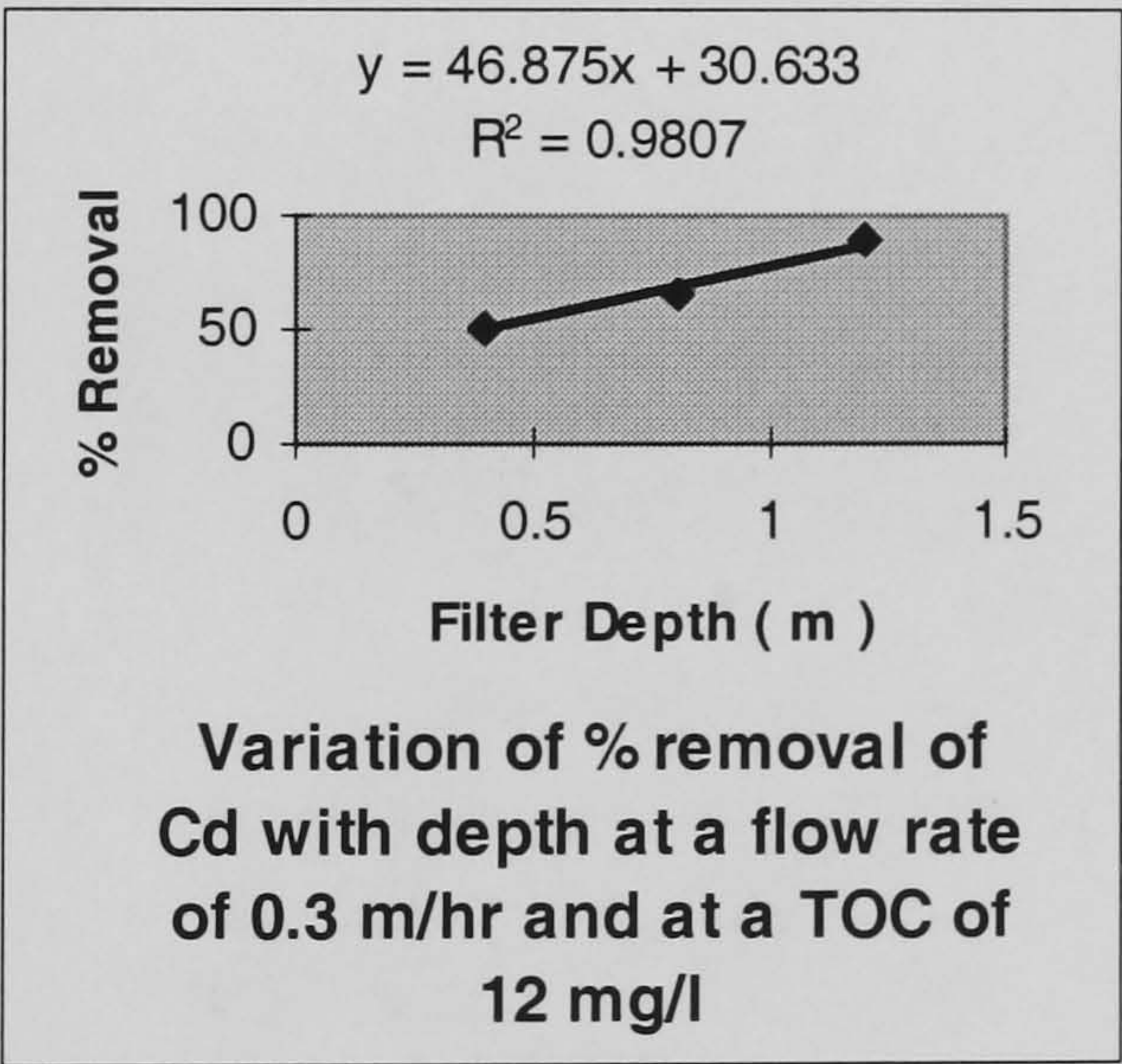
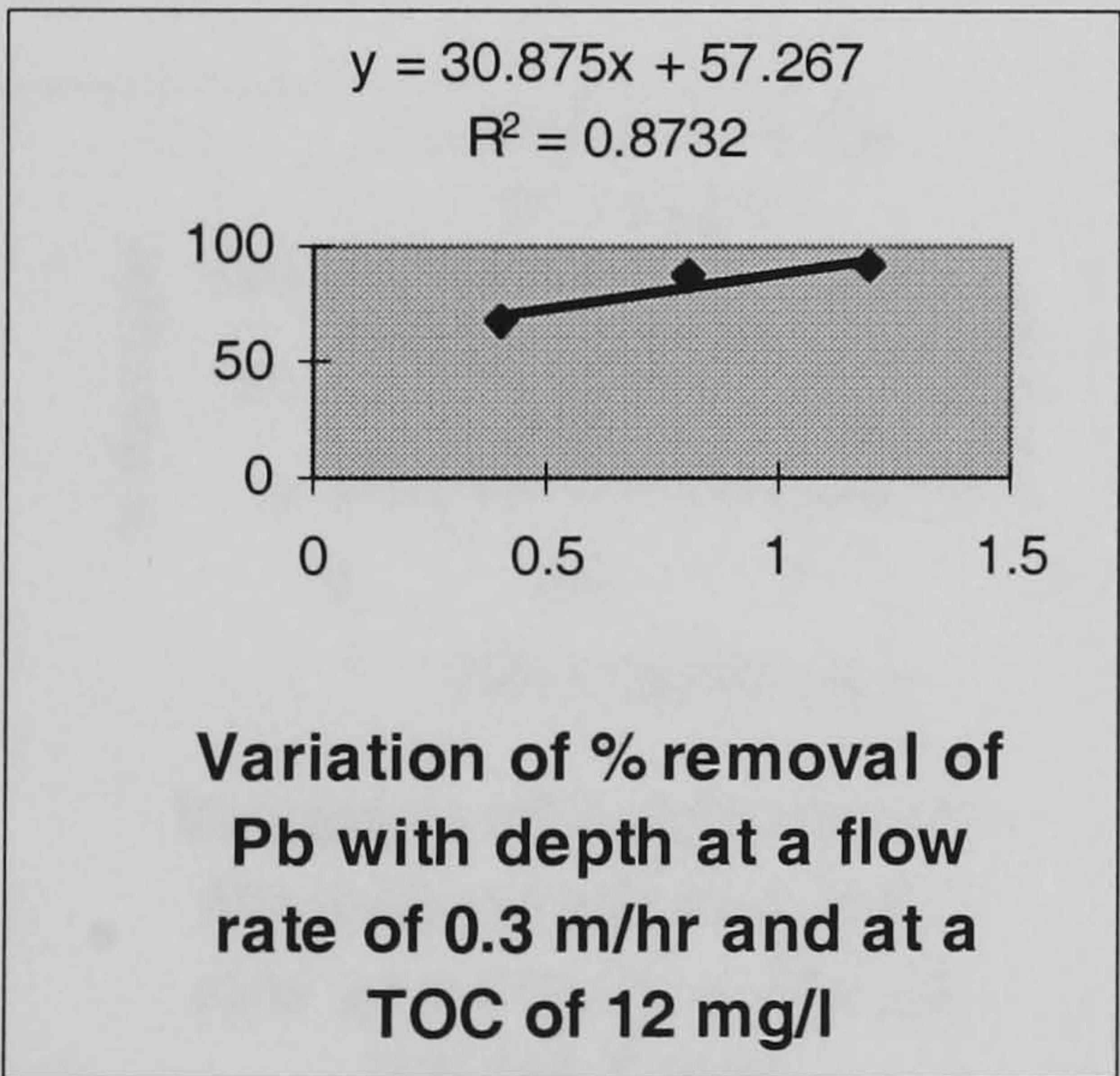
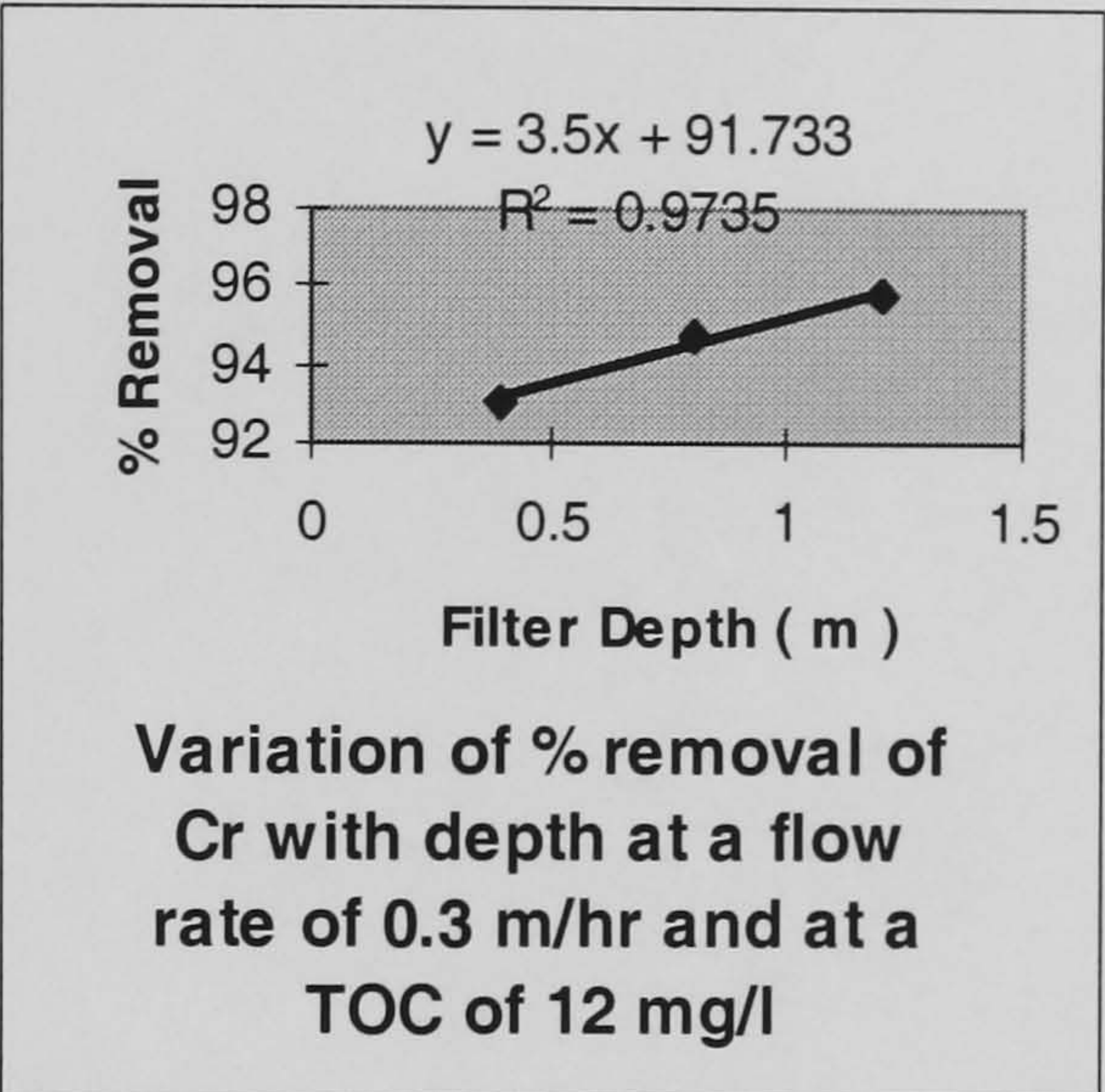
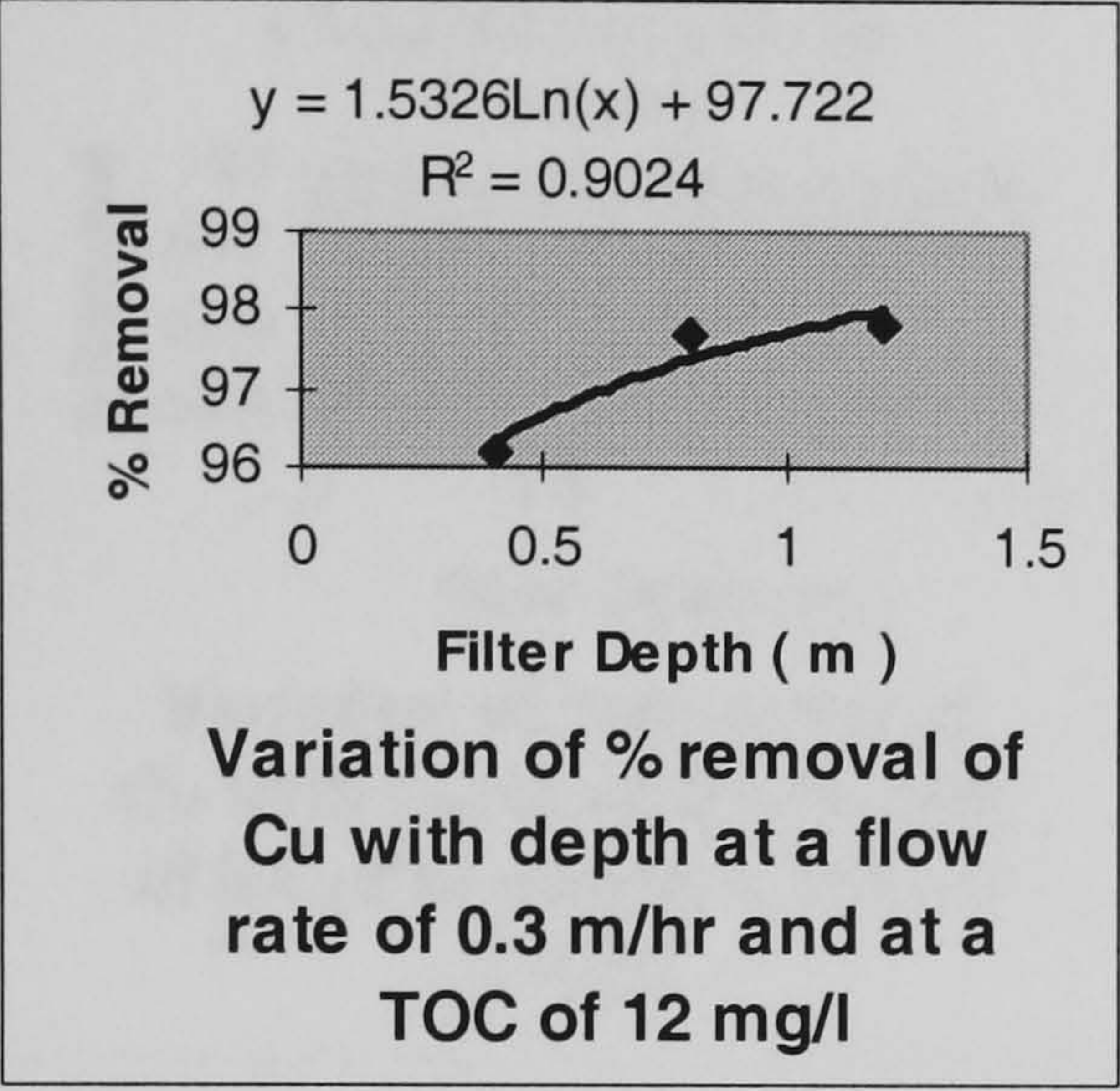


Figure 5.37 Variation of % removal of different heavy metals with filter depth at a flow rate of 0.3 m/hr and at a TOC of 12 mg/l.



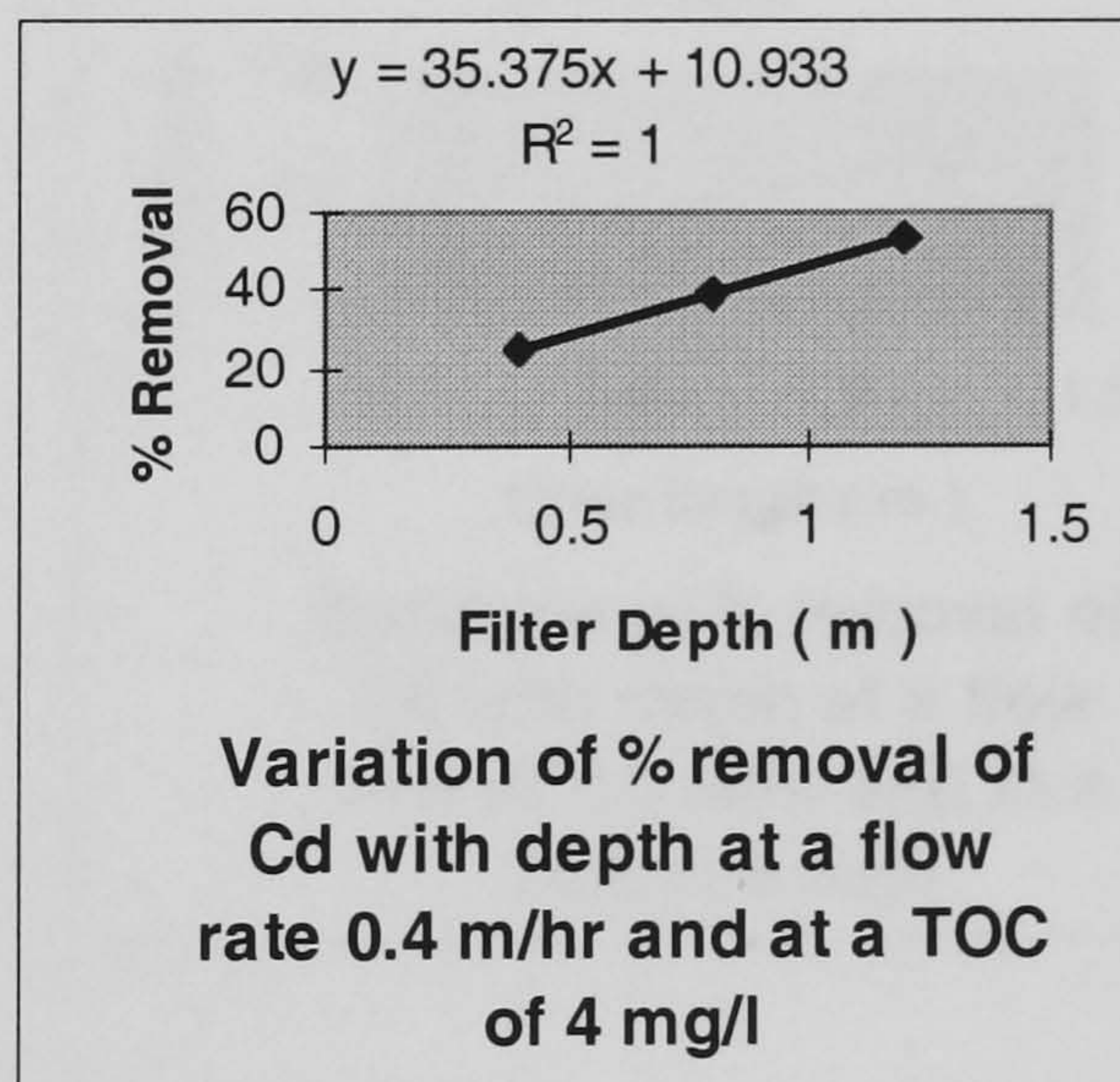
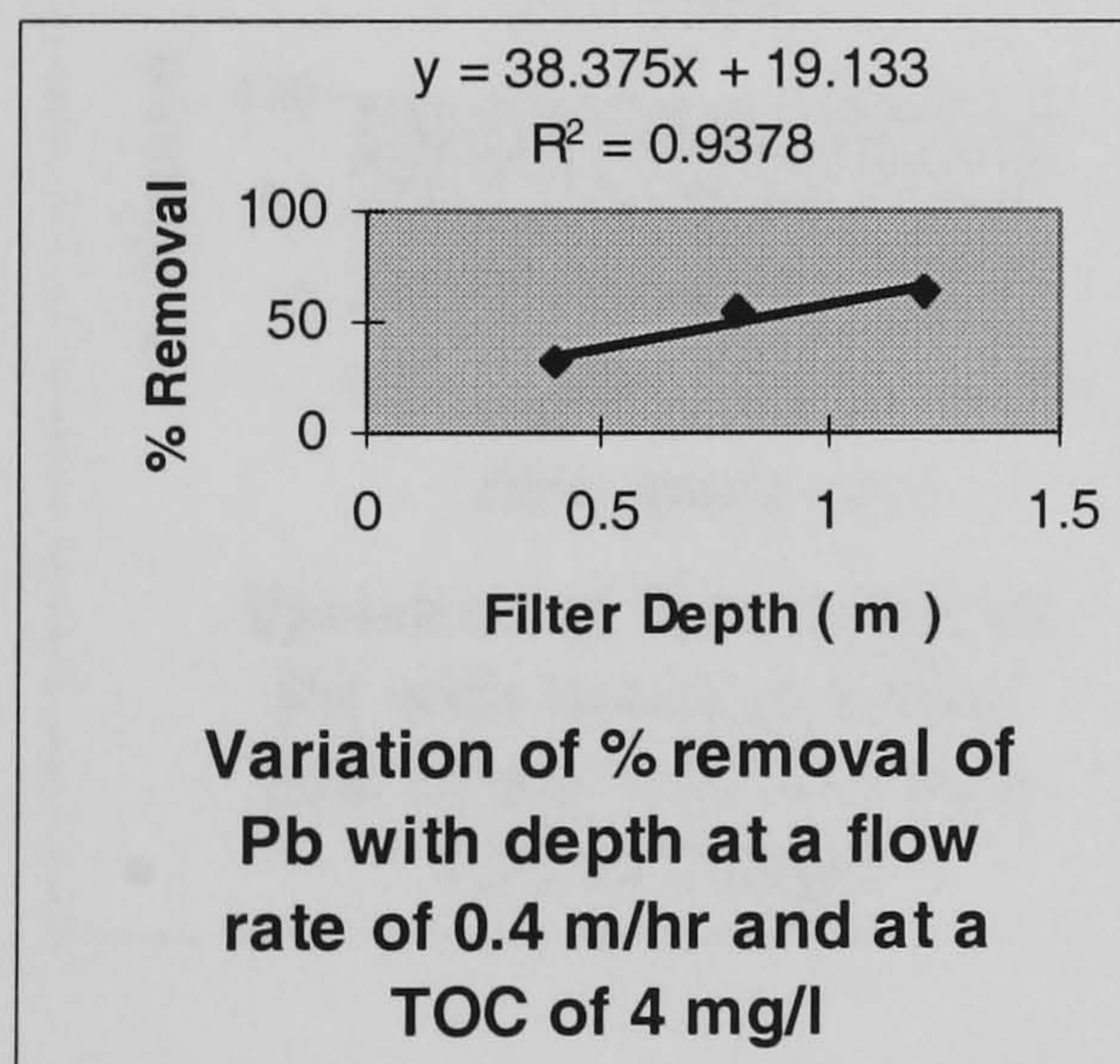
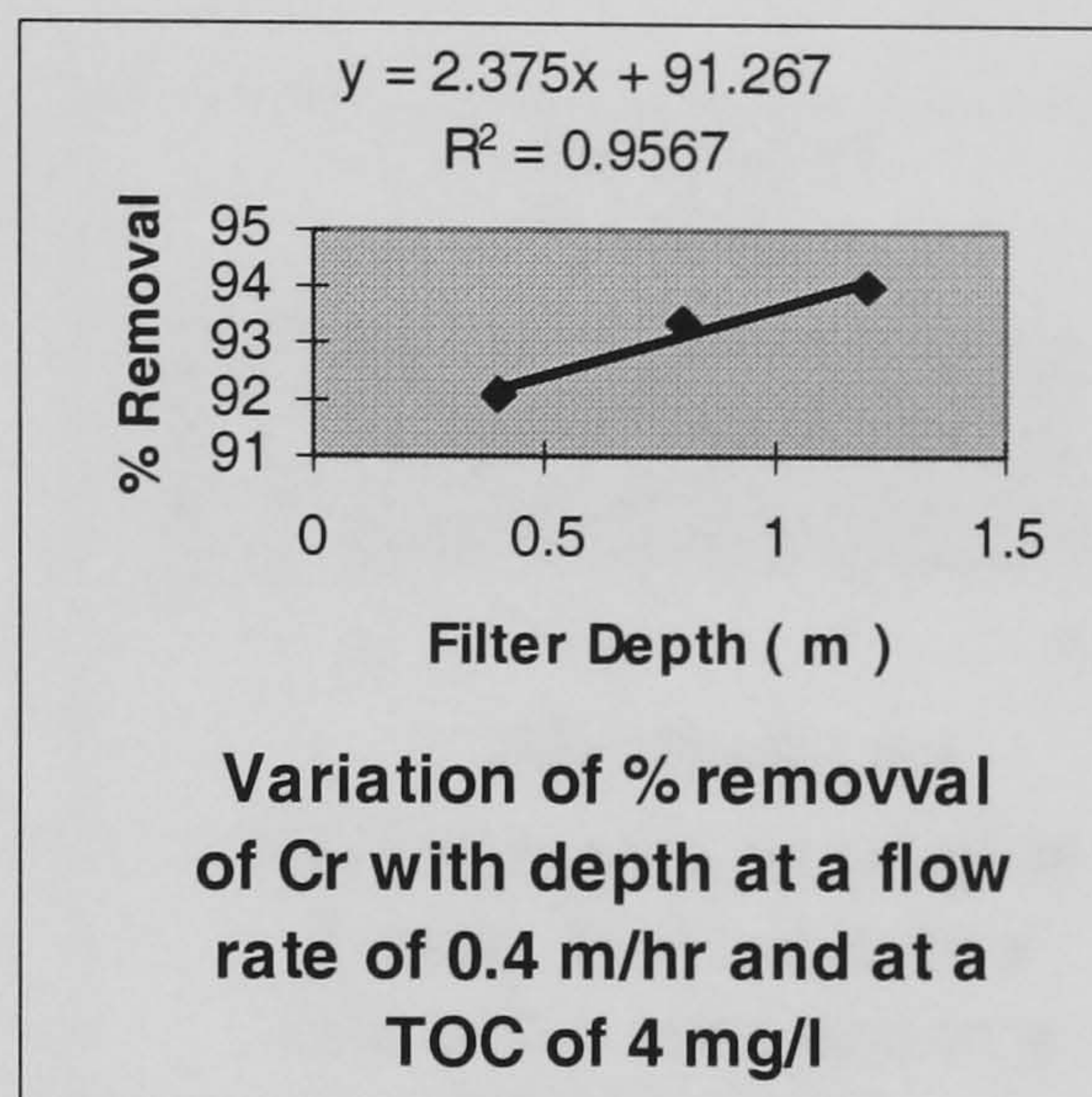
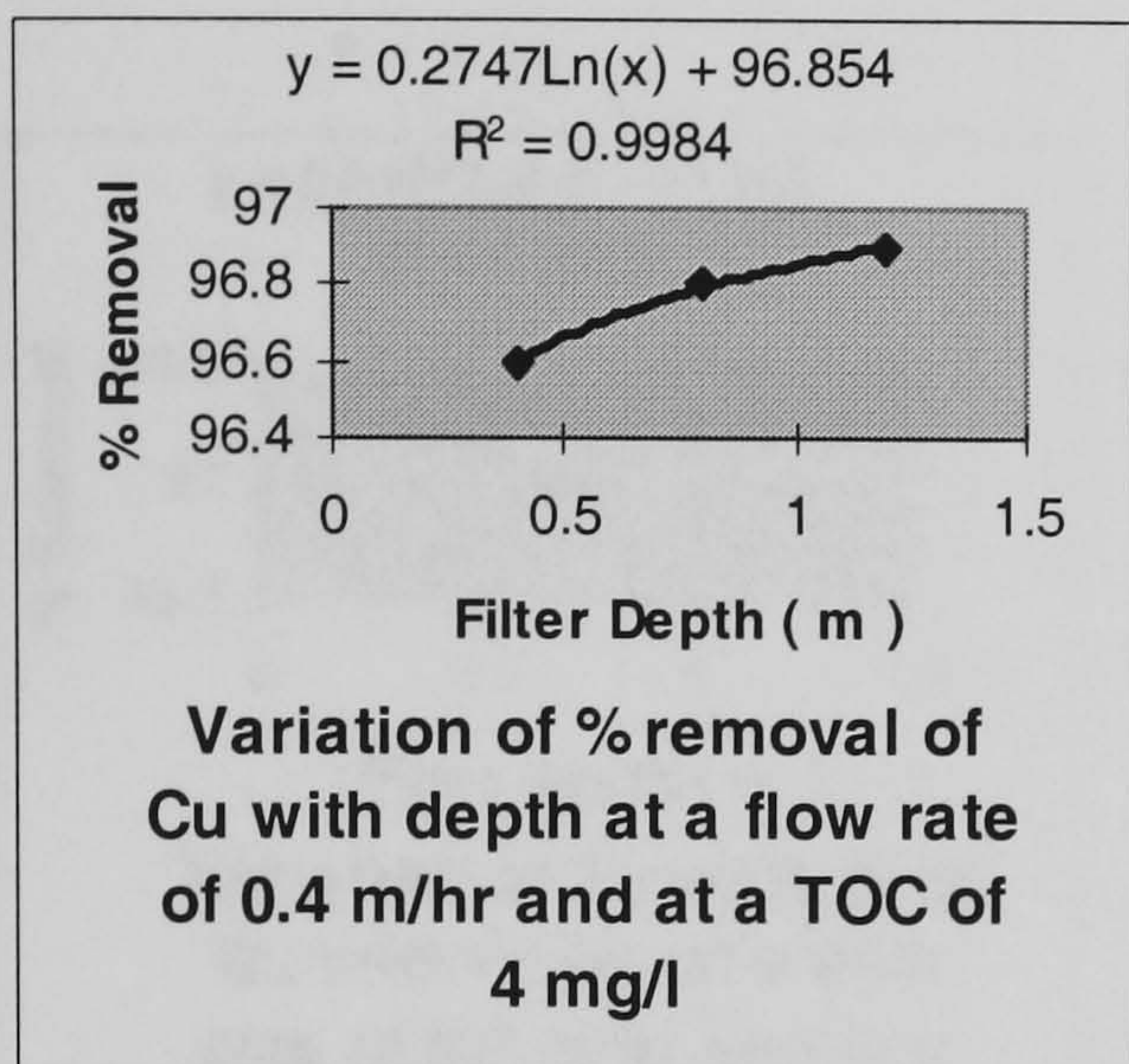


Figure 5.38 Variation of % removal of different heavy metals with filter depth at a flow rate of 0.4 m/hr and at a TOC of 4 mg/l.



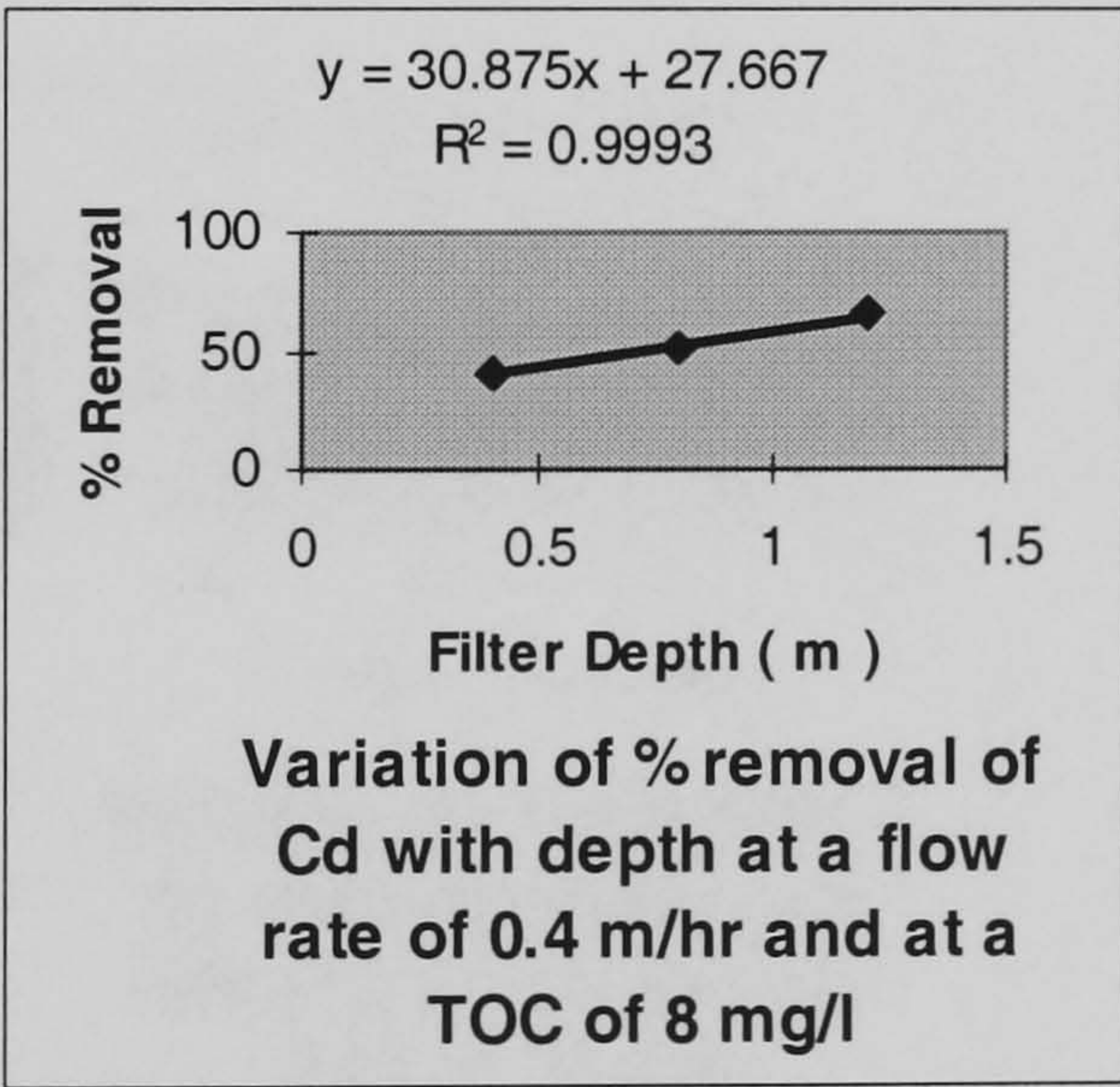
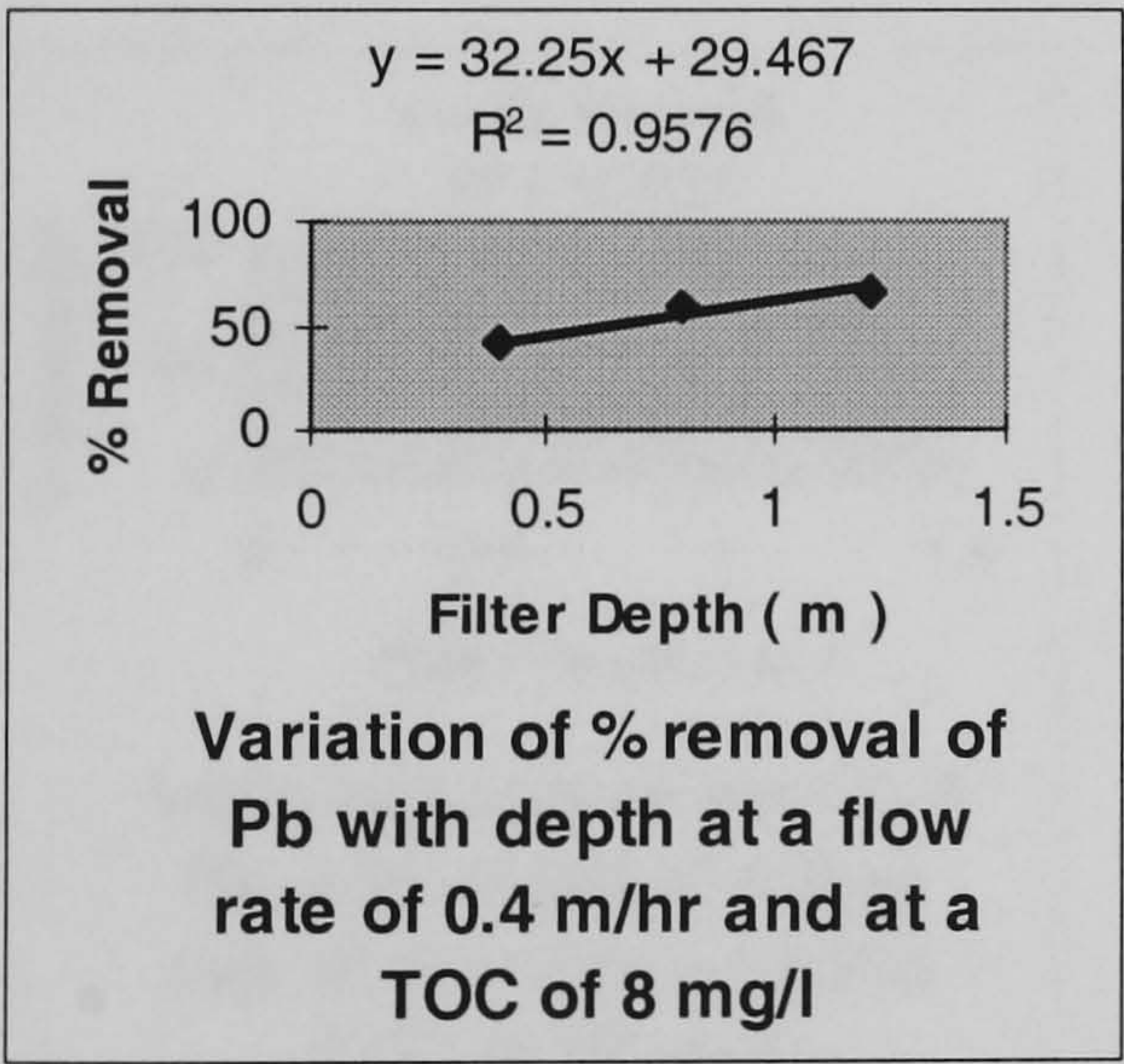
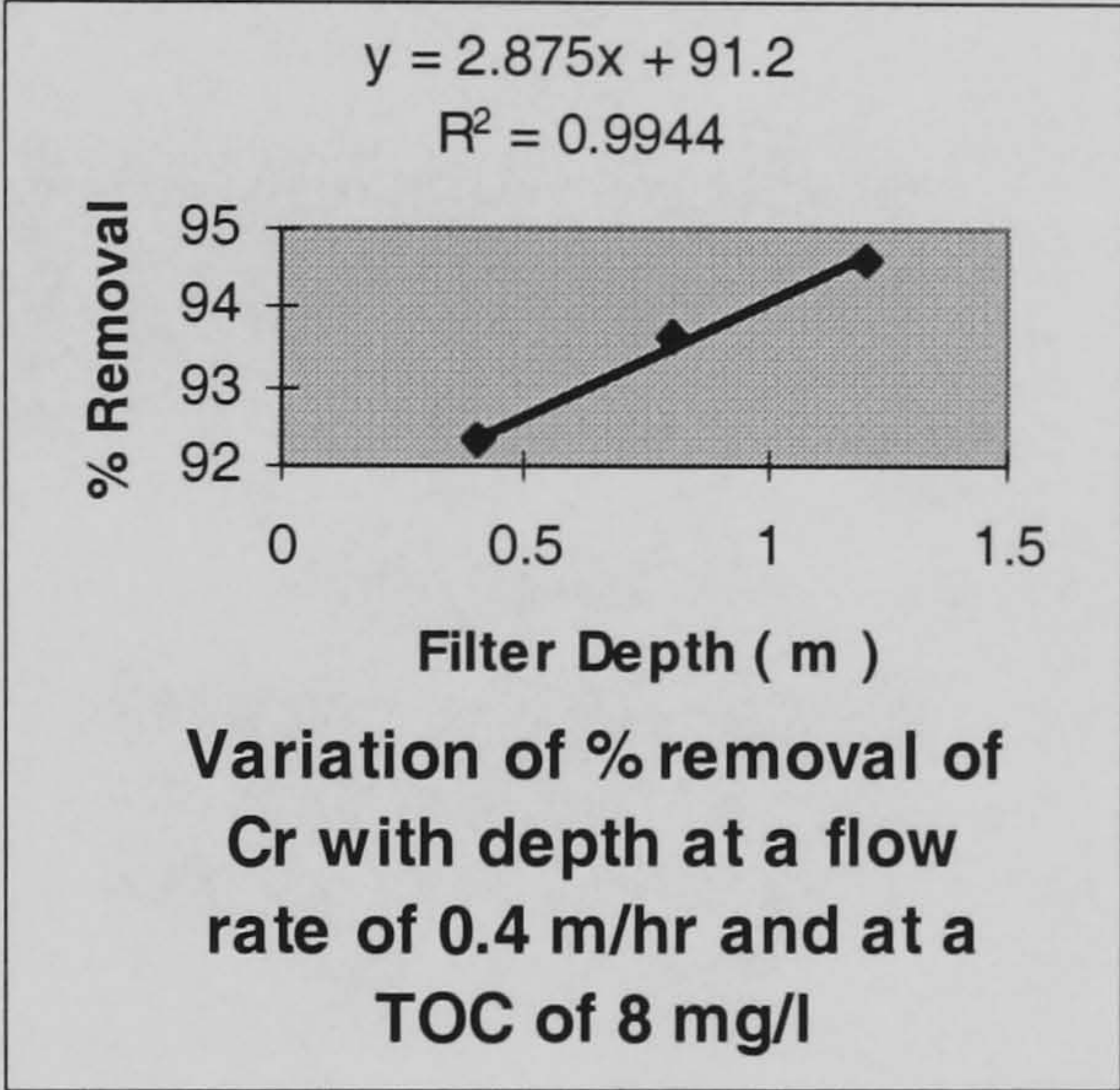
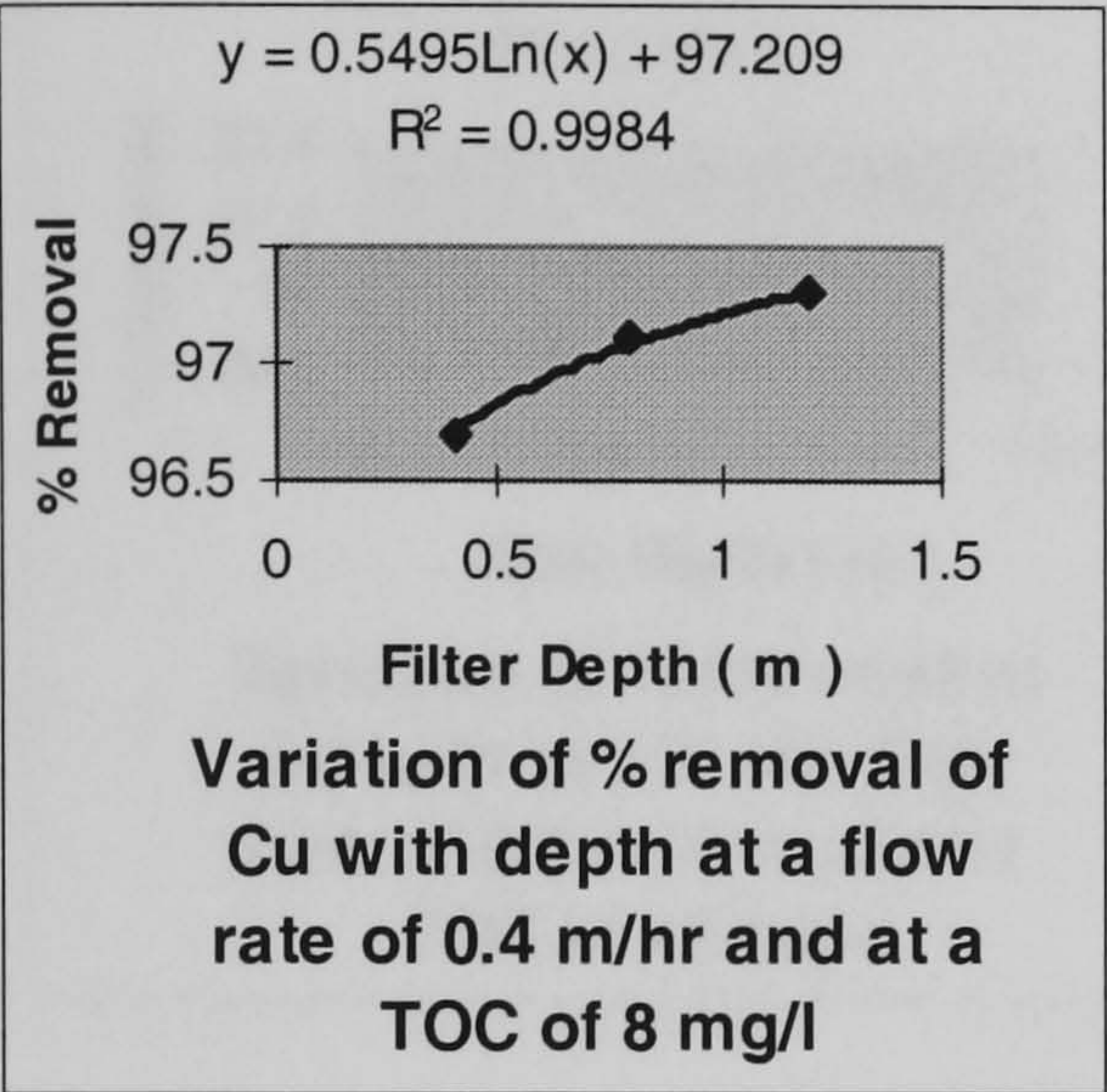


Figure 5.39 Variation of % removal of different heavy metals with filter depth at a flow rate of 0.4 m/hr and at a TOC of 8 mg/l.



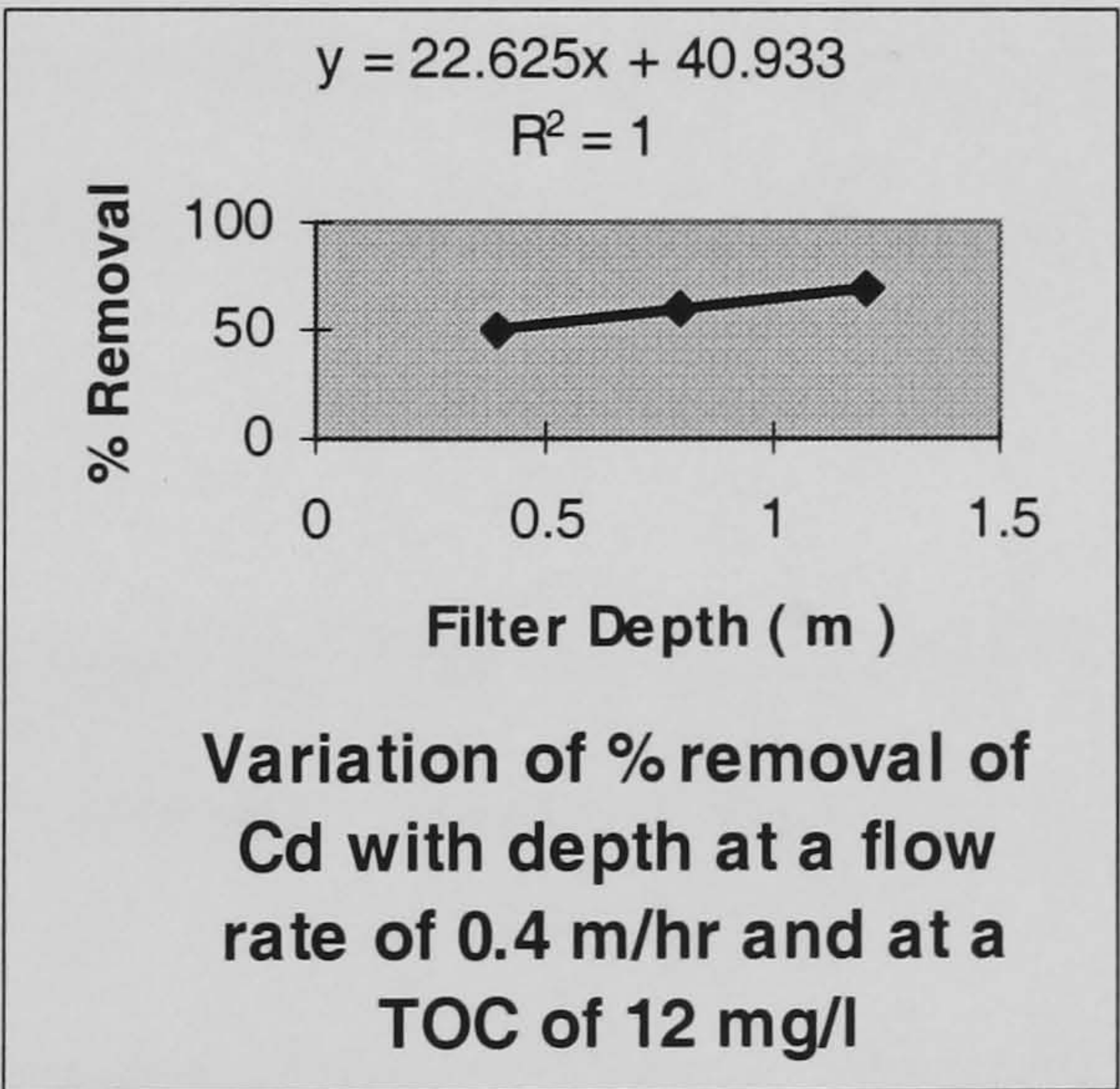
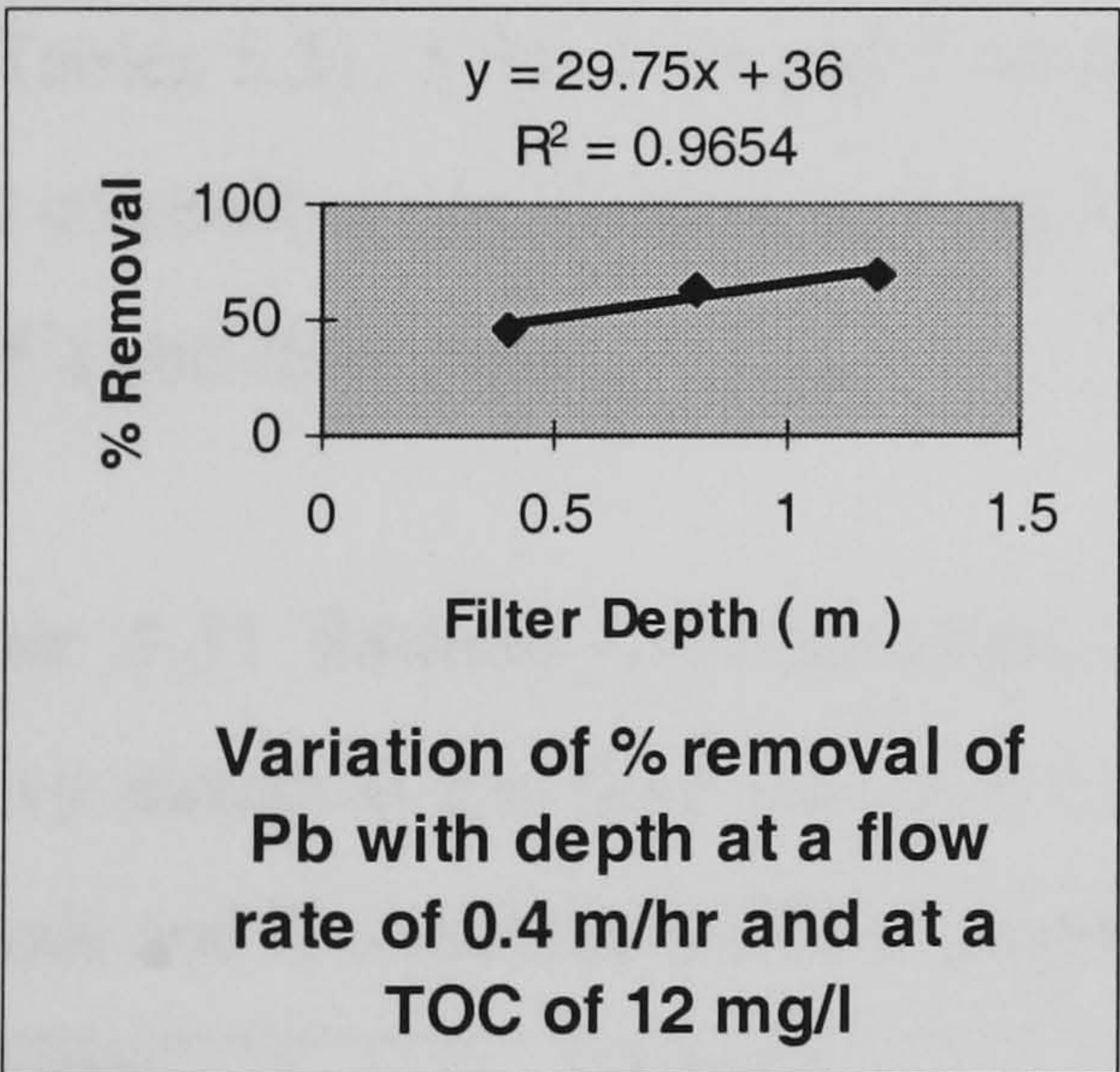
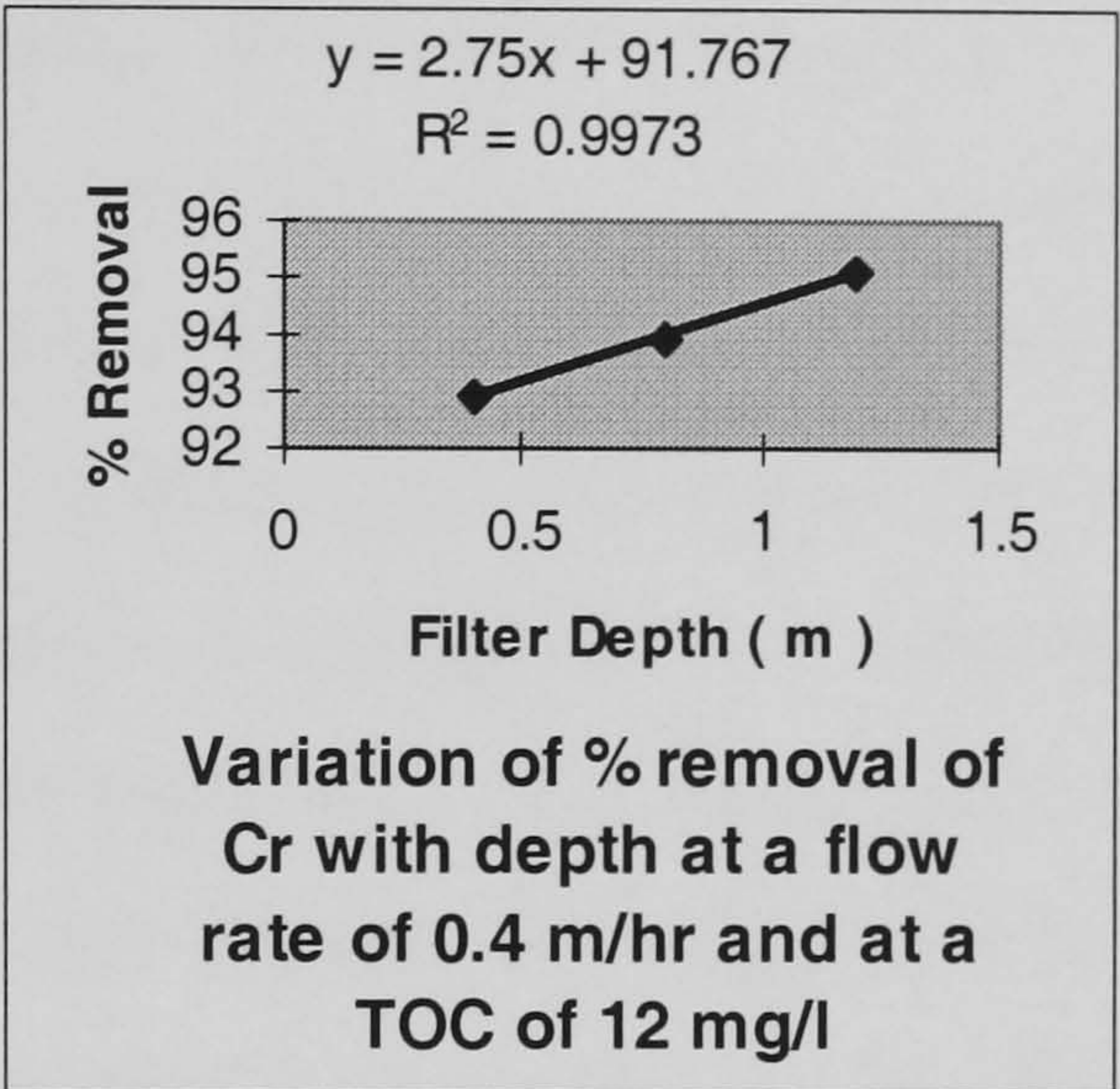
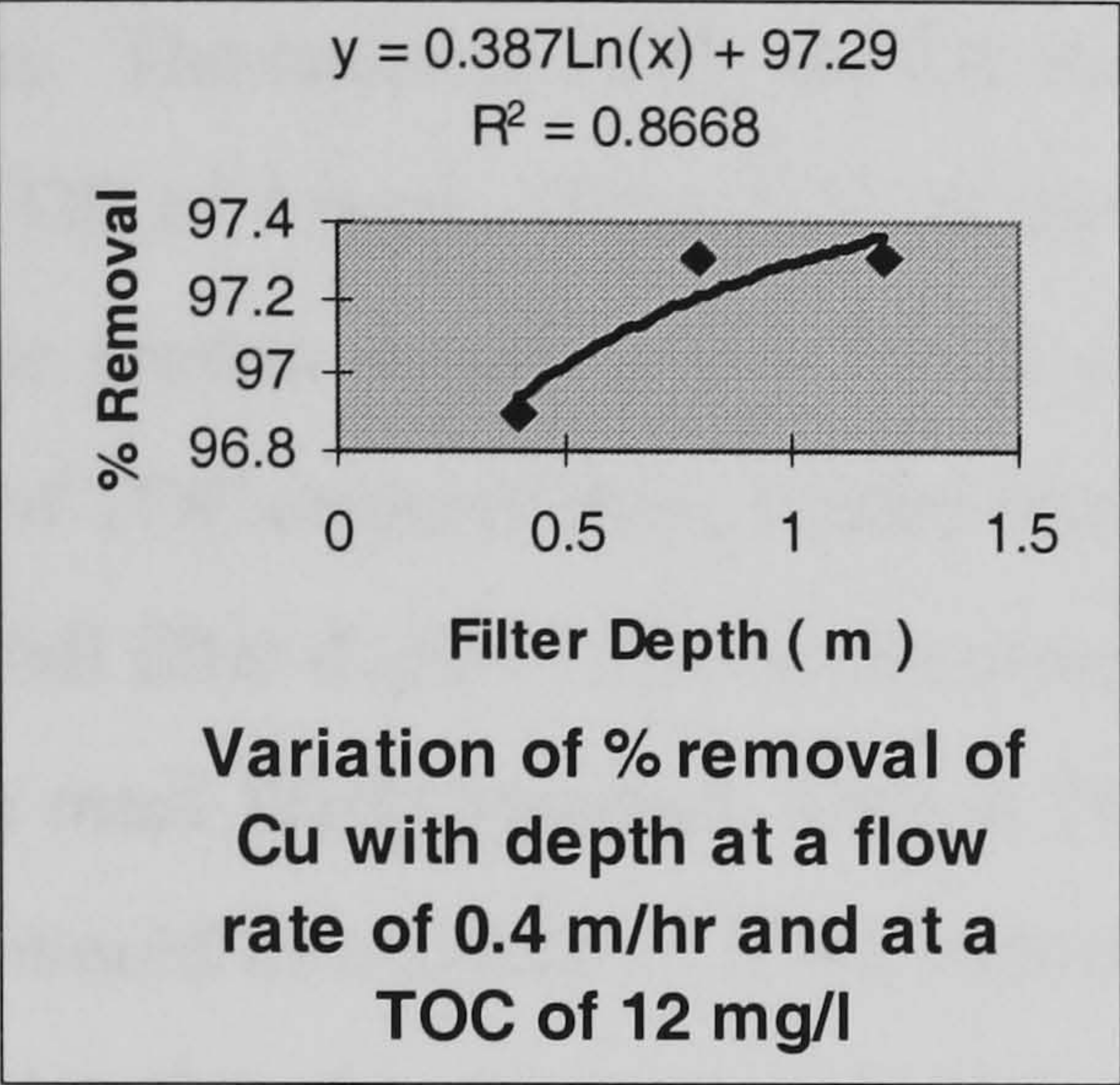


Figure 5.40 Variation of % removal of different heavy metals with filter depth at a flow rate of 0.4 m/hr and at a TOC of 12 mg/l.



- The removal efficiencies of Cu and Cr declined slightly with bed depth. The removal of Cu remained more or less same at 0.8m and 1.2m is negligible. The effects of filter bed depth are more pronounced at higher flow rates and lower TOCs. In the case of Cu and Cr, the removal efficiencies are still high enough at 0.4m of bed depth at 0.4 m/hr flow rate and at a TOC of 4 mg/l to meet the WHO standards for drinking water.
- The removal efficiencies of Pb and Cd were relatively poorer at shallower filter depths. The removal of Pb and Cd were the worst at 0.4 m of bed depth at 0.4 m/hr and at a TOC of 4 mg/l. If the TOC of the influent water is 8 mg/l, a full filter depth (1.20 m for the present research) at a filtration rate of 0.3 m/hr is recommended for Pb. In the case of TOC concentration higher than 8 mg/l, a filter depth of 0.8m can also be adopted.
- A full filter depth (1.2m for the present research) is recommended to efficiently remove Cd to meet WHO standard. Then a TOC of 12 mg/l and a conventional flow rate of 0.1 m/hr would be necessary. If the influent TOC is lower than 12 mg/l and the filtration rate is higher than the conventional value, a deeper filter is recommended for the removal of Cd.
- Tables 5.31, 5.32, 5.33 and 5.34 describe the summary of the mathematical equations and correlation coefficients relating the percentage removal and filter bed depth at various TOCs and flow rates.

Table 5.31 Summary of regression analysis regarding filter depths and the % removal of heavy metals at the flow rate of 0.1 m/hr (Y indicates the percentage removal of heavy metals and X indicates the filter depth).

Filter/Metal	TOC 4 mg/l		TOC 8 mg/l		TOC 12 mg/l	
	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )
F1/Cu	Y = X + 97.03	0.9796	Y = 0.68 Ln(X) + 98.59	0.8668	Y = 1.38X + 98.08	0.8811
F2/Cr	Y = 2.5X + 93.6	0.9709	Y = 1.5X + 95.17	0.9908	Y = 1.13X + 95.94	0.9067
F3/Pb	Y = 10.38X + 79.17	0.8474	Y = 10.38X + 82.17	0.9706	Y = 27.25X + 69.57	0.8853
F4/Cd	Y = 32.63X + 57.03	0.9225	Y = 30.75X + 60.833	0.9555	Y = 29.38X + 69.57	0.9544



Table 5.32 Summary of regression analysis regarding filter depths and the % removal of heavy metals at the flow rate of 0.2 m/hr (Y indicates the percentage removal of heavy metals and X indicates the filter depth).

Filter/Metal	TOC 4 mg/l		TOC 8 mg/l		TOC 12 mg/l	
	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )
F1/Cu	Y = 0.774 ln(X) + 97.58	0.8668	Y = 0.79 Ln(X) + 97.82	0.7908	Y = 0.79 Ln(X) + 98.312	0.7908
F2/Cr	Y = 2.875X + 93.07	0.9994	Y = 2.88X + 93.5	0.9944	Y = 1.75X + 95.06	0.9932
F3/Pb	Y = 47.38X + 27.04	0.9914	Y = 29.62X + 53.67	0.9943	Y = 34.38X + 54.1	0.8997
F4/Cd	Y = 27.37X + 54.24	0.9643	Y = 22.13X + 63.3	0.8841	Y = 23.5X + 62.64	0.9231

Table 5.33 Summary of regression analysis regarding filter depths and the % removal of heavy metals at the flow rate of 0.3 m/hr (Y indicates the percentage removal of heavy metals and X indicates the filter depth).

Filter/Metal	TOC 4 mg/l		TOC 8 mg/l		TOC 12 mg/l	
	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )
F1/Cu	Y = 0.79 ln(X) + 97.22	0.7905	Y = 0.693 Ln(X) + 97.52	0.7797	Y = 1.53Ln(X) + 97.72	0.9024
F2/Cr	Y = 2.5X + 92.87	0.9231	Y = 2.5X + 93.07	0.9967	Y = 3.5X + 91.74	0.9735
F3/Pb	Y = 54X + 15.24	0.9845	Y = 35.13X + 40	0.9891	Y = 30.88X + 57.27	0.8732
F4/Cd	Y = 42.13X + 28.57	0.8626	Y = 44.5X + 32.27	0.9995	Y = 46.88X + 30.64	0.9807



Table 5.34 Summary of regression analysis regarding filter depths and the % removal of heavy metals at the flow rate of 0.4 m/hr (Y indicates the percentage removal of heavy metals and X indicates the filter depth).

Filter/Metal	TOC 4 mg/l		TOC 8 mg/l		TOC 12 mg/l	
	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )	Math. Eqn.	Reg. Coeff.(R <sup>2</sup> )
F1/Cu	Y = 0.28 ln(X) + 96.85	0.9984	Y = 0.55 Ln(X) + 97.209	0.9984	Y = 0.39Ln(X) + 97.29	0.8668
F2/Cr	Y = 2.38X + 91.27	0.9567	Y = 2.88X + 91.2	0.9944	Y = 2.75X + 91.77	0.9973
F3/Pb	Y = 38.38X + 19.13	0.9378	Y = 32.25X + 29.47	0.9576	Y = 29.75X + 36	0.9654
F4/Cd	Y = 35.37X + 10.93	1	Y = 30.88X + 27.67	0.9993	Y = 22.63X + 40.93	1

- Linear correlation has been observed between the filter bed depth and the percentage removal of Cr, Pb and Cd. In the case of Cu, the variation is logarithmic. The critical regression coefficient (R<sup>2</sup>) for d.f of 1 is 0.9938 (Blend, 1985). In most of the cases the regression coefficients for Cu, Cr, Pb and Cd were greater or very close to their critical value. In some of the cases of Cu, the regression coefficients were less but very close the critical value. Hence a very strong correlation exists between the filter bed depth and the percentage removal of Cr, Pb and Cd. And a reasonably correlation exists between the filter bed depth and the percentage removal of Cu.

## 5.8 PREDICTION OF THE MECHANISMS OF HEAVY METAL REMOVAL BY SSFs

### 5.8.1 Adsorption of Heavy Metals onto Organic Matter

It is evident from the test results that increase in TOC of the influent improved the removal efficiencies of all four heavy metals at all flow rates and filter depths. The results demonstrated a definite influence of influent TOC on the optimisation of process variables of SSF in removing heavy metals. Hence adsorption of heavy metals onto organic matter is one of the likely mechanisms for removing heavy metals by SSF.



### **5.8.2 Adsorption of Heavy Metals onto Sand Surfaces**

As mentioned earlier, removal efficiencies of heavy metals decreased with increase in flow rates. This indicates adsorption of heavy metals on sand. A reduction in adsorption capacity is expected at higher filtration rates which consequently reduces the removal efficiency. It has also been mentioned earlier that an increase in filter bed depth improved the removal efficiency of heavy metals. This also emphasises the role of adsorption of heavy metals on sand. As the depth increases, the total adsorption capacity increases. Consequently it improves the removal efficiency of heavy metals, so adsorption on sand surfaces is one of the other likely mechanisms for removing heavy metals by SSFs.

### **5.8.3 Microbial Uptake of Heavy Metals in SSF**

It has been observed that the pH of the filtrate was always lower than that of their influent. An average drop of 0.3-0.5 occurred in almost all test conditions. This drop in pH indicates the probable microbial activity in SSFs. Microbial activity produces CO<sub>2</sub> causing a drop in pH. The removal of selected metals in the schumutzdecke also indicates the importance of microbial activities.

### **5.8.4 Precipitation of Heavy Metals in SSFs**

The test results regarding the influence of filter bed depth demonstrated that Cr and Cu required comparatively lower filter depth than Pb and Cd. The variation of filter depth depending on the individual metals indicates the probability of precipitation of heavy metals in SSF. Because precipitation of individual metals depends on the metal itself and pH, hence precipitation is also another probable mechanism for heavy metal removal by SSF.

## **5.9 COMMENTS ON STATISTICAL ANALYSIS**

- Statistical analysis was carried out to correlate the percentage removal of heavy metals and the various control parameters. In the case of sand bed depth, three different depths were considered resulting in three data points. Similarly three different TOC control



values were used resulting in three data points. For flow rate, four control values were used, giving four data points. Although better correlation is generally achieved with large number of data points, a minimum of three data points are recommended (Blend, 1985). In such case, a higher correlation coefficient is required to demonstrate good correlation, than would be the case with a larger data set.

- In the present research although only three or four data points were used for correlation, each data point itself was derived from the average of three individual sets of data, and all the data were within the 95% confidence limit. The correlation line always pass through the average point (Godfrey, *et al*, 1984). Figure A1.1 in annex 1 shows that if the average values are plotted and compared to a plot of the absolute values, the resulting correlation equations are virtually identical, and the correlation coefficients are statistically significant for the sample size under consideration.

## 5.10 OVERALL COMMENTS

- SSFs are effective in removing heavy metals from surface water. In general the removal efficiency decreases with the increase of filtration rates whereas the removal efficiency increase with the increase of TOC. The removal efficiency increases with the increase of filter bed depths. The optimisation of the design variables depends on the individual heavy metal and the TOC content of the influent water.
- Linear correlations were found between the percentage removal and process variables for most of the metals under investigations. Only a logarithmic variation was observed between the percentage removal of Cu and filter depth. In most of the cases the regression coefficients were either greater or equal or very close to the critical value of the regression coefficient.
- The removal of heavy metals by SSFs is predicted to take place through the combination of a number of mechanisms. Adsorption of heavy metals on to sand and organic matter, precipitation and bioaccumulation are the likely mechanisms of removal.



## **CHAPTER 6**

### **BATCH ADSORPTION TEST RESULTS**

#### **6.1 INTRODUCTION**

Experimental investigations of the influences of process variables in removing heavy metals by SSFs demonstrated that adsorption was one of the likely mechanisms of the removal of heavy metals. To confirm this hypothesis batch adsorption tests were carried out. This chapter deals with the results of the batch adsorption tests to establish adsorption isotherms and adsorption capacity of sand for the selected heavy metals.

#### **6.2 THEORY OF ADSORPTION**

##### **6.2.1 Basic Concepts**

Adsorption is the accumulation of a molecule at the surface of an adsorbent. The materials which adsorb the other molecules are called adsorbents and the materials which are being adsorbed are called adsorbates. Adsorption is caused by the unbalanced forces associated with the surface molecules of adsorbates and adsorbents. The high potential energy of the molecules can be reduced by the attraction of the other substances. Adsorption, therefore, occurs exclusively on the surface of the adsorbent (Ho, 1995).

There are two types of adsorption – physical adsorption or physiosorption and chemical adsorption or chemisorption. Physical adsorption involves intermolecular forces where the binding between adsorbent and adsorbate is caused by Van der Waals forces and the hydrogen bonds. Chemical adsorption or chemisorption involves valency forces through sharing or exchange of electrons between adsorbent and adsorbate as covalent forces. If the adsorbent is solid, the usual need is for large surface areas which offer many active sites for adsorbates. The rate of adsorption depends on the surface areas of the adsorbent, type of adsorbent and adsorbate, pH and temperature.



## 6.2.2 Adsorption Isotherms

Two important physiochemical aspects for the evaluation of the adsorption process as a unit operation are the equilibria of the adsorption and the kinetics. Equilibrium studies give the capacity of the adsorbent (Ho, 1995). The equilibrium relationship between adsorbent and adsorbate are described by adsorption isotherms, usually the ratio between the quantity adsorbed and that remaining in solution at a fixed temperature at equilibrium. There are two types of adsorption isotherms: Langmuir adsorption isotherms and Freundlich adsorption isotherms (Ho, 1995; Apak *et al*, 1998). These isotherms relate metal uptake per unit weight of adsorbent to the equilibrium adsorbate concentration in the bulk fluid phase (Apak *et al*, 1998).

### Langmuir Adsorption Isotherms

Irving Langmuir, an American chemist, who was awarded the Nobel Prize for Chemistry in 1932 for “his discoveries and researches in the realm of surface chemistry”, developed a relationship between the amount of gas adsorbed on a surface and the pressure of that gas (Ho, 1995). Such equations are now referred to as Langmuir adsorption isotherms: a theoretical adsorption isotherm in the ideal case. The Langmuir adsorption isotherm is often used for adsorption of a solute from a liquid solution. The Langmuir adsorption isotherm is based on the assumptions that:

- adsorption proceeds only until a single adsorption layer is formed (a monolayer)
- adsorbed molecules are not free to move on the surface (Ho, 1995; Apak *et al*, 1998; Weber and DiGiano, 1995; Weber *et al*, 1996).

The Langmuir adsorption isotherm is perhaps the best known of all isotherms describing adsorption and is often expressed as:

$$Q_e = \frac{X_m K C_e}{1 + K C_e} \text{ (Casey, 1997; Apak } et al, 1998)$$



where:

$Q_e$  is adsorption density at the equilibrium solute concentration  $C_e$  ( $\mu\text{g}$  of adsorbate per g of adsorbent);

$C_e$  is the concentration of adsorbate in solution ( $\mu\text{g/l}$ );

$X_m$  is the maximum adsorption capacity corresponding to complete monolayer coverage ( $\mu\text{g}$  of solute adsorbed per g of adsorbent);

$K$  is the Langmuir constant related to energy of adsorption (l of adsorbent per  $\mu\text{g}$  of adsorbate).

The above equation can be rearranged to the following linear form:

$$\frac{C_e}{Q_e} = \frac{1}{X_m K} + \frac{C_e}{X_m}, \text{ where, slope of the equation is } \frac{1}{X_m} \text{ and the intercept is } \frac{1}{X_m K}.$$

Hence the Langmuir constants  $X_m$  and  $K$  can be evaluated from the slope and intercept of the linear equation.

### Freundlich isotherm

Herbert Max Finlay Freundlich, a German physical chemist, presented an empirical adsorption isotherm for non-ideal systems in 1906. The Freundlich isotherm is the earliest known relationship describing the adsorption equation. This fairly satisfactory empirical isotherm can be used for non-ideal adsorption that is multilayer adsorption and is expressed by the following equation:

$$Q_e = K_f C_e^{1/n} \text{ (Casey, 1997; Apak *et al*, 1998; Namasivayam and Ranganathan, 1995).}$$

where:

$Q_e$  is the adsorption density ( $\mu\text{g}$  of adsorbate per g of adsorbent);



$C_e$  is the concentration of adsorbate in solution ( $\mu\text{g/l}$ )

$K_f$  and  $n$  are empirical constants dependent on several environmental factors (Ho, 1995)

Apak *et al* (1998) and Jain and Ram (1997) described  $K_f$  as an indication of adsorption capacity and  $n$  as sorption intensity. According to Ho (1995), the value of  $n$  is greater than one for adsorption whereas McKay *et al* (1980) has suggested the value of  $n$  as 2-10 for good adsorption.

This equation is conveniently used in the linear form by taking the logarithmic of both sides as:

$$\ln Q_e = \ln K_f + 1/n \ln C_e$$

where,

$$\text{Slope} = 1/n$$

$$\text{Intercept} = \ln K_f$$

A plot of  $\ln C_e$  against  $\ln Q_e$  yielding a straight line indicates the conformation of the Freundlich isotherm for adsorption. The constants can be determined from slope and intercept. The Freundlich equation is most useful for dilute solutions over small concentration ranges.

### 6.3 METHOD USED FOR BATCH ADSORPTION TESTS

The method developed by Ho in 1995 was used for the batch adsorption of different heavy metals. The procedures for the tests were as follows:

- 1g of sand as an adsorbent was taken in 250 mls of metal solution. The concentration of the adsorbent was, therefore, 4g/l.
- the conical flasks were capped and shaken in the flask shaker at 200 rpm for four hours
- the temperature was fixed at 20°C and pH was adjusted from 7.2 to 7.5
- at least five different concentrations of each metal were considered



- the sample was filtered through the 540µm filter paper and the effluent concentration was measured
- $Q_e$  was determined and  $C_e$  vs  $C_e/Q_e$  was plotted.

## 6.4 RESULTS AND DISCUSSION

To establish the adsorption isotherms and evaluate the adsorption capacity of sand, individual metal was tested in triplicate. The results described in this chapter are the average of three sets of tests.

### 6.4.1 Batch Adsorption Test Results for Cu

#### Langmuir Isotherms

Table 6.1 describes the batch adsorption test results for Cu. Sample calculations are shown in the text.

Table 6.1: Batch adsorption test results for Cu

No of Observations	Influent (µg/l)	Effluent (µg/l)	Amount Absorbed µg	% Absorbed
1	940	360	580	61.7
2	1860	860	990	53.9
3	2750	1540	1210	44.0
4	3200	1870	1330	41.6

#### Sample calculations:

*Observation No1:*

Amount of Cu adsorbed =- 940-360 = 580 µg/l which is equivalent to 145 µg/250 ml of solution. As 1g of sand was taken in 250 ml solution, the amount of Cu adsorbed per g of sand is 145 µg.

Hence  $Q_e = 145$  mg/g of sand,  $C_e = 940$  ,  $C_e/Q_e = 940/145 = 6.48$ .

Similarly the  $Q_e$  and  $C_e/Q_e$  values for all other observations were calculated and the results are summarised in Table 6.2.



Table 6.2: Summary of the Batch Adsorption Results for Cu

No of Observations	$C_e$ ( $\mu\text{g/l}$ )	$C_e/Q_e$
1	940	6.48
2	1860	7.44
3	2750	8.80
4	3200	9.62

Figure 6.1 shows the plot of  $C_e$  vs  $C_e/Q_e$  which is a straight line. This indicates that the adsorption of Cu on sand follows the Langmuir adsorption isotherm. Regression analysis yields the relation between  $C_e$  and  $C_e/Q_e$  as linear with the regression coefficient very close to one (0.9916).

From the equation:

Slope = 0.0011  $\therefore \frac{1}{X_m} = 0.0011$  i.e  $X_m = 719 \mu\text{g/g}$  of sand.

Intercept = 5.390  $\therefore \frac{1}{X_m \cdot K} = 5.390$  i.e.  $K = 0.0071$

Hence the maximum adsorption capacity of sand for Cu is  $719 \mu\text{g/g}$  of sand.

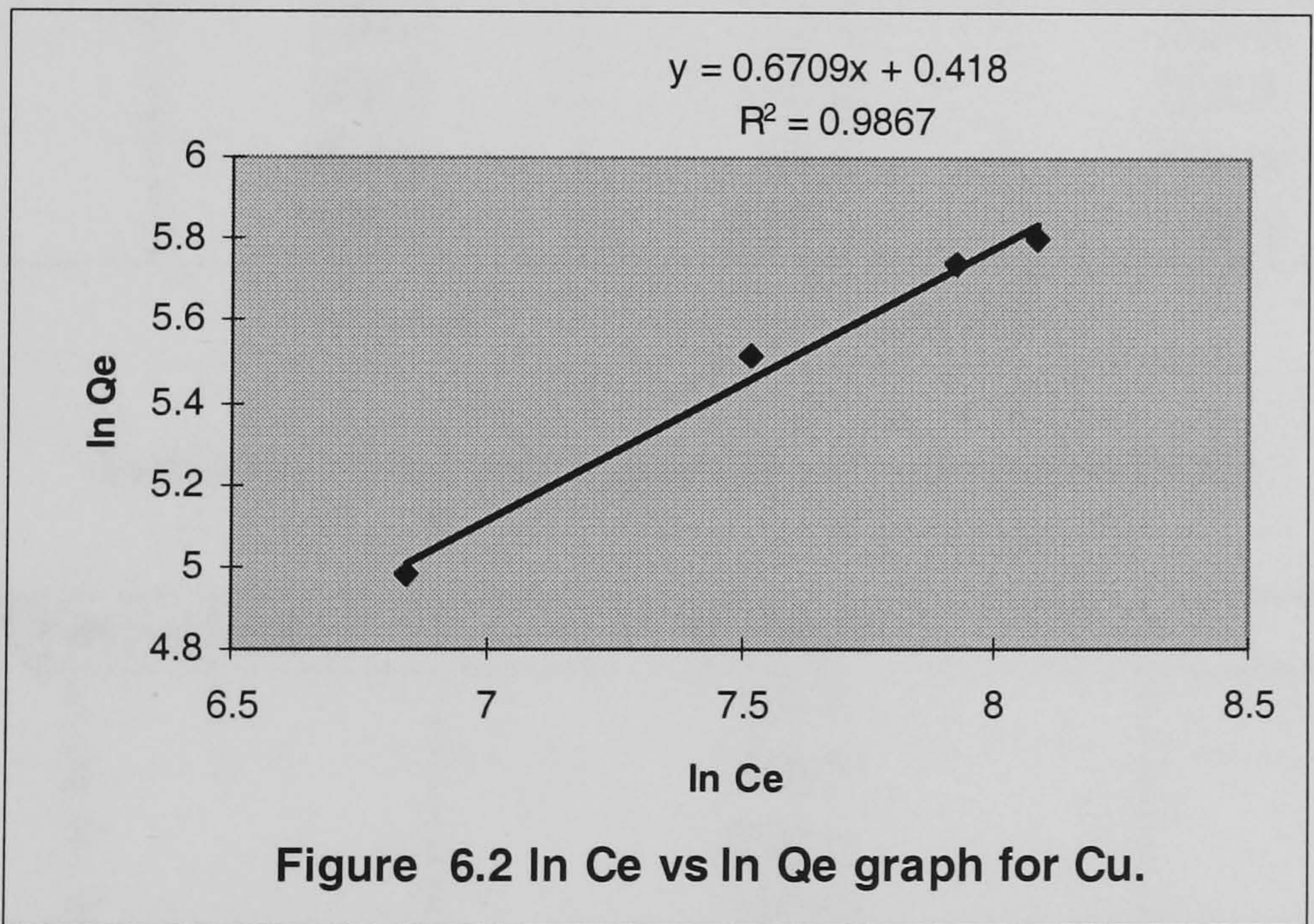
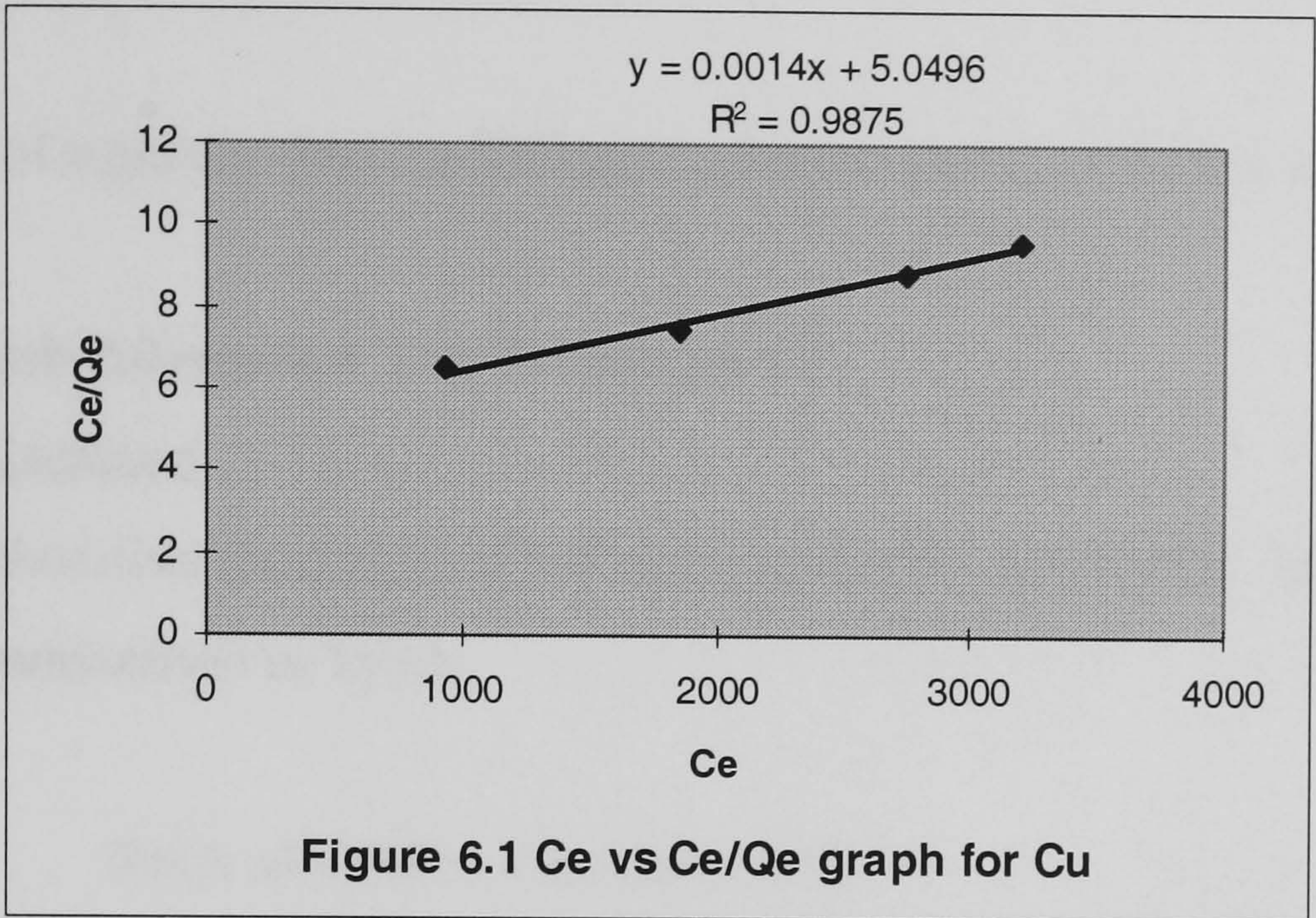
Freundlich Isotherm

Table 6.3: Summary of the test results converted into logarithmic value for Cu.

No of Observations	$C_e$ ( $\mu\text{g/l}$ )	$Q_e$ ( $\mu\text{g/g}$ of sand)	$\ln C_e$	$\ln Q_e$
1	940	145.0	6.84	4.98
2	1860	250.0	7.52	5.52
3	2750	312.5	7.92	5.74
4	3200	332.5	8.08	5.80

Figure 6.2 describes the plot of  $\ln C_e$  vs  $\ln Q_e$ . The straight line equation confirms the adsorption of Cu onto sand according to the Freundlich isotherm. The regression







coefficient close to one indicates the perfect linearity

From the equation:

Slope = 0.67 and intercept = 0.42.

So n = 1/0.67 = 1.5

C = 0.142 ∴ ln K<sub>f</sub> = 0.42 i.e. K<sub>f</sub> = 1.52

The value of n greater than one indicates adsorption of Cu onto the sand surface.

6.4.2 Batch Adsorption Test Results for Cr

Langmuir Isotherm

Table 6.4 describes the results of the batch adsorption test for Cr. The summary of the test results is summarised in Table

Table 6.4: Batch adsorption test result for Cr

No of Observations	Influent (µg/l)	Effluent (µg/l)	Amount Adsorbed (µg)	% Adsorbed
1	128.0	12.6	115.6	90.3
2	268.5	45.6	222.9	83.0
3	404.6	85.0	319.6	79.0
4	560.0	125.6	434.4	77.6

Table 6.5: Summary of the batch adsorption test results for Cr

No of Observations	C <sub>e</sub> (µg/l)	C <sub>e</sub> /Q <sub>e</sub>
1	128.0	4.43
2	268.5	4.82
3	404.6	5.06
4	560.0	5.20

Figure 6.3 describes the plot of C<sub>e</sub> vs C<sub>e</sub>/Q<sub>e</sub>. The linear variation with regression coefficient close to one indicates the adsorption of Cr onto the sand surface according to the Langmuir isotherm.



From the equation:

Slope = 0.0018 and intercept = 4.3.

$$\therefore X_m = 1/0.0018 = 556; 4.3 = \frac{1}{556K} \therefore K = 0.0077$$

Hence the maximum adsorption capacity of sand for Cr is 556 µg/g of sand.

Freundlich Isotherm

Table 6.6 describes the test results for Cr converted into logarithmic values.

No of Observations	C <sub>e</sub> (µg/l)	Q <sub>e</sub> (µg /g of sand)	ln C <sub>e</sub>	ln Q <sub>e</sub>
1	128.0	28.9	4.85	3.36
2	268.5	55.8	5.60	4.02
3	404.6	79.9	6.00	4.38
4	560.0	108.6	6.32	4.69

Figure 6.4 describes the plot of the ln C<sub>e</sub> vs ln Q<sub>e</sub>. The straight line equation with regression coefficient close to one demonstrates the adsorption of Cr onto sand.

From the equation:

Slope = 0.90 and intercept = -1.02.

Hence n = 1.1 and K<sub>f</sub> = 0.36.

The value of n is greater than one which indicates adsorption of Cr onto the sand surface.

**6.4.3 Batch Adsorption Test Results for Pb**

Table 6.7 describes the batch adsorption test results for Pb. The summary of the results is described in Table 6.8.



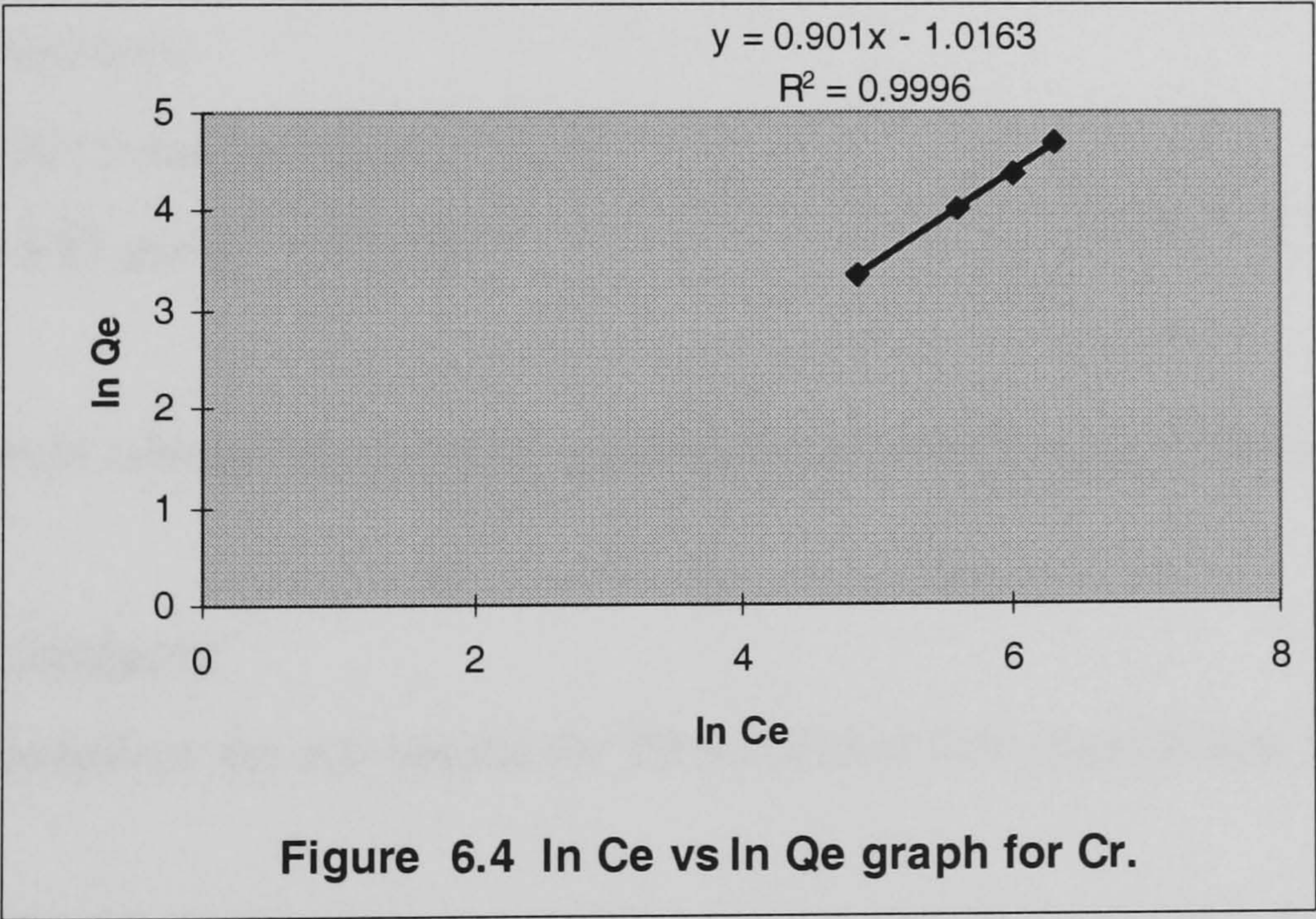
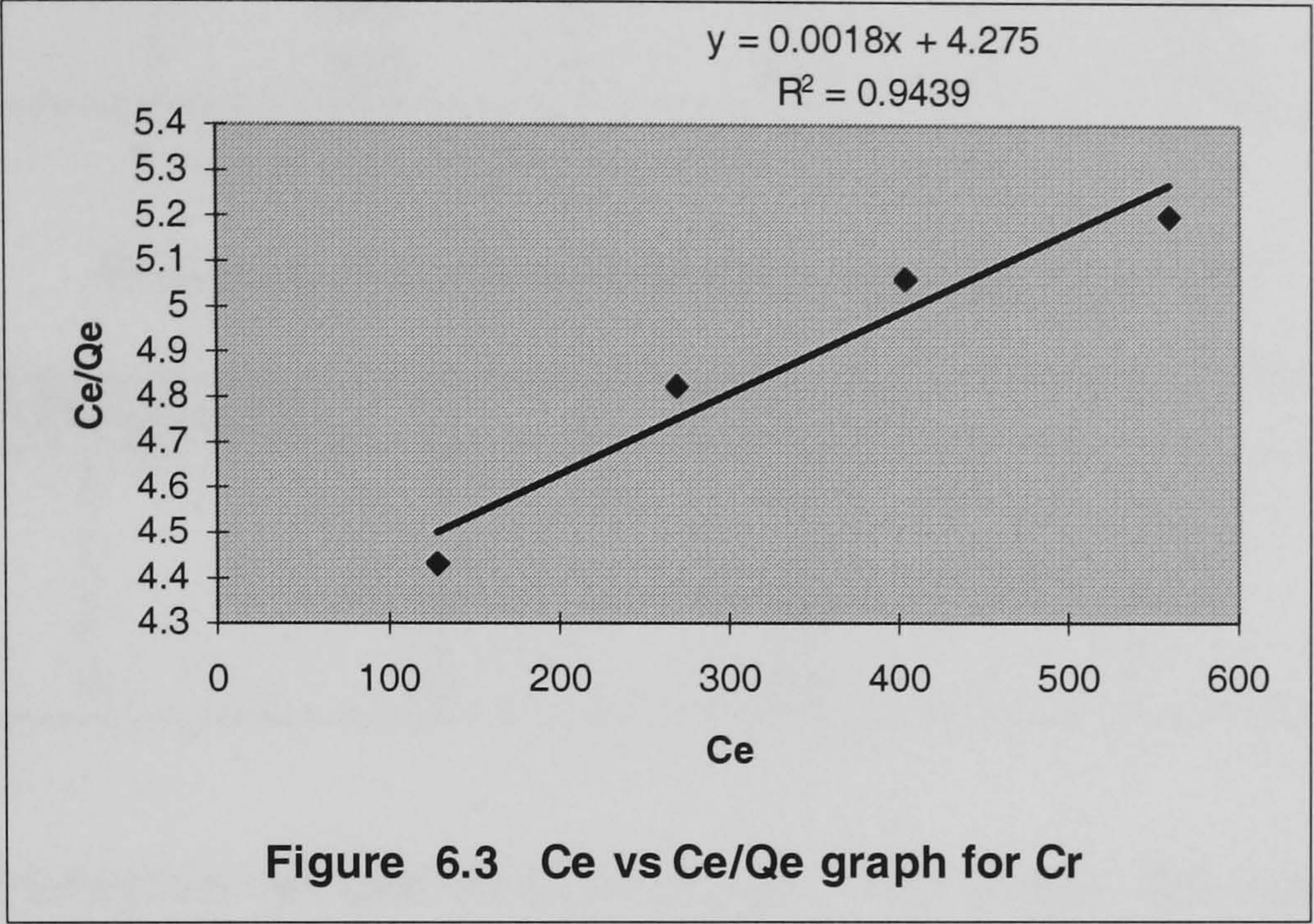




Table 6.7: Batch adsorption test results for Pb

No of Observations	Influent (µg/l)	Effluent (µg/l)	Amount Adsorbed (µg)	% Adsorbed
1	68	8	60	88.3
2	96	14	82	85.4
3	260	44	216	83.0
4	355	69	286	80.5

Table 6.8: Summary of the batch adsorption test results for Pb

No of Observations	C <sub>e</sub> (µg/l)	C <sub>e</sub> /Q <sub>e</sub>
1	68	4.54
2	86	4.70
3	260	4.80
4	355	4.96

Figure 6.5 describes the plot of C<sub>e</sub> vs C<sub>e</sub>/Q<sub>e</sub>. The straight line equation with regression coefficient close to one confirms the adsorption of Pb onto the sand surface.

From the equation:

Slope = 0.0012 and Intercept = +4.5.

Hence X = 833 and K = 0.0003.

The maximum adsorption capacity of sand for Pb is 833 µg/g of sand.

Freundlich Isotherm

Table 6.9 describes the test results for Pb converted into logarithmic values.

No of Observations	C <sub>e</sub> (µg/l)	Q <sub>e</sub> (µg/g of sand)	ln C <sub>e</sub>	ln Q <sub>e</sub>
1	68	15.0	4.22	2.71
2	96	20.5	4.56	3.02
3	260	54.0	5.56	3.99
4	355	71.5	5.87	4.27



Figure 6.6 describes the plot of  $\ln C_e$  vs  $\ln Q_e$ . The linear variation indicates the adsorption of Pb onto sand.

From the equation:

Slope = 0.95 and Intercept = -1.31.

The values of  $n$  and  $K_f$  are obtained as 1.06 and 0.27 respectively. The value of  $n$  greater than one indicates adsorption of Pb onto sand.

### 6.4.4 Batch Adsorption Test Results for Cd

#### Langmuir Isotherm

Table 8.10 describes the batch adsorption test results. The summary of the results is described in Table 6.11.

Table 6.10: Batch adsorption test results for Cd

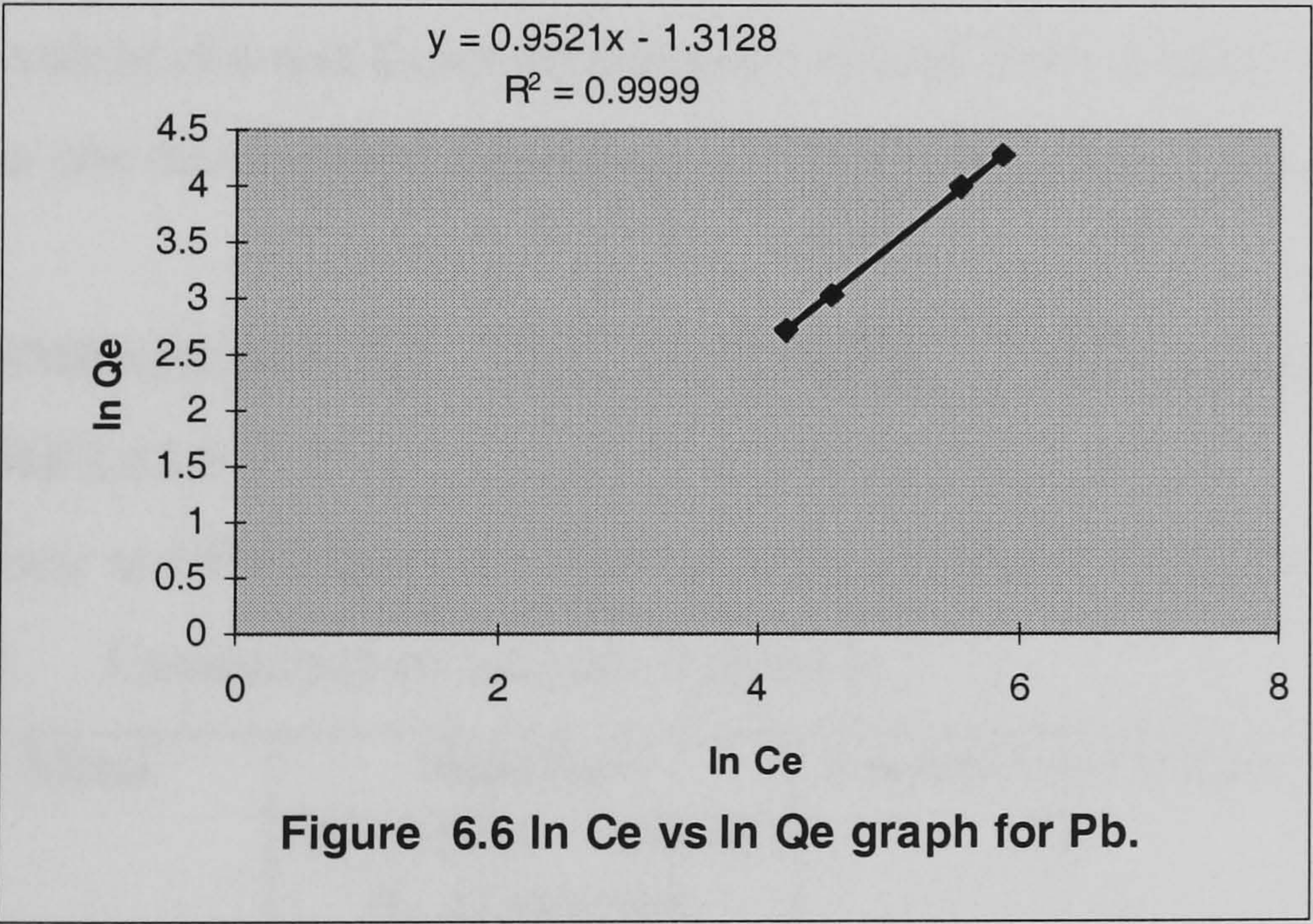
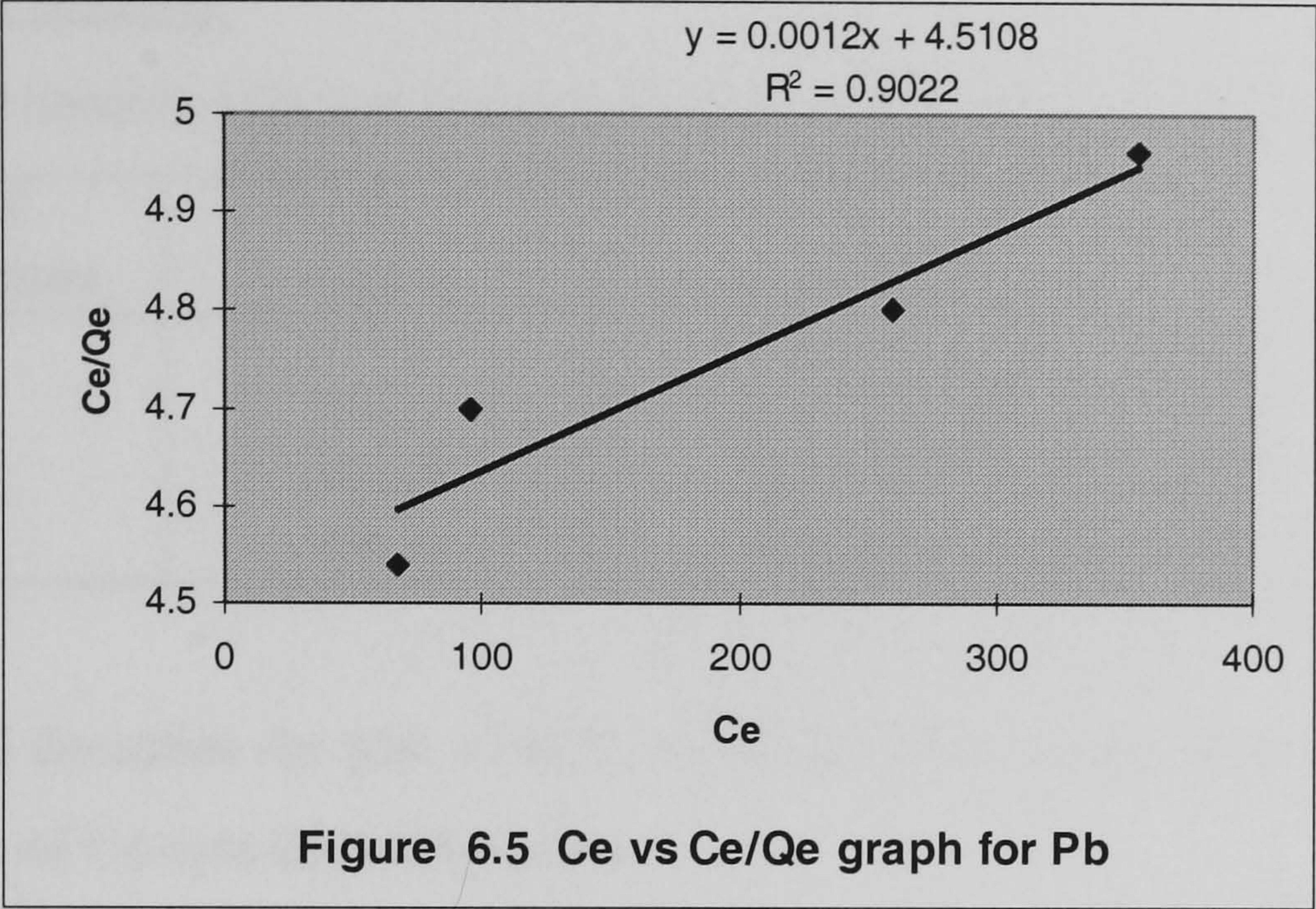
No of Observations	Influent (µg/l)	Effluent (µg/l)	Amount Adsorbed (µg)	% Adsorbed
1	114.8	58.6	57.2	49.4
2	256.3	139.4	116.9	45.5
3	412.9	251.3	161.6	39.1
4	543.6	346.9	196.7	36.2

Table 6.11: Summary of the batch adsorption test results for Cd

No of Observations	$C_e$ (µg/l)	$C_e/Q_e$
1	115.8	8.1
2	256.3	8.8
3	412.9	10.2
4	543.6	11.1

Figure 6.7 demonstrates the linear variation of the  $C_e$  vs  $C_e/Q_e$  with regression coefficient close to one which confirms the adsorption of Cd onto the sand surface.







From the equation:

Slope = 0.0072 and Intercept = +7.14.

Hence the values of  $X_m$  and K are obtained as 139 and 0.0011 respectively.

The maximum adsorption capacity of sand for Cd is 139  $\mu\text{g/g}$  of sand.

Freundlich Isotherm

Table 6.12 describes the test results for Cd converted into logarithmic values.

No of Observations	$C_e$ ( $\mu\text{g/l}$ )	$Q_e$ ( $\mu\text{g/g}$ of sand)	$\ln C$	$\ln Q_e$
1	115.8	14.3	4.75	2.66
2	256.3	29.3	5.55	3.38
3	412.9	40.4	6.02	3.70
4	543.6	49.2	6.30	3.90

Figure 6.8 describes the plot of  $\ln C_e$  vs  $\ln Q_e$ . The straight line variation indicates the adsorption of Cd onto the sand surface.

Slope = 0.8 and Intercept = -1.08.

Hence the values of n and  $K_f$  are obtained as 1.25 and 0.34 respectively. The value of n greater than one demonstrates adsorption of Cd onto the sand surface.

**6.5 COMPARISON OF THE ISOTHERM CONSTANTS FOR DIFFERENT HEAVY METALS**

The Langmuir and Freundlich constants are summarised in table 6.13

Table 6.13: Comparison of Isotherm Constants

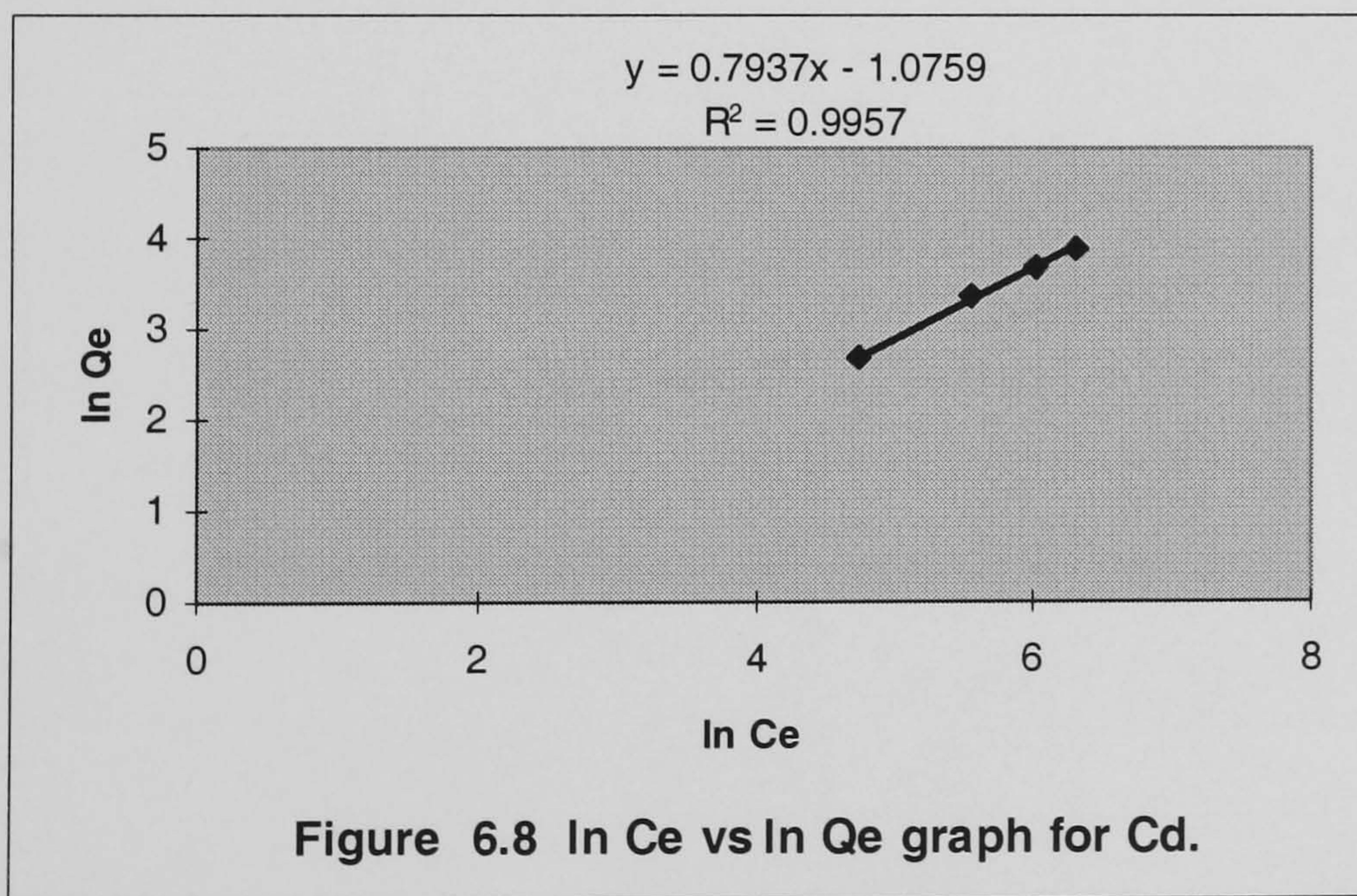
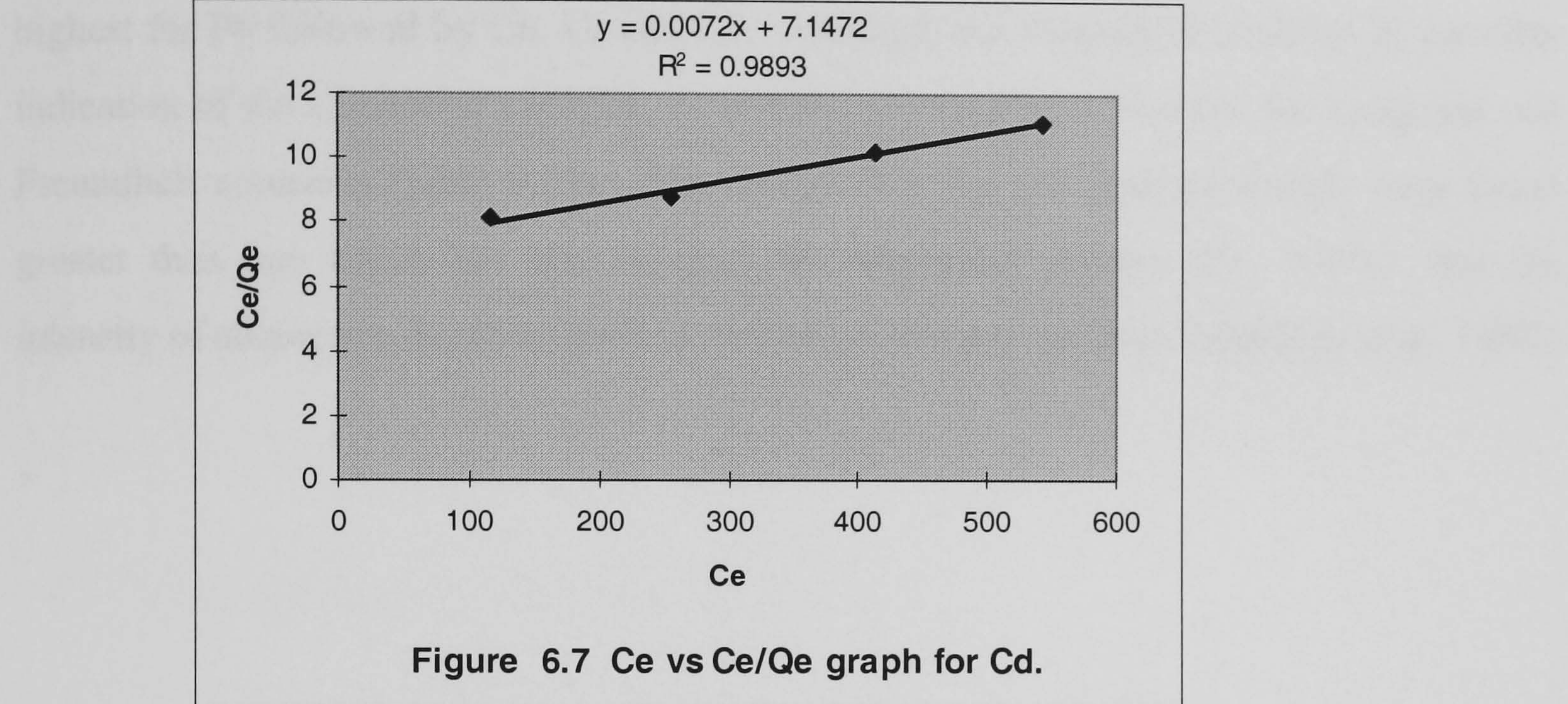
Heavy Metal	Maximum Adsorption Capacity $X_m$ (Langmuir Constant) ( $\mu\text{g/g}$ of sand)	Freundlich Constant $K_f$	Freundlich exponent n
Cu	719	1.52	1.50
Cr	556	0.36	1.10
Pb	833	0.27	1.06
Cd	139	0.34	1.25



## 6.6 COMMENTS

\* Adsorption of Cu, Cr, Pb and Zn has been studied by using the Freundlich adsorption isotherm. Hence the Freundlich adsorption isotherm equation was used to study the adsorption of Cd. The results are confirmed.

\* According to Langmuir adsorption isotherm equation, the plot of  $C_e/Q_e$  vs  $C_e$  is a straight line.





## 6.6 COMMENTS

- Adsorption of Cu, Cr, Pb and Cd has satisfied the Langmuir and Freundlich isotherms. Hence the hypothesis of the adsorption of heavy metals onto sand surface in SSFs has been confirmed.

- According to Langmuir adsorption isotherms, the adsorption capacity of sand is the highest for Pb followed by Cu, Cr and Cd. Although the Freundlich constant  $K_f$  provides indication of the adsorption capacity, no correlation was found between the Langmuir and Freundlich constants (table 6.13). The values of  $n$  for the selected metals were found greater than one which has also satisfied the adsorption criteria (Ho, 1995). But the intensity of adsorption is not so good as the values of  $n$  are less than 2 (McKey *et al*, 1980).



# CHAPTER 7

## SETTLEMENT TEST RESULTS

### 7.1 INTRODUCTION

Tests were carried out over a two week period to determine whether settlement is a mechanism of heavy metal removal by SSFs. One litre of each of the raw feed influent to the test filters from the four tanks containing the four different heavy metals (Cu, Cr, Pb and Cd) were taken and kept unstirred. The monitoring of metal concentration in the supernatant and pH was carried out for the whole two week period. Monitoring of metal concentration was also carried out at different pHs to identify the variation in settlement pattern of the different metals. The pH of the batch sample was varied from 3.5 to 9.

### 7.2 EXPERIMENTAL DATA AND ANALYSIS

Tests were carried out in triplicate. The test data presented in this chapter are the average of the three sets of tests.

#### 7.2.1 Monitoring of Metal Concentration in the Influent

The metal concentration and pH of each sample were tested on different dates and the results are shown in Tables 7.1 and 7.2 respectively.

Table 7.1: Variation of metal concentration of influent with time (Figures in the parenthesis indicates number of days)

Date/Days	Concentration of Metals			
	Copper (Cu) (mg/l)	Chromium (Cr) (µg/l)	Lead (Pb) (µg/l)	Cadmium (Cd) (µg/l)
28.3.96(1)	7.46	109.50	37.30	75.12
29.3.96(2)	4.46	91.43	36.80	73.00
31.3.96(4)	3.30	69.40	34.92	74.20
01.4.96(5)	3.11	60.61	36.81	73.10
03.4.96(7)	2.51	41.92	35.83	73.13
05.4.96(9)	2.35	33.42	38.00	72.20
09.4.96(13)	1.80	17.10	37.70	73.10



Table 7.2: Variation of pH with time (Figures in the parenthesis indicates the number of days).

Date/Days	pH			
	Cu	Cr	Pb	Cd
28.3.96(1)	7.8	7.7	7.5	7.6
29.3.96(2)	7.7	7.5	7.4	7.5
31.3.96(4)	7.4	7.4	7.4	7.5
01.4.96(5)	7.4	7.4	7.3	7.4
03.4.96(7)	7.3	7.3	7.3	7.4
05.4.96(9)	7.3	7.3	7.3	7.4
09.4.96(13)	7.3	7.3	7.3	7.4

The percentage drops in heavy metal concentration after one day, two days and thirteen days are shown in Table 7.3.

Table 7.3: Percentage reduction in metal concentration with time (Compared to initial concentration)

Metal	Percentage reduction after		
	1 day	2 days	13 days
Cu	40.2	55.8	75.8
Cr	16.5	36.6	83.8
Pb	1.3	6.4	0.0
Cd	2.6	1.3	2.6

7.2.2 Monitoring of Metal Concentration at Different pHs

Tables 7.4, 7.5, 7.6 and 7.7 show the variation of concentration of Cu, Cr, Pb and Cd respectively at different pHs with time.

Table 7.4: Variation of Cu concentration at different pHs with time (Figures in the parenthesis indicates the number of days)

Date/Days	Concentration of Cu in mg/l at the pH of			
	9	7.5	5.5	3.5
24.4.96(1)	9.6	9.3	11.0	11
26.4.96(3)	4.5	5.54	10.9	11
30.4.96(7)	2.2	3.34	10.5	11



Table 7.5: Variation of Cr concentration at different pHs with time (Figures in the parenthesis indicates the number of days)

Date/Days	Concentration of Cr in µg/l at the pH of			
	9	7.5	5.5	3.5
24.4.96(1)	230	220	236	234
26.4.96(3)	92	125	220	230
30.4.96(7)	18	52	215	220

Table 7.6: Variation of Pb concentration at different pHs with time (Figures in the parenthesis indicates the number of days)

Date/Days	Concentration of Pb in µg/l at the pH of			
	9	7.5	5.5	3.5
28.4.96(1)	56	54	53	55
01.5.96(4)	48	54	54	55
04.5.96(7)	42	52	53	54

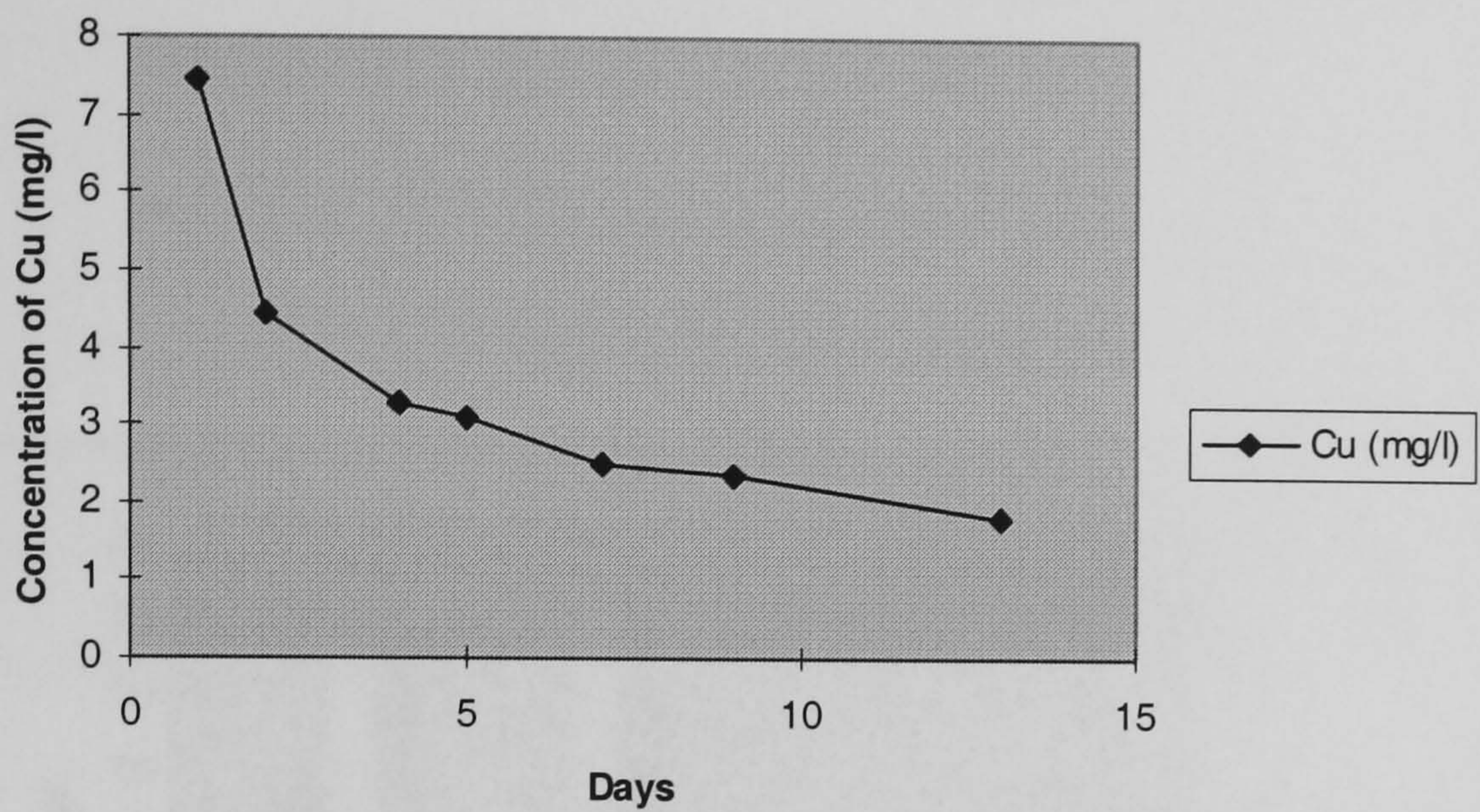
Table 7.7: Variation of Cd concentration at different pHs with time (figures in the parenthesis indicates the number of days)

Date/Days	Concentration of Cd in µg/l at the pH of			
	9	7.5	5.5	3.5
28.4.96(1)	110	110	108	110
01.5.96(4)	100	112	110	112
04.5.96(7)	92	112	110	110

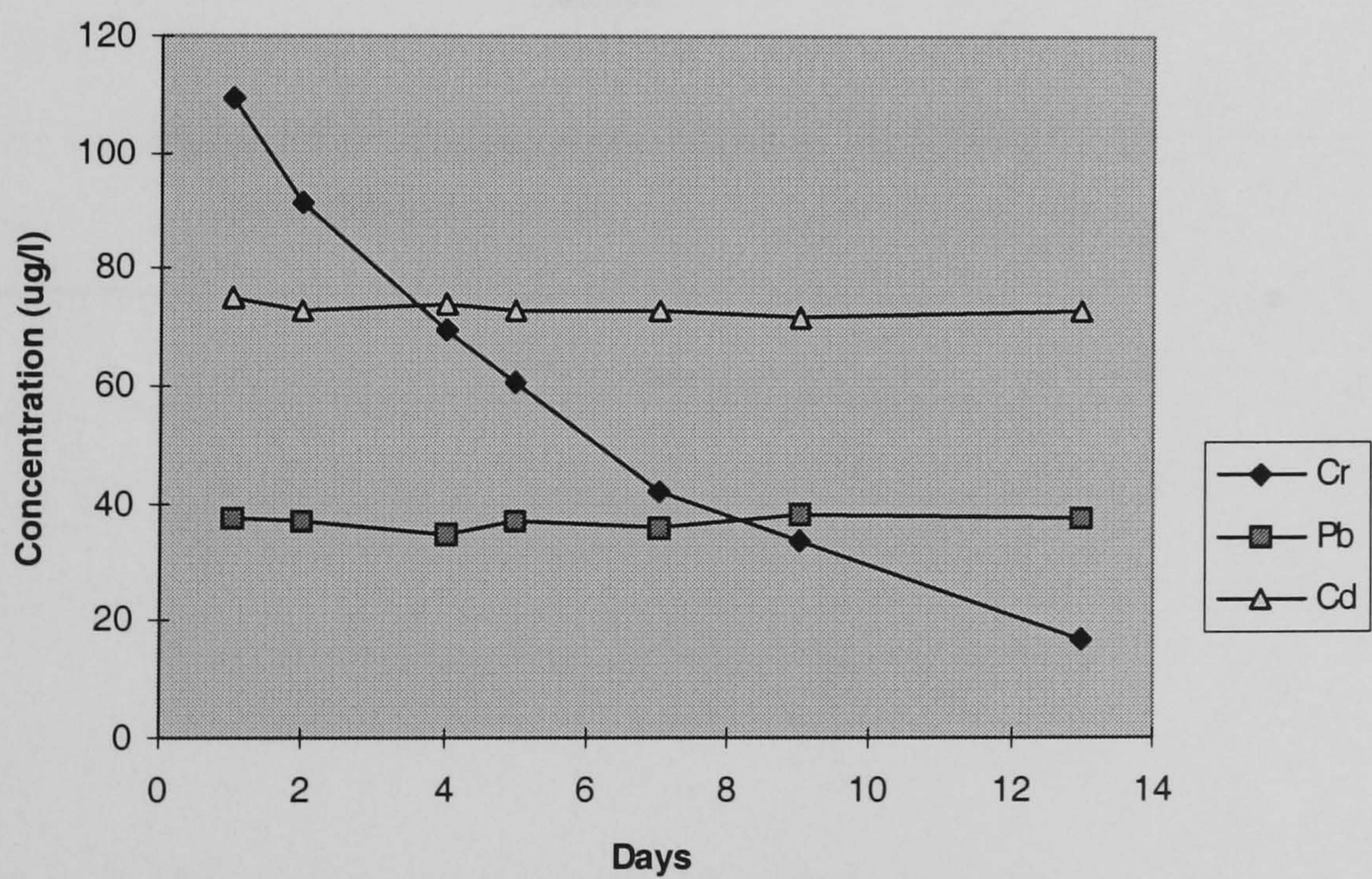
7.3 DISCUSSION

Table 7.1 shows the variation of Cu, Cr, Pb and Cd concentration respectively with time (over a two week period). Figure 7.1 shows the variation of Cu concentration with time. Figure 7.2 shows the variation of concentration of Cr, Pb and Cd with time. Figure 7.3 demonstrates the comparison of the percentage reduction of different heavy metals over a specific period of time. The concentration of Cu dropped rapidly during the first day and then gradually with a lower rate of reduction for the rest of the test period. Figure 7.3 shows that 40.2% of Cu concentration had dropped in one day, 55.8% in two days and



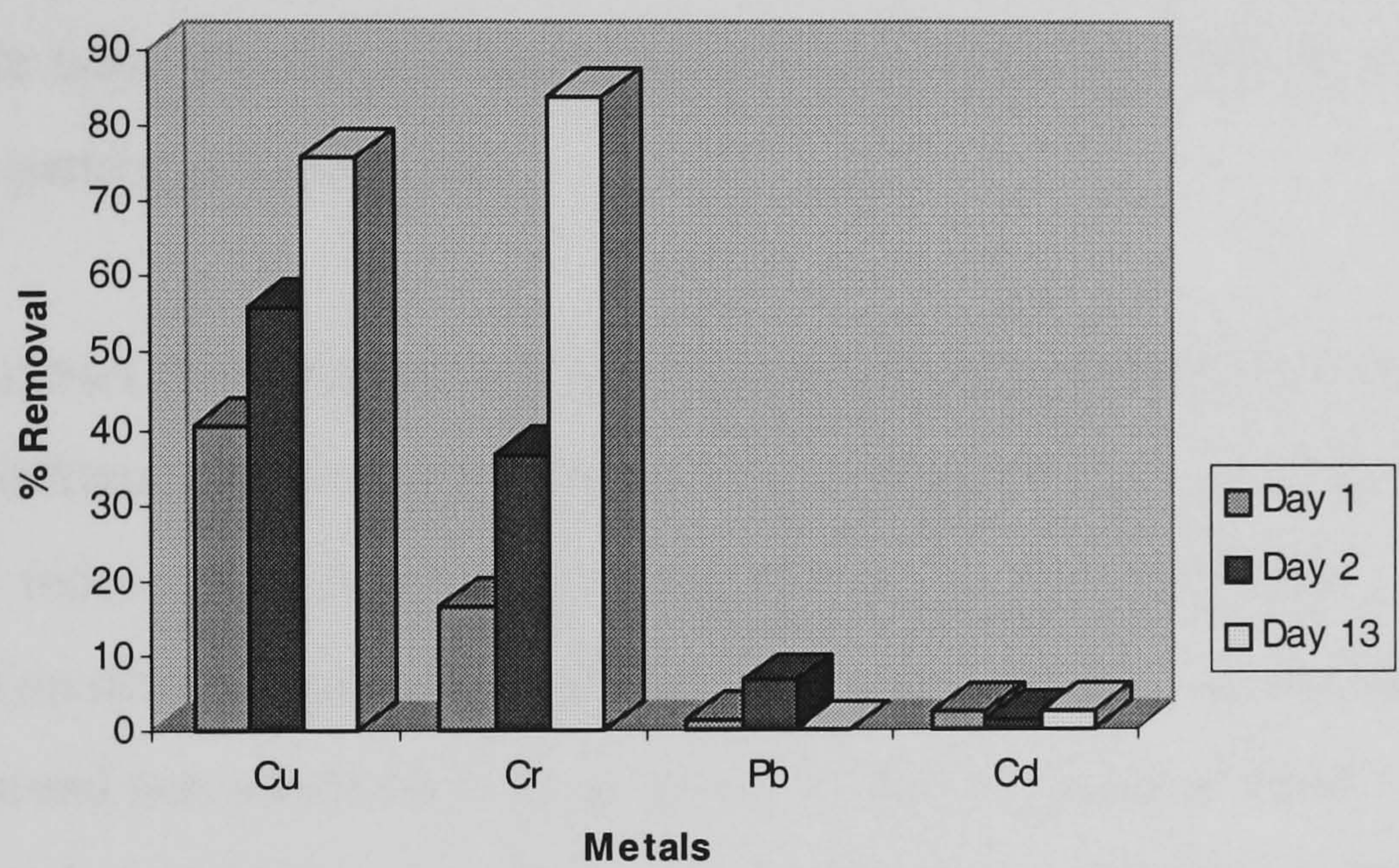


**Figure 7.1** Variation of Cu concentration with time



**Figure 7.2** Variation of the concentration of Cr, Pb and Cd with time





**Figure 7.3 Comparison of percentage drop of the concentration of Cu, Cr, Pb and Cd with time**

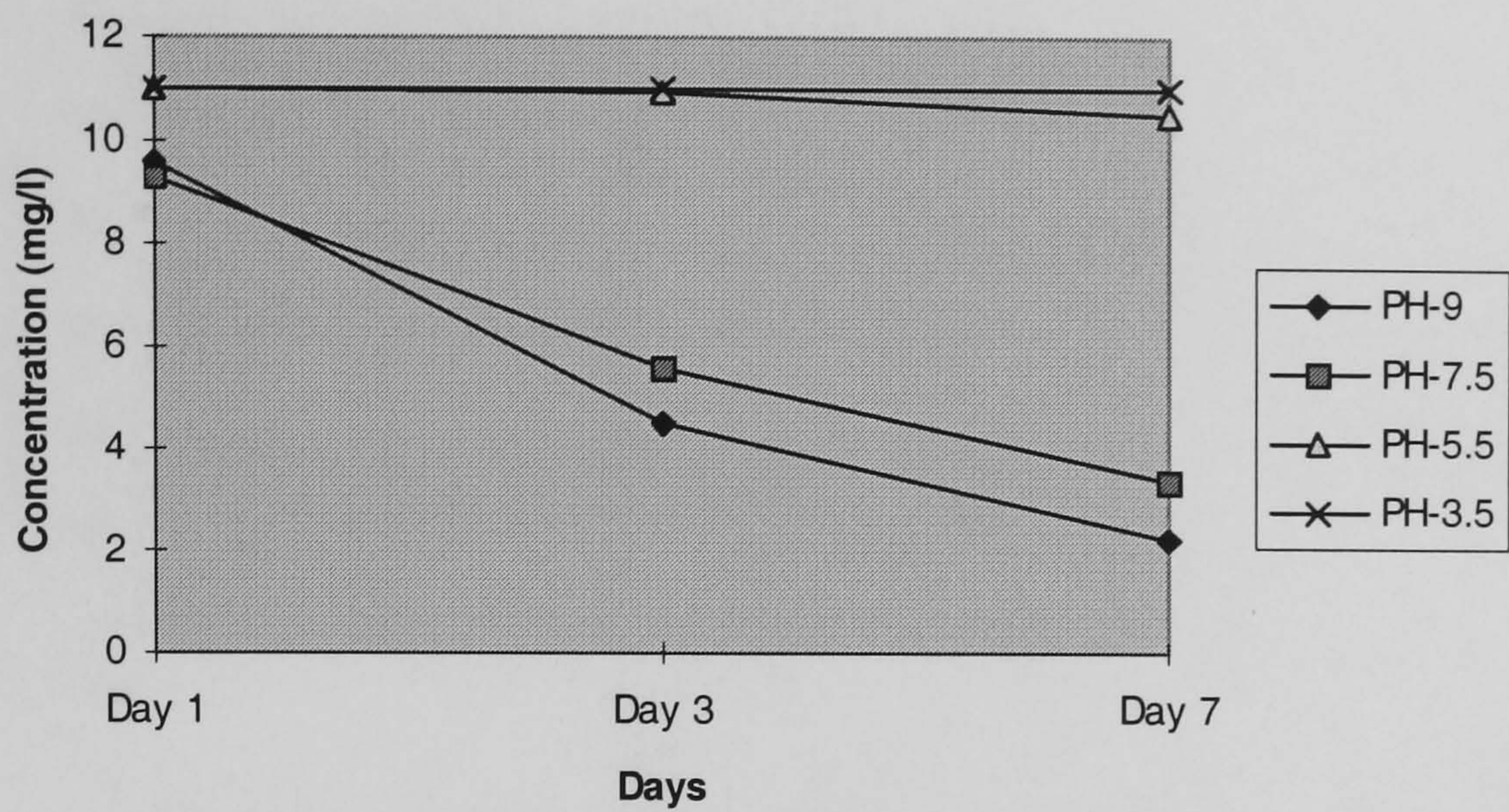


75.8% in thirteen days. The concentration of Cr dropped by 16.5% in one day, 36.6% in two days and 83.8% in thirteen days. The concentration of Pb remained virtually the same for the whole two week period. The concentration of Cd also did not change with time significantly. The settlement pattern has demonstrated similarity between Cu and Cr. This is may be because of their position in the same series of the periodic table. Both of them are transitional metal which may be the other reason of similarity in the settlement pattern. Although Cd is a transitional metal, the settlement pattern is different from the other transitional metal (Cu and Cr) because of its greater solubility. It is not clear to the author the reason of similar settlement pattern of Pb and Cd in spite of their different position in the periodic table. Further investigations were carried out to identify any difference in the settlement pattern at various pH.

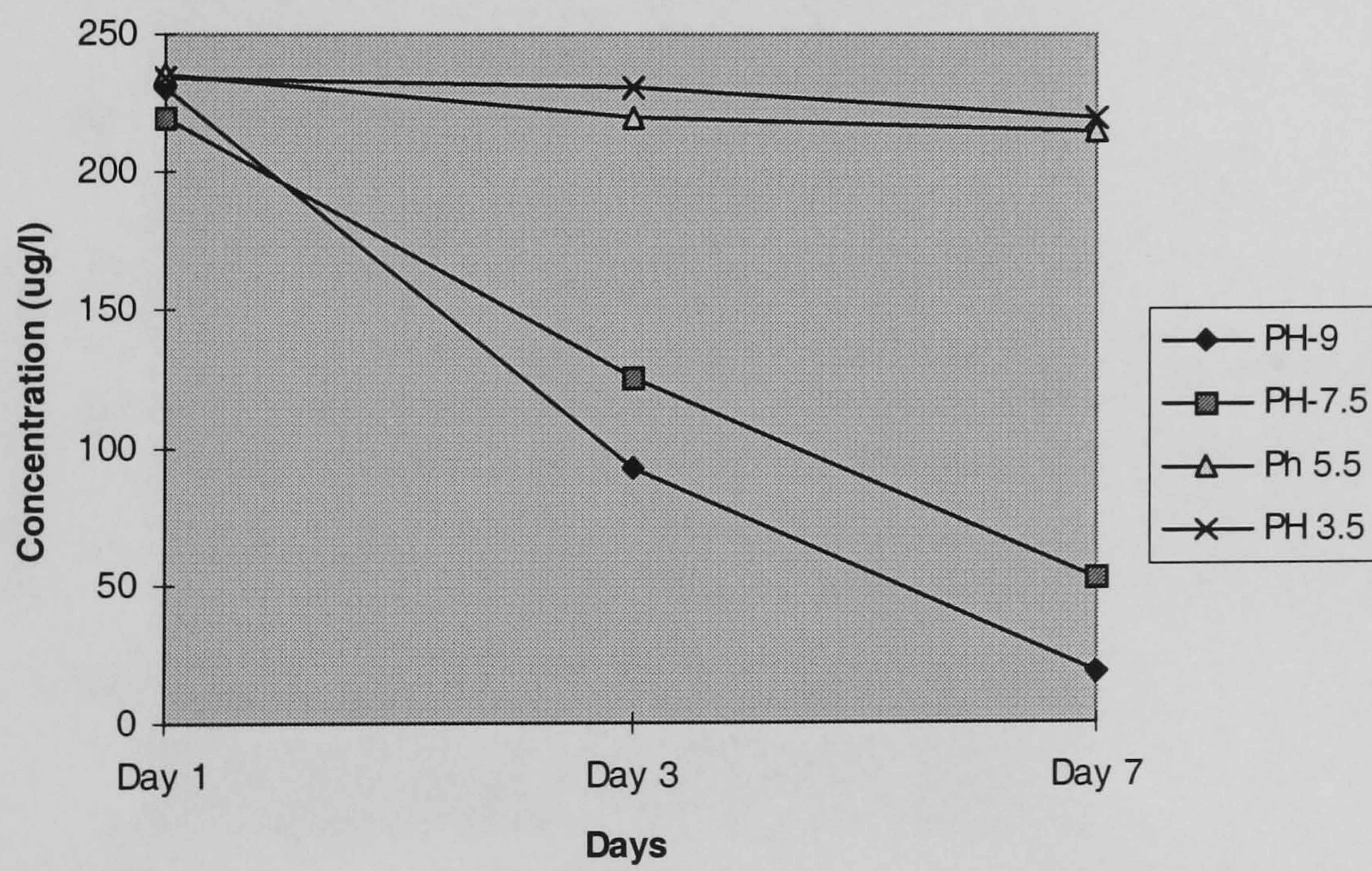
Table 7.2 shows the variation of pH of different metals containing influent with time. The pH of the influent containing Cu dropped to 7.3 from 7.8 over the two week period. Most of the pH reduction (7.8→7.4) occurred during the first four days. It dropped slightly (7.4→7.3) on the following day and then remained the same for the rest of the test period. A similar trend was observed in the case of Cr. The pH changed from 7.7 to 7.4 for the first four days and remained at 7.3 for the rest of the test period. For both Pb and Cd, the pH did not drop appreciably. It changed from 7.5 to 7.3 for the first five days and then remained at 7.3 for the rest of the test period. The reduction of pH is greater in the case of Cu and Cr than that of Pb and Cd. The reduction of concentration over time is also greater in the case of Cu and Cr than that of Pb and Cd. Hence there is a similarity between the reduction of pH and the reduction of heavy metal concentrations. The main reason for the reduction of metal concentration may be due to the entanglement of metal ions in the turbid material.

Figures 7.4, 7.5, 7.6 and 7.7 show the variation of Cu, Cr, Pb and Cd concentration respectively at different pHs with time. Figure 7.4 shows that the Cu concentration dropped more and at a higher rate at a pH of 9. The same trend was observed at a pH of 7.5 but with a slightly lower rate. A very small drop in Cu concentration was observed at



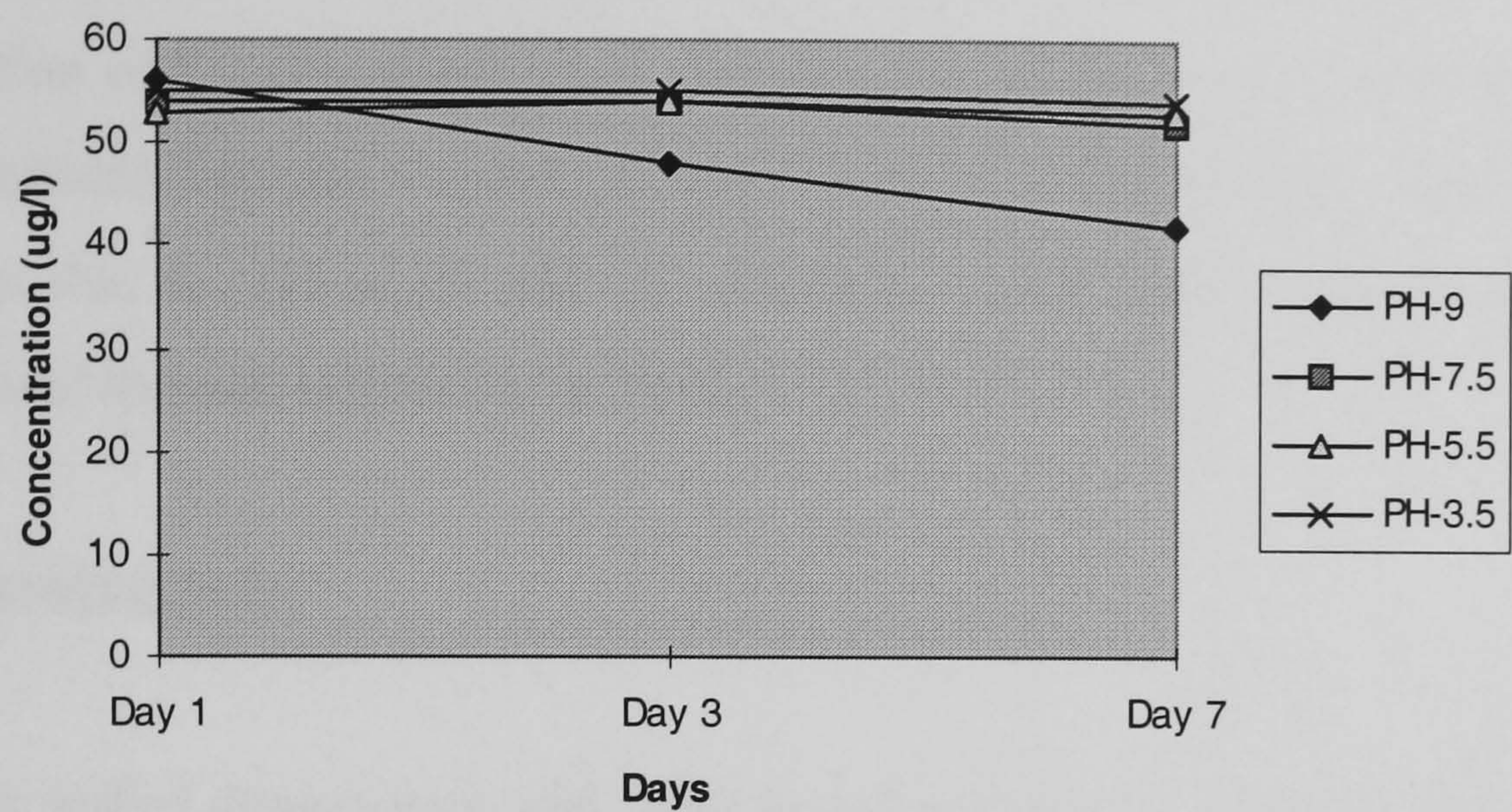


**Figure 7.4** Variation of the concentration of Cu with time at different pH

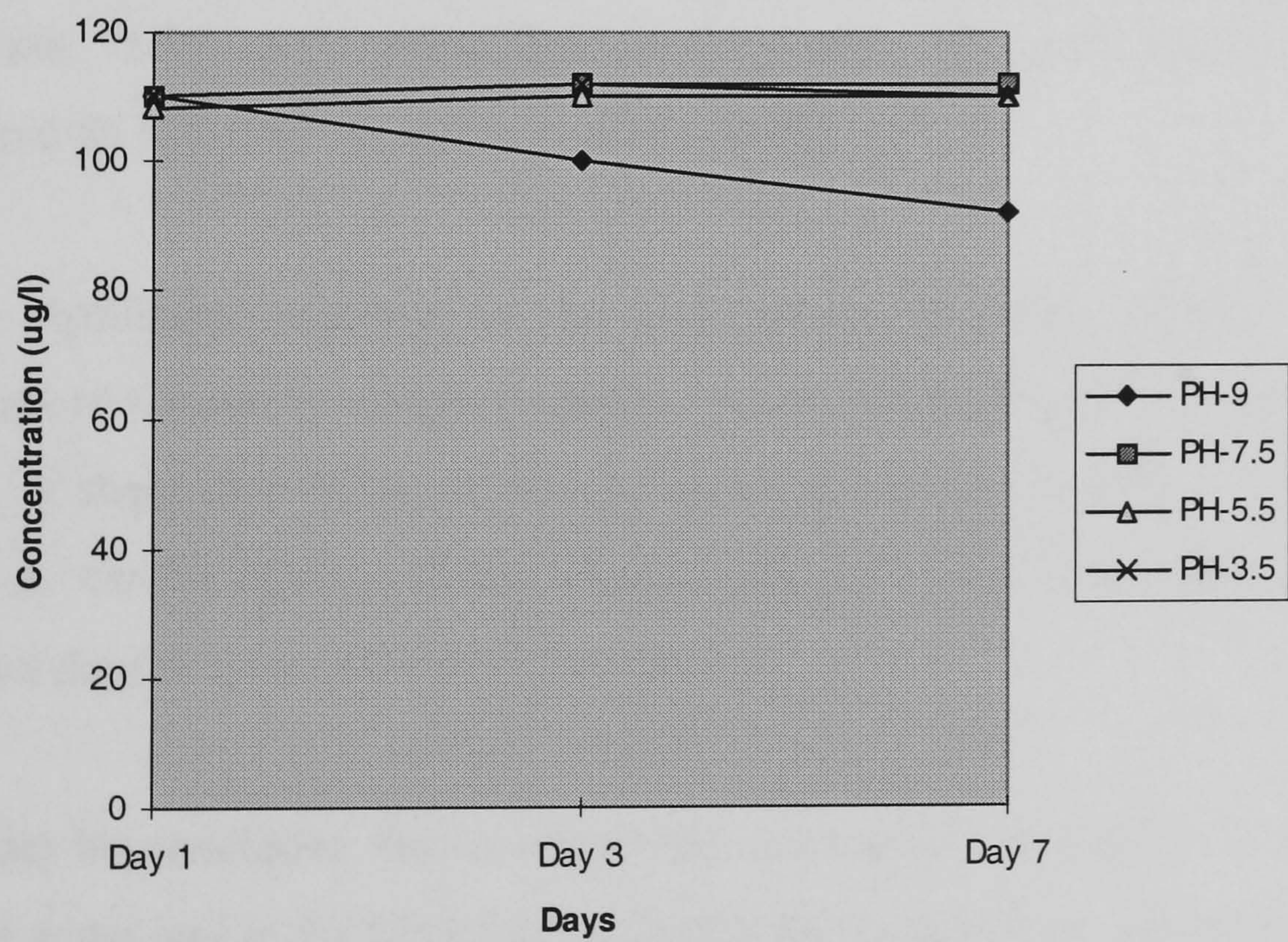


**Figure 7.5** Variation of the concentration of Cr with time at different pH





**Figure 7.6** Variation of the concentration of Pb with time at different pH



**Figure 7.7** Variation of the concentration of Cd with time at different pH



pH 5.5 and it did not drop at all at pH 3.5. A similar trend was observed in the case of Cr which is demonstrated in Figure 7.5. The only difference is that at pH 3.5, Cr dropped slightly. The concentration of Pb dropped slightly at pH 9. At other pHs (7.5, 5.5 and 3.5) the concentration of Pb remained more or less the same. A similar trend was observed to the reduction of Cd concentration at various pHs. Hence the settlement pattern has also shown similarity between Cu and Cr and Pb and Cd at various pH. It is obvious from the test results that the pH of Pb and Cd containing water needs to be increased to enhance their removal through settlement in SSFs.

#### **7.4 COMMENTS**

Cu and Cr settled down along with other turbid materials if stirring was not provided, but Pb and Cd remained in the solution even if stirring was not provided. This was may because of the relatively greater solubility of Pb and Cd than that of Cu and Cr.

The Cu concentration dropped significantly during the first day and gradually with a lower reduction rate, 75.8% of Cu precipitated in two weeks. The concentration of Cr dropped gradually and 85.5% of Cr precipitated in two weeks.

pH has a significant influence on the precipitation of heavy metals. At pH 9 the concentration of Cu and Cr dropped rapidly. It also dropped at pH 7.5 but with a slightly lower rate. A slight drop of Cu and Cr concentration occurred at pH 5.5. It did not drop at all at pH 3.5. On the other hand the concentration of Pb and Cd dropped slightly at pH 9. They did not drop at all at pHs of 7.5, 5.5 and 3.5.

Hence it can be concluded that a substantial amount of Cu and Cr is removed in the supernatant water and in the filter bed at normal pH by means of precipitation in SSF. In the case of Pb and Cd, precipitation is significant at a pH > 9. To enhance the settlement of Pb and Cd, the pH needs to be increased upto more than 9.



# **CHAPTER 8**

## **MICROBIAL UPTAKE OF HEAVY METALS IN SLOW SAND FILTERS**

### **8.1 INTRODUCTION**

This chapter is concerned with the microbiological uptake of heavy metals in Slow Sand Filtration (SSF) and the determination of active biomass by organic nitrogen analysis described herein. The heavy metal accumulation and the total biomass in the schmutzdecke scrapings were determined and compared to identify microbial uptake as a probable mechanism for heavy metal removal by SSF. The summaries of the test results regarding the metal accumulation in the schmutzdecke and the amount of biomass are analysed and discussed in this chapter. Details of the test results are described in the Annex 2. The general literature review on the microbial uptake of heavy metals is described in Chapter 2. This chapter includes a brief review of the biofilm/biomass concept and the methods for its determination.

### **8.2 BIOFILM AND ITS COMPONENTS**

Biofilms are very complex systems consisting of microbial cells and colonies embedded in a polymer matrix whose structure and composition is a function of biofilm age and environmental conditions (Lazarova and Manem, 1995). The main components of biomass are bacterial cells and exopolymers. The quantitative and qualitative estimation of the specific components is a very difficult task (Lazarova and Manem, 1995). The matrix of exopolymers has been defined as those “materials which can be removed from microorganisms without disrupting the cells and without which the microorganisms are still viable” (Gehr and Henry, 1983). The extracellular matrix of the biofilm is often termed as ‘biopolymers’ or ‘polysaccharides’. In fact, although polysaccharides predominate and represent up to 65% of extracellular materials (Horan and Eccles, 1986), other substances are also present, such as proteins, nucleic acids and lipids (Goodwin and



Foster, 1985). Another important biofilm component is protein. According to Sperandio and Puchner (1993), the dry solids of bacteria are made up of the following biopolymers: protein (50%), cell wall (15%), RNA (12%), DNA (3%) and lipids (10%). Protein is the largest fraction of these polymers with possible variations from 30% in activated sludges to 80% for a pure strain of *E.coli* and is characterised by an average value of 50% in various bacterial cultures (Lazarova and Manem, 1995). The content of protein in the extracellular matrix has also been estimated at up to 10-15% the total mass (Ford *et al*, 1991).

### 8.3 MEASUREMENT OF BIOFILM/BIOMASS

The total biofilm amount is measured either in terms of dry weight (Lazarova and Manem, 1995; Bratback and Dundas, 1984; Bratback 1985; Nouvion *et al*, 1987; Ritman *et al*, 1986) or of volatile solids (Lazarova and Manem, 1995; Oga *et al*, 1991). The main disadvantage of the use of these parameters for biofilm characterisation is that their estimation includes not only active microorganisms, but also inert mass, exopolymers and absorbed organic matter (Lazarova and Manem, 1995). Rodier (1981) described the determination of volatile solids, VS, as the standard method of estimating biomass. Marquez and Costa (1996) suggest an improvement of the method which includes filtering of the samples through 0.45 µm millipore filter paper to eliminate dissolved organic matter, then drying for 24 hours at 105°C and weighing the dried filter.

Total organic carbon (TOC), which represents approximately 50% of the cell biomass (Harris and Kell, 1985) can also be used for indirect quantification of total biofilm amount. The results are imprecise and do not represent the actual bacterial content without the adsorbed carbon (Lazarova and Manem, 1995). Biomass can be estimated by measuring its specific components such as polysaccharides, protein, lipids etc (Sperandio and Puchner, 1993). Horan and Eccles (1986), Ford *et al* (1991), and Dubois *et al* (1956) measured polysaccharides as an estimation of biomass. The main disadvantage of these methods is that they are complex to analyse and also lack reproducibility (Lazarova and Manem, 1995).



The methods of biomass measurement described above all have disadvantages and are not truly representative of the actual biomass. In this study volatile solids (VS) of the schmutzdecke scrapings were determined in the first stage of estimation of the biomass but because this overestimates the active biomass, the next step was to determine the total nitrogen content of the sample. This should have been more representative of the actual bacterial mass. As every simple protein contains an amino acid of which 16% is nitrogen (Lehinger, 1975) and biomass contains 50% protein (Lazarova and Manem, 1995), the percentage of nitrogen content of VS has been used in this study to represent the total biomass. Nitrogen content was determined by the standard Kjeldahl method (AWWA, 1986).

#### **8.4 METHODOLOGY USED IN THIS STUDY**

The heavy metals were extracted from the schmutzdecke scrapings by means of a standard acid digestion method as described by AWWA (1986). The concentration of metal was determined by the ICP (Inductively Coupled Plasma) method of spectrophotometry. The total amount of metal accumulated in the schmutzdecke scrapings was determined by the known weight of scrapings. Only 10-15 mm (depending on the depth of the schmutzdecke of the individual filter) of sand surface was scraped each time during cleaning. The scrapings were then digested by standard nitric-hydrochloric acid digestion and 100 ml of each sample was taken for analysis. The samples were diluted if required. The total metal accumulation was then calculated from the known weight of the schmutzdecke scrapings. The total amount of metal input was obtained from the metal dose and the total volume of water passed. As the amount of heavy metal input was not the same for the filters, the removal efficiency was considered for the comparison instead of the absolute value of the metal accumulation. The filters were cleaned three times and consequently the results were termed as first set, second set and third set respectively.



The estimation of biomass was carried out on a portion of the same sample taken for each of the metal determinations. As mentioned earlier, the percentage of N content of the volatile solids (VS) was considered as the active biomass. Total solids, volatile solids and nitrogen content were determined by standard methods. Nitrogen content was determined by the standard Kjeldahl method (AWWA,1986).

As the amount of sand scraped depended on the depth of the schmutzdecke, there was no control over the total amount of TS, VS and N content. Hence the proportion of N in the VS was considered as representative of active biomass instead of their absolute value.

### 8.5 EXPERIMENTAL DATA AND ANALYSIS

The filters were cleaned three times during the experimental investigation. Hence the results are termed as first set, second set and third set respectively. In every set the parameters were tested in triplicate and the results presented here are the average of three individual observations. Detail results are described in annex 2.

#### 8.5.1 First Set

The filters were first cleaned after 10 weeks of operation. An example calculation of the estimation of metal accumulation and the amount of biomass in the schmutzdecke are described here:

*Estimation of metal accumulation in the schmutzdecke:*

Total amount of sand including biomass scraped from the schmutzdecke of different filters:  
Cu: 84.2477g, Cr: 75.0230g; Pb: 84.0975g and Cd: 81.0350g.

Amount of sand taken for digestion depending on the doses of metal in the filters was:

Cu: 0.7760g, Cr: 1.37001b, Pb: 1.2071g and Cd: 1.2335g

Samples were digested and 100 ml of each sample was taken for analysis. Dilution was made as required.

Copper:	The concentration of Cu	=	154.43 mg/l
		=	15.443 mg per 100 ml



$$\begin{aligned}
&= 15.443/0.7760 \text{ mg/g of sand} \\
&= 19.88 \text{ mg/g of sand} \\
\text{So total amount of Cu accumulated} &= 19.88 \times 84.2477 = 1674.6\text{g} \\
\text{Total amount of water passed} &= 1215 \text{ litres} \\
\text{Average concentration of Cu in the influent water} &= 9.37 \text{ mg/l} \\
\text{So total mount of Cu input} &= 1215 \times 9.37 = 11384.55 \text{ mg} \\
\text{Cu accumulated in the schmutzdecke as a \% of the total Cu passing} &= 1674.6/11384.55 \times 100\% = 14.7\%
\end{aligned}$$

Percentage accumulation of Cr, Pb and Cd were calculated in a similar way (Annex 2).

*Estimation of Biomass:* The estimation of biomass was carried out on a portion of the same sample taken for each of the metal determinations. As mentioned earlier, the percentage of N content of the volatile solids (VS) is considered as the active biomass. Total solids, volatile solids and nitrogen content were determined by the standard methods. Detailed results are described in Annex 10. Sample calculations for Cu are shown below:

*Total Solids (TS):* A known amount of the sample was dried at 105°C and the percentage of TS was obtained as 40.55%. So total weight of TS =  $0.4055 \times 84.2474 = 34.16\text{g}$ .

*Volatile Solids (VS):* The sample was again dried at 550°C for 2 hours. The weight of the remaining solid and the volatile solids was determined. The percentage of VS was obtained as 3.32%, so the total weight of VS =  $0.0332 \times 34.16 = 1.1341$

*Total Nitrogen:* The total N content was calculated by the standard Kjehldahl method (AWWA, 1986). The N content in the sand containing Cu was found as 0.441 mg/g of wet sand. So the total amount of N =  $0.441 \times 84.2747 = 37.41 \text{ mg}$ . Therefore the percentage of N of VS =  $0.03471/1.1341 \times 100\% = 3.30\%$ . So the percentage of N in VS was measured in the Cu containing filter at 3.30%. Similarly the equivalent biomass in Cr, Pb and Cd containing sand scrapings was calculated. The amount and percentage of metal accumulation is shown in Table 8.1.



Table 8.1: Percentage accumulation of different metals in the schmutzdecke scrapings for the first set

Filter/ Metal	Amount of scraped sand including biomass (g)	Total amount of metal applied (mg)	Metal accumulation mg/g of sand	Percentage accumulation
F <sub>1</sub> /Cu	84.25	11384.55	19.88	14.71
F <sub>2</sub> /Cr	75.02	93.94	0.18	14.60
F <sub>3</sub> /Pb	84.08	42.74	0.05	9.08
F <sub>4</sub> /Cd	81.04	90.69	0.01	1.09

The results for N content of VS (the indicator of biomass used here) are shown in Table 8.2.

Table 8.2: TS, VS and N content of schmutzdecke scrapings for different metal containing filters

Filter/ Metal	Percentage of TS	Percentage of VS	Percentage of N of VS (biomass)
F <sub>1</sub> /Cu	40.55	3.32	3.30
F <sub>2</sub> /Cr	41.85	2.12	3.16
F <sub>3</sub> /Pb	48.80	2.95	2.10
F <sub>4</sub> /Cd	51.54	2.49	1.90

The accumulation of metals in the schmutzdecke and the amount of biomass are compared in Table 8.3.

Table 8.3: Comparison between the metal accumulation and biomass in the schmutzdecke of filters for different metals

Filter/ Metal	Percentage Accumulation of Metals	Percentage of Biomass
F <sub>1</sub> /Cu	14.71	3.30
F <sub>2</sub> /Cr	14.60	3.26
F <sub>3</sub> /Pb	9.08	2.10
F <sub>4</sub> /Cd	1.09	1.90



8.5.2 Second Set

After 14 weeks the filters were cleaned again. The metal accumulation and the biomass were determined by the methods developed. The results were termed as the second set and are tabulated in Table 8.4.

Table 8.4: Percentage accumulation of different metals in the schmutzdecke scrapings for the second set

Filter/ Metal	Amount of scraped sand including biomass (g)	Total amount of metal applied (mg)	Metal accumulation mg/g of sand	Percentage accumulation
F <sub>1</sub> /Cu	125.33	22879.4	25.74	14.10
F <sub>2</sub> /Cr	80.51	288.65	0.55	15.20
F <sub>3</sub> /Pb	83.09	128.68	0.13	8.53
F <sub>4</sub> /Cd	90.74	265.23	0.04	1.30

Table 8.5: TS, VS and N content of schmutzdecke scrapings for different metal containing filters for second set

Filter/ Metal	Percentage of TS	Percentage of VS	Percentage of N of VS Biomass
F <sub>1</sub> /Cu	39.67	3.23	3.64
F <sub>2</sub> /Cr	41.21	2.00	4.12
F <sub>3</sub> /Pb	49.86	2.89	2.08
F <sub>4</sub> /Cd	53.66	2.29	1.75

8.5.3 Third Set

The filters were cleaned again after 16 weeks. The metal accumulation and biomass were calculated by the same methods as used previously. The results are shown in Tables 8.6 and 8.7.



Table 8.6: Percentage accumulation of different metals in the schmutzdecke scrapings for the third set

Filter/ Metal	Amount of scraped sand including biomass (g)	Total amount of metal applied (mg)	Metal accumulation mg/g of sand	Percentage accumulation
F <sub>1</sub> /Cu	110.31	12797.8	16.95	14.61
F <sub>2</sub> /Cr	95.26	163.8	0.27	15.70
F <sub>3</sub> /Pb	93.12	76.24	0.07	8.55
F <sub>4</sub> /Cd	88.64	149.65	0.026	1.54

Table 8.7: TS, VS and N content of schmutzdecke scrapings for different metal containing filters for third Set

Filter/ Metal	Percentage of TS	Percentage of VS	Percentage of N of VS Biomass
F <sub>1</sub> /Cu	40.21	3.43	3.66
F <sub>2</sub> /Cr	41.52	2.56	3.96
F <sub>3</sub> /Pb	48.72	2.92	2.21
F <sub>4</sub> /Cd	52.86	2.43	1.86

8.5.4 Summary of the Three Sets of Results

Table 8.8 shows the average percentage accumulation of different heavy metals and biomass content in the schmutzdecke scrapings for different filters from the three sets of data.

Table 8.8: Comparison between the average metal accumulation and biomass in the schmutzdecke of different metal containing filters

Filter/ Metal	Percentage accumulation of metals	Percentage of biomass	Percentage of VS
F <sub>1</sub> /Cu	14.47 (0.33)	3.51 (0.18)	3.33 (0.11)
F <sub>2</sub> /Cr	15.20 (0.55)	3.78 (0.46)	2.23 (0.29)
F <sub>3</sub> /Pb	8.72 (0.31)	2.13 (0.07)	2.92 (0.03)
F <sub>4</sub> /Cd	1.31 (0.23)	1.84 (0.08)	2.40 (0.11)



Regression analysis shows a positive correlation between the percentage of metal accumulation and the percentage of biomass in the schmutzdecke. The resulting equation is percentage accumulation of metals =  $(6.1657 \times \text{percentage of biomass}) - 7.4314$ . A negative intercept indicates that the removal of metal depends on a number of mechanisms and not only on the microbial uptake.

The correlation coefficient is found as 0.94 which indicates strong correlation between the metal accumulation and the biomass in the schmutzdecke.

## 8.6 DISCUSSION

This chapter is concerned with the accuracy and reliability of using percentage N content of VS as the measure of biomass and its relationship with heavy metal accumulation in the schmutzdecke of the SSF. The repeatability and uniformity of the percentage N content of VS from the three sets of data has proved it can be a reliable method of measuring biomass. It has also been observed however that some of the filters obtained higher VS but lower N content and vice versa. Hence the percentage N content of VS may be a better representation of active biomass than is VS. The results in Table 10.8 show that the higher the biomass, the more the metal accumulation in the schmutzdecke. The results show a significant correlation between biomass and the metal accumulation in the schmutzdecke and a linear equation was used to link the percentage accumulation of metals with biomass. The total percentage removal of Cu, Cr, Pb and Cd in the test SSF columns used has been found as 99.6, 97.2, 100 and 96.6% respectively at the conventional flow rate of 0.1 m/hr. These results show that only a modest portion of heavy metal removal in SSFs is through accumulation in the schmutzdecke. Hence, unlike many other pollutants, the metal removal in SSF does not occur in the schmutzdecke only. The majority of removal must therefore be occurring through the depth of the filter. The results also show that the accumulation of metal as well as biomass content is not uniform for all metals. This appears to relate to the degree of toxicity of the metal to microorganisms, as Pb and Cd are known to be more toxic than Cu and Cr. Consequently the accumulation of Cu and Cr as



well as the biomass content of filters containing those metals are more than for the filters containing Pb and Cd. Toxicity of metal affects the activity of microorganisms which consequently affects the accumulation of metal in the schmutzdecke. This observation confirms the importance of microorganisms on the accumulation of metal in the schmutzdecke.

## 8.7 COMMENTS

- Nitrogen content of the sludge or schmutzdecke has been shown to be a useful method of measuring the biomass. The distinct advantage of this approach over the conventional VS method is that it represents the active biomass only, and does not involve organic and other inert material.
- Filters having more biomass tend to accumulate more metals in the schmutzdecke of SSF. A positive relationship has been found between the two parameters.
- Only a portion of metal accumulates in the schmutzdecke. This indicates the metal accumulation/uptake in the schmutzdecke is one of the mechanisms for removing heavy metals by SSF and is not the most significant mechanism.
- The more toxic the metal, the less the amount of biomass and the metal accumulation is less in the schmutzdecke. This also indicates the importance of microbiological uptake/accumulation of metals in the schmutzdecke of SSF.



## **CHAPTER 9**

### **SPECIATION OF HEAVY METALS IN THE SLOW SAND FILTER BEDS**

#### **9.1 INTRODUCTION**

Metal speciation refers to the form or species of a metal in a given set of physical and chemical conditions and yields information such as whether the metal is complexed with an organic chelator, precipitated with an inorganic anion or remains in solution (Forstner and Wittman, 1983). Experimental investigations were carried out to identify the different species of the accumulated metals in the slow sand filter bed with a view to determine the relative importance of the various mechanisms involved in the removal of heavy metals by slow sand filtration.

#### **9.2 BRIEF THEORY OF THE CHEMISTRY OF COMPLEX FORMATION**

The basic theory of the chemistry of complex formation as summarised by Snoeyink and Jenkins (1980) is described in the following text :

Complexes (or co-ordination compounds) consist of one or more central atoms or central ions, usually metals, with a number of ions or molecules called ligands, surrounding them and attached to them. Ligands are attached to the central species by co-ordinate covalent bonds in which both of the electrons participating in the bond are derived from the ligands. Thus the central species (metal) is the electron acceptor and the ligand the electron donor. Since all metal ions have an affinity for accepting electrons they all form co-ordination compounds, with a tendency that increases as the electron accepting affinity of the metal ion increases. The complex can be non-ionic, cationic or anionic depending on the charges of the central ions and the ligands. Ligands that attach to a central metal ion at only one point are called as monodentate ligands. Ligands that attach to two or more sites are called as multidentate ligands or chelating agents. The total possible number attachments to a central ion is known as the co-ordination number.

The rates of co-ordination reactions are characterised by the terms labile (very fast reactions) and inert (very slow reactions). These terms describe the interaction of



ligands and a central ion, they do not indicate the stability of a complex. Complex stability is described by the magnitude of the equilibrium constant, known as the formation or stability constants. Large values for stability constants indicates stable complexes.

Some general statements can be made about the stability of chelates (Snoeyink and Jenkins, 1980) :

- Co-ordination compounds containing five and six rings are the most stable. EDTA and 1,10 phenanthroline complexes with five-numbered rings are more stable than some carbonate and sulphate complexes that have four rings.
- The stability of a chelate generally increases with an increase in the number of points of attachment between the chelating agent and the central metal ion.
- If a chelate that forms complexes with 2 metal ions is introduced into a solution containing equal concentrations of both metal ions, the ligand will form complexes preferentially with the metal ion that produces the complex with the larger stability constant.
- If a number of ligands are competing for a single metal ion, the complex with the largest stability constant forms preferentially. Therefore, when a ligand that forms a very stable complex with a metal ion is added to a solution in which the metal ion is already complexed with another ligand in a less stable complex, the stronger ligand will tend to decompose the existing complex and withdraw the metal ion into a complex itself. The weaker complex must be sufficiently liable for this to occur.

### **9.3 METHODOLOGY FOR SPECIATION OF METALS IN THE SAND FILTER BED**

Methods to fractionate metals into specific species can be broadly divided into those employing physical fractionate techniques (centrifugation, sedimentation, filtration) and those using chemical extraction techniques. A sequential chemical extraction technique which is used in this project is discussed in the following sections.



### 9.3.1 Sequential Chemical Extraction (Theory)

The technique used is based on that developed by Stover et al (1976). Although the method was originally developed for the speciation of metals in soil, it is now widely used for the speciation of metals in sludges. As the schumtzdecke of the SSFs is similar to sludge, and sand, in general is similar to soil, this method is considered for the speciation of heavy metals in the filter bed in this study. The method is used in the present project to segregate the metals in sand into 5 fractions, i.e. exchangeable metals, adsorbed metals, organic-bound metals, metal carbonates and sulphides.

#### 1) Exchangeable metals

*Procedure:*

KNO<sub>3</sub> is used as the initial extractant for the metals bound by exchange sites in sand. When the sand sample is saturated with K<sup>+</sup>, exchangeable metals will be displaced from exchange sites located on sand inorganic and organic compounds.

*Significance:*

This fraction represents the loosely bound metals onto sand. Hence this fraction is considered as the metal accumulation due to settlement in the filter bed.

#### 2) Adsorbed metals

*Procedure:*

KF is used to extract adsorbed metals from sand. The pH and concentration of KF permits the removal of adsorbed metals through the formation of soluble metal-fluoride complexes but minimises solubilization of organically bound metals.

*Significance:*

Due to the formation of metal fluoride complexes, the adsorbed metals are detached from sand and become soluble. Hence this fraction represents the amount of metals adsorbed onto sand surface.

#### 3) Organically-bound metals

*Procedure:*

Na<sub>4</sub>P<sub>2</sub>O<sub>7</sub> is used to remove metals chelated or complexed by the organic fraction in sand and was chosen because of the low recovery of the metal precipitates.



*Significance:*

As  $\text{Na}_4\text{P}_2\text{O}_7$  removes the already complexed metal with organic matter, this fraction represents the amount of metal adsorbed or entangled in the organic matter in the schumtzdecke as well as in the filter bed.

#### **4) Metal carbonates**

*Procedure:*

EDTA is used for dissolution of the metal carbonates. Although EDTA is commonly used for the release of elements bound by organic matter, when  $\text{Na}_4\text{P}_2\text{O}_7$  is used prior to the EDTA the metals recovered in this fraction should primarily be in the carbonate form.

*Significance:*

The carbonate fraction of the metal is predicted to evolve due to the microbiological activity in the filter bed and also due to the available  $\text{CO}_2$  in the feed water. Hence this fraction mainly represent the microbial uptake of metals.

#### **5) Metal sulphides**

*Procedure:*

$\text{HNO}_3$  is used to dissolve metal sulphides.

*Significance:*

Heavy metal has a general tendency to combine with sulphur materials to form metal sulphide (Manahan,1990). This fraction is assumed to evolve due to the sulphur containing materials in the sewage added to the tap water.

#### **6) Residual metals**

*Procedure:*

The residual sand pellet is subjected to acid digestion to recover any remaining metals.

*Significance:*

This further recovery of the metal from sand is significant to check the mass balance between the total accumulation and the sum of the various fractions.



### 9.3.2 Sequential Extraction Procedures

The detail sequential extraction procedures developed by Stover *et al* (1976) and later modified by Oake *et al* (1984) and finally summarised by Carliell and Wheatley (1997) are described below :

- 1) 0.8g of wet sand was taken in a 250 ml Erlenmeyer containing 40 ml of 1M KNO<sub>3</sub> and was shaken in flask shaker for 16 hours. The content was then centrifuged at 10800 rpm for 10 minutes. The supernatant and wash water made upto 100 ml was analysed by ICP for exchangeable metals.
- 2) The pellet from step1 was then taken in an Erlenmeyer containing 80 ml of KF (pH 6.5) and was shaken in a flask shaker for 16 hours. The content was then centrifuged at 10800 rpm for 10 minutes. The supernatant and wash water made upto 100 ml was analysed by ICP for adsorbed metals
- 3) The pellet from step 2 was then taken in 250 ml Erlenmeyer containing 64 ml of 0.1M Na<sub>4</sub>P<sub>2</sub>O<sub>7</sub> and was shaken for 16 hours in a flask shaker. The content was then centrifuged at 10800 rpm for 10 minutes. The supernatant and wash water made upto 100 ml was analysed by ICP for organically-bound metals.
- 4) The pellet from step 3 was then taken in 250 ml Erlenmeyer containing 0.1M EDTA (pH 6.5) and was shaken for 16 hours for 16 hours. The content was then centrifuged at 10800 rpm for 10 minutes. The supernatant and wash water made upto 100 ml was analysed by ICP for metal carbonates.
- 5) The pellet from step 4 was taken in 250 ml Erlenmeyer containing 1M HNO<sub>3</sub> and was shaken for 16 hours in a flask shaker. The content was centrifuged at 10800 rpm for 10 minutes. The supernatant and wash water made upto 100 ml was analysed by ICP for metal sulphides.
- 6) The pellet from step 5 was digested by 4% Aqua Regia and the metal found in this step was termed as residual metal.



In the original Stover method 1M HNO<sub>3</sub> was used to extract the sulphide metal fraction. However, subsequent researchers have reported 1M HNO<sub>3</sub> as unsatisfactory for recovery of metal sulphides, resulting in a large proportion of sulphide metal remaining in the residual fraction (Oake *et al* 1984). An increased concentration of HNO<sub>3</sub> (6M) was found to yield a greater recovery of metal in the fraction and was adopted for use in the extraction by Oake *et al* (1984), Lake *et al* (1985), Tester *et al* (1985) and Rudd *et al* (1988). This project used 1M HNO<sub>3</sub> and found good recovery of sulphide metals.

The total recovery of metal was carried out by the standard HNO<sub>3</sub>- H<sub>2</sub>SO<sub>4</sub> digestion method (AWWA, 1986).

### **9.3.3 Sampling Regime Procedure**

To identify the speciation of heavy metals in the SSF bed, certain amount of sands were collected from 10, 20, 30, 200, 400, 800 and 1200 mm of filter depth. The collected sands were mixed thoroughly to make a uniform sample. Then 1g of the sample was taken for analysis by acid digestion to measure the total concentration of heavy metals and 0.8g of the sample was taken for analysis by the Stover method for the fractional speciation. As the accumulation varied along the depth of the filter bed, the concentration of the various fractions were expressed as mg/gm of sand and then normalised as percentages.

## **9.4 RESULTS**

The detail experimental data and related calculations are described in Appendix 3. The accumulation of different heavy metals per gm of sand is summarised in Table 9.1. The various fractional species of different heavy metals are summarised in Tables 9.2, 9.3, 9.4 and 9.5. The different fractional species does not sum up to 100 % always because of losses of metals during step by step analysis or due to minor experimental errors.



Table 9.1 Accumulation of various heavy metals (mg per gm of sand) at different depths of the filter bed. (Note: Cu values are higher because of its high dose)

Filter/ Metals	Accumulation of different heavy metals per gm of sand at a depth of						
	10 mm	20 mm	30 mm	200 mm	400 mm	800 mm	1200 mm
F1/Cu	52.125	7.315	3.700	0.875	0.440	0.006	0.000
F2/Cr	0.550	0.425	0.128	0.050	0.013	0.001	0.000
F3/Pb	0.400	0.090	0.080	0.023	0.016	0.005	0.003
F4/Cd	0.080	0.018	0.015	0.010	0.008	0.005	0.004

Table 9.2 Speciation (as percentage) of Cu accumulated per gm of sand at different depths of the filter bed.

Filter Depth (mm)	Easily Exchange able	Adsorbed	Organic Bound	Carbonate	Sulphide	Residual
10	0.12	1.21	87.50	8.37	0.36	2.30
20	3.35	20.30	63.40	8.10	3.78	1.40
30	5.80	36.30	43.20	7.60	3.78	1.40
200	15.70	44.30	27.20	7.10	4.30	1.40
400	19.90	51.20	17.00	8.50	2.90	1.40
800	28.40	56.90	4.75	2.85	1.90	0.00
1200	0.00	0.00	0.00	0.00	0.00	0.00

Table 9.3 Speciation (as percentage) of Cr accumulated per gm of sand at different depths of the filter bed.

Filter Depth (mm)	Easily Exchange able	Adsorbed	Organic Bound	Carbonate	Sulphide	Residual
10	0.36	8.20	71.00	9.60	11.50	2.20
20	3.90	15.00	65.00	10.30	5.90	2.40
30	10.90	24.50	53.90	7.80	5.00	5.00
200	12.50	31.20	46.30	5.00	3.70	1.30
400	20.00	38.00	35.00	4.00	3.00	0.00
800	40.00	45.00	10.00	0.00	0.00	5.00
1200	0.00	0.00	0.00	0.00	0.00	0.00



Table 9.4 Speciation (as percentage) of Pb accumulated per gm of sand at different depths of the filter bed.

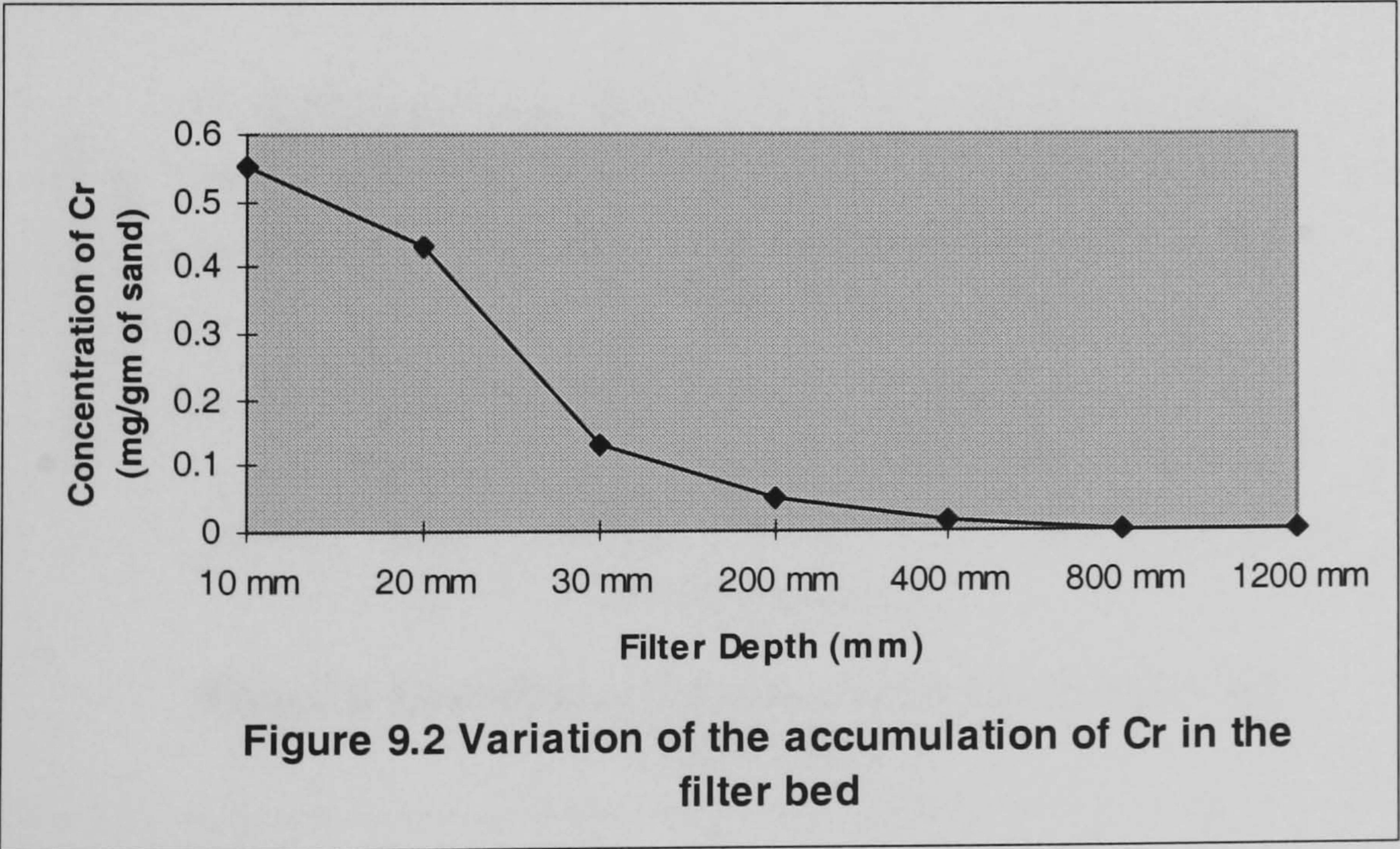
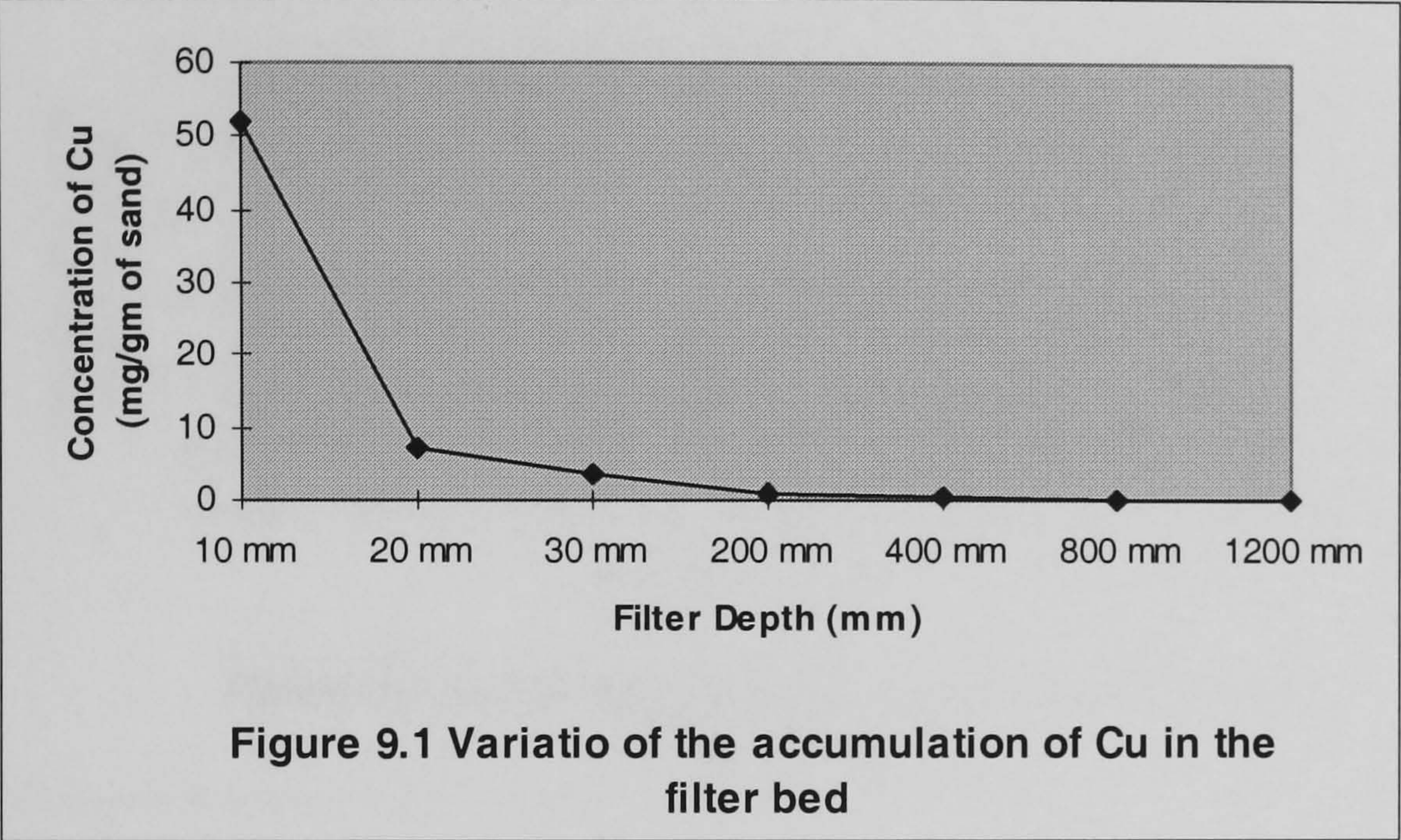
Filter Depth (mm)	Easily Exchange able	Adsorbed	Organic Bound	Carbonate	Sulphide	Residual
10	0.63	11.00	75.00	7.00	1.25	3.50
20	3.75	25.00	49.00	11.10	8.30	2.80
30	4.60	35.50	35.50	12.50	9.30	6.20
200	6.70	44.50	28.00	11.10	5.60	4.40
400	17.80	46.90	15.60	7.80	6.30	6.30
800	55.00	25.00	7.00	3.00	2.00	5.00
1200	85.00	15.00	0.00	0.00	0.00	0.00

Table 9.5 Speciation (as percentage) of Cd accumulated per gm of sand at different depths of the filter bed.

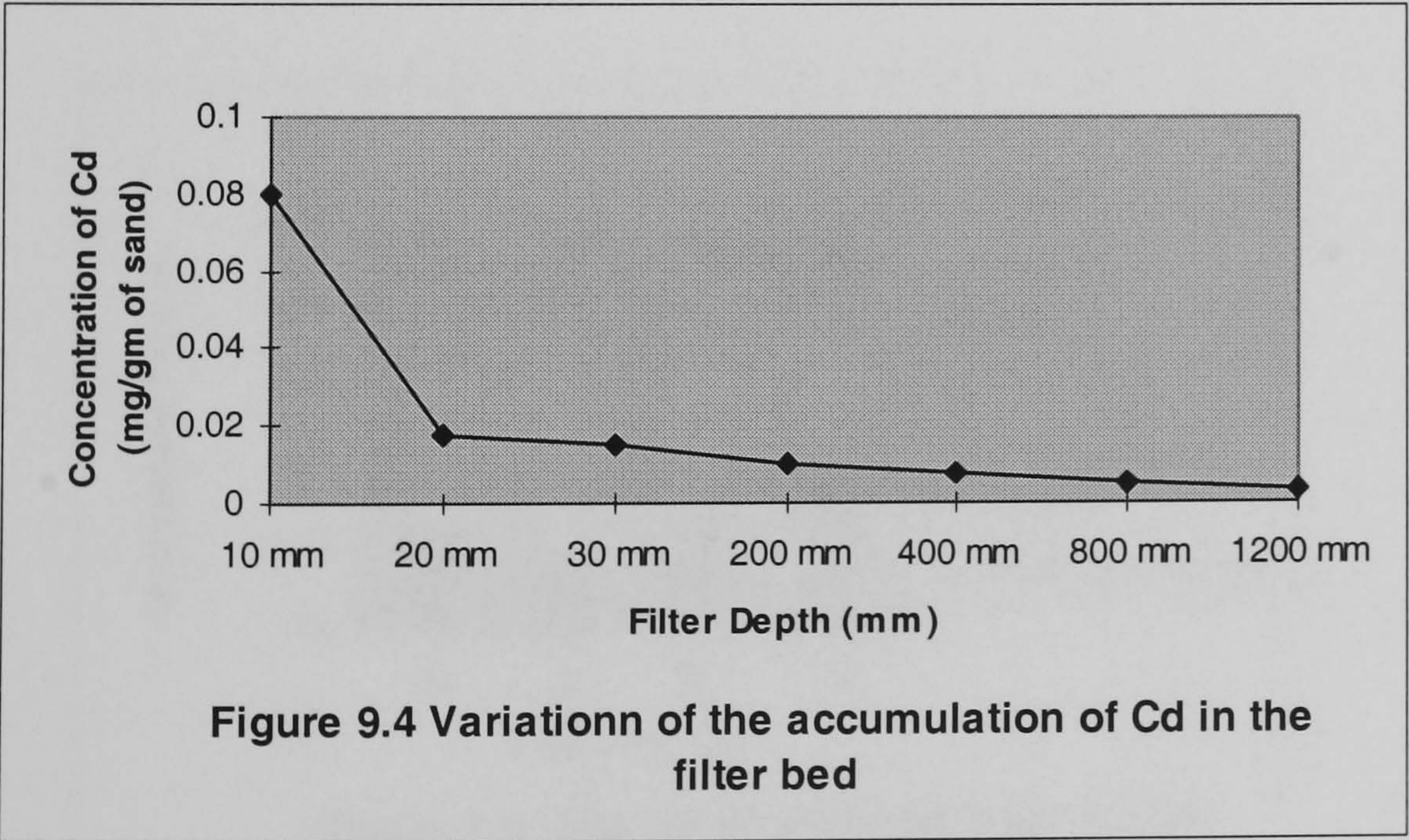
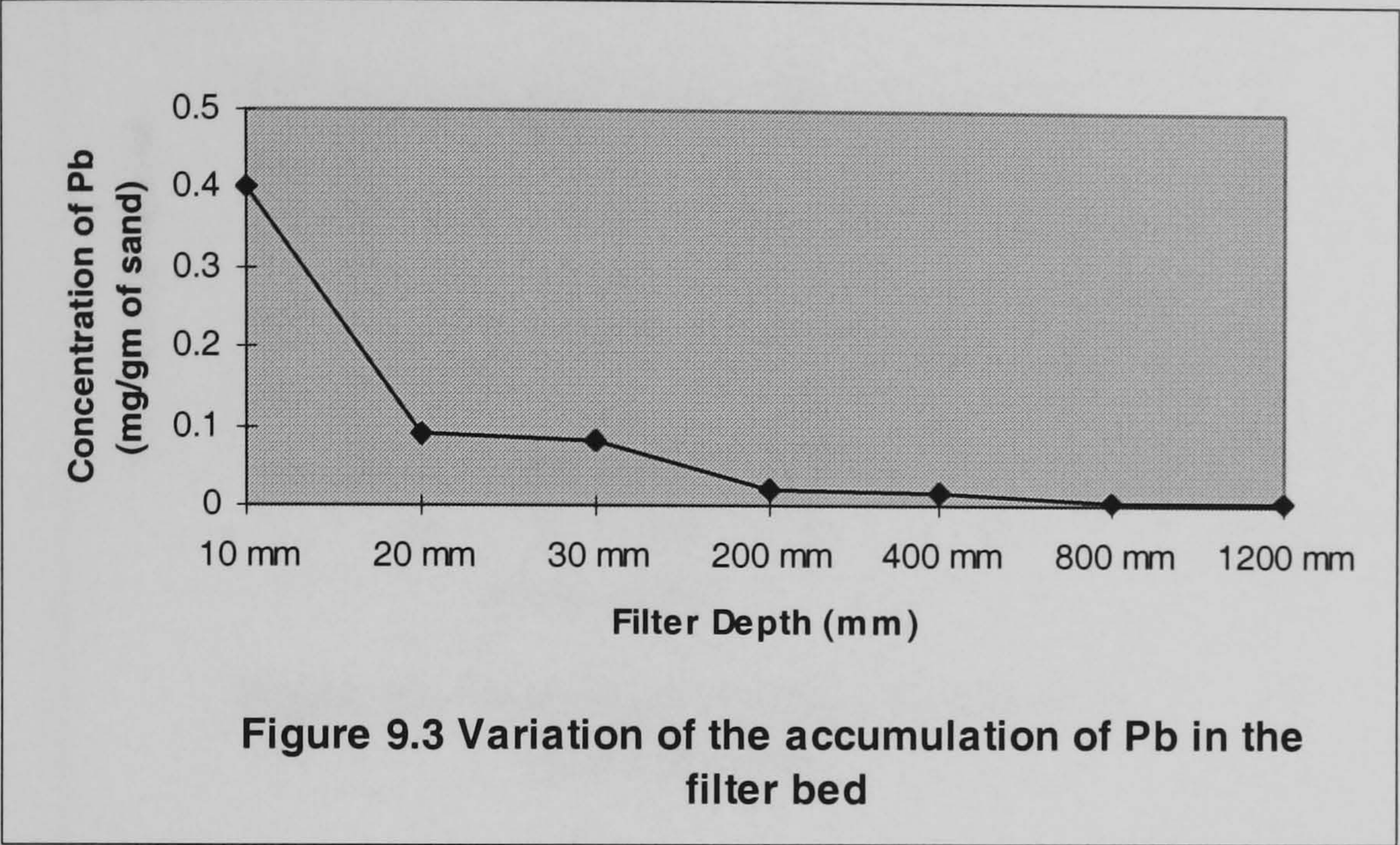
Filter Depth (mm)	Easily Exchange able	Adsorbed	Organic Bound	Carbonate	Sulphide	Residual
10	1.25	20.00	66.30	6.60	3.80	0.78
20	11.10	27.80	30.80	8.40	6.70	6.25
30	12.50	30.00	20.30	8.30	6.70	7.50
200	25.00	38.00	14.00	5.00	5.00	3.80
400	28.00	42.00	10.00	5.00	5.00	3.30
800	35.00	50.00	10.00	2.50	2.50	0.00
1200	50.00	50.00	0.00	0.00	0.00	0.00

Figures 9.1, 9.2, 9.3 and 9.4 describe the relative accumulation of Cu, Cr, Pb and Cd respectively at different depths of the filter bed. The fractional speciations of Cu, Cr, Pb and Cd at different depths are shown in figures 9.5 through to 9.11. The graphs represent the relative proportions of the various species of a particular metal because the losses during analysis are ignored.

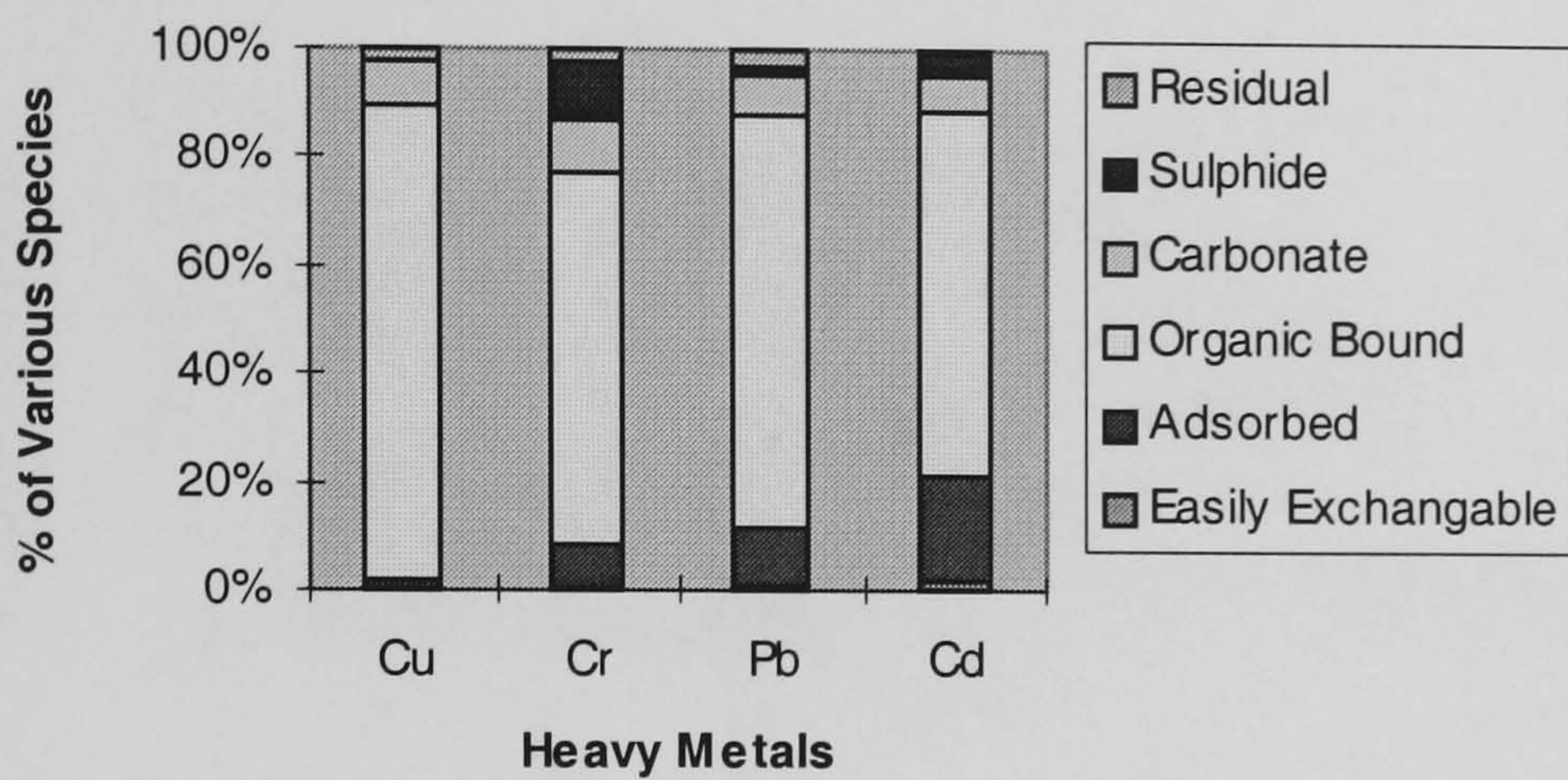




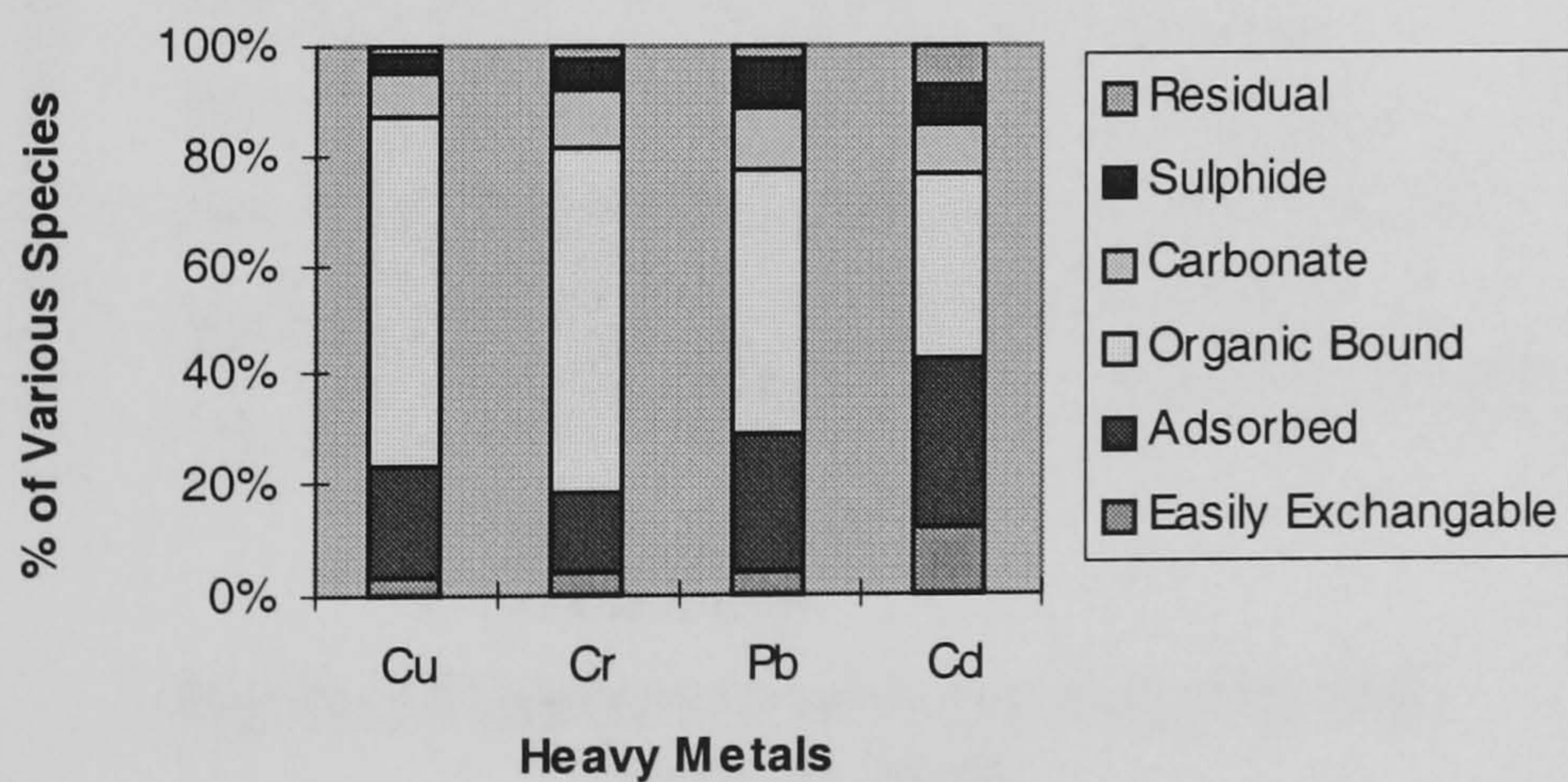






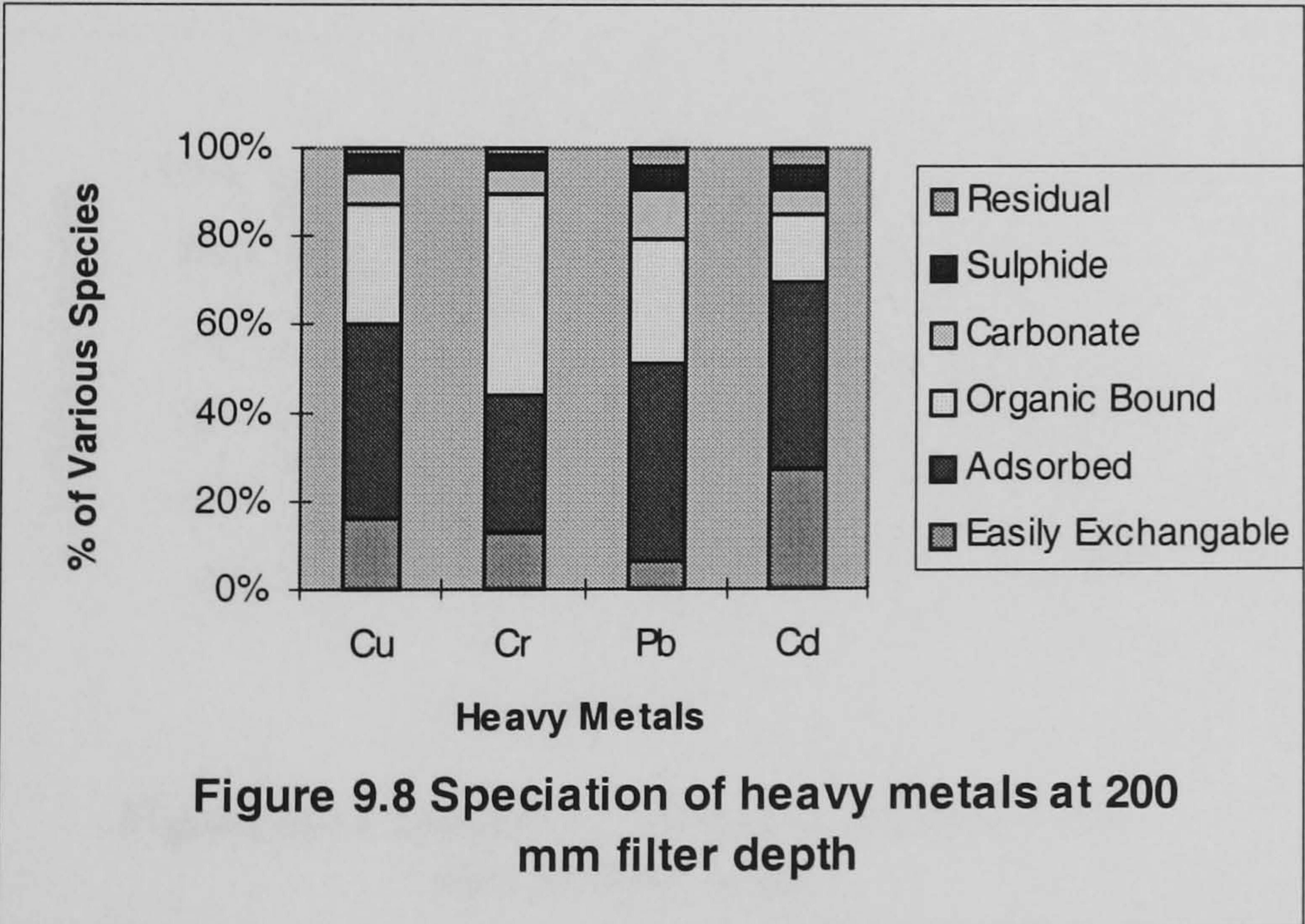
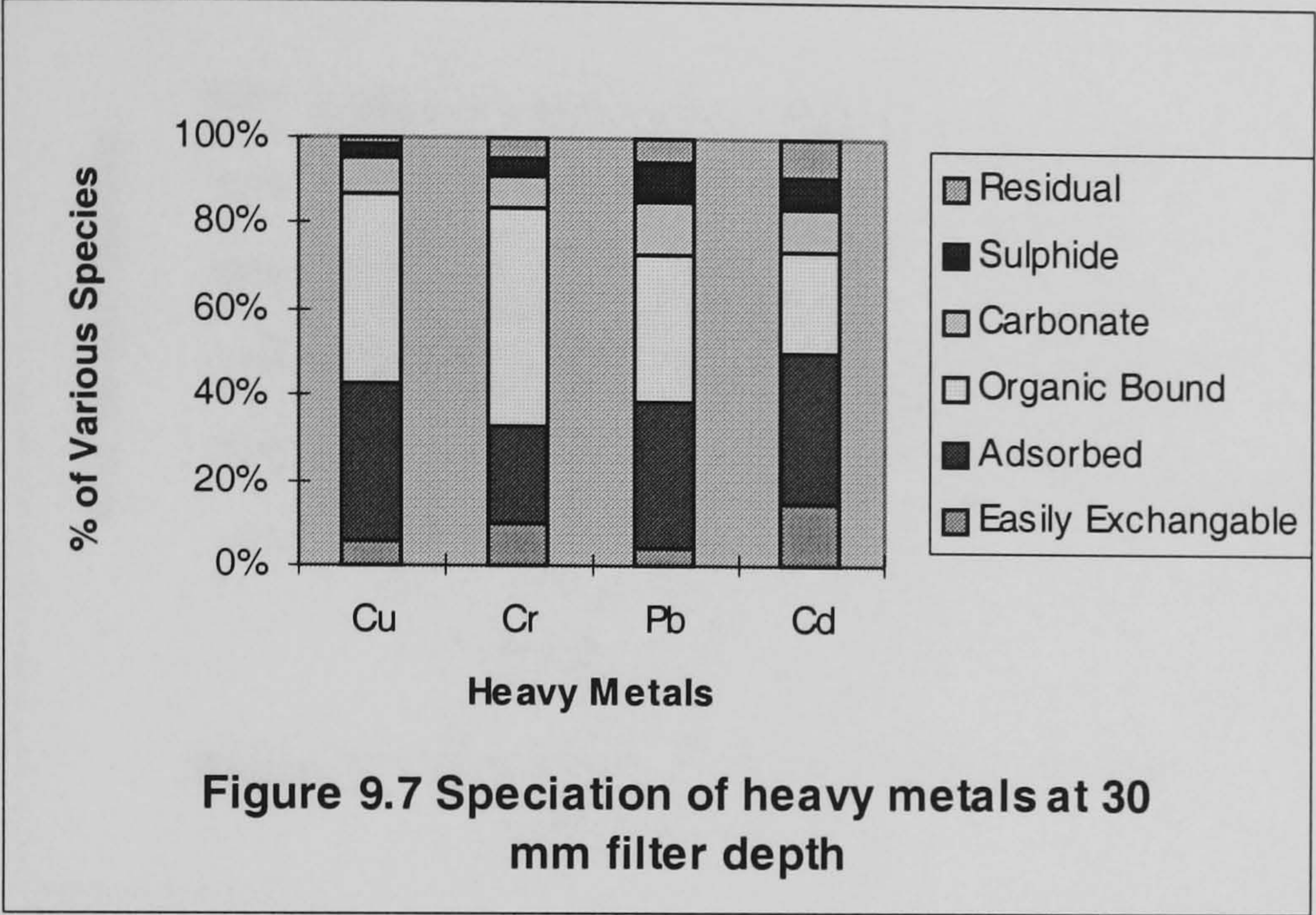


**Figure 9.5 Speciation of heavy metals at 10 mm filter depth**

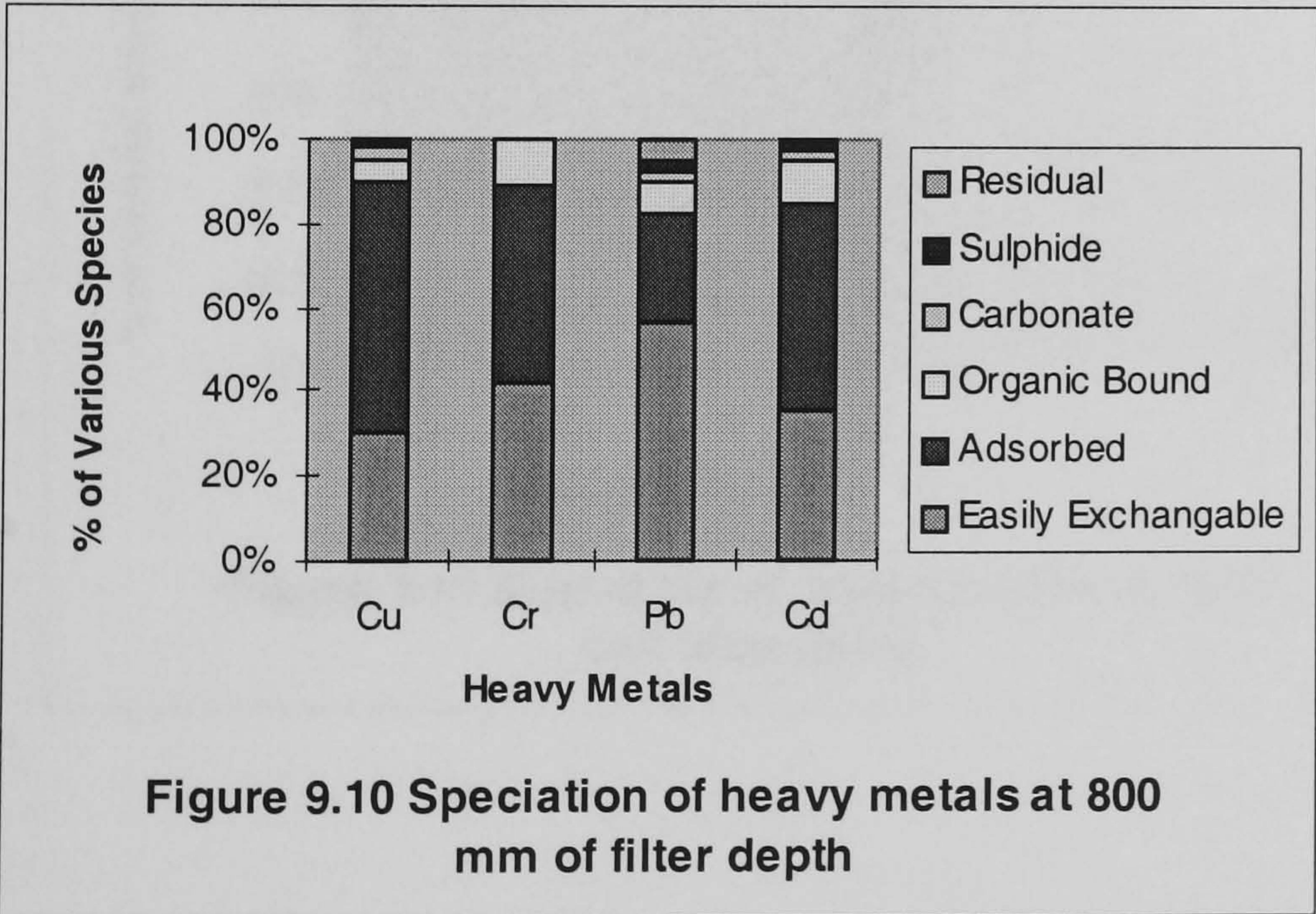
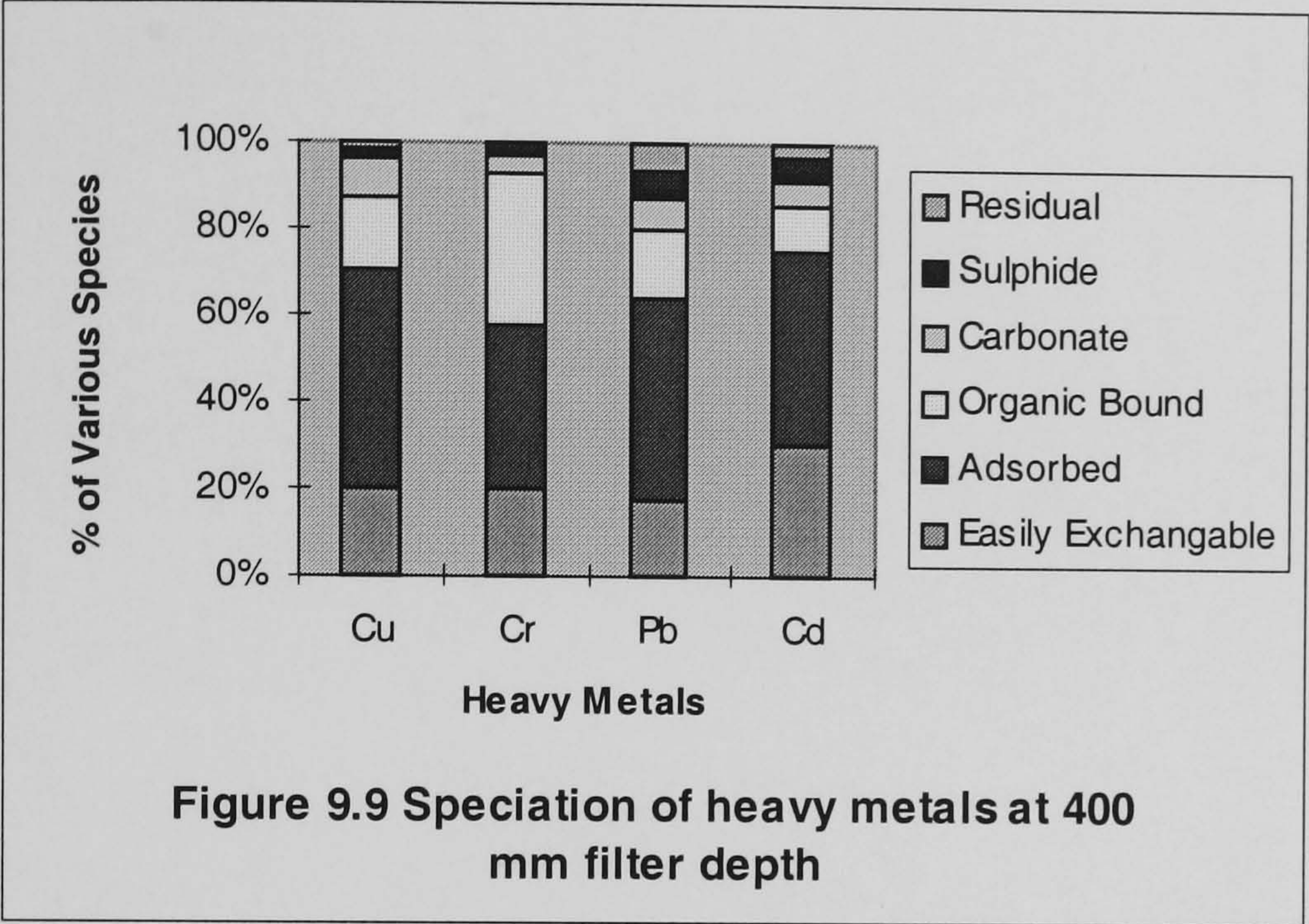


**Figure 9.6 Speciation of Heavy Metals at 20 mm of filter depth**

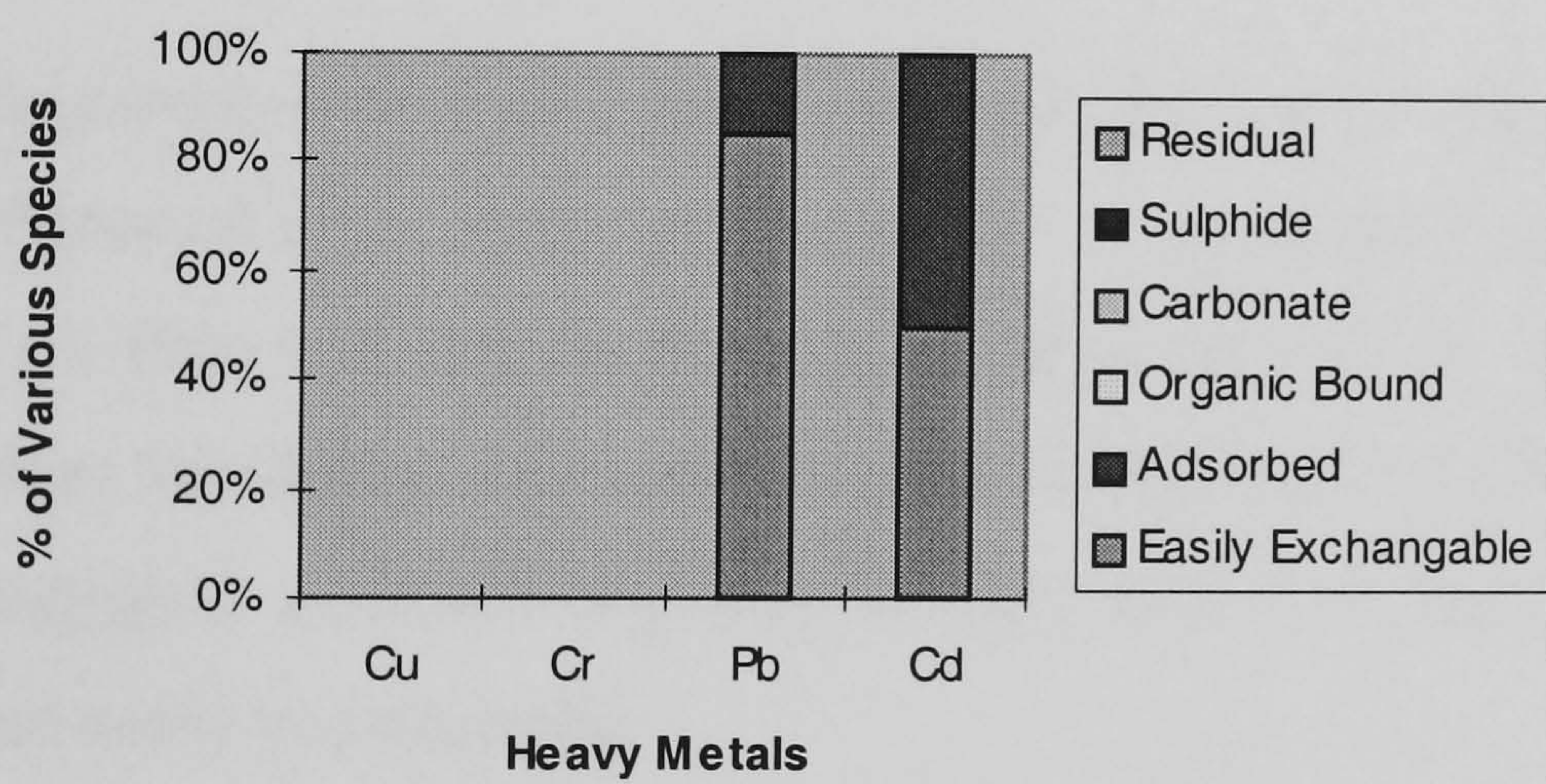












**Figure 9.11 Speciation of heavy metals at 1200 mm filter depth**



## 9.5 DISCUSSION

It is obvious from the test results that :

- Most of the metals are accumulated in the top 30 mm of filter bed. In case of Cu and Cr the accumulation extended upto 800 mm with very negligible amount. The accumulation of Pb and Cd extended upto 1200 mm of the filter bed. This confirms the earlier test results of the metal concentration in the sample taken from different depths of the filter.
- The sequential fraction of the metals varied along the depth of the filter bed. Most of the metal accumulated in the top 10 mm is organic bound. As the filter depth increases the organic-bound metal fraction decreases and the adsorbed fraction increases. At 200 mm of the filter depth, the adsorbed fraction started becoming more than the organic bound fraction. This is because of the decrease of the organic matter accumulation at greater depth of the filter bed.
- The easily exchangeable metal fraction was negligible in the top 10 mm of the filter bed and it increased as the filter depth increased. As the metal accumulation in the top 10 mm of the filter bed was mainly accomplished through the entanglement in the organic matter, the amount of metal available for the easily exchangeable sites were naturally negligible. At greater depth of the filter the accumulated metal were mainly adsorbed and easily exchangeable.
- The carbonate fraction of the metal is generally was found relatively more in the top 400 mm of the filter bed and then decreased. It has already been mentioned (section 9.3.2) that carbonate fraction mainly represent the microbial uptake of metals. As the schumutzdecke of the filter contains a large microbial population, a certain portion of microbial uptake of metals is also associated with the organic fraction
- The sulphide metal fraction was generally found negligible in the top 10 mm of the filter bed and then increased at 20 mm of the bed and after that remained more less same upto 400 mm. The sulphide fraction was found negligible at greater depth of 800



mm and 1200 mm of the filter. The sulphide fraction of the metal is assumed to evolve due to the sulphur containing materials in the sewage.

- Although all the four metals followed the similar trend (as described above), the amount of different fraction depended on the individual metal.

## **9.6 RELATIVE IMPORTANCE OF THE VARIOUS MECHANISMS OF REMOVAL**

In Chapter 5 it has been predicted from the test data that removal of heavy metals by SSFs are accomplished through the combination of a number of mechanisms, such as adsorption of heavy metals to sand and organic matter, microbial uptake and settlement. Batch adsorption test results have also confirmed that adsorption of heavy metals to sand is one of the important mechanisms. Microbial uptake of heavy metals has been confirmed by means of a positive correlation between the accumulation of heavy metals in the schumtzdecke and the amount of associated biomass. Sequential extraction of different fraction of various metals in the filter bed has further confirmed the associated mechanisms and also provided information regarding the relative importance of the various mechanisms involved in the removal of heavy metals by SSFs.

- Easily exchangeable fraction of the metals may be explained as being accumulated due to the settlement of the metals in the filter bed. Hence the importance of settlement is not very significant in the top of the filter bed because of the excessive organic matter in the top surface. As the depth increased the influences of organic matter decreased and the role of settlement also increased.
- In the top 200 mm of the filter bed adsorption/entanglement of heavy metals onto organic matter was found to be most significant. In between 200 mm and 400 mm of the filter bed the influences of the adsorption to organic matter and adsorption to sand are more or less equal. As the total accumulation of metal is relatively very high at the top part of the filters (Figures 9.1, 9.2, 9.3 and 9.4), adsorption onto organic matter is the most significant mechanism of heavy metal removal by SSFs.



- Adsorption to sand surface was found to be more important beyond the depth of 400 mm. Although the adsorption fraction increased at greater depth, it is not the most significant mechanism because of the relatively less accumulation of metals at greater depths (Figures 9.1, 9.2, 9.3 and 9.4).
- Carbonate fraction of sequential extraction is mainly assumed to be associated with the microbial activity in the filter. Microbial activities produce  $\text{CO}_2$  which combines with metal to produce carbonate metal. A little amount of carbonate metal may also be produced due to the naturally available  $\text{CO}_2$  in water and sewage. Microbial uptake of heavy metals is also associated in the organic fraction as well as in the easily exchangeable fraction. As the carbonate fraction is mainly found within 400 mm of filter depth, the microbial uptake is also assumed to take place within this depth of the filter bed.
- Sulphide fraction of the accumulation is mainly due to the sulphide material of sewage in the fed water. Sulphide fraction is associated mainly within the top 400 mm of the filter bed.

## 9.7 COMMENTS

- Settlement, adsorption of heavy metals onto organic matter and sand surface and microbial uptake has further been proved as the mechanisms associated with the removal of heavy metals by SSFs. Formation of sulphide complexes in the filter bed was identified as another mechanism of removal.
- The relative importances of the associated mechanisms depended on the depth of the filter bed. At the top part of the filter bed, adsorption onto organic matter, microbial uptake, carbonate and sulphide formation were found as the significant mechanisms. At relatively greater depth, the role of adsorption onto sand is significant. Overall adsorption onto organic matter is found as the most significant mechanism of removal. Although the trend of the fractional sequence was similar, the magnitude of the different fraction depended on the individual metal.



## **CHAPTER 10**

### **DISCUSSION**

#### **10.1 INTRODUCTION**

The results of the present research have shown evidence that SSFs are effective in removing heavy metals from surface water. The optimisation of the design parameters, the mechanisms of removal as well as their relative importance have already been discussed in the related chapters. In this chapter the standard design parameters, the general application of the research and the particular aspect of maintenance in the field conditions are discussed.

#### **10.2 STANDARD DESIGN PARAMETERS**

It has already been discussed that optimisation of the SSF parameters for the effective removal of heavy metals depends on the individual heavy metal and TOC of the influent water. It should be noted that general guidelines of the design parameters at the considered doses only are discussed in this section.

- Cu and Cr can be effectively removed by a SSF of much shallower depth of 0.4 m, operated at much higher filtration rate of 0.4 m/hr and at a TOC of 4 mg/l. Hence in the case of a conventional SSF to remove Cu and Cr, resanding needs to be carried out at a depth of 0.4 m after a number of subsequent filter cleanings.
- Pb can be removed at a level to meet WHO standards (at the dose applied) of drinking water by employing a SSF operated at 0.3 m/hr. An influent water TOC of 12 mg/l is required and the filter needs to be resanded at 0.8 m. However the minimum depth of resanding can be reduced to 0.4 m by reducing the filtration rate and increasing the influent water TOC. The model equations can be used to select the filtration rate and the TOC. As the SSFs are found effective to remove organic matter, slight increase of TOC is acceptable by means of adding artificial organic matter.
- To remove Cd to meet the WHO standard (at the dose applied) the SSF needs to be operated at a conventional filtration rate of 0.1 m/hr and at a filter depth of 1.2 m at a



TOC of 12 mg/l. Although a reasonably good removal of Cd (88.4 % at 0.3 m/hr at filter depth of 1.20 m , 89.3 % at 0.1 m/hr at a filter depth of 0.8 m) is achieved at higher filtration rate and lower filter depth, the very conservative design parameters have been selected due to a very strict WHO guideline of Cd (3 ppb) for drinking purpose.

### **10.3 RESEARCH IMPLICATIONS**

The scope of the implications of the output of the present research has been thought of in two different ways : a) the general field of application and b) the generalisation of the results for other heavy metals.

#### **10.3.1 General Areas of Application**

There are three main points :

- The major application is in the treatment of surface water containing heavy metals to meet the WHO standard for drinking purposes. In Bangladesh and other developing countries where the regulations regarding the disposal of industrial effluent are yet to be under strict control, surface waters are often polluted by industrial effluent. The problems become worse if the pollution is due to the discharge of metal containing effluents. In such circumstances SSFs (with a regular monitoring of the organic matter content) can be an effective solution. Of course, this research has shown SSFs to be effective in removing heavy metals at the doses considered. There will be limits to the treatment capacity, and real life situations may be more complicated due to factors such as combination of heavy metals and shock loads. These are the areas for further research, and are discussed in section 11.2.
- The treatment of highway runoff is another possible application of the present research. Highway runoff contains a high degree of various heavy metals (Section 2. ). If the runoff, especially from near filling stations and car parks, is collected in a storage tank and then regulated to pass through a SSF bed with controlled flow rate, then a major pollution problem of surface water courses can be minimised.
- The output of the present research can also have application in the tertiary stage of sewage treatment to remove heavy metals from the effluent. SSFs have already been



found effective in treating the effluent at the tertiary stage of sewage treatment (Ellis, 87). Hence SSFs are specially recommended for the tertiary stage of sewage treatment if the sewage contains heavy metals. The organic content of the effluent at tertiary stage will even favour the performance of the SSFs in removing heavy metals. In that case the effluent could be directly discharged for irrigation of land as well as to surface water courses.

### **10.3.2 Generalisation of the Results for Other Heavy Metals**

The experimental investigations were carried out on the removal of four specific heavy metals only. Thoughts have been provided to generalise the results for the other heavy metals.

Although the removal efficiencies were different for all the four metals, a definite similarity has been observed between Cu and Cr in the removal performance and mechanisms of removal. A certain degree of similarity has also been observed between Pb and Cd. Cu and Cr are in the same series in the periodic table. They also showed a similar pattern of settlement in the settlement batch test. Hence a similar removal of other transitional metals like, Zn, Ni, Co, Fe and Mn of the same series can be predicted. The removal of the metalloid As can also be predicted as similar to Cu and Cr because of its position in the same series of the periodic table.

As a whole the removal of other transitional metals, like Hg and Au can be similar as Cu and Cr because of the similar behaviour of transitional metals. Although Cd is a transitional metal, it behaves differently from Cu and Cr because of its greater solubility. According to the position in the periodic table, the removal of Ag could be similar to Cd.

The removal of Pb is different from Cu and Cr because of its different position from other transitional metals in periodic table. The removal of Ti and Bi can be predicted as similar to Pb as they are in the same series of the periodic table. The removal of Sn might be same as Pb because of their position in the same group of the periodic table.



## **10.4 MAINTENANCE**

The general procedures and sequence of SSF maintenance have been discussed in chapter 3 of this report. In case of SSFs it is conventional to use scraped sand for resanding of the filter following a suitable washing up of the sand. If SSFs are employed to remove heavy metals, the scraped sand from the top surface will have a very high metal concentration. Severe metal pollution will occur if the scraped sand is washed and the wash water is drained to a surface water course. In addition, it is not possible that all the metals with the scraped sand can be detached by simple washing. Hence there are two options available to deal with the scraped sand ; either to recover the associated metals or to dispose of the sand. Recovery of the metals is not within the scope of the present research and the formulation needs further research.

Normally the scraped sand is washed and used in resanding of the filters. As in the case removing heavy metals by SSFs, the sand needs to be disposed off, fresh sand will be used in resanding the filters. Standard maturation period should be provided before the filtrate can be used for drinking purposes. In this circumstance, a parallel stand-by filters should be constructed to avoid interruption of supply.

Disposal of scraped sand to the usual solid waste dumping area or in a sanitary landfill is not a good idea because of the risk of metal leachate and pollution of ground water. Hence it should be considered as a hazardous waste and several options in this respect are discussed bellow :

### **10.4.1 Glassification**

One of the most effective ways to contain very dangerous materials is to incorporate the material into glass. This technique is called glassification. Glass is a very effective means of fixing wastes that can be incorporated in glass structure. This is because glass is one of the most inert synthetic materials and is strongly resistant to leaching (Manhan,1990). Hence the scraped sand can be used in manufacturing glass. The basic procedures involved in glassification as described by Manham (1990) is outlined below :



- The basic ingredient of glass is silicon dioxide  $\text{SiO}_2$ , which occurs as natural sand. It is mixed with Sodium Carbonate ( $\text{Na}_2\text{CO}_3$ ) and Calcium Carbonate ( $\text{CaCO}_3$ ) and then fused together by heating to a very high temperature to form glass.
- Use of Boric Oxide ( $\text{B}_2\text{O}_3$ ) instead of  $\text{CaCO}_3$  gives borosilicate glass, which is specially resistant to chemical attack and changes in temperature.

#### **10.4.2 Cement-based Fixation**

In this method, the waste is mixed with common cement (portland cement) such as that used in construction. The mixture hardens to form concrete material in which the hazardous materials is immobilised. This method was developed for the safe disposal of low level radioactive wastes (Manham, 1990). It can be used to dispose the SSF scraping sand as well.

#### **10.4.3 Disposal in Landfill Cell**

Another way of disposing hazardous solid wastes is in an especially made landfill system which is termed as 'landfill cell' by the EPA (Environmental Protection Agency), America (Manham, 1990). Such a landfill has several features not found in a landfill designed for the disposal of ordinary municipal wastes. These includes clay seal that prevents migration of chemicals into ground water ; a drainage system that enables collection of leachate, which can be treated to remove contaminants and monitoring wells for detecting contamination of ground water. When several different kinds of wastes are placed in the same landfill, it is often necessary to keep them segregated (McGahan, 1980). Isolation of different wastes is accomplished by placing the wastes in different cells in the landfill (Josepson, 1981).

The scraped sand from the SSFs can conveniently disposed of in a particular cell of an existing hazardous waste landfill cell.



## CHAPTER 11

### CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

#### 11.1 CONCLUSIONS

The following conclusions have been summarised regarding the removal of heavy metals from the investigation based on the operation of the four laboratory scale slow sand filters :

**a) Slow sand filters are effective in removing heavy metals from surface water.**

- Literature review has shown that a very little research has been carried out before on the aspect of heavy metal removal by slow sand filters. Although a few works have been reported, the published works are taken from the experience of different water works where there is a little control of other variables. Virtually no extensive laboratory and pilot studies have been carried out to find the mechanisms and efficiency of SSFs in removing heavy metals.

- Four laboratory-scale SSFs were developed and operated as per design criteria in the present study to investigate the removal of four heavy metals, Cu, Cr, Pb and Cd. The doses of Cu, Cr, Pb and Cd were considered as 10 mg/l, 100 µg/l, 60 µg/l and 100 µg/l respectively. The removals of Cu, Cr, Pb and Cd were found as 99.6, 97.2, 100 and 96.6 % respectively at conventional flow rate of 0.1 m/hr, filter depth of 1.20 m (full filter depth for the present study) and at usual river water TOC of 12 mg/l.

**b) The performance of the SSFs in removing heavy metals depends on the flow rate, filter depth and TOC of the feed water.**

- In general the removal of heavy metals decreased with the increase of flow rate while the removal efficiency increased with the increase of TOC of the feed water. The removal efficiency declined at shallower filter depths. Regression models have shown a positive linear correlation between the percentage removal and the TOC content of the influent water for all four metals. Linear regression coefficients were found equal or more than the critical regression coefficient with the exception of Cd.



In the case of Cd, the linear regression coefficient was found very close to the critical regression coefficient. A negative linear correlation was observed between the percentage removal and the flow rates for all the four metals with regression coefficients greater than the critical value. A positive linear correlation was also observed between the percentage removal and the filter bed depth for heavy metals with the exception of the case of Cu. In case of Cu, the variation was found to be logarithmic. In most of the cases the regression coefficients were greater than the critical regression coefficients. Only in a few cases the regression coefficients were found less but close to the critical value.

- The optimisation of the SSFs variables for the removal of heavy metals depends on the individual metal and TOC of the influent water. Cu and Cr was found to be removed to meet the WHO standards (at the applied dose) of drinking water at a higher flow rate, shallower filter depth and lower TOC whereas a relatively lower flow rate, deeper filter bed and higher TOC were needed for the removal of Pb and Cd to meet the WHO standards. The optimised values of the design variables for the removal of the selected heavy metals are shown in Table 11.1.

Table 11.1 Optimised parameters of SSF for the removal of selected heavy metals to meet the WHO standards of drinking water.

Metals	TOC (mg/l)	Flow Rate (m/hr)	Filter Depth (m)
Cu	4	0.4	0.4
Cr	4	0.4	0.4
Pb	8	0.3	1.2
	12	0.3	0.8
Cd	12	0.1	1.2



**c) The removal of heavy metals was found to be accomplished through the combination of a number of mechanisms, such as adsorption onto sand and organic matter, settlement and microbial uptake.**

- The decrease of removal efficiency with the increase of filtration rate indicates the adsorption of heavy metals onto sand. The increase of removal efficiency with the increase of filter bed depth also indicate the importance of adsorption of heavy metals onto sand surface. Batch adsorption tests were carried out to confirm the adsorption criteria of heavy metals onto sand surface. The adsorption of Cu, Cr, Pb and Cd onto sand surface satisfied the Langmuir and Freundlich isotherms. The adsorption capacity of sand was found the highest for Pb followed by Cu, Cr and Cd. The values of Freundlich exponent  $n$  were found greater than one for all four metals confirming the adsorption of these metals onto sand. Speciation of heavy metals in the SSFs bed has also shown that adsorption is one of the mechanisms of removal of heavy metals by SSF.

- The increase of the removal of heavy metals with the increase of TOC indicates the importance of adsorption of heavy metals onto organic matter. Speciation tests have shown that the most of the accumulated metals in the top of the sand bed is organic bound which confirms the importance of organic matter in removing heavy metals by SSFs.

- Batch tests on settlement were carried out to confirm settlement as being one of the mechanisms of heavy metal removal by SSFs. Cu and Cr were found to be settled down along with the other turbid materials if stirring was not provided, but Pb and Cd remained in solution even if stirring was not provided. pH has a significant influence on the precipitation/ settlement of heavy metals. Cu and Cr settled at a higher rate at a pH of 7.5 whereas Pb and Cd started to be settled at a pH > 9.

- The accumulation of heavy metals in the schumtzdecke was determined and compared with the associated biomass. Regression models showed a positive linear correlation between the accumulation of metal and the available biomass with linear regression coefficients more than the critical value. This has confirmed the importance of microbial uptake of heavy metals in SSFs. The amount of biomass was measured by means of a novel method which considered the amount of total nitrogen expressed as the percentage of VS (Volatile Solids) as the active biomass. The



conventional method of using VS as the biomass was not considered because of the overestimation of biomass by this method. Speciation of heavy metals in the SSFs has shown a substantial amount of carbonate species which indicates the importance of microbial uptake because the carbonate fraction of heavy metals is predicted to evolve partly due to the microbiological activity in the filter bed.

**d) Formation of metal sulphide in the SSFs bed enhance the removal efficiency.**

- Speciation analysis has shown the evidence of metal sulphide in the SSFs bed. The sulphide fraction of the metal is assumed to evolve due to the sulphur containing materials in the sewage. Hence the formation of metal sulphide has enhanced the removal efficiency of heavy metals by SSFs.

**e) The relative importance of the individual mechanism depends on the depth of the filter bed.**

- Speciation of heavy metals in the SSFs bed was carried out with a view to further confirmation of the mechanisms and also to identify the relative importance of the selected mechanisms. The accumulated metals were divided into 6 categories; easily exchangeable, adsorbed, organic-bound, carbonate, sulphide and residual metals.
- It was found that at the top 200 mm of the filter bed, organic-bound fraction predominated. As the depth increased the easily exchangeable and adsorbed fraction increased and the organic-bound fraction decreased.
- Carbonate fraction of metals referred to the microbial uptake of metals although a part of it might have evolved from the natural CO<sub>2</sub> content of water and sewage. Microbial uptake of heavy metal was also associated with the organic-bound fraction as well as easily exchangeable fraction. Sulphide metals were assumed to be evolved from the sulphide materials in the sewage added in the feed water. Carbonate and sulphide metals were found mostly within the top 400 mm of the filter bed.
- Although the adsorbed and easily exchangeable fraction increases with the increase of filter depth, they are not the most significant mechanisms because of the decreasing



accumulation of metals at greater depth. As relatively more metals are accumulated at the top of the filter bed and organic-bound fraction predominates, adsorption of metals onto organic matter is the most significant mechanism.

**f) The application of the research output is assumed to be in the field of treating surface water containing heavy metals at the specified doses. The research output may also be used in treating highway run-off containing heavy metals. The output of the present research may also be used as the tertiary treatment of metal containing wastewater.**

***In Summary :***

***Heavy metals are removed very effectively in SSFs at the dose applied. By far the most significant mechanism has been proved to be adsorption onto organic matter at the top of the filter bed (top 30 mm). Other mechanisms occur, but are not anywhere near as significant. This research has shown that these mechanisms, in approximate order of importance, are adsorption onto organic matter, adsorption to sand surface, microbial uptake, settlement and sulphide formation.***

## **11.2 RECOMMENDATIONS FOR FURTHER STUDY**

As it is evident from the literature review that a very little research has been carried out in this field before, there are a number of options still available for further research.

- The investigation reported here were carried out on individual metal. Similar investigations can be carried on the combination of number of heavy metals. Both the hydraulic and metal load can be varied to determine the filter response under extreme conditions. The sand size can be used as a control variable because only one specific sand was used in the present study. The doses of the metals can also be varied to know the maximum treatable metal concentration.
- Experimental investigations can be carried out to generalise the removal of heavy metals according to their position in the periodic table. Specially the removal of As can be investigated as it is a major current pollution problem of ground water in Bangladesh.



- In the present research, a similar pattern of removal and mechanism has been observed between Cu and Cr and also between Pb and Cd. Further investigation by analysing the various salt species and anions in the supernatant water can be carried out to evaluate these patterns.
- Nitrate salts have mostly been used in the present investigation. The use of nitrates might have an effect on the measurement of nitrogen as the active biomass content in the schumtzdecke (as measured by the method explained in chapter 8). Hence further investigation can be carried out by considering the different species of metal salts in order to identify whether this has an effect on filter performance.
- TOC has been considered as a control parameter to identify its effects on the filter performance. In developing country situations it is costly to monitor the TOC as a continuous basis. As turbidity is relatively cheap to monitor, further investigation can be carried out by considering turbidity as a control parameter to evaluate its effects on the filter performance.
- The filters can be run on a very long term basis to monitor the extent and stability of adsorption and microbial uptake of heavy metals in the sand bed. The removal of heavy metals in SSFs is a complex and dynamic process and the long term capability of SSFs to sustain high level of treatment over a long time period deserves further investigation.
- Further investigation can be carried out to identify any other mechanisms (ion exchange, electrostatic forces etc.) associated with the removal of heavy metals by SSFs.
- Microbiological investigation of the schumtzdecke can be carried out to identify the specific microorganism associated with the removal of heavy metals by SSFs. These can then be isolated and their treatment capabilities rigorously determined.
- The disposal of metal contaminated sand is a major maintenance problem that needs to be investigated further. Some of the options have been discussed in chapter 10. The prospects of regeneration/ recovery of the heavy metals from sand is worthy of further investigation. There are two sources of metal contaminated sand which need to be considered : from the scrapings of the schumtzdecke, and from the full sand bed depth when replacement of the media is required.



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## **ANNEX 1**

### **EXPERIMENTAL DATA FOR THE PROCESS VARIABLES TESTS**

All the results of the process variables tests including the standard deviation and confidence limit are presented in the following section.



TABLE A1.1.1.1: Percentage removal efficiencies of different filters in removing heavy metals at a flow rate of 0.1 m/hr and a TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	9290	78	9370-9200	9350-9200	154	19	175-133	172-135	98.2	0.07	98.3-98.1	98.3-98.2
F <sub>2</sub> /Cr	101.5	6.4	108.7-94.3	108-95.2	3.40	0.66	4.16-266	4.2-3.0	96.7	0.46	97.1-96.1	97.0-96.1
F <sub>3</sub> /Pb	50	7.08	58.42	52.6-48.5	4.7	0.75	5.35-3.84	5.1-4.0	90.6	1.04	91.7-89.4	91.8-89.8
F <sub>4</sub> /Cd	94.4	5.52	100.6-88.1	96.5-92.6	5.6	2.09	8.3-2.3	8-4	94.0	2.23	96.5-91.5	95.7-91.5



TABLE A1.1.2: Variation of metal concentration at different depths of the filters at a flow rate of 0.1 m/hr and a TOC of 4 mg/l

Filter/ Metal	0.4m depth					0.8m depth					1.2m depth				
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	
F <sub>1</sub> /Cu	240	64	312-167	293-167		170	23	196-144	196-146		154	19	175-133	172-135	
F <sub>2</sub> /Cr	5.40	1.71	7.4-3.45	7.6-3.9		4.60	1.27	4.7-3.16	4.6-3.10		3.40	0.66	4.16-2.66	4.2-3.0	
F <sub>3</sub> /Pb	8.9	0.81	9.81-8.0	9.6-8		5.30	0.93	6.35-4.25	6.30-4.50		4.7	0.75	5.55-3.84	5.1-4.0	
F <sub>4</sub> /Cd	30.2	4.16	34.9-25.5	34.9-27.6		11.8	1.06	13-10.6	13-11		5.6	2.09	8.3-2.3	8-4	



TABLE A1.1.3: Percentage removal efficiencies of different filters in removing TOC at a flow rate of 0.1 m/hr and influent TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	4.28	0.22	4.53-4.03	4.53-4.11	2.14	0.061	2.21-2.10	2.21-2.10	49.9	1.16	51.2-48.6	51.2-48.9
F <sub>2</sub> /Cr	4.11	0.21	4.35-3.87	4.34-3.93	2.14	0.14	2.30-1.98	2.30-2.02	48	0.83	48.9-47.0	48.6-47.0
F <sub>3</sub> /Pb	4.50	0.62	5.20-3.80	5.20-4.00	2.42	0.33	2.79-2.05	2.79-2.17	46.3	0.36	46.6-45.8	46.5-45.8
F <sub>4</sub> /Cd	4.18	0.08	4.18-4.09	4.25-4.09	2.22	0.032	2.26-2.18	2.25-2.20	46.9	0.82	47.8-45.9	47.6-46.0



TABLE A1.1.4: Percentage removal efficiencies of different filters in removing turbidity at a flow rate of 0.1 m/hr and influent TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	3.12	0.01	3.13-3.10	3.13-3.10	0.31	0.01	0.32-0.31	0.32-0.30	90	0.35	90.4-89.6	90.4-89.7
F <sub>2</sub> /Cr	3.20	0.00	3.10-3.10	3.10-3.10	0.32	0.00	0.32-0.32	0.32-0.32	89.7	0.00	89-7-89.7	89-7-89.7
F <sub>3</sub> /Pb	3.10	0.00	3.10-3.10	3.10-3.10	0.33	0.01	0.34-0.32	0.34-0.32	89.4	0.35	89.8-89.0	89.7-89.0
F <sub>4</sub> /Cd	3.10	0.02	3.13-3.08	3.12-3.08	0.33	0.01	0.34-0.32	0.34-0.32	89.4	0.35	89.8-89.0	89.7-89.0



TABLE A1.1.5: Variation of pH in different filters at a flow rate of 0.1 m/hr and a TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				Drop			
	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>2</sub> /Cr	7.7	0.00	7.7-7.7	7.7-7.7	7.4	0.00	7.4-7.4	7.4-7.4	0.3	0.00	0.3-0.3	0.3-0.3
F <sub>3</sub> /Pb	7.6	0.00	7.6-7.6	7.6-7.6	7.3	0.00	7.3-7.3	7.3-7.3	0.3	0.00	0.3-0.3	0.3-0.3
F <sub>4</sub> /Cd	7.6	0.00	7.6-7.6	7.6-7.6	7.3	0.00	7.3-7.3	7.3-7.3	0.3	0.00	0.3-0.3	0.3-0.3



TABLE A5.1.6    Percentage removal efficiencies of different filters in removing faecal coliform at a flow rate of 0.1 m/hr and a TOC of 4 mg/l

Filter/Metal	Influent /100 ml	Effluent /100 ml	% removal
F1/Cu	35000	0	100
F2/Cr	30000	0	100
F3/Pb	35000	0	100
F4/Cd	30000	0	100



TABLE A1.2.1: Percentage removal efficiencies of different filters in removing heavy metals at a flow rate of 0.2 m/hr and a TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	9960	240	10200-9730	10100-9720	240	17	260-220	250-220	97.6	0.17	97.8-97.4	97.8-97.5
F <sub>2</sub> /Cr	98.4	2.52	101.3-95.4	101-96	3.50	0.50	4.10-2.90	4.0-3.0	96.5	0.42	97.0-96.0	96.8-96.0
F <sub>3</sub> /Pb	56	1.51	57.7-54.3	57.5-54.5	8.50	0.64	9.30-7.80	9.20-8.0	84.9	0.78	85.8-84.0	85.4-84.0
F <sub>4</sub> /Cd	93.4	2.31	96.0-90.8	88.9-86.9	11.0	1.86	13.1-8.90	12.5-10.2	88.3	1.08	89.5-87.0	88.9-86.9



TABLE A1.2.2: Variation of metal concentration at different depths of the filters at a flow rate of 0.2 m/hr and a TOC of 4 mg/l

Filter/ Metal	0.4m depth					0.8m depth					1.2m depth				
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)			
F <sub>1</sub> /Cu	320	20	340-300	340-300	230	10	242-220	240-200	240	17	260-220	250-200			
F <sub>2</sub> /Cr	5.70	0.26	6.0-5.40	6.0-5.50	4.50	0.31	4.90-4.16	4.80-4.20	3.50	0.50	4.10-2.2.90	4.0-3.0			
F <sub>3</sub> /Pb	29.7	0.56	30.3-29.0	30.3-29.2	20.8	0.62	21.5-20.1	21.4-20.2	8.50	0.64	9.30-7.80	9.20-8.0			
F <sub>4</sub> /Cd	31.4	0.84	32.4-30.5	32.0-30.4	24.9	1.48	25.6-23.3	26.0-23.2	11.0	1.86	13.1-8.90	12.5-10.2			



TABLE A1.2.3: Percentage removal efficiencies of different filters in removing TOC at a flow rate of 0.2 m/hr and influent TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	4.30	0.07	4.39-4.22	4.30-4.20	2.21	0.01	2.22-2.20	2.21-2.20	48.6	0.72	49.4-47.8	48.8-47.6
F <sub>2</sub> /Cr	4.25	0.017	4.27-4.23	4.26-4.16	2.22	0.01	2.23-2.21	2.23-2.21	47.8	0.1	47.8-47.6	47.9-47.7
F <sub>3</sub> /Pb	4.19	0.05	4.25-4.13	4.25-4.16	2.26	0.025	2.29-2.23	2.29-2.24	46.1	0.30	46.5-45.7	46.2-45.7
F <sub>4</sub> /Cd	4.22	0.08	4.31-4.14	4.30-4.16	2.24	0.035	2.26-2.20	2.28-2.21	46.8	0.17	47.0-46.6	46.9-46.6



TABLE A1.2.4: Percentage removal efficiencies of different filters in removing turbidity at a flow rate of 0.2 m/hr and influent TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	3.16	0.041	3.21-3.11	3.20-3.12	0.54	0.02	0.56-0.52	0.56-0.52	82.9	0.59	83.6-82.3	83.3-82.1
F <sub>2</sub> /Cr	3.18	0.041	3.23-3.13	3.21-3.16	0.55	0.02	0.57-0.53	0.56-0.53	82.9	0.58	83.6-82.2	83.2-82.2
F <sub>3</sub> /Pb	3.14	0.021	3.16-3.12	3.16-3.12	0.56	0.01	0.57-0.55	0.56-0.55	82.2	0.38	82.6-81.8	82.6-82.0
F <sub>4</sub> /Cd	3.13	0.030	3.16-3.10	3.16-3.10	0.56	0.00	0.56-0.56	0.56-0.56	82.1	0.33	82.5-81.8	82.4-81.8



TABLE A1.2.5: Variation of pH in different filters at a flow rate of 0.2 m/hr and a TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				Drop			
	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>2</sub> /Cr	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>3</sub> /Pb	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>4</sub> /Cd	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4



TABLE A1.2.6    Percentage removal efficiencies of different filters in removing faecal coliform at a flow rate of 0.2 m/hr and a TOC of 4 mg/l

Filter/Metal	Influent /100 ml	Effluent /100 ml	% removal
F1/Cu	30000	2	100
F2/Cr	30000	0	100
F3/Pb	30000	1	100
F4/Cd	30000	0	100



TABLE A1.3.1: Percentage removal efficiencies of different filters in removing heavy metals at a flow rate of 0.3 m/hr and a TOC of 4 mg/l

Filter/ Metal	Influent					Effluent					% removal			
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean value	Standard deviation	95% confidence interval	Range of data		
F <sub>1</sub> /Cu	9450	440	9960-8950	9960-9150	260	00	260-260	260-260	97.2	0.16	97.4-97.0	97.4-97.1		
F <sub>2</sub> /Cr	99.7	2.17	102.2-97.2	102.2-98	4.30	0.58	5.00-3.60	5.0-4.0	95.7	0.59	96.4-95.0	96.1-95.0		
F <sub>3</sub> /Pb	58.8	1.20	60.2-57.4	60.0-57.6	10.80	0.55	11.40-10.20	11.3-10.2	81.6	1.14	82.9-80.3	82.6-80.4		
F <sub>4</sub> /Cd	89.7	2.08	92.1-87.3	92.0-88.0	15.30	0.95	16.30-15.30	16.0-14.2	83.0	0.42	83.0-82.5	83.9-82.5		



TABLE A1.3.2: Variation of metal concentration at different depths of the filters at a flow rate of 0.3 m/hr and a TOC of 4 mg/l

Filter/ Metal	0.4m depth					0.8m depth					1.2m depth				
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	
F <sub>1</sub> /Cu	340	60	410-270	380-270		250	26.5	280-190	270-220		260	00	260-260	260-260	
F <sub>2</sub> /Cr	6.30	0.70	7.10-5.50	6.80-5.50		4.8	0.71	5.60-4.00	5.40-4.00		4.3	0.58	5.00-3.60	5.0-4.0	
F <sub>3</sub> /Pb	36.30	2.46	39.1-33.5	38.9-34.0		26.4	1.13	27.7-25.1	27.3-25.1		10.8	0.55	11.4-10.2	11.3-10.2	
F <sub>4</sub> /Cd	45.5	0.50	46.1.1-44.9	46.0-45.0		40.8	3.41	44.6-36.8	44.0-37.2		15.3	0.95	16.3-14.3	16.0-14.2	



TABLE A1.3.3: Percentage removal efficiencies of different filters in removing TOC at a flow rate of 0.3 m/hr and influent TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	4.32	0.12	4.46-4.18	4.44-4.20	2.22	0.12	2.36-2.08	2.34-2.22	48.6	1.35	50.1-47.0	50.0-47.3
F <sub>2</sub> /Cr	4.39	0.21	4.63-4.15	4.65-4.26	2.29	0.12	2.43-2.15	2.42-2.20	48.2	0.70	49.0-47.4	49.0-47.7
F <sub>3</sub> /Pb	4.11	0.09	4.22-4.00	4.20-4.00	2.19	0.05	2.25-2.13	2.23-2.13	46.7	1.02	47.8-45.5	47.6-45.6
F <sub>4</sub> /Cd	4.21	0.02	4.23-4.19	4.24-4.20	2.26	0.05	2.31-2.21	2.31-2.22	46.3	1.12	47.6-45.0	47.1-45.0



TABLE A1.3.4: Percentage removal efficiencies of different filters in removing turbidity at a flow rate of 0.3 m/hr and influent TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	3.11	0.10	3.22-3.00	3.20-3.00	0.76	0.03	0.79-0.73	0.79-0.74	75.6	0.50	76.2-75.0	76.2-75.3
F <sub>2</sub> /Cr	3.12	0.07	3.21-3.04	3.20-3.06	0.77	0.01	0.78-0.76	0.78-0.76	75.3	0.23	75.6-75.0	75.6-75.2
F <sub>3</sub> /Pb	3.10	0.07	3.19-3.02	3.20-3.00	0.78	0.03	0.81-0.75	0.80-0.75	74.8	0.21	75.0-74.6	75.0-74.9
F <sub>4</sub> /Cd	3.14	0.05	3.26-3.08	3.20-3.10	0.79	0.012	0.81-0.78	0.80-0.78	74.8	0.21	75.0-74.6	75.0-74.9



TABLE A1.3.5: Variation of pH in different filters at a flow rate of 0.3 m/hr and a TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				Drop			
	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>2</sub> /Cr	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>3</sub> /Pb	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>4</sub> /Cd	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4



TABLE A1.3.6    Percentage removal efficiencies of different filters in removing faecal coliform at a flow rate of 0.3 m/hr and a TOC of 4 mg/l

Filter/Metal	Influent /100 ml	Effluent /100 ml	% removal
F1/Cu	35000	12	99.99
F2/Cr	30000	10	99.99
F3/Pb	35000	12	99.99
F4/Cd	35000	10	99.99



TABLE A1.4.1: Percentage removal efficiencies of different filters in removing heavy metals at a flow rate of 0.4 m/hr and a TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	10400	690	11200-9600	11260-9600	320	30	350-290	340-292	96.9	0.45	97.4-96.4	97.4-96.5
F <sub>2</sub> /Cr	98	1.00	99.3-96.9	99.0-97.0	5.83	0.35	6.30-5.40	6.2-5.5	94.0	0.40	94.5-93.5	94.4-93.6
F <sub>3</sub> /Pb	58.8	1.20	60.2-57.4	60.0-57.6	21.88	0.35	22.20-21.40	22.0-21.4	62.9	1.29	64.4-61.4	64.3-61.8
F <sub>4</sub> /Cd	90	1.73	92.0-88.0	92.0-89.0	42.00	1.78	44.00-40.00	43.4-40.0	53.4	1.52	55.2-51.7	55.0-52.1



TABLE A1.4.2: Variation of metal concentration at different depths of the filters at a flow rate of 0.4 m/hr and a TOC of 4 mg/l

Filter/ Metal	0.4m depth					0.8m depth					1.2m depth				
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	
F <sub>1</sub> /Cu	350	20	370-328	370-330		3300	36	370-280	360-290		320	30	350-290	340-292	
F <sub>2</sub> /Cr	7.80	0.25	8.10-7.50	8.0-7.50		6.5	0.23	6.80-6.20	6.80-6.20		5.83	0.35	6.30-5.40	6.20-5.50	
F <sub>3</sub> /Pb	39.90	2.75	43.0-36.8	43.0-38.0		26.8	0.82	27.7-25.9	27.7-26.1		21.88	0.35	22.20-21.40	22.0-21.4	
F <sub>4</sub> /Cd	67.5	1.80	69.5-65.5	69.5-66.0		54.7	3.14	58.3-50.8	57.2-51.0		42.0	1.78	44.0-40.0	43.4-40.0	



TABLE A1.4.3: Percentage removal efficiencies of different filters in removing TOC at a flow rate of 0.4 m/hr and influent TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	4.20	0.11	4.33-4.08	4.32-4.10	2.18	0.06	2.25-2.11	2.22-2.10	48.0	1.90	50.2-45.8	50.0-46.3
F <sub>2</sub> /Cr	4.30	0.08	4.40-4.21	4.32-4.19	2.30	0.09	2.40-2.20	2.30-2.20	46.5	2.20	49.0-44.0	49.0-45.1
F <sub>3</sub> /Pb	4.15	0.05	4.21-4.09	4.20-4.10	2.25	0.05	2.31-2.20	2.30-2.20	45.8	1.66	47.7-43.9	47.6-44.3
F <sub>4</sub> /Cd	4.14	0.14	4.30-3.98	4.20-3.98	2.26	0.06	2.33-2.20	2.31-2.20	45.4	1.08	46.6-44.2	46.7-44.7



TABLE A1.4.4: Percentage removal efficiencies of different filters in removing turbidity at a flow rate of 0.4 m/hr and influent TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	3.00	0.08	3.10-2.91	3.12-3.00	0.86	0.02	0.88-0.84	0.88-0.84	71.4	1.00	72.5-70.3	72.4-70.6
F <sub>2</sub> /Cr	3.10	0.00	3.10-3.10	3.10-3.10	0.87	0.01	0.88-0.86	0.89-0.86	71.9	0.40	72.4-71.4	71.9-71.3
F <sub>3</sub> /Pb	3.10	0.08	3.20-3.02	3.10-3.00	0.87	0.02	0.89-0.85	0.88-0.85	71.9	0.5	72.5-71.4	71.7-71.3
F <sub>4</sub> /Cd	3.08	0.06	3.15-3.00	3.12-3.00	0.86	0.02	0.88-0.84	0.88-0.84	71.4	1.27	72.8-70.0	73.0-70.6



TABLE A1.4.5: Variation of pH in different filters at a flow rate of 0.4 m/hr and a TOC of 4 mg/l

Filter/ Metal	Influent				Effluent				Drop			
	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>2</sub> /Cr	7.7	0.00	7.7-7.7	7.7-7.7	7.3	0.00	7.3-7.3	7.3-7.3	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>3</sub> /Pb	7.7	0.00	7.7-7.7	7.7-7.7	7.3	0.00	7.3-7.3	7.3-7.3	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>4</sub> /Cd	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4



TABLE A1.4.6    Percentage removal efficiencies of different filters in removing faecal coliform at a flow rate of 0.4 m/hr and a TOC of 4 mg/l

Filter/Metal	Influent /100 ml	Effluent /100 ml	% removal
F1/Cu	30000	24	99.92
F2/Cr	30000	26	99.91
F3/Pb	35000	28	99.90
F4/Cd	35000	28	99.90



TABLE A1.5.1: Percentage removal efficiencies of different filters in removing heavy metals at a flow rate of 0.1 m/hr and a TOC of 8 mg/l

Filter/ Metal	Influent					Effluent					% removal			
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean value	Standard deviation	95% confidence interval	Range of data		
F <sub>1</sub> /Cu	9900	300	10200-9800	10100-9540	140	16	160-120	140-120	98.6	0.20	98.8-98.4	98.8-98.4		
F <sub>2</sub> /Cr	96.4	2.52	99.3-93.6	99.0-94.0	2.90	0.31	3.30-2.60	3.2-2.6	97.0	0.25	97.3-96.7	97.3-96.2		
F <sub>3</sub> /Pb	51.8	0.74	52.6-51.0	52.3-51.1	3.0	0.68	3.77-2.20	3.5-2.2	94.2	1.27	95.6-92.8	95.7-93.3		
F <sub>4</sub> /Cd	95.2	0.29	95.6-94.9	95.5-95.0	3.6	0.17	3.84-3.40	3.80-3.50	96.2	0.17	96.4-96.0	96.3-96.0		



TABLE A1.5.2: Variation of metal concentration at different depths of the filters at a flow rate of 0.1 m/hr and a TOC of 8 mg/l

Filter/ Metal	0.4m depth					0.8m depth					1.2m depth				
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)			
F <sub>1</sub> /Cu	210	10	220-200	220-200	130	17	150-116	150-120	140	16	160-120	140-120			
F <sub>2</sub> /Cr	4.00	0.08	4.08-3.92	4.10-4.00	3.6	0.23	3.90-3.30	3.80-3.50	2.90	0.31	3.30-2.60	3.27-2.60			
F <sub>3</sub> /Pb	7.30	0.26	7.60-7.00	7.60-7.10	4.5	0.84	5.45-3.50	5.50-4.00	3.00	0.68	3.77-2.20	3.50-2.20			
F <sub>4</sub> /Cd	27.0	1.00	28.1-25.9	28.0-26.0	10.9	0.17	11.1-10.7	11.0-10.7	3.60	0.17	3.84-3.40	3.80-3.50			



TABLE A1.5.3: Percentage removal efficiencies of different filters in removing TOC at a flow rate of 0.1 m/hr and influent TOC of 8 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	8.96	0.02	8.98-8.93	8.98-8.94	4.35	0.18	4.55-4.15	4.50-4.15	51.9	1.99	53.7-49.3	53.7-49.9
F <sub>2</sub> /Cr	8.26	0.05	8.32-8.20	8.30-8.20	4.10	0.18	4.30-3.90	4.25-3.50	50.4	2.21	52.9-47.9	52.9-48.8
F <sub>3</sub> /Pb	8.50	0.09	8.64-8.34	8.60-8.45	4.45	0.18	4.65-4.25	4.60-4.25	47.7	1.71	49.7-45.7	49.7-46.5
F <sub>4</sub> /Cd	8.60	0.10	8.72-8.48	8.70-8.50	4.32	0.43	4.81-3.83	4.60-3.80	49.8	5.16	55.8-44.2	55.8-48.3



TABLE A1.5.4: Percentage removal efficiencies of different filters in removing turbidity at a flow rate of 0.1 m/hr and influent TOC of 8 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	4.92	0.21	5.20-4.70	5.10-4.70	0.48	00	0.48-0.48	0.48-0.48	90.3	0.50	90.9-89.7	90.6-89.8
F <sub>2</sub> /Cr	4.86	0.25	5.15-4.60	5.10-4.60	0.48	00	0.48-0.48	0.48-0.48	90.2	0.61	90.0-89.5	90.7-89.6
F <sub>3</sub> /Pb	4.86	00	4.86-4.86	4.86-4.86	0.48	00	0.48-0.48	0.48-0.48	90.2	00	90.2-90.2	90.2-90.2
F <sub>4</sub> /Cd	4.90	0.30	5.20-4.60	5.20-4.60	0.48	00	0.48-0.48	0.48-0.48	90.3	0.70	91.1-89.5	91.0-89.5



TABLE A1.5.5: Variation of pH in different filters at a flow rate of 0.1 m/hr and a TOC of 8 mg/l

Filter/ Metal	Influent					Effluent					Drop				
	Mean concen- tration	Standard deviation	95% confidence interval	Range of data		Mean concen- tration	Standard deviation	95% confidence interval	Range of data		Mean value	Standard deviation	95% confidence interval	Range of data	
F <sub>1</sub> /Cu	7.8	0.00	7.8-7.8	7.8-7.8		7.3	0.00	7.3-7.3	7.3-7.3		0.5	0.00	0.5-0.5	0.5-0.5	
F <sub>2</sub> /Cr	7.8	0.00	7.8-7.8	7.8-7.8		7.3	0.00	7.3-7.3	7.3-7.3		0.5	0.00	0.5-0.5	0.5-0.5	
F <sub>3</sub> /Pb	7.7	0.00	7.7-7.7	7.7-7.7		7.3	0.00	7.3-7.3	7.3-7.3		0.4	0.00	0.4-0.4	0.4-0.4	
F <sub>4</sub> /Cd	7.7	0.00	7.7-7.7	7.7-7.7		7.3	0.00	7.3-7.3	7.3-7.3		0.4	0.00	0.4-0.4	0.4-0.4	



TABLE A1.5.6    Percentage removal efficiencies of different filters in removing faecal coliform at a flow rate of 0.1 m/hr and a TOC of 8 mg/l

Filter/Metal	Influent /100 ml	Effluent /100 ml	% removal
F1/Cu	120000	01	100
F2/Cr	113000	01	100
F3/Pb	90000	00	100
F4/Cd	90000	00	100



TABLE A1.6.1: Percentage removal efficiencies of different filters in removing heavy metals at a flow rate of 0.2 m/hr and a TOC of 8 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	10100	398	10550-9650	10600-9860	220	12	234-206	230-210	97.8	0.173	98.0-97.6	98.0-97.7
F <sub>2</sub> /Cr	101	2.28	103.6-98.4	102.0-98.0	03	0.14	3.16-2.84	3.2-3.0	97.0	0.71	97.8-96.2	96.9-96.0
F <sub>3</sub> /Pb	47	1.73	49.0-45.0	48.0-45.0	5.3	0.52	5.90-4.70	5.90-5.0	88.7	1.41	90.3-87.1	89.6-87.0
F <sub>4</sub> /Cd	89	3.08	92.5-85.5	92.0-86.0	08	1.58	9.80-6.20	10.0-8.0	91.0	1.32	92.5-89.5	92.4-89.8



TABLE A1.6.2: Variation of metal concentration at different depths of the filters at a flow rate of 0.2 m/hr and a TOC of 8 mg/l

Filter/ Metal	0.4m depth					0.8m depth					1.2m depth				
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	
F <sub>1</sub> /Cu	300	10	311-290	310-300		210	10	221-2000	220-200		220	12	234-206	230-210	
F <sub>2</sub> /Cr	5.30	0.53	5.90-4.70	5.70-4.70		4.3	0.58	4.95-3.90	5.00-4.00		3.00	0.14	3.16-2.84	3.20-3.00	
F <sub>3</sub> /Pb	16.2	2.75	19.3-13.1	19.0-13.5		10.0	1.00	11.1-8.90	11.0-9.00		5.30	0.52	5.90-4.70	5.90-5.00	
F <sub>4</sub> /Cd	24.7	2.91	28.0-21.4	26.6-21.3		20.8	2.36	23.6.6-18.2	22.8-18.2		8.00	1.58	9.80-6.20	10.0-8.0	



TABLE A1.6.3: Percentage removal efficiencies of different filters in removing TOC at a flow rate of 0.2 m/hr and influent TOC of 8 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	8.50	0.25	8.80-8.20	8.70-8.20	3.97	0.19	4.18-3.76	4.18-3.82	53.3	1.67	55.2-51.4	55.0-52.0
F <sub>2</sub> /Cr	8.20	0.10	8.30-8.10	8.30-8.10	3.87	0.31	4.22-3.52	3.92-3.44	52.8	3.40	56.6-49.0	57.6-52.4
F <sub>3</sub> /Pb	8.00	0.30	8.34-7.67	8.21-7.70	3.83	0.08	3.92-3.44	3.91-3.75	52.1	1.15	53.4-50.8	53.5-51.3
F <sub>4</sub> /Cd	8.00	0.27	8.30-7.70	8.30-7.80	3.76	0.15	3.93-3.60	3.90-3.60	53.0	1.40	54.6-51.4	54.3-51.5



TABLE A1.6.4: Percentage removal efficiencies of different filters in removing turbidity at a flow rate of 0.2 m/hr and influent TOC of 8 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	4.90	0.07	4.98-4.82	4.93-4.80	0.73	0.01	0.74-0.72	0.74-0.72	85.1	0.26	85.4-84.8	85.4-84.9
F <sub>2</sub> /Cr	4.83	0.12	4.96-4.70	4.93-4.70	0.74	0.02	0.76-0.72	0.74-0.71	84.7	0.59	85.4-84.0	85.6-84.3
F <sub>3</sub> /Pb	4.84	0.03	4.88-4.80	4.86-4.80	0.74	0.02	0.76-0.72	0.76-0.72	84.7	0.42	85.2-84.3	85.2-84.4
F <sub>4</sub> /Cd	4.78	0.15	4.95-4.61	4.87-4.60	0.71	0.02	0.73-0.69	0.72-0.69	85.1	0.37	85.5-84.7	85.6-85.0



TABLE A1.6.5: Variation of pH in different filters at a flow rate of 0.2 m/hr and a TOC of 8 mg/l

Filter/ Metal	Influent				Effluent				Drop			
	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	7.8	0.00	7.8-7.8	7.8-7.8	7.3	0.00	7.3-7.3	7.3-7.3	0.5	0.00	0.5-0.5	0.5-0.5
F <sub>2</sub> /Cr	7.8	0.00	7.8-7.8	7.8-7.8	7.3	0.00	7.3-7.3	7.3-7.3	0.5	0.00	0.5-0.5	0.5-0.5
F <sub>3</sub> /Pb	7.7	0.00	7.7-7.7	7.7-7.7	7.3	0.00	7.3-7.3	7.3-7.3	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>4</sub> /Cd	7.8	0.00	7.8-7.8	7.8-7.8	7.3	0.00	7.3-7.3	7.3-7.3	0.5	0.00	0.5-0.5	0.5-0.5



TABLE A1.6.6    Percentage removal efficiencies of different filters in removing faecal coliform at a flow rate of 0.2 m/hr and a TOC of 8 mg/l

Filter/Metal	Influent /100 ml	Effluent /100 ml	% removal
F1/Cu	60000	08	99.99
F2/Cr	60000	06	99.99
F3/Pb	60000	09	99.99
F4/Cd	60000	10	99.99



TABLE A1.7.1: Percentage removal efficiencies of different filters in removing heavy metals at a flow rate of 0.3 m/hr and a TOC of 8 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concentration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concentration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	9400	280	9710-9100	9740-9230	240	20	243-217	260-220	97.5	0.17	97.7-97.3	97.6-97.3
F <sub>2</sub> /Cr	94.6	3.17	98.2-91.0	97.0-91.0	3.70	1.18	5.03-2.40	4.70-2.40	96.1	1.18	97.4-94.8	97.4-95.1
F <sub>3</sub> /Pb	55.5	2.47	58.3-52.7	57.2-52.7	9.40	0.96	10.5-8.3	10.5-8.3	83.0	1.56	84.8-81.3	84.7-81.6
F <sub>4</sub> /Cd	103	4.10	107.6-98.4	107.0-99.0	14.5	2.5	17.3-11.5	17.0-12.0	85.9	2.21	88.4-83.4	88.5-85.5



TABLE A1.7.2: Variation of metal concentration at different depths of the filters at a flow rate of 0.3 m/hr and a TOC of 8 mg/l

Filter/ Metal	0.4m depth					0.8m depth					1.2m depth				
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	
F <sub>1</sub> /Cu	300	20	324-280	320-280		220	24	250-192	240-200		240	20	243-217	260-220	
F <sub>2</sub> /Cr	5.4	0.32	5.80-5.00	5.60-5.00		4.5	0.16	4.7-4.3	4.60-4.30		3.70	1.18	5.03-2.40	4.70-2.40	
F <sub>3</sub> /Pb	24.8	1.31	26.3-23.3	26.0-23.3		18.4	1.96	20.3-16.2	20.3-16.6		9.4	0.96	10.5-8.3	10.5-8.7	
F <sub>4</sub> /Cd	51.2	0.60	51.8-50.5	51.6-50.5		33.4	1.76	35.4-31.4	35.4-33.1		14.5	2.50	17.3-11.7	17.0-12.0	



TABLE A1.7.3: Percentage removal efficiencies of different filters in removing TOC at a flow rate of 0.3 m/hr and influent TOC of 8 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	8.10	0.36	8.52-7.69	8.35-7.65	3.71	0.26	4.00-3.42	3.96-3.45	54.2	1.76	56.2-52.2	56.1-52.4
F <sub>2</sub> /Cr	7.54	0.41	8.00-7.08	7.94-7.13	3.37	0.11	3.50-3.25	3.47-3.26	55.4	1.00	56.5-54.3	56.4-54.4
F <sub>3</sub> /Pb	7.26	0.04	7.31-7.24	7.30-7.23	3.28	0.04	3.33-3.23	3.31-3.23	54.8	0.71	55.6-54.0	55.6-54.2
F <sub>4</sub> /Cd	7.47	0.30	7.80-7.14	7.76-7.17	3.65	0.06	3.73-3.58	3.72-3.63	51.2	1.82	53.3-49.2	52.9-49.3



TABLE A1.7.4: Percentage removal efficiencies of different filters in removing turbidity at a flow rate of 0.3 m/hr and influent TOC of 8 mg/l

Filter/ Metal	Influent					Effluent					% removal			
	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean value	Standard deviation	95% confidence interval	Range of data		
F <sub>1</sub> /Cu	4.90	0.27	5.21-4.60	5.13-4.60	0.84	0.02	0.86-0.82	0.86-0.82	82.9	0.78	83.8-82.0	83.7-82.2		
F <sub>2</sub> /Cr	4.90	0.07	4.98-4.82	4.97-4.83	0.84	0.02	0.86-0.82	0.85-0.82	82.9	0.53	83.5-82.3	83.5-82.5		
F <sub>3</sub> /Pb	4.88	0.08	4.97-4.79	4.93-4.79	0.83	0.02	0.85-0.81	0.85-0.82	83.0	0.17	83.2-82.8	83.2-82.8		
F <sub>4</sub> /Cd	4.91	0.08	5.00-4.81	4.96-4.81	0.83	0.00	0.83-0.83	0.83-0.83	83.1	0.26	83.4-82.8	83.3-82.8		



TABLE A1.7.5: Variation of pH in different filters at a flow rate of 0.3 m/hr and a TOC of 8 mg/l

Filter/ Metal	Influent					Effluent					Drop			
	Mean concen- tration	Standard deviation	95% confidence interval	Range of data		Mean concen- tration	Standard deviation	95% confidence interval	Range of data		Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	7.7	0.00	7.7-7.7	7.7-7.7		7.3	0.00	7.3-7.3	7.3-7.3		0.4	0.00	0.4-0.4	0.4-0.4
F <sub>2</sub> /Cr	7.7	0.00	7.7-7.7	7.7-7.7		7.3	0.00	7.3-7.3	7.3-7.3		0.4	0.00	0.4-0.4	0.4-0.4
F <sub>3</sub> /Pb	7.8	0.00	7.8-7.8	7.8-7.8		7.3	0.00	7.3-7.3	7.3-7.3		0.5	0.00	0.5-0.5	0.5-0.5
F <sub>4</sub> /Cd	7.7	0.00	7.7-7.7	7.7-7.7		7.3	0.00	7.3-7.3	7.3-7.3		0.4	0.00	0.4-0.4	0.4-0.4



TABLE A1.7.6    Percentage removal efficiencies of different filters in removing faecal coliform at a flow rate of 0.3 m/hr and a TOC of 8 mg/l

Filter/Metal	Influent /100 ml	Effluent /100 ml	% removal
F1/Cu	60000	12	99.99
F2/Cr	60000	12	99.99
F3/Pb	60000	16	99.99
F4/Cd	60000	16	99.99



TABLE A1.8.1: Percentage removal efficiencies of different filters in removing heavy metals at a flow rate of 0.4 m/hr and a TOC of 8 mg/l

Filter/ Metal	Influent					Effluent					% removal			
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean value	Standard deviation	95% confidence interval	Range of data		
F <sub>1</sub> /Cu	10220	370	10650-9800	10640-10100	290	20	320-260	300-270	97.1	0.36	97.5-96.7	97.5-97.0		
F <sub>2</sub> /Cr	107.5	11.15	120.1-94.9	120.7-101	5.80	0.61	6.50-5.10	6.50-5.40	94.6	00	94.6-94.6	94.6-94.6		
F <sub>3</sub> /Pb	58.4	1.51	60.1-56.7	59.8-56.8	19.5	0.50	20.0-18.9	20.0-19.0	66.6	0.10	66.7-66.5	66.7-66.5		
F <sub>4</sub> /Cd	95	7.10	103-87	103-89.4	33.3	2.54	36.2-30.4	36.0-31.0	64.9	3.86	69.3-60.5	68.3-61.1		



TABLE A1.8.2: Variation of metal concentration at different depths of the filters at a flow rate of 0.4 m/hr and a TOC of 8 mg/l

Filter/ Metal	0.4m depth					0.8m depth					1.2m depth				
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	
F <sub>1</sub> /Cu	330	10	340-320	340-320		290	20	312-268	310-270		290	20	320-260	300-270	
F <sub>2</sub> /Cr	7.80	0.87	8.80-6.80	8.80-7.40		6.90	0.53	7.5-6.3	7.50-6.7		5.80	0.61	6.50-5.10	6.50-5.40	
F <sub>3</sub> /Pb	34.6	0.60	35.3-33.9	35.2-34.0		24.3	2.29	26.9-21.7	26.2-22.3		19.5	0.50	20.0-18.9	20.0-19.0	
F <sub>4</sub> /Cd	56.8	3.17	60.4-53.2	59.2-53.2		45.6	2.62	48.6-42.6	48.0-42.8		33.3	2.54	36.2-30.4	36.0-31.0	



TABLE A1.8.3: Percentage removal efficiencies of different filters in removing TOC at a flow rate of 0.4 m/hr and influent TOC of 8 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	8.13	0.08	8.22-8.04	8.20-8.10	3.78	0.21	4.05-3.55	4.00-3.60	53.5	2.65	56.5-50.5	56.8-52.5
F <sub>2</sub> /Cr	8.10	0.14	8.26-7.94	8.21-7.96	3.67	0.38	4.10-3.24	4.10-3.40	54.7	1.96	56.9-52.5	57.2-50.0
F <sub>3</sub> /Pb	7.91	0.07	8.00-7.83	7.98-7.84	3.47	0.46	4.00-2.95	3.96-3.04	56.1	1.59	57.8 -54.4	57.0-50.3
F <sub>4</sub> /Cd	7.94	0.07	8.02-7.86	8.00-7.88	3.74	0.32	4.10-3.38	4.10-3.55	52.9	1.50	54.6-51.8	54.6-51.5



TABLE A1.8.4: Percentage removal efficiencies of different filters in removing turbidity at a flow rate of 0.4 m/hr and influent TOC of 8 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concentration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean concentration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	4.81	0.09	4.91-4.71	4.90-4.72	1.03	0.04	1.08-0.98	1.06-0.98	78.6	0.71	79.4-77.8	79.2-77.9
F <sub>2</sub> /Cr	4.82	0.00	4.82-4.82	4.82-4.82	1.05	0.02	1.07-1.03	1.06-1.04	78.1	0.26	78.4-77.8	78.4-77.9
F <sub>3</sub> /Pb	4.82	0.08	4.91-4.74	4.90-4.75	1.07	0.03	1.10-1.04	1.10-1.05	77.8	0.29	78.2-77.5	78.1-77.6
F <sub>4</sub> /Cd	4.79	0.04	4.83 -4.75	4.83-4.76	1.07	0.03	1.10-1.04	1.10-1.05	77.7	0.35	78.1-77.3	78.0-77.3



TABLE A1.8.5: Variation of pH in different filters at a flow rate of 0.4 m/hr and a TOC of 8 mg/l

Filter/ Metal	Influent				Effluent				Drop			
	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>2</sub> /Cr	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>3</sub> /Pb	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.5	0.00	0.5-0.5	0.5-0.5
F <sub>4</sub> /Cd	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4



TABLE A1.8.6    Percentage removal efficiencies of different filters in removing faecal coliform at a flow rate of 0.4 m/hr and a TOC of 8 mg/l

Filter/Metal	Influent /100 ml	Effluent /100 ml	% removal
F1/Cu	60000	32	99.95
F2/Cr	60000	30	99.94
F3/Pb	60000	36	99.93
F4/Cd	60000	38.	99.92



TABLE A1.9.1: Percentage removal efficiencies of different filters in removing heavy metals at a flow rate of 0.1 m/hr and a TOC of 12 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	9310	780	10200-8430	9900-8430	34	03	37-31	36-31	99.6	0.58	100.3-98.9	99.8-99.5
F <sub>2</sub> /Cr	92	5.87	98.6-85.4	96.0-85.0	2.60	0.45	3.11-2.10	3.00 - 2.10	97.2	0.64	97.9-96.5	97.3-96.4
F <sub>3</sub> /Pb	49.1	0.17	49.3-48.9	49.3-49.0	00	00	00-00	00-00	100	00	100-100	100-100
F <sub>4</sub> /Cd	99	5.59	105.3-92.7	105-94.5	3.40	0.55	4.03-2.80	4.00-3.00	96.6	0.35	97.0-96.2	96.8-96.2



TABLE A1.9.2: Variation of metal concentration at different depths of the filters at a flow rate of 0.1 m/hr and a TOC of 12 mg/l

Filter/ Metal	0.4m depth					0.8m depth					1.2m depth				
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	
F <sub>1</sub> /Cu	140	060	210-070	190-060		60	030	90-30	80-30		34	03	37-31	36-31	
F <sub>2</sub> /Cr	3.40	0.71	4.20-2.60	4.00-3.77		2.80	0.41	3.30-2.34	3.00-2.30		2.60	0.45	3.11-2.10	3.00-2.10	
F <sub>3</sub> /Pb	10.7	1.13	12.0-9.40	12.0-10.0		02	1.60	3.76-0.24	4.20-00		00	00	00-00	00-00	
F <sub>4</sub> /Cd	26.6	3.09	30.0-23.1	30.1-22.4		10.6	1.31	12.0-9.12	11.3-4.00		3.40	0.55	4.03-2.80	4.00-3.00	



TABLE A1.9.3: Percentage removal efficiencies of different filters in removing TOC at a flow rate of 0.1 m/hr and influent TOC of 12 mg/l

Filter/ Metal	Influent					Effluent					% removal			
	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean value	Standard deviation	95% confidence interval	Range of data		
F <sub>1</sub> /Cu	12.0	0.25	12.30-11.7	12.3-11.8	4.94	0.41	5.40-4.50	5.32-4.50	58.8	2.65	61.8-55.8	61.9-56.7		
F <sub>2</sub> /Cr	11.9	00	11.9-11.9	11.9-11.9	4.96	0.16	5.14-4.80	5.12-4.80	58.3	1.44	59.9-56.7	59.9-56.9		
F <sub>3</sub> /Pb	11.6	00	11.6-11.6	11.6-11.6	4.90	0.52	5.50-4.31	5.12-4.80	57.8	1.73	59.8-55.8	59.8.8-56.7		
F <sub>4</sub> /Cd	11.90	0.16	12.1-11.7	12.1-11.8	4.95	0.55	5.60-4.30	5.50-4.40	58.3	1.71	60.2-56.4	60.0-56.7		



TABLE A1.9.4: Percentage removal efficiencies of different filters in removing turbidity at a flow rate of 0.1 m/hr and influent TOC of 12 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concentration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean concentration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	6.85	0.00	6.85-6.85	6.85-6.85	0.64	0.00	0.64-0.64	0.64-0.64	90.7	0.47	91.3-90.2	90.8-90.1
F <sub>2</sub> /Cr	6.80	0.00	6.80-6.80	6.80-6.80	0.64	0.02	0.66-0.62	0.66-0.62	90.6	0.52	91.2-90.0	91.2-90.3
F <sub>3</sub> /Pb	6.80	0.00	6.80-6.80	6.80-6.80	0.63	0.07	0.71-0.55	0.67-0.60	90.7	0.39	91.2-90.3	90.9-90.2
F <sub>4</sub> /Cd	6.80	0.00	6.80 -6.80	6.80-6.80	0.63	0.00	0.63-0.63	0.63-0.63	90.7	00	90.7-90.7	90.7-90.7



TABLE A1.9.5: Variation of pH in different filters at a flow rate of 0.1 m/hr and a TOC of 12 mg/l

Filter/ Metal	Influent					Effluent					Drop				
	Mean concen- tration	Standard deviation	95% confidence interval	Range of data		Mean concen- tration	Standard deviation	95% confidence interval	Range of data		Mean value	Standard deviation	95% confidence interval	Range of data	
F <sub>1</sub> /Cu	7.8	0.00	7.8-7.8	7.8-7.8		7.3	0.00	7.3-7.3	7.3-7.3		0.5	0.00	0.5-0.5	0.5-0.5	
F <sub>2</sub> /Cr	7.8	0.00	7.8-7.8	7.8-7.8		7.3	0.00	7.3-7.3	7.3 -7.3		0.5	0.00	0.5-0.5	0.5-0.5	
F <sub>3</sub> /Pb	7.8	0.00	7.8-7.8	7.8-7.8		7.3	0.00	7.3-7.3	7.3-7.3		0.5	0.00	0.5-0.5	0.5-0.5	
F <sub>4</sub> /Cd	7.8	0.00	7.8-7.8	7.8-7.8		7.3	0.00	7.3-7.3	7.3-7.3		0.5	0.00	0.5-0.5	0.5-0.5	



TABLE A1.9.6    Percentage removal efficiencies of different filters in removing faecal coliform at a flow rate of 0.1 m/hr and a TOC of 12 mg/l

Filter/Metal	Influent /100 ml	Effluent /100 ml	% removal
F1/Cu	60000	03	100
F2/Cr	60000	03	100
F3/Pb	60000	04	100
F4/Cd	60000	04	100



TABLE A1.10.1: Percentage removal efficiencies of different filters in removing heavy metals at a flow rate of 0.2 m/hr and a TOC of 12 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	9100	910	10100-8100	9860-8100	150	50	210-100	200-110	98.3	0.45	98.8-97.8	98.8-97.9
F <sub>2</sub> /Cr	102.7	1.16	104-101.4	104-102	2.80	0.57	3.50-2.20	3.30 - 2.20	97.2	0.67	98.0-96.5	97.8-96.5
F <sub>3</sub> /Pb	57.2	3.58	61.3-53.2	61.3-55.0	4.2	1.61	6.00-2.38	6.00-3.00	92.7	2.27	95.3-90.2	94.5-90.2
F <sub>4</sub> /Cd	93	6.16	99.9-86.0	99.9-88.0	7.10	2.76	10.3-3.98	9.30-4.00	92.4	3.12	95.9-988.9	95.6-89.4



TABLE A1.10.2: Variation of metal concentration at different depths of the filters at a flow rate of 0.2 m/hr and a TOC of 12 mg/l

Filter/ Metal	0.4m depth					0.8m depth					1.2m depth				
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)		Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	
F <sub>1</sub> /Cu	230	060	300-160	270-160		140	40	185-95	180-100		150	50	210-100	200-110	
F <sub>2</sub> /Cr	4.30	0.51	4.90-3.72	4.70-3.70		3.70	0.55	4.32-3.08	3.70-3.20		2.80	0.57	3.50-2.20	3.30-2.20	
F <sub>3</sub> /Pb	20	1.73	22.0-18.0	22.0-19.0		7.50	2.54	10.4-4.62	10.4-6.00		4.2	1.61	6.00-2.38	6.00-3.00	
F <sub>4</sub> /Cd	24.5	0.92	25.6-23.5	35.5-23.7		20.2	4.72	25.6-14.9	25.3-16.0		7.1	2.76	10.3-3.98	9.3-4.00	



TABLE A1.10.3: Percentage removal efficiencies of different filters in removing TOC at a flow rate of 0.2 m/hr and influent TOC of 12 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	11.8	0.17	12.0-11.6	11.9-11.6	4.90	0.11	5.03-4.78	5.00-4.80	58.5	0.36	58.9-58.1	58.6-58.0
F <sub>2</sub> /Cr	11.8	00	11.8-11.8	11.8-11.8	4.80	0.16	4.98-4.72	5.00-4.80	59.3	1.33	60.8-57.8	61.0-58.5
F <sub>3</sub> /Pb	11.7	0.16	11.9-11.5	11.8-11.5	4.80	0.10	4.91-4.70	4.90-4.70	58.9	0.35	59.3-58.5	59.2-58.5
F <sub>4</sub> /Cd	11.8	0.10	11.9-11.7	11.9-11.7	4.90	0.08	5.00-4.80	4.90-4.80	58.5	0.35	58.9-58.0	58.9-58.5



TABLE A1.10.4: Percentage removal efficiencies of different filters in removing turbidity at a flow rate of 0.2 m/hr and influent TOC of 12 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	6.76	0.05	6.81-6.71	6.80-6.72	0.83	00	0.83-0.83	0.83-0.83	87.8	00	87.8-87.8	87.8-87.8
F <sub>2</sub> /Cr	6.76	0.05	6.81-6.71	6.80-6.72	0.83	00	0.83-0.83	0.83-0.83	87.8	00	87.8-87.8	87.8-87.8
F <sub>3</sub> /Pb	6.70	0.03	6.73-6.68	6.73-6.70	0.84	0.01	0.85-0.83	0.85-0.83	87.5	0.16	87.7-87.3	87.7-87.4
F <sub>4</sub> /Cd	6.77	0.03	6.81 -6.73	6.80-6.74	0.84	00	0.84-0.84	0.84-0.84	87.7	00	87.7-87.7	87.7-87.7



TABLE A1.10.5: Variation of pH in different filters at a flow rate of 0.2 m/hr and a TOC of 12 mg/l

Filter/ Metal	Influent				Effluent				Drop			
	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>2</sub> /Cr	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4 -7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>3</sub> /Pb	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>4</sub> /Cd	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4



TABLE A1.10.6    Percentage removal efficiencies of different filters in removing faecal coliform at a flow rate of 0.2 m/hr and a TOC of 12 mg/l

Filter/Metal	Influent /100 ml	Effluent /100 ml	% removal
F1/Cu	60000	12	99.99
F2/Cr	60000	10	99.99
F3/Pb	60000	18	99.99
F4/Cd	60000	16	99.99



TABLE A1.11.1: Percentage removal efficiencies of different filters in removing heavy metals at a flow rate of 0.3 m/hr and a TOC of 12 mg/l

Filter/ Metal	Influent					Effluent					% removal			
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean value	Standard deviation	95% confidence interval	Range of data		
F <sub>1</sub> /Cu	8600	465	9126-8073	9070-8140	190	10	201.3-178.6	200-180	97.8	0.17	98.0-97.6	98.0-97.7		
F <sub>2</sub> /Cr	100.5	9.52	111-89.7	109-90.5	4.20	1.91	6.30-2.1	5.6-2.0	95.8	2.10	98.2-93.4	98.2-94.5		
F <sub>3</sub> /Pb	52.7	2.51	55.5-49.9	55.4-50.5	4.40	0.82	5.30-3.50	5.0-3.50	91.6	1.27	93.2-90.7	93.1-90.4		
F <sub>4</sub> /Cd	94.8	3.37	98.6-91	98.5-92	11.0	0.85	12.0-10.0	11.9-10.2	88.4	1.25	89.7-86.9	89.7-87.3		



TABLE A1.11.2:

Variation of metal concentration at different depths of the filters at a flow rate of 0.3 m/hr and a TOC of 12 mg/l

Filter/ Metal	0.4m depth					0.8m depth					1.2m depth				
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)			
F <sub>1</sub> /Cu	270	080	360-180	380-220	200	40	245-155	220-180	190	10	201.3-178.6	200-180			
F <sub>2</sub> /Cr	6.70	3.70	10.9-2.50	9.7-2.5	5.00	1.64	6.85-3.15	6.7-2.3	4.20	1.91	6.30-2.10	5.60-2.00			
F <sub>3</sub> /Pb	17.5	2.15	19.9-15.1	20-16	6.70	0.71	7.50-5.90	7.40-6.00	4.40	0.82	5.30-3.50	5.00-3.50			
F <sub>4</sub> /Cd	46.7	4.10	51.3-42.1	50.6-42.4	33.2	2.05	35.5-30.9	35.0-31.0	11.0	0.85	12.0-10.0	12.0-10.0			



TABLE A1.11.3:      Percentage removal efficiencies of different filters in removing TOC at a flow rate of 0.3 m/hr and influent TOC of 12 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	11.9	0.42	12.3-11.4	12.3-11.5	5.10	00	5.10-5.10	5.10-5.10	57.0	1.34	58.5-55.5	58.0-55.6
F <sub>2</sub> /Cr	11.8	00	11.8-11.8	11.8-11.8	5.25	0.21	5.50-5.00	5.30-4.96	56.4	1.46	58.0-54.4	57.5-54.5
F <sub>3</sub> /Pb	11.7	0.1	11.8-11.7	11.8-11.7	5.25	0.07	5.33-5.16	5.30-5.16	55.6	0.57	56.2-54.9	56.0-55.0
F <sub>4</sub> /Cd	11.4	0.4	11.9-10.9	11.8-11.0	5.00	0.30	5.33-4.66	5.25-4.78	56.0	0.47	56.5-55.5	56.4-55.5



TABLE A1.11.4: Percentage removal efficiencies of different filters in removing turbidity at a flow rate of 0.3 m/hr and influent TOC of 12 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	6.60	00	6.60-6.60	6.60-6.60	0.95	0.01	0.96-0.94	0.96-0.94	85.6	0.17	85.8-85.8	85.8-85.8
F <sub>2</sub> /Cr	6.90	0.07	6.98-6.82	6.92-6.80	0.95	0.01	0.96-0.94	0.96-0.94	86.2	0.06	86.1-86.1	86.1-86.1
F <sub>3</sub> /Pb	6.50	0.17	6.70-6.30	6.60-6.40	0.94	0.01	0.94-0.92	0.94-0.92	85.8	0.46	86.4-86.0	86.4-86.0
F <sub>4</sub> /Cd	6.50	0.07	6.58-6.42	6.60-6.50	0.95	0.01	0.95-0.94	0.95-0.94	85.6	0.35	88.5-88.5	88.5-88.5



TABLE A1.11.5: Variation of pH in different filters at a flow rate of 0.3 m/hr and a TOC of 12 mg/l

Filter/ Metal	Influent				Effluent				Drop			
	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	7.7	0.00	7.7-7.7	7.7-7.7	7.3	0.00	7.3-7.3	7.3-7.3	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>2</sub> /Cr	7.7	0.00	7.7-7.7	7.7-7.7	7.3	0.00	7.3-7.3	7.3 -7.3	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>3</sub> /Pb	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>4</sub> /Cd	7.7	0.00	7.7-7.7	7.7-7.7	7.3	0.00	7.3-7.3	7.3-7.3	0.4	0.00	0.4-0.4	0.4-0.4



TABLE A1.11.6    Percentage removal efficiencies of different filters in removing faecal coliform at a flow rate of 0.3 m/hr and a TOC of 12 mg/l

Filter/Metal	Influent /100 ml	Effluent /100 ml	% removal
F1/Cu	60000	20	99.99
F2/Cr	60000	25	99.99
F3/Pb	60000	25	99.99
F4/Cd	60000	30	99.99



TABLE A1.12.1: Percentage removal efficiencies of different filters in removing heavy metals at a flow rate of 0.4 m/hr and a TOC of 12 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	9860	40	9905-9815	9900-9820	270	10	281-259	280-260	97.3	0.17	97.5-97.1	97.3-97.2
F <sub>2</sub> /Cr	99.7	2.08	102-97.4	102-98	4.90	0.12	5.04-4.76	5.00-4.80	95.1	0.12	95.3-95.0	95.3-95.2
F <sub>3</sub> /Pb	55.9	1.92	58.1-53.7	58.0-54.3	16.5	1.33	18.0-15.0	18.0-15.0	70.4	1.32	71.9-68.9	71.7-69.0
F <sub>4</sub> /Cd	96.2	1.70	98.1-94.3	98.0-94.6	30.7	1.10	31.9-29.5	32.0-30.0	68.1	0.70	68.9-67.3	68.8-67.5



TABLE A1.12.2: Variation of metal concentration at different depths of the filters at a flow rate of 0.4 m/hr and a TOC of 12 mg/l

Filter/ Metal	0.4m depth					0.8m depth					1.2m depth				
	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)	Mean concen- tration (µg/l)	Standard deviation	95% confidence interval (µg/l)	Range of data (µg/l)			
F <sub>1</sub> /Cu	300	7	308-292	310-300	270	26	300-240	300-260	270	10	281-259	280-260			
F <sub>2</sub> /Cr	7	0.10	7.12-6.90	7.10-7.10	6.10	0.08	6.10-6.00	6.10-6.00	4.90	0.12	5.04-4.76	5.0-4.8			
F <sub>3</sub> /Pb	29.8	0.47	30.3-29.3	30.3-29.4	21.0	0.35	21.4-20.6	21.3-20.6	16.5	1.33	18.0-15.0	18.0-15.0			
F <sub>4</sub> /Cd	48.1	0.61	48.8-47.4	48.6-47.2	39.5	0.56	40.1-38.9	40.0-38.9	30.7	1.10	31.9-29.5	32.0-30.0			



TABLE A1.12.3:                      Percentage removal efficiencies of different filters in removing TOC at a flow rate of 0.4 m/hr and influent TOC of 12 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean concen- tration (mg/l)	Standard deviation	95% confidence interval (mg/l)	Range of data (mg/l)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	12.0	0.10	12.1-11.9	12.1-11.9	5.10	0.08	5.1-5.0	5.1-5.0	57.5	0.95	58.5-56.4	58.5-56.6
F <sub>2</sub> /Cr	11.9	0.10	12.0-11.8	12.0-11.8	5.20	0.17	5.4-5.0	5.3-5.0	56.2	1.32	57.7-54.7	57.5-55.0
F <sub>3</sub> /Pb	11.9	00	11.9-11.9	11.9-11.9	5.30	0.02	5.32-5.27	5.31-5.27	55.5	0.23	55.8-55.2	55.7-55.4
F <sub>4</sub> /Cd	11.6	0.10	11.7-11.5	11.7-11.5	5.10	0.04	5.15-5.05	5.15-5.10	56.0	0.45	56.5-55.5	56.4-55.6



TABLE A1.12.4: Percentage removal efficiencies of different filters in removing turbidity at a flow rate of 0.4 m/hr and influent TOC of 12 mg/l

Filter/ Metal	Influent				Effluent				% removal			
	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean concen- tration (NTU)	Standard deviation	95% confidence interval (NTU)	Range of data (NTU)	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	6.90	00	6.90-6.90	6.90-6.90	1.07	0.01	1.08-1.07	1.08-1.07	84.5	0.15	84.7-84.3	84.7-84.3
F <sub>2</sub> /Cr	6.90	00	6.90-6.90	6.90-6.90	1.07	0.01	1.08-1.07	1.08-1.07	84.5	0.06	84.6-84.4	84.6-84.4
F <sub>3</sub> /Pb	6.70	00	6.70-6.70	6.70-6.70	1.06	0.01	1.07-1.06	1.07-1.06	84.3	0.27	84.6-84.0	84.6-84.0
F <sub>4</sub> /Cd	6.70	00	6.70-6.70	6.70-6.70	1.07	0.01	1.08-1.07	1.08-1.07	84.0	0.15	84.2-83.8	84.2-83.8



TABLE A1.12.5: Variation of pH in different filters at a flow rate of 0.4 m/hr and a TOC of 12 mg/l

Filter/ Metal	Influent				Effluent				Drop			
	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean concen- tration	Standard deviation	95% confidence interval	Range of data	Mean value	Standard deviation	95% confidence interval	Range of data
F <sub>1</sub> /Cu	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>2</sub> /Cr	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4 -7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>3</sub> /Pb	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.4-7.4	0.4	0.00	0.4-0.4	0.4-0.4
F <sub>4</sub> /Cd	7.8	0.00	7.8-7.8	7.8-7.8	7.4	0.00	7.4-7.4	7.3-7.3	0.4	0.00	0.4-0.4	0.4-0.4



TABLE A1.12.6    Percentage removal efficiencies of different filters in removing faecal coliform at a flow rate of 0.4 m/hr and a TOC of 12 mg/l

Filter/Metal	Influent /100 ml	Effluent /100 ml	% removal
F1/Cu	60000	34	99.99
F2/Cr	60000	36	99.99
F3/Pb	60000	42	99.99
F4/Cd	60000	46	99.99



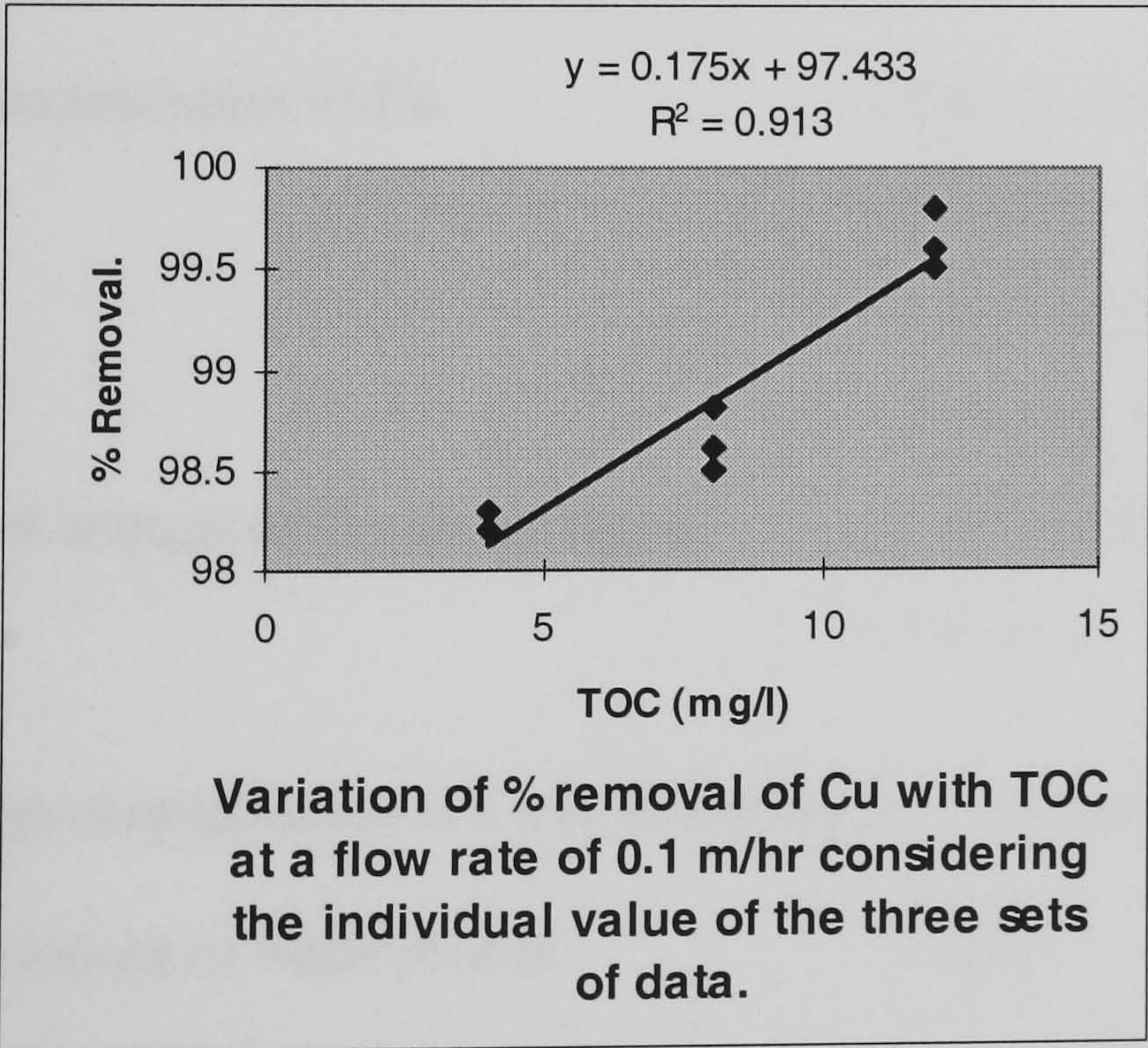
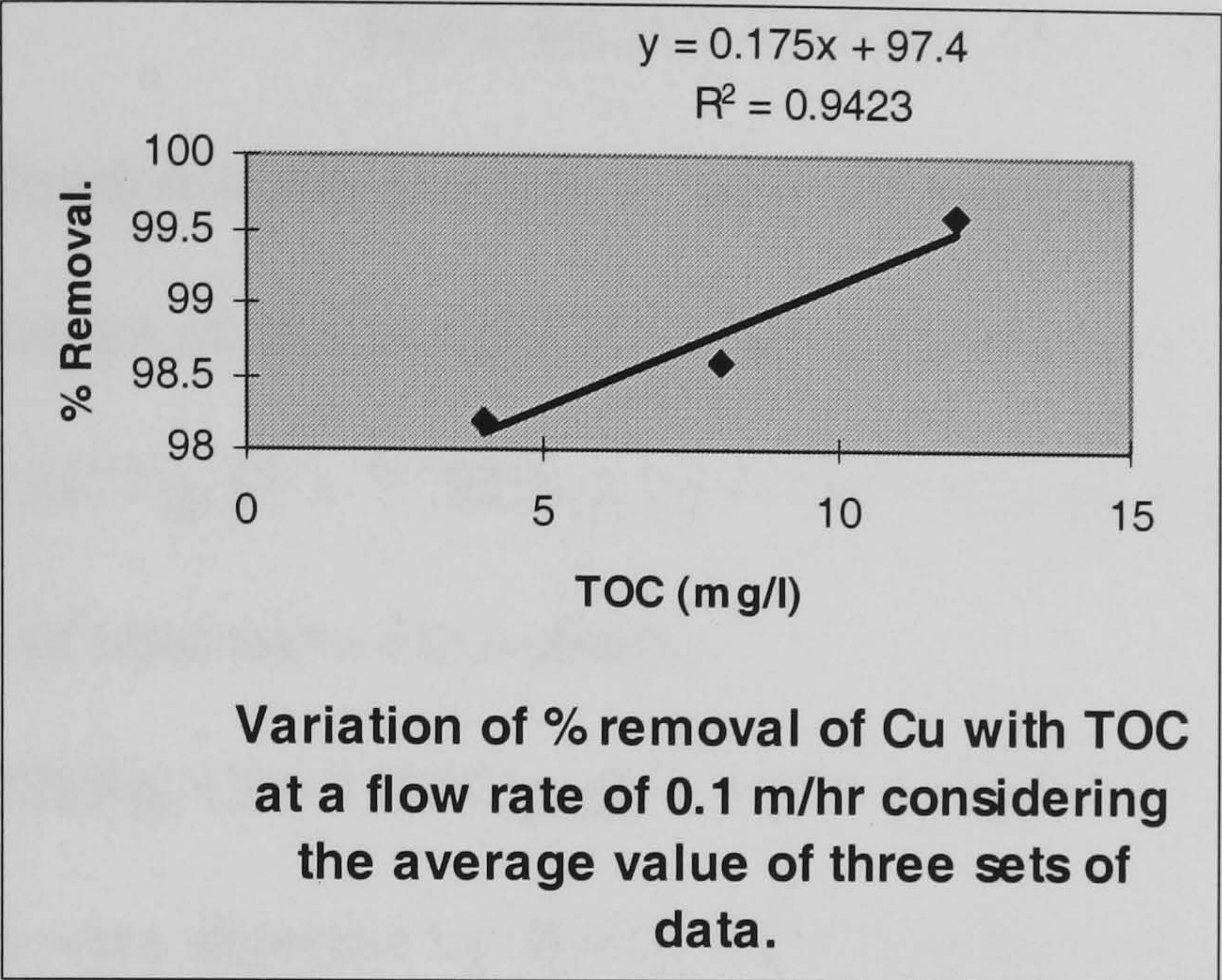


Figure A1.1 Comparison between the regression equations comprising of average and individual sets of data.



## ANNEX 2

# EXPERIMENTAL DATA AND RELATED CALCULATIONS FOR THE MICROBIAL UPTAKE OF HEAVY METALS BY SLOW SAND FILTERS.

## TEST RESULTS FOR THE FIRST SET

### **Determination of the amount of metal accumulation in the Schmutzdecke:**

Total Amount of sand scraped from the schmutzdecke:

Cu = 84.2477 g, Cr = 75.0230 g, Pb = 84.0750 g and Cd = 81.0349 g.

Amount of sand taken for analysis:

Cu = 0.7769 g, Cr = 1.3701 g, pb = 1.2017 g and Cd = 1.2335 g.

Samples were digested by HNO<sub>3</sub>- HCl digestion and 100 mls of each sample was taken for analysis. Dilution was made if required.

## Copper

The concentration of Cu  $= 154.43 \text{ mg/l}$   
 $= 15.443 \text{ mg/100 ml.}$   
 $= 15.443 \text{ mg/ 0.7769 g of sand.}$   
 $= 19.88 \text{ mg /g of sand.}$

So total amount of Cu accumulated  $= 19.88 \times 84.2477 \text{ g}$   
 $= 1674.6 \text{ g.}$

Average concentration of Cu in the influent = 9.37 mg/l

Total amount of water passed = 1215 l

$$\begin{aligned}\text{So total amount of Cu input} &= 1215 \times 9.37 \text{ mg} \\ &= 11384.55 \text{ mg}\end{aligned}$$

Cu accumulated in the schmutzdecke as a % of total Cu passing

$$= 1674.6/11384.55 \times 100 \%$$
$$= 14.7 \%$$



## ***Chromium***

$$\begin{aligned}\text{The concentration of Cr} &= 2.5045 \text{ mg/l} \\ &= 0.25045 \text{ mg/100 ml} \\ &= 0.25045 / 1.3701 \text{ mg / g of sand} \\ &= 0.1828 \text{ mg / g of sand}\end{aligned}$$

$$\begin{aligned}\text{So total amount of Cr accumulated in the schmutzdecke} &= 0.18 \times 75.023 \text{ mg} \\ &= 13.7134 \text{ mg}\end{aligned}$$

$$\text{Average concentration of Cr in the influent} = 77.4 \text{ } \mu\text{g/l}$$

$$\begin{aligned}\text{Total amount of Cr} &= 77.4 \times 1215 \text{ } \mu\text{g} \\ &= 94041 \text{ } \mu\text{g} \\ &= 94.041 \text{ mg}\end{aligned}$$

Cr accumulated in the schmutzdecke as a % of total Cr passing

$$\begin{aligned}&= 13.7134/94.041 \times 100 \% \\ &= 14.6 \%\end{aligned}$$

## ***Lead***

$$\begin{aligned}\text{The concentration of Pb} &= 0.5547 \text{ mg/l} \\ &= 0.05547 \text{ mg/100 ml} \\ &= 0.05547 \text{ mg / 1.2017 g of sand} \\ &= 0.04615 \text{ mg / g of sand}\end{aligned}$$

$$\begin{aligned}\text{Total amount of Pb accumulated} &= 0.04615 \times 84.0751 \text{ mg} \\ &= 3.88 \text{ mg}\end{aligned}$$

$$\text{Average concentration of Pb in the influent} = 35.2 \text{ } \mu\text{g /l}$$

$$\begin{aligned}\text{Total amount of Pb input} &= 35.2 \times 1215 \text{ } \mu\text{g} \\ &= 42768 \text{ } \mu\text{g}\end{aligned}$$



$$= 42.768 \text{ mg}$$

Pb accumulated in the schmutzdecke as a % of total Pb passing

$$= 3.88 / 42.768 \times 100 \%$$

$$= 9.08 \%$$

### ***Cadmium***

The concentration of Cd

$$= 150.49 \text{ } \mu\text{g / l}$$

$$= 15.049 \text{ } \mu\text{g / 100 ml.}$$

$$= 15.049 \text{ } \mu\text{g / 1.2335 g of sand}$$

$$= 12.197 \text{ } \mu\text{g/ g of sand}$$

Total amount of Cd accumulated

$$= 12.197 \times 81.0349 \text{ } \mu\text{g}$$

$$= 988.34 \text{ } \mu\text{g}$$

Average concentration of Cd in the influent = 75  $\mu\text{g / l}$

Total amount of Cd input

$$= 75 \times 1215 \text{ } \mu\text{g}$$

$$= 91125 \text{ } \mu\text{g}$$

Cd accumulated in the schmutzdecke as a % of total Cd passing

$$= 988.34 / 91125 \times 100 \%$$

$$= 1.09 \%$$

Note : The average concentration of different heavy metals were determined considering the whole period before cleaning. At the beginning, the filters were run without any metal.



### Estimation of Biomass:

The percentage N content of the Volatile Solids (VS) is considered as the active biomass. Total Solids, Volatile Solids and N content were determined by standard method.

***Copper***                      ***Total Solids, Volatile Solids and N content***

***Total Solids (TS)***

Table A2.1 Experimental data for TS

Sample No	Weight of sand (g)	Wt of sand after drying at 105°C (g)	Percentage of TS	Average Percentage of TS
1	6.1528	2.5227	41	40.55
2	6.4016	2.5606	40.1	

Therefore percentage of TS = 40.55 %

$$\begin{aligned}\text{So total weight of TS} &= 84.2447 \times 0.4055 \\ &= 34.16 \text{ g}\end{aligned}$$

### *Volatile Solids (VS)*

Table A2.2 Experimental data for VS

Sample No	Weight of TS (g)	Wt of sand after drying at 550°C (g)	Percentage of VS	Average Percentage of VS
1	2.5216	2.4427	3.17	3.32
2	2.5606	2.4721	3.46	

Percentage of VS of TS = 3.32 %

$$\begin{aligned}\text{Total weight of VS} &= 34.16 \times 0.0332 \\ &= 1.1341 \text{ g}\end{aligned}$$

### **Total Nitrogen**



The total nitrogen content was determined by the standard Kjeldahl method. The following formula was used for calculation:

Total N in mg/g of sand = 14.01 × 0.02 × ( S- B) / W

Where 14.01 = atomic weight of nitrogen  
0.02 = molarity of acid used.  
S = sample titration  
B = blank titration  
W = weight of the sample digested

So total N in the Cu containing sand = 14.01 × 0.02 × ( 12.20- 1.90) / 6.50  
= 0.4441 mg of N / g o sand.

Therefore amount of N = 0.4441 × 84.2474 mg  
= 37.41 mg  
= 0.03741g  
So percentage N of VS = 0.03741/1.1341 × 100 %  
= 3.30 %

So biomass for Cu containing filter schmutzdecke = 3.30 % of VS.

**Chromium                      Total Solids, Volatile Solids and N content**

**Total Solids (TS)**

Table A2.3 Experimental data for TS

Sample No	Weight of sand (g)	Wt of sand after drying at 105°C (g)	Percentage of TS	Average Percentage of TS
1	6.2320	2.6174	42	41.85
2	6.3125	2.6071	41.7	

Therefore percentage of TS = 41.85%



So total weight of TS
= 75.0203 × 0.4185
= 31.40 g

***Volatile Solids (VS)***

Table A2.4 Experimental data for VS

Sample No	Weight of TS (g)	Wt of sand after drying at 550°C (g)	Percentage of VS	Average Percentage of VS
1	2.6174	2.5608	2.16	2.12
2	2.6071	2.5529	2.08	

Percentage of VS of TS
= 2.12 %

Total weight of VS
=31.40 × 0.0212
= 0.6657 g

***Total Nitrogen***

The total nitrogen content was determined by the standard Kjeldahl method. The following formula was used for calculation:

Total N in mg/g of sand
= 14.01 × 0.02 × ( S- B) / W

So total N in the Cu containing sand = 14.01 × 0.02 × ( 10.60- 3.90) / 6.50
= 0.2893 mg of N / g of sand.

Therefore amount of N
= 0.2893 × 75.0203 mg
= 21.7 mg
= 0.0217 g

So percentage N of VS
= 0.0217/0.6657 × 100 %
= 3.26 %

So biomass for Cu containing filter schmutzdecke = 3.26 % of VS.



***Lead***                      ***Total Solids, Volatile Solids and N content***

***Total Solids (TS)***

Table A2.5 Experimental data for TS

Sample No	Weight of sand (g)	Wt of sand after drying at 105°C (g)	Percentage of TS	Average Percentage of TS
1	6.2190	3.0224	48.6	48.80
2	6.3320	3.1037	49	

Therefore percentage of TS = 48.80%

$$\begin{aligned}\text{So total weight of TS} &= 84.074 \times 0.4880 \\ &= 41.03 \text{ g}\end{aligned}$$

### ***Volatile Solids (VS)***

Table A2.6 Experimental data for VS

Sample No	Weight of TS (g)	Wt of sand after drying at 550°C (g)	Percentage of VS	Average Percentage of VS
1	3.0224	2.9317	3.0	2.95
2	3.1027	3.0128	290	

Percentage of VS of TS = 2.95 %

$$\begin{aligned}\text{Total weight of VS} &= 41.03 \times 0.0295 \\ &= 1.2104 \text{ g}\end{aligned}$$

### ***Total Nitrogen***

The total nitrogen content was determined by the standard Kjeldahl method. The following formula was used for calculation:



$$\text{Total N in mg/g of sand} = 14.01 \times 0.02 \times (S - B) / W$$

$$\begin{aligned} \text{So total N in the Cu containing sand} &= 14.01 \times 0.02 \times (10.90 - 3.00) / 6.40 \\ &= 0.3021 \text{ mg of N / g of sand.} \end{aligned}$$

$$\begin{aligned} \text{Therefore amount of N} &= 0.3021 \times 84.075 \text{ mg} \\ &= 25.4 \text{ mg} \\ &= 0.0254 \text{ g} \end{aligned}$$

$$\begin{aligned} \text{So percentage N of VS} &= 0.0254 / 1.2104 \times 100 \% \\ &= 2.10 \% \end{aligned}$$

So biomass for Cu containing filter schmutzdecke = 2.10 % of VS.

**Cadmium                      Total Solids, Volatile Solids and N content**

**Total Solids (TS)**

Table A2.7 Experimental data for TS

Sample No	Weight of sand (g)	Wt of sand after drying at 105°C (g)	Percentage of TS	Average Percentage of TS
1	6.2560	3.2844	52.5	52.54
2	6.3410	3.3341	52.58	

$$\text{Therefore percentage of TS} = 52.54 \%$$

$$\begin{aligned} \text{So total weight of TS} &= 81.0349 \times 0.5254 \\ &= 42.58 \text{ g} \end{aligned}$$



***Volatile Solids (VS)***

Table A2.8 Experimental data for VS

Sample No	Weight of TS (g)	Wt of sand after drying at 550°C (g)	Percentage of VS	Average Percentage of VS
1	3.2844	3.2023	2.50	2.49
2	3.3341	3.2514	2.48	

Percentage of VS of TS

= 2.49 %

Total weight of VS

=42.58 × 0.0249

= 1.061 g

***Total Nitrogen***

The total nitrogen content was determined by the standard Kjeldahl method. The following formula was used for calculation:

Total N in mg/g of sand

= 14.01 × 0.02 × ( S- B) / W

So total N in the Cu containing sand = 14.01 × 0.02 × ( 10.0- 3.90) / 6.50

= 0.2592 mg of N / g of sand.

Therefore amount of N

= 0.2592 × 81.0349 mg

= 21 mg

= 0.021 g

So percentage N of VS

= 0.021/1.061 × 100 %

= 1.90 %

So biomass for Cu containing filter schmutzdecke = 1.90 % of VS.



## TEST RESULTS FOR THE SECOND SET

### Determination of the amount of metal accumulation in the Schmutzdecke:

Total Amount of sand scrapped from the schmutzdecke:

Cu = 125.3300 g, Cr = 80.5050 g, Pb = 83.0924g and Cd = 90.7371 g.

Amount of sand taken for analysis:

Cu = 1.20 g, Cr = 2.30 g, pb = 2.11 g and Cd = 2.00 g.

Samples were digested by HNO<sub>3</sub>- HCl digestion and 100 mls of each sample was taken for analysis. Dilution was made if required.

### *Copper*

The concentration of Cu = 308.9 mg/l  
= 30.89mg/100 ml.  
= 30.89 mg/ 1.2 g of sand.  
= 25.74 mg /g of sand.  
So total amount of Cu accumulated = 25.74 × 125.33 g  
= 3225.68 g.

Average concentration of Cu in the influent = 8.00 mg/l

Total amount of water passed = 2860 l

So total amount of Cu input = 2860 × 8.00 mg  
= 22880 mg

Cu accumulated in the schmutzdecke as a % of total Cu passing

$$= 3225.68/22880 \times 100 \%$$
$$= 14.1 \%$$

### *Chromium*

The concentration of Cr = 12.5225 mg/l



$$\begin{aligned}
 &= 1.25225 \text{ mg/100 ml} \\
 &= 1.25225 / 2.3 \text{ mg / g of sand} \\
 &= 0.545 \text{ mg / g of sand}
 \end{aligned}$$

$$\begin{aligned}
 \text{So total amount of Cr accumulated in the schmutzdecke} &= 0.545 \times 80.505 \text{ mg} \\
 &= 43.88 \text{ mg}
 \end{aligned}$$

$$\text{Average concentration of Cr in the influent} = 101 \text{ } \mu\text{g/l}$$

$$\begin{aligned}
 \text{Total amount of Cr} &= 101 \times 2860 \text{ } \mu\text{g} \\
 &= 288860 \text{ } \mu\text{g} \\
 &= 288.60 \text{ mg}
 \end{aligned}$$

$$\begin{aligned}
 \text{Cr accumulated in the schmutzdecke as a \% of total Cr passing} \\
 &= 43.88/288.60 \times 100 \% \\
 &= 15.2 \%
 \end{aligned}$$

### ***Lead***

$$\begin{aligned}
 \text{The concentration of Pb} &= 2.774 \text{ mg/l} \\
 &= 0.2774 \text{ mg/100 ml} \\
 &= 0.2774 \text{ mg / 2.1 g of sand} \\
 &= 0.1321 \text{ mg / g of sand}
 \end{aligned}$$

$$\begin{aligned}
 \text{Total amount of Pb accumulated} &= 0.1321 \times 83.0924 \text{ mg} \\
 &= 10.970
 \end{aligned}$$

$$\text{Average concentration of Pb in the influent} = 45.0 \text{ } \mu\text{g /l}$$

$$\begin{aligned}
 \text{Total amount of Pb input} &= 45.0 \times 2860 \text{ } \mu\text{g} \\
 &= 128700 \text{ } \mu\text{g} \\
 &= 128.7 \text{ mg}
 \end{aligned}$$

$$\begin{aligned}
 \text{Pb accumulated in the schmutzdecke as a \% of total Pb passing} \\
 &= 10.97/ 128.7 \times 100 \%
 \end{aligned}$$



$$= 8.53 \%$$

### ***Cadmium***

$$\begin{aligned} \text{The concentration of Cd} &= 752.25 \mu\text{g / l} \\ &= 75.225 \mu\text{g / 100 ml.} \\ &= 75.225 \mu\text{g / 2 g of sand} \\ &= 37.6125 \mu\text{g/ g of sand} \end{aligned}$$

$$\begin{aligned} \text{Total amount of Cd accumulated} &= 37.6125 \times 90.7371 \mu\text{g} \\ &= 3412.85 \mu\text{g} \end{aligned}$$

$$\text{Average concentration of Cd in the influent} = 92 \mu\text{g / l}$$

$$\begin{aligned} \text{Total amount of Cd input} &= 92 \times 2860 \mu\text{g} \\ &= 263120 \mu\text{g} \end{aligned}$$

Cd accumulated in the schmutzdecke as a % of total Cd passing

$$\begin{aligned} &= 3413 / 263120 \times 100 \% \\ &= 1.30 \%. \end{aligned}$$

### **Estimation of Biomass:**

The percentage N content of the Volatile Solids (VS) is considered as the active biomass. Total Solids, Volatile Solids and N content were determined by standard method.

### ***Copper                      Total Solids, Volatile Solids and N content***

#### ***Total Solids (TS)***

Table A2.9 Experimental data for TS

Sample No	Weight of sand (g)	Wt of sand after drying at 105°C (g)	Percentage of TS	Average Percentage of TS
1	6.2130	2.4852	40	39.69
2	6.2980	2.4776	39.34	



Therefore percentage of TS = 39.69 %

So total weight of TS = 125.33 × 0.3969  
= 49.72 g

***Volatile Solids (VS)***

Table A2.10 Experimental data for VS

Sample No	Weight of TS (g)	Wt of sand after drying at 550°C (g)	Percentage of VS	Average Percentage of VS
1	2.4852	2.4056	3.20	3.23
2	2.4776	2.3968	3.26	

Percentage of VS of TS = 3.23 %

Total weight of VS = 49.72 × 0.0323  
= 1.61 g

***Total Nitrogen***

The total nitrogen content was determined by the standard Kjeldahl method. The following formula was used for calculation:

Total N in mg/g of sand = 14.01 × 0.02 × ( S- B) / W  
So total N in the Cu containing sand = 14.01 × 0.02 × ( 12.50- 1.70) / 6.50  
= 0.4676 mg of N / g of sand.

Therefore amount of N = 0.4676 × 125.33 mg  
= 58.604 mg  
= 0.0586 g

So percentage N of VS = 0.0586/1.61 × 100 %  
= 3.64 %

So biomass for Cu containing filter schmutzdecke = 3.64 % of VS.



### ***Total Solids, Volatile Solids and N content***

## Table A2.11 Experimental data for TS

Sample No	Weight of sand (g)	Wt of sand after drying at 105°C (g)	Percentage of TS	Average Percentage of TS
1	6.2190	2.5498	41	41.21
2	6.2830	2.6024	41.42	

Therefore percentage of TS = 41.21%

$$\begin{aligned}\text{So total weight of TS} &= 80.505 \times 0.4121 \\ &= 33.18 \text{ g}\end{aligned}$$

## Table A2.12 Experimental data for VS

Sample No	Weight of TS (g)	Wt of sand after drying at 550°C (g)	Percentage of VS	Average Percentage of VS
1	2.5498	2.4988	2.00	2.00
2	2.6024	2.5504	2.00	

Percentage of VS of TS = 2.00 %

$$\begin{aligned}\text{Total weight of VS} &= 33.18 \times 0.02 \\ &= 0.6636 \text{ g}\end{aligned}$$

The total nitrogen content was determined by the standard Kjeldahl method. The following formula was used for calculation:

$$\text{Total N in mg/g of sand} = 14.01 \times 0.02 \times (S - B) / W$$



So total N in the Cu containing sand =  $14.01 \times 0.02 \times (11.8 - 3.90) / 6.50$   
 $= 0.34 \text{ mg of N / g of sand.}$

Therefore amount of N  $= 0.34 \times 80.505 \text{ mg}$   
 $= 27.37 \text{ mg}$   
 $= 0.02737 \text{ g}$   
 So percentage N of VS  $= 0.02737 / 0.6636 \times 100 \%$   
 $= 4.12 \%$

So biomass for Cu containing filter schmutzdecke = 4.12 % of VS.

**Lead                    Total Solids, Volatile Solids and N content**

**Total Solids (TS)**

Table A2.13 Experimental data for TS

Sample No	Weight of sand (g)	Wt of sand after drying at 105°C (g)	Percentage of TS	Average Percentage of TS
1	6.1920	3.0960	50	49.86
2	6.2880	3.1264	49.72	

Therefore percentage of TS  $= 49.86 \%$   
 So total weight of TS  $= 83.0924 \times 0.4986$   
 $= 41.43 \text{ g}$

**Volatile Solids (VS)**

Table A2.14 Experimental data for VS

Sample No	Weight of TS (g)	Wt of sand after drying at 550°C (g)	Percentage of VS	Average Percentage of VS
1	3.0960	3.006	2.90	2.89
2	3.1264	3.0365	2.88	



Percentage of VS of TS

= 2.89 %

Total weight of VS

=41.43 × 0.0289

= 1.20 g

**Total Nitrogen**

The total nitrogen content was determined by the standard Kjeldahl method. The following formula was used for calculation:

Total N in mg/g of sand

= 14.01 × 0.02 × ( S- B) / W

So total N in the Cu containing sand = 14.01 × 0.02 × ( 10.80- 3.80) / 6.50

= 0.3004 mg of N / g of sand.

Therefore amount of N

= 0.3004 × 83.0924 mg

= 24.96 mg

= 0.02496 g

So percentage N of VS

= 0.02496/1.20 × 100 %

= 2.08 %

So biomass for Cu containing filter schmutzdecke = 2.08 % of VS.

Cadmium

Total Solids, Volatile Solids and N content

**Total Solids (TS)**

Table A2.15 Experimental data for TS

Sample No	Weight of sand (g)	Wt of sand after drying at 105°C (g)	Percentage of TS	Average Percentage of TS
1	6.1250	3.2769	53.5	53.66
2	6.3210	3.4019	53.82	

Therefore percentage of TS

= 53.66 %



So total weight of TS
= 90.7371 × 0.5366
= 48.69 g

***Volatile Solids (VS)***

Table A2.16 Experimental data for VS

Sample No	Weight of TS (g)	Wt of sand after drying at 550°C (g)	Percentage of VS	Average Percentage of VS
1	3.2769	3.2019	2.30	2.29
2	3.4019	3.3244	2.28	

Percentage of VS of TS
= 2.29 %

Total weight of VS
=48.69 × 0.0229
= 1.12 g

***Total Nitrogen***

The total nitrogen content was determined by the standard Kjeldahl method. The following formula was used for calculation:

Total N in mg/g of sand
= 14.01 × 0.02 × ( S- B) / W

So total N in the Cu containing sand = 14.01 × 0.02 × ( 9.5- 4) / 6.50
= 0.2160 mg of N / g of sand.

Therefore amount of N
= 0.2160 × 90.7371 mg
= 19.6 mg
= 0.0196 g

So percentage N of VS
= 0.0196/1.12 × 100 %
= 1.75 %

So biomass for Cu containing filter schmutzdecke = 1.75 % of VS.



## TEST RESULTS FOR THE THIRD SET

### Determination of the amount of metal accumulation in the Schmutzdecke:

Total Amount of sand scraped from the schmutzdecke:

Cu = 110.31 g, Cr = 95.26 g, Pb = 93.12 g and Cd = 88.64 g.

Amount of sand taken for analysis:

Cu = 1.10 g, Cr = 1.90 g, pb = 2.00 g and Cd = 1.95 g.

Samples were digested by HNO<sub>3</sub>- HCl digestion and 100 mls of each sample was taken for analysis. Dilution was made if required.

#### *Copper*

The concentration of Cu = 186.5 mg/l  
= 18.65 mg/100 ml.  
= 18.65 mg/ 1.10 g of sand.  
= 16.95 mg /g of sand.

So total amount of Cu accumulated = 16.95 × 110.31 g  
= 1869.76 g.

Average concentration of Cu in the influent = 9.90 mg/l

Total amount of water passed = 1293 l

So total amount of Cu input = 1293 × 9.90 mg  
= 12797.81 mg

Cu accumulated in the schmutzdecke as a % of total Cu passing

$$= 1869.76/12797.81 \times 100 \%$$
$$= 14.61 \%$$

#### *Chromium*

The concentration of Cr = 5.13 mg/l  
= 0.513 mg/100 ml



$$= 0.513 / 1.90 \text{ mg / g of sand}$$

$$= 0.27 \text{ mg / g of sand}$$

So total amount of Cr accumulated in the schmutzdecke =  $0.27 \times 95.26 \text{ mg}$

$$= 25.72 \text{ mg}$$

Average concentration of Cr in the influent =  $101 \mu\text{g/l}$

Total amount of Cr

$$= 101 \times 1622 \mu\text{g}$$

$$= 163820 \mu\text{g}$$

$$= 163.82 \text{ mg}$$

Cr accumulated in the schmutzdecke as a % of total Cr passing

$$= 25.72 / 163.82 \times 100 \%$$

$$= 15.7 \%$$

### ***Lead***

The concentration of Pb

$$= 1.334 \text{ mg/l}$$

$$= 0.1334 \text{ mg/100 ml}$$

$$= 0.1334 \text{ mg / 2.0 g of sand}$$

$$= 0.0667 \text{ mg / g of sand}$$

Total amount of Pb accumulated

$$= 0.07 \times 93.12 \text{ mg}$$

$$= 6.52$$

Average concentration of Pb in the influent =  $47.0 \mu\text{g / l}$

Total amount of Pb input

$$= 47.0 \times 1620 \mu\text{g}$$

$$= 76140 \mu\text{g}$$

$$= 76.140 \text{ mg}$$

Pb accumulated in the schmutzdecke as a % of total Pb passing



$$= 6.52 / 76.140 \times 100 \%$$

$$= 8.55 \%$$

### ***Cadmium***

The concentration of Cd

$$= 507 \mu\text{g} / \text{l}$$

$$= 50.7 \mu\text{g} / 100 \text{ ml.}$$

$$= 50.7 \mu\text{g} / 1.95\text{g of sand}$$

$$= 26 \mu\text{g} / \text{g of sand}$$

Total amount of Cd accumulated

$$= 26 \times 88.64 \mu\text{g}$$

$$= 2304.64 \mu\text{g}$$

Average concentration of Cd in the influent =  $92.4 \mu\text{g} / \text{l}$

Total amount of Cd input

$$= 92.4 \times 1620 \mu\text{g}$$

$$= 149688 \mu\text{g}$$

Cd accumulated in the schmutzdecke as a % of total Cd passing

$$= 2304.64 / 149688 \times 100 \%$$

$$= 1.54 \%$$

### **Estimation of Biomass:**

The percentage N content of the Volatile Solids (VS) is considered as the active biomass. Total Solids, Volatile Solids and N content were determined by standard method.

### ***Copper                      Total Solids, Volatile Solids and N content***

#### ***Total Solids (TS)***

Table A2.17 Experimental data for TS

Sample No	Weight of sand (g)	Wt of sand after drying at 105°C (g)	Percentage of TS	Average Percentage of TS
1	6.2250	2.5161	40.42	40.21
2	6.3180	2.5272	40	



Therefore percentage of TS = 40.21 %

So total weight of TS = 110.31 × 0.4021  
= 44.36 g

***Volatile Solids (VS)***

Table A2.18 Experimental data for VS

Sample No	Weight of TS (g)	Wt of sand after drying at 550°C (g)	Percentage of VS	Average Percentage of VS
1	2.5161	2.4281	3.50	3.43
2	2.5272	2.4423	3.36	

Percentage of VS of TS = 3.43 %

Total weight of VS =44.36 × 0.0343  
= 1.52 g

***Total Nitrogen***

The total nitrogen content was determined by the standard Kjeldahl method. The following formula was used for calculation:

Total N in mg/g of sand = 14.01 × 0.02 × ( S- B) / W

So total N in the Cu containing sand = 14.01 × 0.02 × ( 12.80- 1.10) / 6.50  
= 0.5040 mg of N / g of sand.

Therefore amount of N = 0.5040 × 110.31 mg  
=55.6 mg  
= 0.0556 g

So percentage N of VS = 0.0556/1.52 × 100 %  
= 3.66 %



So biomass for Cu containing filter schmutzdecke = 3.66 % of VS.

**Chromium**                      **Total Solids, Volatile Solids and N content**

**Total Solids (TS)**

Table A2.19 Experimental data for TS

Sample No	Weight of sand (g)	Wt of sand after drying at 105°C (g)	Percentage of TS	Average Percentage of TS
1	6.2160	2.5673	41.3	41.52
2	6.2730	2.6184	41.74	

Therefore percentage of TS                      = 41.52%

So total weight of TS                                      = 95.26 × 0.4152  
    = 39.55 g

**Volatile Solids (VS)**

Table A2.20 Experimental data for VS

Sample No	Weight of TS (g)	Wt of sand after drying at 550°C (g)	Percentage of VS	Average Percentage of VS
1	2.5673	2.5031	2.50	2.56
2	2.6184	2.5498	2.62	

Percentage of VS of TS                                      = 2.56 %

Total weight of VS    =39.55 × 0.0256  
    = 1.01 g

**Total Nitrogen**

The total nitrogen content was determined by the standard Kjeldahl method. The following formula was used for calculation:

Total N in mg/g of sand                                      = 14.01 × 0.02 × ( S- B) / W



So total N in the Cu containing sand =  $14.01 \times 0.02 \times (11.7 - 2.0) / 6.50$   
 $= 0.4189 \text{ mg of N / g of sand.}$

Therefore amount of N  $= 0.4189 \times 95.26 \text{ mg}$   
 $= 39.9 \text{ mg}$   
 $= 0.0399 \text{ g}$   
 So percentage N of VS  $= 0.0399 / 1.01 \times 100 \%$   
 $= 3.96 \%$

So biomass for Cu containing filter schmutzdecke = 3.96 % of VS.

**Lead                      Total Solids, Volatile Solids and N content**

**Total Solids (TS)**

Table A2.21 Experimental data for TS

Sample No	Weight of sand (g)	Wt of sand after drying at 105°C (g)	Percentage of TS	Average Percentage of TS
1	6.1850	2.9960	48.44	48.72
2	6.2630	3.0689	49.0	

Therefore percentage of TS  $= 48.72 \%$   
 So total weight of TS  $= 93.12 \times 0.4872$   
 $= 45.36 \text{ g}$



***Volatile Solids (VS)***

Table A2.22 Experimental data for VS

Sample No	Weight of TS (g)	Wt of sand after drying at 550°C (g)	Percentage of VS	Average Percentage of VS
1	2.9960	2.9091	2.90	2.92
2	3.0689	2.9787	2.94	

Percentage of VS of TS = 2.92 %

Total weight of VS = 45.36 × 0.0292

= 1.33 g

***Total Nitrogen***

The total nitrogen content was determined by the standard Kjeldahl method. The following formula was used for calculation:

Total N in mg/g of sand = 14.01 × 0.02 × ( S- B) / W

So total N in the Cu containing sand = 14.01 × 0.02 × ( 10.90- 3.60) / 6.50

= 0.3157 mg of N / g of sand.

Therefore amount of N = 0.3157 × 93.12 mg

= 29.4 mg

= 0.0294 g

So percentage N of VS = 0.0294/1.32 × 100 %

= 2.21 %

So biomass for Cu containing filter schmutzdecke = 2.21 % of VS.







$$\begin{aligned}
 \text{Therefore amount of N} &= 0.2392 \times 88.64 \text{ mg} \\
 &= 21.3 \text{ mg} \\
 &= 0.0212 \text{ g}
 \end{aligned}$$

$$\begin{aligned}
 \text{So percentage N of VS} &= 0.0212/1.14 \times 100 \% \\
 &= 1.86 \%
 \end{aligned}$$

So biomass for Cu containing filter schmutzdecke = 1.86 % of VS.



## ANNEX 3

### DATA FOR THE SPECIATION OF HEAVY METALS IN SLOW SAND FILTERS

#### Copper (Cu)

##### Speciation of Cu at the 10 mm of sand scrapings

##### Concentration of Cu in the original sample:

$$[(41.8+42.14+41.18) / 3] \times 10 = 417 \text{ mg/l} = 41.7 \text{ mg/100 ml} = 52.125 \text{ mg/gm of sand}$$

##### 1)Extraction of Cu by $\text{KNO}_3$ i.e. easily exchangeable Cu :

$$\text{Concentration} = (0.58+0.50 +0.42)/ 3 =0.50 \text{ mg/l} = 0.050 \text{ mg/100 ml} =0.0625 \text{ mg /gm of sand.}$$

$$\text{So \% of easily exchangeable Cu} = 0.12 \%$$

##### 2)Extraction of Cu by KF i.e. adsorbed Cu :

$$\text{Concentration} = (5.06 + 4.87 + 5.08) / 3 =5 \text{ mg/l} =0.5 \text{ mg/100 ml} =0.63 \text{ mg /gm of sand}$$

$$\% \text{ of adsorbed Cu} = 1.21 \%$$

##### 3) Extraction of Cu by $\text{Na}_2\text{P}_4\text{O}_7$ i.e. organic-bound Cu :

$$\text{Concentration} = [( 35.79+ 36.54 +37.14 )/ 3] \times 10 = 364.9 \text{ mg/l} = 36.49 \text{ mg/ 100 ml} = 45.61 \text{ mg/gm of sand.}$$

$$\% \text{ of organic bound Cu} = 87.5 \%$$

##### 4) Extraction of Cu by EDTA i.e. carbonate Cu :

$$\text{Concentration} = (32.40+ 36.34+36.03)/3 = 34.9 \text{ mg/l} =3.49 \text{ mg/100 ml} = 4.36 \text{ mg/gm of sand}$$

$$\% \text{ of carbonate Cu} = 8.37 \%$$

##### 5) Extraction of Cu by $\text{HNO}_3$ i.e. Sulphide Cu :

$$\text{Concentration} = ( 1.43+ 1.53 + 1.54 ) / 3 = 1.50 \text{ mg/l} = 0.15 \text{ mg/100 ml} = 0.19 \text{ mg /gm of sand.}$$

$$\% \text{ of sulphide Cu} = 0.36 \%$$



## 6) Residual Cu

Concentration = ( 0.75+ 0.78 + 0.78 )/ 3 = 0.77 mg/l = 0.077 mg/100 ml =0.010 mg/gm of sand.

% of residual Cu = 0.02 %

### Amount of Cu lost during analysis :

Total Cu in = 52.12 mg/gm of sand

Total Cu removed = 50.95 mg/gm of sand. So % lost =2.3 %

### Speciation of Cu at 20 mm of sand bed depth

#### Concentration of Cu in the original sample:

(58.6+58.5+58.42) / 3 = 58.52 mg/l = 5.852 mg/100 ml = 7.315 mg/gm of sand

#### 1)Extraction of Cu by KNO<sub>3</sub> i.e. easily exchangeable Cu:

concentration = (1.90+1.97 +2.00)/ 3 = 1.96 mg/l = 0.196 mg/100 ml = 0.245 mg /gm of sand

So % of easily exchangeable Cu = 3.35 %

#### 2) Extraction of Cu by KF i.e. adsorbed Cu :

Concentration = (11.88 + 11.88 + 11.89) / 3 = 11.89 mg/l = 1.188 mg/100 ml = 1.485 mg /gm of sand.

% of adsorbed Cu = 20.3 %

#### 3) Extraction of Cu by Na<sub>2</sub>P<sub>4</sub>O<sub>7</sub> i.e. organic-bound Cu :

Concentration = ( 37.1+ 37.2 +37.1 )/ 3 = 37.1 mg/l = 3.71 mg/ 100 ml = 4.6375 mg/gm of sand

% of organic bound Cu = 63.4 %

#### 4) Extraction of Cu by EDTA i.e. carbonate Cu :

Concentration = (4.70+ 4.69+4.69)/3 = 4.69 mg/l = 0.469 mg/100 ml = 0.58625 mg/gm of sand

% of carbonate Cu = 8.1 %

#### 5) Extraction of Cu by HNO<sub>3</sub> i.e. Sulphide Cu :



Concentration =  $(1.90 + 1.91 + 1.92) / 3 = 1.91 \text{ mg/l} = 0.191 \text{ mg/100 ml} = 0.2388 \text{ mg/gm of sand.}$

% of sulphide Cu = 3.26 %

#### **6) Residual Cu**

Concentration =  $(0.50 + 0.50 + 0.51) / 3 = 0.50 \text{ mg/l} = 0.05 \text{ mg/100 ml} = 0.0625 \text{ mg/gm of sand}$

% of residual Cu = 0.86 %

#### **Amount of Cu lost during analysis :**

Total Cu in = 7.315 mg/gm of sand

Total Cu removed = 7.26 mg/gm of sand. So % lost = 0.69 %

#### **Speciation of Cu at 30 mm of sand bed depth**

##### **Concentration of Cu in the original sample:**

$(29.6 + 29.6 + 29.7) / 3 = 29.6 \text{ mg/l} = 2.96 \text{ mg/100 ml} = 3.70 \text{ mg/gm of sand}$

##### **1) Extraction of Cu by $\text{KNO}_3$ i.e. easily exchangeable Cu:**

Concentration =  $(1.72 + 1.74 + 1.70) / 3 = 1.72 \text{ mg/l} = 0.172 \text{ mg/100 ml} = 0.215 \text{ mg/gm of sand.}$

So % of easily exchangeable Cu = 5.8 %

##### **2) Extraction of Cu by KF i.e. adsorbed Cu :**

Concentration =  $(10.77 + 10.73 + 10.73) / 3 = 10.74 \text{ mg/l} = 1.074 \text{ mg/100 ml} = 1.3425 \text{ mg/gm of sand.}$

% of adsorbed Cu = 36.3 %

##### **3) Extraction of Cu by $\text{Na}_2\text{P}_4\text{O}_7$ i.e. organic-bound Cu :**

Concentration =  $(12.8 + 12.6 + 13.0) / 3 = 12.8 \text{ mg/l} = 1.28 \text{ mg/100 ml} = 1.60 \text{ mg/gm of sand.}$

% of organic bound Cu = 43.2 %



#### **4) Extraction of Cu by EDTA i.e. carbonate Cu :**

Concentration =  $(2.26 + 2.24 + 0.2.29)/3 = 2.26 \text{ mg/l} = 0.226 \text{ mg/100 ml} = 0.2825 \text{ mg/gm of sand.}$

% of carbonate Cu = 7.64 %

#### **5) Extraction of Cu by HNO<sub>3</sub> i.e. Sulphide Cu :**

Concentration =  $(1.12 + 1.12 + 1.10) / 3 = 1.12 \text{ mg/l} = 0.112 \text{ mg/100 ml} = 0.14 \text{ mg /gm of sand.}$

% of sulphide Cu = 3.78 %

#### **6) Residual Cu :**

Concentration =  $(0.44 + 0.40 + 0.41) / 3 = 0.42 \text{ mg/l} = 0.042 \text{ mg/100 ml} = 0.0525 \text{ mg/gm of sand.}$

% of residual Cu = 1.4 %

#### **Amount of Cu lost during analysis :**

Total Cu in = 3.70 mg/gm of sand

Total Cu removed = 3.632 mg/gm of sand. So % lost = 1.9 %

#### **Speciation of Cu at 200 mm of sand bed depth**

##### **Concentration of Cu in the original sample:**

$(7.2 + 7.0 + 6.88) / 3 = 7 \text{ mg/l} = 0.7 \text{ mg/100 ml} = 0.875 \text{ mg/gm of sand}$

##### **1) Extraction of Cu by KNO<sub>3</sub> i.e. easily exchangeable Cu:**

Concentration =  $(1.12 + 1.10 + 1.11) / 3 = 1.11 \text{ mg/l} = 0.111 \text{ mg/100 ml} = 0.1375 \text{ mg /gm of sand.}$

So % of easily exchangeable Cu = 15.7 %

##### **2) Extraction of Cu by KF i.e. adsorbed Cu :**

Concentration =  $(3.0 + 3.3 + 3.2) / 3 = 3.1 \text{ mg/l} = 0.31 \text{ mg/100 ml} = 0.3875 \text{ mg /gm of sand}$

% of adsorbed Cu = 44.3 %



### 3) Extraction of Cu by $\text{Na}_2\text{P}_4\text{O}_7$ i.e. organic-bound Cu :

Concentration =  $(2.0 + 1.85 + 1.86) / 3 = 1.90 \text{ mg/l} = 0.19 \text{ mg/100 ml} = 0.2375 \text{ mg/gm of sand}$

% of organic bound Cu = 27.2 %

### 4) Extraction of Cu by EDTA i.e. carbonate Cu :

Concentration =  $(0.5 + 0.5 + 0.52) / 3 = 0.5 \text{ mg/l} = 0.05 \text{ mg/100 ml} = 0.0625 \text{ mg/gm of sand}$

% of carbonate Cu = 7.1 %

### 5) Extraction of Cu by $\text{HNO}_3$ i.e. Sulphide Cu :

Concentration =  $(0.3 + 0.28 + 0.31) / 3 = 0.3 \text{ mg/l} = 0.03 \text{ mg/100 ml} = 0.0375 \text{ mg/gm of sand}$

% of sulphide Cu = 4.3 %

### 6) Residual Cu :

Concentration =  $(0.1 + 0.1 + 0.09) / 3 = 0.1 \text{ mg/l} = 0.01 \text{ mg/100 ml} = 0.0125 \text{ mg/gm of sand}$

% of residual Cu = 1.42 %

### Amount of Cu lost during analysis :

Total Cu in = 0.875 mg/gm of sand

Total Cu removed = 0.875 mg/gm of sand. So % lost = 0 %

### Speciation of Cu at 400 mm of sand bed depth

#### Concentration of Cu in the original sample:

$(3.4 + 3.6 + 3.5) / 3 = 3.5 \text{ mg/l} = 0.35 \text{ mg/100 ml} = 0.44 \text{ mg/gm of sand}$

#### 1) Extraction of Cu by $\text{KNO}_3$ i.e. easily exchangeable Cu :

Concentration =  $(0.7 + 0.7 + 0.65) / 3 = 0.7 \text{ mg/l} = 0.07 \text{ mg/100 ml} = 0.0875 \text{ mg/gm of sand}$

So % of easily exchangeable Cu = 19.9 %



## **2) Extraction of Cu by KF i.e. adsorbed Cu :**

Concentration =  $(1.9 + 1.8 + 1.72) / 3 = 1.8 \text{ mg/l} = 0.18 \text{ mg/100 ml} = 0.018 \text{ mg/gm of sand}$

% of adsorbed Cu = 51.2 %

## **3) Extraction of Cu by $\text{Na}_2\text{P}_4\text{O}_7$ i.e. organic-bound Cu :**

Concentration =  $(0.6 + 0.6 + 0.6) / 3 = 0.6 \text{ mg/l} = 0.06 \text{ mg/100 ml} = 0.075 \text{ mg/gm of sand}$

% of organic-bound C = 17 %

## **4) Extraction of Cu by EDTA i.e. carbonate Cu :**

Concentration =  $(0.3 + 0.3 + 0.3) / 3 = 0.3 \text{ mg/l} = 0.03 \text{ mg/100 ml} = 0.0375 \text{ mg/gm of sand}$

% of carbonate Cu = 8.5 %

## **5) Extraction of Cu by $\text{HNO}_3$ i.e. Sulphide Cu :**

Concentration =  $(0.1 + 0.1 + 0.1) / 3 = 0.1 \text{ mg/l} = 0.01 \text{ mg/100 ml} = 0.0125 \text{ mg/gm of sand}$

% of carbonate Cu = 2.9 %

## **6) Residual Cu :**

Concentration =  $(0.05 + 0.06 + 0.038) / 3 = 0.05 \text{ mg/l} = 0.005 \text{ mg/100 ml} = 0.00625 \text{ mg/gm of sand}$

% of residual Cu = 1.4 %

## **Amount of Cu lost during analysis :**

Total Cu in = 0.44 mg/gm of sand

Total Cu removed = 0.44 mg/gm of sand. So % lost = 0 %

## **Speciation of Cu at 800 mm of sand bed depth**

### **Concentration of Cu in the original sample:**

$(0.05 + 0.06 + 0.04) / 3 = 0.05 \text{ mg/l} = 0.005 \text{ mg/100 ml} = 0.00625 \text{ mg/gm of sand}$

## **1) Extraction of Cu by $\text{KNO}_3$ i.e. easily exchangeable Cu :**



Concentration =  $(0.014 + 0.014 + 0.016) / 3 = 0.015 \text{ mg/l} = 0.0015 \text{ mg/100 ml}$   
 $= 0.001785 \text{ mg/gm of sand.}$

So % of easily exchangeable Cu = 28.4 %

**2) Extraction of Cu by KF i.e. adsorbed Cu :**

Concentration =  $(0.029 + 0.029 + 0.032) / 3 = 0.03 \text{ mg/l} = 0.003 \text{ mg/100 ml}$   
 $= 0.00375 \text{ mg/gm of sand}$

% of adsorbed Cu = 56.9 %

**3) Extraction of Cu by  $\text{Na}_2\text{P}_4\text{O}_7$  i.e. organic-bound Cu :**

Concentration =  $(0.0024 + 0.0023 + 0.0023) / 3 = 0.0023 \text{ mg/l} = 0.00023 \text{ mg/100 ml}$   
 $= 0.00029 \text{ mg/gm of sand}$

% of organic bound Cu = 4.75 %

**4) Extraction of Cu by EDTA i.e. carbonate Cu :**

Concentration =  $(0.0014 + 0.0014 + 0.0015) / 3 = 0.0014 \text{ mg/l} = 0.00014 \text{ mg/100 ml}$   
 $= 0.00018 \text{ mg/gm of sand}$

% of carbonate Cu = 2.85 %

**5) Extraction of Cu by  $\text{HNO}_3$  i.e. Sulphide Cu :**

Concentration =  $(0.00095 + 0.00095 + 0.00095) / 3 = 0.00095 \text{ mg/l} = 0.000095 \text{ mg/100 ml}$   
 $= 0.00012 \text{ mg/gm of sand}$

% of carbonate Cu = 1.9 %

**6) Residual Cu**

Concentration = 0 mg/l

% of residual Cu = 0 %

**Amount of Cu lost during analysis :**



Total Cu in = 0.0625 mg/gm of sand

Total Cu removed = 0.057 mg/gm of sand. So % lost = 10 %

### **Speciation of Cu at 1200 mm of sand bed**

Total concentration = 0 mg/l

All other fractions were also found 0 mg/l

## **Chromium (Cr)**

### **Speciation of Cr at the 10 mm of sand scrapings**

**Concentration of Cr in the original sample:**

$(4.43+4.50+4.45) / 3 = 4.46 \text{ mg/l} = 0.446 \text{ mg/100 ml} = 0.55 \text{ mg/gm of sand}$

**1) Extraction of Cr by  $\text{KNO}_3$  i.e. easily exchangeable Cr :**

Concentration =  $(0.016+0.014 +0.017)/ 3 =0.016 \text{ mg/l} = 0.0016 \text{ mg/100 ml} =0.002 \text{ mg/gm of sand}$

So % of easily exchangeable Cr = 0.36 %

**2) Extraction of Cr by KF i.e. adsorbed Cr :**

Concentration =  $(0.37 + 0.35 + 0.35) / 3 =0.36 \text{ mg/l} =0.036 \text{ mg/100 ml} =0.045 \text{ mg/gm of sand}$

% of adsorbed Cr = 8.20 %

**3) Extraction of Cr by  $\text{Na}_2\text{P}_4\text{O}_7$  i.e. organic-bound Cr :**

Concentration =  $( 2.90+ 3.11 +3.31 )/ 3 = 3.11 \text{ mg/l} = 0.311 \text{ mg/ 100 ml} = 0.39 \text{ mg/gm of sand}$

% of organic bound Cr = 71 %

**4) Extraction of Cr by EDTA i.e. carbonate Cr :**

concentration =  $(0.45+ 0.42+0.42)/3 = 0.43 \text{ mg/l} =0.043 \text{ mg/100 ml} = 0.053 \text{ mg/gm of sand}$



% of carbonate Cr = 9.6 %

### **5) Extraction of Cr by HNO<sub>3</sub> i.e. Sulphide Cr**

Concentration = ( 0.50+ 0.54 + 0.50) / 3 = 0.51 mg/l = 0.051 mg/100 ml = 0.063 mg /gm of sand

% of sulphide Cr = 11.5 %

### **6) Residual Cr**

Concentration = ( 0.10+ 0.09 + 0.09 )/ 3 = 0.10 mg/l = 0.010 mg/100 ml =0.012 mg/gm of sand

% of residual Cr = 2.2 %

**Amount of Cr lost during analysis :**

Total Cr in = 0.55 mg/gm of sand

Total Cr removed = 0.55 mg/gm of sand. So % lost = 0 %

### **Speciation of Cr at 20 mm of sand bed depth**

**Concentration of Cr in the original sample:**

(3.40+3.55+3.30) / 3 = 3.41 mg/l = 0.341 mg/100 ml = 0.425 mg/gm of sand

#### **1) Extraction of Cr by KNO<sub>3</sub> i.e. easily exchangeable Cr :**

Concentration = (0.12+0.16 +0.10)/ 3 = 0.13 mg/l = 0.013 mg/100 ml = 0.01625 mg /gm of sand

So % of easily exchangeable Cr = 3.90 %

#### **2 )Extraction of Cr by KF i.e. adsorbed Cr :**

Concentration = (0.60 + 0.70 + 0.70) / 3 = 0.66 mg/l = 0.066 mg/100 ml = 0.0825 mg /gm of sand

% of adsorbed Cr = 15 %

#### **3) Extraction of Cr by Na<sub>2</sub>P<sub>4</sub>O<sub>7</sub> i.e. organic-bound Cr :**



Concentration = ( 1.80+ 1.82 +1.77 )/ 3 = 1.80 mg/l = 0.18 mg/ 100 ml = 0.225 mg/gm of sand

% of organic bound Cr = 65 %

#### **4) Extraction of Cr by EDTA i.e. carbonate Cr :**

Concentration = (0.30+ 0.40+0.36)/3 = 0.35 mg/l = 0.035 mg/100 ml = 0.04375 mg/gm of sand

% of carbonate Cr = 10.3 %

#### **5) Extraction of Cr by HNO<sub>3</sub> i.e. Sulphide Cr :**

Concentration = (0.20+ 0.20+ 0.20) / 3 = 0.20 mg/l = 0.025 mg/100 ml = 0.2388 mg /gm of sand

% of sulphide Cr = 5.9 %

#### **6) Residual Cr**

Concentration = ( 0.10+ 0.09 + 0.09 )/ 3 = 0.10 mg/l = 0.01mg/100 ml = 0.0125mg/gm of sand

% of residual Cr = 2.4 %

#### **Amount of Cr lost during analysis :**

Total Cr in = 0.42 mg/gm of sand

Total Cu removed = 0.41 mg/gm of sand. So % lost = 2.4 %

#### **Speciation of Cr at 30 mm of sand bed depth**

##### **Concentration of Cr in the original sample:**

(1.05+0.95+1.04) / 3 = 1.02 mg/l = 0.102 mg/100 ml = 0.1275 mg/gm of sand

##### **1) Extraction of Cr by KNO<sub>3</sub> i.e. easily exchangeable Cr:**

Concentration = (0.12+0.10 +0.11)/ 3 = 0.11 mg/l = 0.011 mg/100 ml = 0.01375 mg /gm of sand

So % of easily exchangeable Cr = 10.88 %

##### **2) Extraction of Cr by KF i.e. adsorbed Cr :**



Concentration =  $(0.22 + 0.28 + 0.26) / 3 = 0.25 \text{ mg/l} = 0.025 \text{ mg/100 ml} = 0.03125 \text{ mg/gm of sand}$

% of adsorbed Cr = 24.5 %

**3) Extraction of Cr by  $\text{Na}_2\text{P}_4\text{O}_7$  i.e. organic-bound Cr :**

Concentration =  $(0.55 + 0.51 + 0.59) / 3 = 0.55 \text{ mg/l} = 0.055 \text{ mg/100 ml} = 0.06875 \text{ mg/gm of sand}$

% of organic bound Cr = 53.9 %

**4) Extraction of Cr by EDTA i.e. carbonate Cr :**

Concentration =  $(0.08 + 0.08 + 0.08) / 3 = 0.08 \text{ mg/l} = 0.008 \text{ mg/100 ml} = 0.01 \text{ mg/gm of sand}$

% of carbonate Cr = 7.80 %

**5) Extraction of Cr by  $\text{HNO}_3$  i.e. Sulphide Cr :**

Concentration =  $(0.05 + 0.05 + 0.05) / 3 = 0.05 \text{ mg/l} = 0.005 \text{ mg/100 ml} = 0.00625 \text{ mg/gm of sand}$

% of sulphide Cr = 5 %

**6) Residual Cu :**

Concentration =  $(0.05 + 0.05 + 0.04) / 3 = 0.05 \text{ mg/l} = 0.005 \text{ mg/100 ml} = 0.00625 \text{ mg/gm of sand}$

% of residual Cr = 5 %

**Amount of Cr lost during analysis :**

Total Cr in = 0.13 mg/gm of sand

Total Cr removed = 0.13 mg/gm of sand. So % lost = 0 %

**Speciation of Cr at 200 mm of sand bed depth**

**Concentration of Cr in the original sample:**

$(0.42 + 0.38 + 0.39) / 3 = 0.40 \text{ mg/l} = 0.04 \text{ mg/100 ml} = 0.05 \text{ mg/gm of sand}$

**1) Extraction of Cr by  $\text{KNO}_3$  i.e. easily exchangeable Cr :**



Concentration =  $(0.05+0.05 + 0.05)/ 3 = 0.05 \text{ mg/l} = 0.005\text{mg}/100 \text{ ml} = 0.0625 \text{ mg/gm of sand}$

So % of easily exchangeable Cr = 12.5 %

**2) Extraction of Cr by KF i.e. adsorbed Cr :**

Concentration =  $(0.13 + 0.13 + 0.11) / 3 = 0.125 \text{ mg/l} = 0.0125 \text{ mg}/100 \text{ ml} = 0.01576 \text{ mg/gm of sand}$

% of adsorbed Cr = 31.2 %

**3) Extraction of Cr by  $\text{Na}_2\text{P}_4\text{O}_7$  i.e. organic-bound Cr :**

Concentration =  $(0.2 + 0.18 + 0.17)/ 3 = 0.185 \text{ mg/l} = 0.019 \text{ mg}/100 \text{ ml} = 0.0231 \text{ mg/gm of sand}$

% of organic bound Cr = 46.3 %

**4) Extraction of Cr by EDTA i.e. carbonate Cr :**

Concentration =  $(0.02+ 0.02+0.02)/3 = 0.02 \text{ mg/l} = 0.002 \text{ mg}/100 \text{ ml} = 0.0025 \text{ mg/gm of sand}$

% of carbonate Cr = 5 %

**5) Extraction of Cr by  $\text{HNO}_3$  i.e. Sulphide Cr :**

Concentration =  $(0.015+ 0.015 + 0.015) / 3 = 0.015 \text{ mg/l} = 0.0015 \text{ mg}/100 \text{ ml} = 0.0025 \text{ mg/gm of sand}$

% of sulphide Cr = 3.7 %

**6) Residual Cr :**

Concentration =  $(0.005+ 0.005 + 0.005) / 3 = 0.005 \text{ mg/l} = 0.0005 \text{ mg}/100 \text{ ml} = 0.000625 \text{ mg/gm of sand}$

% of residual Cr = 1.25 %

**Amount of Cr lost during analysis :**

Total Cr in = 0.05 mg/gm of sand

Total Cr removed = 0.05 mg/gm of sand. So % lost = 0 %

**Speciation of Cr at 400 mm of sand bed depth**



**Concentration of Cr in the original sample:**

$$(0.10+0.10+0.10) / 3 = 0.10 \text{ mg/l} = 0.01 \text{ mg/100 ml} = 0.0125 \text{ mg/gm of sand}$$

**1) Extraction of Cr by KNO<sub>3</sub> i.e. easily exchangeable Cr :**

$$\text{Concentration} = (0.02+0.018 +0.023)/ 3 = 0.02 \text{ mg/l} = 0.002\text{mg/100 ml} = 0.0025 \text{ mg /gm of sand}$$

$$\text{So \% of easily exchangeable Cr} = 20 \%$$

**2) Extraction of Cr by KF i.e. adsorbed Cr :**

$$\text{Concentration} = (0.038 + 0.040+ 0.035) / 3 = 0.038 \text{ mg/l} = 0.0038 \text{ mg/100 ml} = 0.00475 \text{ mg /gm of sand}$$

$$\% \text{ of adsorbed Cr} = 38 \%$$

**3) Extraction of Cr by Na<sub>2</sub>P<sub>4</sub>O<sub>7</sub> i.e. organic-bound Cr :**

$$\text{Concentration} = ( 0.035 + 0.035 +0.037 )/ 3 = 0.035 \text{ mg/l} = 0.0035 \text{ mg/ 100 ml} = 0.004375\text{mg/gm of sand}$$

$$\% \text{ of organic bound Cr} = 35 \%$$

**4) Extraction of Cr by EDTA i.e. carbonate Cr :**

$$\text{Concentration} = (0.004+ 0.004+0.004)/3 = 0.004 \text{ mg/l} = 0.0004 \text{ mg/100 ml} = 0.0005 \text{ mg/gm of sand}$$

$$\% \text{ of carbonate Cr} = 4 \%$$

**5) Extraction of Cr by HNO<sub>3</sub> i.e. Sulphide Cr :**

$$\text{Concentration} = (0.003+ 0.003+0.003)/3 = 0.003 \text{ mg/l} = 0.0003\text{mg/100 ml} = 0.000375 \text{ mg/gm of sand}$$

$$\% \text{ of sulphide Cr} = 3 \%$$

**6) Residual Cu :**

$$0 \text{ mg/l}$$

$$\% \text{ of residual Cr} = 0 \%$$

**Amount of Cr lost during analysis :**

$$\text{Total Cr in} = 0.0125 \text{ mg/gm of sand}$$



Total Cr removed = 0.0125 mg/gm of sand. So % lost = 0 %

### **Speciation of Cr at 800 mm of sand bed depth**

#### **Concentration of Cr in the original sample:**

$(0.01+0.009+0.01) / 3 = 0.01 \text{ mg/l} = 0.001 \text{ mg/100 ml} = 0.00125 \text{ mg/gm of sand}$

#### **1) Extraction of Cr by $\text{KNO}_3$ i.e. easily exchangeable Cr :**

Concentration =  $(0.004+0.004 +0.004)/ 3 = 0.004 \text{ mg/l} = 0.0004 \text{ mg/100 ml} = 0.0005 \text{ mg /gm of sand}$

So % of easily exchangeable Cr = 40 %

#### **2) Extraction of Cr by KF i.e. adsorbed Cr :**

Concentration =  $( 0.0045 + 0.0047 + 0.0042 ) / 3 = 0.0045 \text{ mg/l} = 0.00045 \text{ mg/100 ml} = 0.000558 \text{ mg /gm of sand}$

% of adsorbed Cr = 45 %

#### **3) Extraction of Cu by $\text{Na}_2\text{P}_4\text{O}_7$ i.e. organic-bound Cr :**

Concentration =  $( 0.0010 + 0.0010 +0.0010 )/ 3 = 0.001 \text{ mg/l} = 0.0001 \text{ mg/ 100 ml}$   
 $= 0.000125 \text{ mg/gm of sand}$

% of organic bound Cr = 10 %

#### **4) Extraction of Cr by EDTA i.e. carbonate Cr :**

Concentration = 0 mg/l So % of carbonate Cr = 0 %

#### **5) Extraction of Cr by $\text{HNO}_3$ i.e. Sulphide Cr :**

Concentration = 0 mg/l

% of sulphide Cr = 0 mg/l %

#### **6) Residual Cr :**

Concentration = 0 mg/l

% of residual Cr = 0 %

**Amount of Cr lost during analysis :**



Total Cr in = 0.00125 mg/gm of sand

Total Cr removed = 0.00120 mg/gm of sand. So % lost = 4 %

### **Speciation of Cr at 1200 mm of sand bed**

Total Concentration = 0 mg/l

All other fractions were also found 0 mg/l

## **Lead (Pb)**

### **Speciation of Pb at the 10 mm of sand scrapings**

**Concentration of Pb in the original sample:**

$(3.16+3.29+3.23) / 3 = 3.23 \text{ mg/l} = 0.323 \text{ mg/100 ml} = 0.40 \text{ mg/gm of sand}$

#### **1) Extraction of Pb by $\text{KNO}_3$ i.e. easily exchangeable Pb:**

Concentration =  $(0.019+0.020 +0.021)/ 3 = 0.02 \text{ mg/l} = 0.0020 \text{ mg/100 ml} = 0.0025 \text{ mg/gm of sand}$

So % of easily exchangeable Pb = 0.63%

#### **2) Extraction of Pb by KF i.e. adsorbed Pb :**

Concentration =  $(0.32 + 0.34 + 0.39) / 3 = 0.35 \text{ mg/l} = 0.035 \text{ mg/100 ml} = 0.044 \text{ mg/gm of sand}$

% of adsorbed Pb =  $0.044/ 0.40 \times 100 \% = 11 \%$

#### **3) Extraction of Pb by $\text{Na}_2\text{P}_4\text{O}_7$ i.e. organic-bound Pb :**

Concentration =  $( 2.36+ 2.42 +2.46 )/ 3 = 2.41 \text{ mg/l} = 0.241 \text{ mg/ 100 ml} = 0.30 \text{ mg/gm of sand}$

% of organic bound Pb =  $0.3/0.4 \times 100 \% = 75 \%$

#### **4) Extraction of Pb by EDTA i.e. carbonate Pb :**

Concentration =  $(0.21+ 0.23+0.26)/3 = 0.23 \text{ mg/l} = 0.023 \text{ mg/100 ml} = 0.028 \text{ mg/gm of sand}$



$$\% \text{ of carbonate pb} = 0.028/0.4 \times 100 \% = 7 \%$$

### **5) Extraction of Pb by HNO<sub>3</sub> i.e. Sulphide Pb :**

$$\text{Concentration} = (0.044 + 0.044 + 0.040) / 3 = 0.043 \text{ mg/l} = 0.0043 \text{ mg/100 ml} = 0.005 \text{ mg/gm of sand}$$

$$\% \text{ of sulphide pb} = 1.25 \%$$

### **6) Residual Pb**

$$\text{Concentration} = (0.11 + 0.09 + 0.12) / 3 = 0.11 \text{ mg/l} = 0.011 \text{ mg/100 ml} = 0.014 \text{ mg/gm of sand}$$

$$\% \text{ of residual Pb} = 0.014/0.4 \times 100 \% = 3.5 \%$$

### **Amount of Pb lost during analysis :**

$$\text{Total Pb in} = 0.40 \text{ mg/gm of sand}$$

$$\text{Total Pb removed} = 0.39 \text{ mg/gm of sand. So } \% \text{ lost} = 2.5 \%$$

### **Speciation of Pb at 20 mm of sand bed depth**

#### **Concentration of Pb in the original sample:**

$$(0.74 + 0.74 + 0.73) / 3 = 0.74 \text{ mg/l} = 0.074 \text{ mg/100 ml} = 0.09 \text{ mg/gm of sand}$$

#### **1) Extraction of Pb by KNO<sub>3</sub> i.e. easily exchangeable Pb:**

$$\text{Concentration} = (0.020 + 0.03 + 0.03) / 3 = 0.027 \text{ mg/l} = 0.0027 \text{ mg/100 ml} = 0.0034 \text{ mg/gm of sand}$$

$$\text{So } \% \text{ of easily exchangeable Pb} = 3.75\%$$

#### **2) Extraction of Pb by KF i.e. adsorbed Pb :**

$$\text{Concentration} = (0.18 + 0.18 + 0.17) / 3 = 0.18 \text{ mg/l} = 0.018 \text{ mg/100 ml} = 0.0225 \text{ mg/gm of sand}$$

$$\% \text{ of adsorbed Pb} = 0.0225 / 0.09 \times 100 \% = 25 \%$$

#### **3) Extraction of Pb by Na<sub>2</sub>P<sub>4</sub>O<sub>7</sub> i.e. organic-bound Pb :**



Concentration =  $(0.35 + 0.36 + 0.34) / 3 = 0.35 \text{ mg/l} = 0.035 \text{ mg/100 ml} = 0.04 \text{ mg/gm}$  of sand

% of organic bound Pb =  $0.04 / 0.09 \times 100 \% = 49 \%$

#### **4) Extraction of Pb by EDTA i.e. carbonate Pb :**

Concentration =  $(0.08 + 0.08 + 0.07) / 3 = 0.08 \text{ mg/l} = 0.008 \text{ mg/100 ml} = 0.01 \text{ mg/gm}$  of sand

% of carbonate Pb =  $0.01 / 0.09 \times 100 \% = 11.1 \%$

#### **5) Extraction of Pb by HNO<sub>3</sub> i.e. Sulphide Pb :**

Concentration =  $(0.06 + 0.06 + 0.06) / 3 = 0.06 \text{ mg/l} = 0.006 \text{ mg/100 ml} = 0.0075 \text{ mg/gm}$  of sand

% of sulphide Pb =  $8.3 \%$

#### **6) Residual Pb**

Concentration =  $(0.02 + 0.02 + 0.02) / 3 = 0.02 \text{ mg/l} = 0.002 \text{ mg/100 ml} = 0.0025 \text{ mg/gm}$  of sand

% of residual Pb =  $0.0025 / 0.09 \times 100 \% = 2.8 \%$

#### **Amount of Pb lost during analysis :**

Total Pb in =  $0.09 \text{ mg/gm}$  of sand

Total Pb removed =  $0.086 \text{ mg/gm}$  of sand. So % lost =  $3.8 \%$

#### **Speciation of Pb at 30 mm of sand bed depth**

##### **Concentration of Pb in the original sample:**

$(0.63 + 0.63 + 0.63) / 3 = 0.63 \text{ mg/l} = 0.063 \text{ mg/100 ml} = 0.08 \text{ mg/gm}$  of sand

##### **1) Extraction of Pb by KNO<sub>3</sub> i.e. easily exchangeable Pb:**

Concentration =  $(0.030 + 0.03 + 0.03) / 3 = 0.03 \text{ mg/l} = 0.003 \text{ mg/100 ml} = 0.0038 \text{ mg/gm}$  of sand

So % of easily exchangeable Pb =  $4.6 \%$

##### **2) Extraction of Pb by KF i.e. adsorbed Pb :**



Concentration =  $(0.22 + 0.21 + 0.24) / 3 = 0.22 \text{ mg/l} = 0.022 \text{ mg/100 ml} = 0.028 \text{ mg/gm of sand}$

% of adsorbed Pb =  $0.028 / 0.08 \times 100 \% = 35 \%$

### **3) Extraction of Pb by $\text{Na}_2\text{P}_4\text{O}_7$ i.e. organic-bound Pb :**

Concentration =  $(0.23 + 0.20 + 0.22) / 3 = 0.22 \text{ mg/l} = 0.022 \text{ mg/100 ml} = 0.028 \text{ mg/gm of sand}$

% of organic bound Pb =  $0.028 / 0.08 \times 100 \% = 35 \%$

### **4) Extraction of Pb by EDTA i.e. carbonate Pb :**

Concentration =  $(0.075 + 0.08 + 0.08) / 3 = 0.08 \text{ mg/l} = 0.008 \text{ mg/100 ml} = 0.01 \text{ mg/gm of sand}$

% of carbonate Pb =  $0.01 / 0.08 \times 100 \% = 12.5 \%$

### **5) Extraction of Pb by $\text{HNO}_3$ i.e. Sulphide Pb :**

Concentration =  $(0.06 + 0.06 + 0.06) / 3 = 0.06 \text{ mg/l} = 0.006 \text{ mg/100 ml} = 0.0075 \text{ mg/gm of sand}$

% of sulphide Pb =  $0.0075 / 0.08 \times 100 \% = 9.3 \%$

### **6) Residual Pb**

Concentration =  $(0.04 + 0.04 + 0.035) / 3 = 0.04 \text{ mg/l} = 0.004 \text{ mg/100 ml} = 0.005 \text{ mg/gm of sand}$

% of residual Pb =  $0.005 / 0.08 \times 100 \% = 6.2 \%$

### **Total amount of Pb lost during analysis :**

Total Pb in =  $0.08 \text{ mg/gm of sand}$

Total Pb removed =  $0.076 \text{ mg/gm of sand}$ . So % lost =  $5 \%$

### **Speciation of Pb at 200 mm of sand bed depth**

#### **Concentration of Pb in the original sample:**

Concentration =  $(0.17 + 0.18 + 0.18) / 3 = 0.18 \text{ mg/l} = 0.018 \text{ mg/100 ml} = 0.0225 \text{ mg/gm of sand}$



**1) Extraction of Pb by  $\text{KNO}_3$  i.e. easily exchangeable Pb:**

Concentration =  $(0.012 + 0.011 + 0.012) / 3 = 0.012 \text{ mg/l} = 0.0012 \text{ mg/100 ml} = 0.0015 \text{ mg/gm of sand}$

So % of easily exchangeable Pb = 6.7%

**2) Extraction of Pb by KF i.e. adsorbed Pb :**

Concentration =  $(0.08 + 0.08 + 0.08) / 3 = 0.08 \text{ mg/l} = 0.008 \text{ mg/100 ml} = 0.01 \text{ mg/gm of sand}$

% of adsorbed Pb = 44.5 %

**3) Extraction of Pb by  $\text{Na}_2\text{P}_4\text{O}_7$  i.e. organic-bound Pb :**

Concentration =  $(0.05 + 0.05 + 0.045) / 3 = 0.05 \text{ mg/l} = 0.005 \text{ mg/100 ml} = 0.0063 \text{ mg/gm of sand}$

% of organic bound Pb = 28 %

**4) Extraction of Pb by EDTA i.e. carbonate Pb :**

Concentration =  $(0.02 + 0.02 + 0.019) / 3 = 0.02 \text{ mg/l} = 0.002 \text{ mg/100 ml} = 0.0025 \text{ mg/gm of sand}$

% of carbonate Pb = 11.1 %

**5) Extraction of Pb by  $\text{HNO}_3$  i.e. Sulphide Pb :**

Concentration =  $(0.01 + 0.01 + 0.01) / 3 = 0.01 \text{ mg/l} = 0.001 \text{ mg/100 ml} = 0.00125 \text{ mg/gm of sand}$

% of sulphide Pb = 5.6 %

**6) Residual Pb**

Concentration =  $(0.008 + 0.008 + 0.008) / 3 = 0.008 \text{ mg/l} = 0.0008 \text{ mg/100 ml} = 0.001 \text{ mg/gm of sand}$

% of residual Pb = 4.4 %

**Amount of Pb lost during analysis :**

Total Pb in = 0.0225 mg/gm of sand

Total Pb removed =  $0.0015 + 0.01 + 0.0063 + 0.0025 + 0.00125 + 0.001 = 0.0225$

mg/gm of sand. So % lost = 0 %



### **Speciation of Pb at 400 mm of sand bed depth**

#### **Concentration of Pb in the original sample:**

$$(0.12+0.14+0.13) / 3 = 0.13 \text{ mg/l} = 0.013 \text{ mg/100 ml} = 0.016 \text{ mg/gm of sand}$$

#### **1) Extraction of Pb by $\text{KNO}_3$ i.e. easily exchangeable Pb:**

$$\text{Concentration} = (0.02+0.022 +0.023)/ 3 = 0.022 \text{ mg/l} = 0.0022 \text{ mg/100 ml} = 0.0028 \text{ mg /gm of sand}$$

$$\text{So \% of easily exchangeable Pb} = 17.2 \%$$

#### **2) Extraction of Pb by KF i.e. adsorbed Pb :**

$$\text{Concentration} = (0.06 + 0.06 + 0.06) / 3 = 0.06 \text{ mg/l} = 0.006 \text{ mg/100 ml} = 0.0075 \text{ mg /gm of sand}$$

$$\% \text{ of adsorbed Pb} = 46.9 \%$$

#### **3) Extraction of Pb by $\text{Na}_2\text{P}_4\text{O}_7$ i.e. organic-bound Pb :**

$$\text{Concentration} = ( 0.02 + 0.02 +0.02 )/ 3 = 0.02 \text{ mg/l} = 0.002 \text{ mg/ 100 ml} = 0.0025 \text{ mg/gm of sand}$$

$$\% \text{ of organic bound Pb} = 15.6 \%$$

#### **4) Extraction of Pb by EDTA i.e. carbonate Pb :**

$$\text{Concentration} = (0.01+ 0.01+0.01)/3 = 0.01 \text{ mg/l} = 0.001 \text{ mg/100 ml} = 0.0025 \text{ mg/gm of sand}$$

$$\% \text{ of carbonate pb} = 7.8 \%$$

#### **5) Extraction of Pb by $\text{HNO}_3$ i.e. Sulphide Pb :**

$$\text{Concentration} = ( 0.008+ 0.008 + 0.008) / 3 = 0.008 \text{ mg/l} = 0.0008 \text{ mg/100 ml} = 0.001 \text{ mg /gm of sand}$$

$$\% \text{ of sulphide Pb} = 6.25 \%$$

#### **6) Residual Pb**



Concentration = ( 0.008+ 0.008 + 0.008 )/ 3 = 0.008 mg/l = 0.0008 mg/100 ml =0.001 mg/gm of sand

% of residual Pb = 6.25 %

**Amount of Pb lost during analysis :**

Total Pb in = 0.016 mg/gm of sand

Total Pb removed = 0.016

mg/gm of sand. So % lost = 0 %

**Speciation of Pb at 800 mm of sand bed depth**

**Concentration of Pb in the original sample:**

(0.04+0.04+0.04) / 3 =0.04 mg/l =0.004mg/100 ml =0.005 mg/gm of sand

**1) Extraction of Pb by KNO<sub>3</sub> i.e. easily exchangeable Pb:**

Concentration = (0.022+0.022 +0.023)/ 3 =0.022 mg/l = 0.0022 mg/100 ml =0.0028 mg /gm of sand

So % of easily exchangeable Pb = 55 %

**2) Extraction of Pb by KF i.e. adsorbed Pb :**

Concentration = ( 0.01 + 0.01 + 0.01 ) / 3 =0.01mg/l =0.001 mg/100 ml =0.00125mg /gm of sand

% of adsorbed Pb = 25 %

**3) Extraction of Pb by Na<sub>2</sub>P<sub>4</sub>O<sub>7</sub> i.e. organic-bound Pb :**

Concentration = ( 0.0028 + 0.0028 +0.0028 )/ 3 = 0.0028 mg/l = 0.00028 mg/ 100 ml  
= 0.00035 mg/gm of sand

% of organic bound Pb = 7 %

**4) Extraction of Pb by EDTA i.e. carbonate Pb :**

Concentration = (0.0008+ 0.0008+0.0008)/3 = 0.0008 mg/l =0.00008 mg/100 ml  
=0.0001 mg/gm of sand

% of carbonate pb = 2 %



### **5) Extraction of Pb by HNO<sub>3</sub> i.e. Sulphide Pb :**

Concentration =  $(0.0008 + 0.0008 + 0.0008)/3 = 0.0008 \text{ mg/l} = 0.00008 \text{ mg/100 ml}$   
 $= 0.0001 \text{ mg/gm of sand}$

% of carbonate pb = 2 %

### **6) Residual Pb**

Concentration =  $(0.00 + 0.00 + 0.00)/3 = 0.00 \text{ mg/l} = 0.00 \text{ mg/100 ml} = 0.00 \text{ mg/gm}$   
of sand

% of residual Pb = 0 %

### **Amount of Pb lost during analysis :**

Total Pb in = 0.005 mg/gm of sand

Total Pb removed = 0.0046 mg/gm of sand. So % lost = 5 %

### **Speciation of Pb at 1200 mm of sand bed depth**

#### **Concentration of Pb in the original sample:**

$(0.02 + 0.02 + 0.02)/3 = 0.02 \text{ mg/l} = 0.002 \text{ mg/100 ml} = 0.0025 \text{ mg/gm of sand}$

#### **1) Extraction of Pb by KNO<sub>3</sub> i.e. easily exchangeable Pb:**

Concentration =  $(0.017 + 0.017 + 0.017)/3 = 0.017 \text{ mg/l} = 0.0017 \text{ mg/100 ml} = 0.002125$   
mg /gm of sand

So % of easily exchangeable Pb = 85 %

#### **2) Extraction of Pb by KF i.e. adsorbed Pb :**

Concentration =  $(0.003 + 0.003 + 0.003)/3 = 0.003 \text{ mg/l} = 0.0003 \text{ mg/100 ml}$   
 $= 0.00375 \text{ mg/gm of sand}$

% of adsorbed Pb = 15 %

#### **3) Extraction of Pb by Na<sub>2</sub>P<sub>4</sub>O<sub>7</sub> i.e. organic-bound Pb :**

Concentration = 0 mg/l

% of organic bound Pb = 0 %



#### **4) Extraction of Pb by EDTA i.e. carbonate Pb :**

Concentration =  $(0.00 + 0.00 + 0.00) / 3 = 0.00 \text{ mg/l} = 0.000 \text{ mg/100 ml} = 0.00 \text{ mg/gm of sand}$

% of carbonate Pb = 0 %

#### **5) Extraction of Pb by HNO<sub>3</sub> i.e. Sulphide Pb :**

Concentration :  $(0.00 + 0.00 + 0.00) / 3 = 0.00 \text{ mg/l} = 0.00 \text{ mg/100 ml} = 0.00 \text{ mg/gm of sand}$

% of sulphide Pb = 0 %

#### **6) Residual Pb**

Concentration =  $(0.00 + 0.00 + 0.00) / 3 = 0.00 \text{ mg/l} = 0.00 \text{ mg/100 ml} = 0.00 \text{ mg/gm of sand}$

% of residual Pb = 0 %

#### **Amount of Pb lost during analysis :**

Total Pb in = 0.0025 mg/gm of sand

Total Pb removed = 0.0025 mg/gm of sand. So % lost = 0 %

### **Cadmium (Cd)**

#### **Speciation of Cd at the 10 mm of sand scrapings**

##### **Concentration of Cd in the original sample:**

$(0.62 + 0.63 + 0.63) / 3 = 0.63 \text{ mg/l} = 0.063 \text{ mg/100 ml} = 0.080 \text{ mg/gm of sand}$

##### **1) Extraction of Cd by KNO<sub>3</sub> i.e. easily exchangeable Cd:**

Concentration =  $(0.008 + 0.008 + 0.007) / 3 = 0.008 \text{ mg/l} = 0.0008 \text{ mg/100 ml} = 0.001 \text{ mg/gm of sand}$

So % of easily exchangeable Cd = 1.25 %

##### **2) Extraction of Cd by KF i.e. adsorbed Cd :**

Concentration =  $(0.14 + 0.11 + 0.14) / 3 = 0.13 \text{ mg/l} = 0.013 \text{ mg/100 ml} = 0.016 \text{ mg/gm of sand}$

% of adsorbed Cd =  $0.016 / 0.08 \times 100 \% = 20 \%$



### 3) Extraction of Cd by $\text{Na}_2\text{P}_4\text{O}_7$ i.e. organic-bound Cd :

Concentration =  $(0.43 + 0.39 + 0.43) / 3 = 0.42 \text{ mg/l} = 0.042 \text{ mg/100 ml} = 0.053 \text{ mg/gm of sand}$

% of organic bound Cd =  $0.053/0.08 \times 100 \% = 66.3 \%$

### 4) Extraction of Cd by EDTA i.e. carbonate Cd :

Concentration =  $(0.045 + 0.04 + 0.042) / 3 = 0.042 \text{ mg/l} = 0.0042 \text{ mg/100 ml} = 0.0053 \text{ mg/gm of sand}$

% of carbonate Cd =  $0.053/0.08 \times 100 \% = 6.6 \%$

### 5) Extraction of Cd by $\text{HNO}_3$ i.e. Sulphide Cd :

Concentration =  $(0.028 + 0.025 + 0.020) / 3 = 0.024 \text{ mg/l} = 0.0024 \text{ mg/100 ml} = 0.003 \text{ mg/gm of sand}$

% of sulphide Cd =  $3.80 \%$

### 6) Residual Cd

Concentration =  $(0.006 + 0.005 + 0.005) / 3 = 0.005 \text{ mg/l} = 0.0005 \text{ mg/100 ml} = 0.00063 \text{ mg/gm of sand}$

% of residual Cd =  $0.78 \%$

### Amount of Cd lost during analysis :

Total Cd in =  $0.08 \text{ mg/gm of sand}$

Total Cd removed =  $0.079 \text{ mg/gm of sand}$ . So % lost =  $1.3 \%$

### Speciation of Cd at 20 mm of sand bed depth

#### Concentration of Pb in the original sample:

$(0.142 + 0.138 + 0.146) / 3 = 0.14 \text{ mg/l} = 0.014 \text{ mg/100 ml} = 0.018 \text{ mg/gm of sand}$

#### 1) Extraction of Cd by $\text{KNO}_3$ i.e. easily exchangeable Cd:

Concentration =  $(0.016 + 0.017 + 0.014) / 3 = 0.016 \text{ mg/l} = 0.0016 \text{ mg/100 ml} = 0.002 \text{ mg/gm of sand}$

So % of easily exchangeable Cd =  $11.1 \%$



## **2) Extraction of Cd by KF i.e. adsorbed Cd :**

Concentration =  $(0.04 + 0.04 + 0.04) / 3 = 0.04 \text{ mg/l} = 0.004 \text{ mg/100 ml} = 0.005 \text{ mg/gm of sand}$

% of adsorbed Pb =  $0.005 / 0.018 \times 100 \% = 27.8 \%$

## **3) Extraction of Cd by $\text{Na}_2\text{P}_4\text{O}_7$ i.e. organic-bound Cd :**

Concentration =  $(0.05 + 0.04 + 0.043) / 3 = 0.045 \text{ mg/l} = 0.0045 \text{ mg/100 ml} = 0.0055 \text{ mg/gm of sand}$

% of organic bound Cd =  $0.0055 / 0.018 \times 100 \% = 30.8 \%$

## **4) Extraction of Cd by EDTA i.e. carbonate Cd :**

Concentration =  $(0.012 + 0.013 + 0.012) / 3 = 0.012 \text{ mg/l} = 0.0012 \text{ mg/100 ml} = 0.0015 \text{ mg/gm of sand}$

% of carbonate pb =  $0.0015 / 0.018 \times 100 \% = 8.4 \%$

## **5) Extraction of Cd by $\text{HNO}_3$ i.e. Sulphide Cd :**

Concentration =  $(0.010 + 0.011 + 0.008) / 3 = 0.010 \text{ mg/l} = 0.001 \text{ mg/100 ml} = 0.0012 \text{ mg/gm of sand}$

% of sulphide Cd =  $6.7 \%$

## **6) Residual Cd :**

$(0.009 + 0.010 + 0.008) / 3 = 0.009 \text{ mg/l} = 0.0009 \text{ mg/100 ml} = 0.00113 \text{ mg/gm of sand}$

% of residual Cd =  $0.00113 / 0.018 \times 100 \% = 6.25 \%$

## **Amount of Cd lost during analysis :**

Total Cd in =  $0.018 \text{ mg/gm of sand}$

Total Cd removed =  $0.017 \text{ mg/gm of sand}$ . So % lost =  $5.6 \%$

## **Speciation of Cd at 30 mm of sand bed depth**

### **Concentration of Cd in the original sample:**

$(0.11 + 0.121 + 0.12) / 3 = 0.12 \text{ mg/l} = 0.012 \text{ mg/100 ml} = 0.015 \text{ mg/gm of sand}$



**1) Extraction of Cd by  $\text{KNO}_3$  i.e. easily exchangeable Cd:**

Concentration =  $(0.016 + 0.014 + 0.015) / 3 = 0.015 \text{ mg/l} = 0.0015 \text{ mg/100 ml} = 0.0019 \text{ mg/gm of sand}$

So % of easily exchangeable Cd = 12.5 %

**2) Extraction of Cd by KF i.e. adsorbed Cd :**

Concentration =  $(0.034 + 0.036 + 0.036) / 3 = 0.035 \text{ mg/l} = 0.0035 \text{ mg/100 ml} = 0.0045 \text{ mg/gm of sand}$

% of adsorbed Cd = 300 %

**3) Extraction of Cd by  $\text{Na}_2\text{P}_4\text{O}_7$  i.e. organic-bound Cd :**

Concentration =  $(0.024 + 0.026 + 0.023) / 3 = 0.024 \text{ mg/l} = 0.0024 \text{ mg/100 ml} = 0.003 \text{ mg/gm of sand}$

% of organic bound Pb = 20.3 %

**4) Extraction of Cd by EDTA i.e. carbonate Cd :**

Concentration =  $(0.010 + 0.009 + 0.010) / 3 = 0.010 \text{ mg/l} = 0.001 \text{ mg/100 ml} = 0.00125 \text{ mg/gm of sand}$

% of carbonate Cd = 8.3 %

**5) Extraction of Cd by  $\text{HNO}_3$  i.e. Sulphide Cd :**

Concentration =  $(0.009 + 0.009 + 0.008) / 3 = 0.008 \text{ mg/l} = 0.0008 \text{ mg/100 ml} = 0.001 \text{ mg/gm of sand}$

% of sulphide Cd = 6.7 %

**6) Residual Cd :**

$(0.009 + 0.009 + 0.008) / 3 = 0.008 \text{ mg/l} = 0.0008 \text{ mg/100 ml} = 0.001125 \text{ mg/gm of sand}$

% of residual Cd = 7.5 %

**Amount of Cd lost during analysis :**

Total Cd in = 0.015 mg/gm of sand

Total Cd removed = 0.013 mg/gm of sand. So % lost = 13 %



### **Speciation of Cd at 200 mm of sand bed depth**

#### **Concentration of Cd in the original sample:**

$$(0.08+0.075+0.08) / 3 = 0.08 \text{ mg/l} = 0.008 \text{ mg/100 ml} = 0.01 \text{ mg/gm of sand}$$

#### **1) Extraction of Cd by $\text{KNO}_3$ i.e. easily exchangeable Cd:**

$$\text{Concentration} = (0.02+0.021 +0.02)/ 3 = 0.02 \text{ mg/l} = 0.002 \text{ mg/100 ml} = 0.0025 \text{ mg /gm of sand}$$

$$\text{So \% of easily exchangeable Cd} = 25 \%$$

#### **2) Extraction of Cd by KF i.e. adsorbed Cd :**

$$\text{Concentration} = (0.031 + 0.029 + 0.028) / 3 = 0.030 \text{ mg/l} = 0.003 \text{ mg/100 ml} = 0.0038 \text{ mg /gm of sand}$$

$$\% \text{ of adsorbed Cd} = 38 \%$$

#### **3) Extraction of Cd by $\text{Na}_2\text{P}_4\text{O}_7$ i.e. organic-bound Cd :**

$$\text{Concentration} = ( 0.011 + 0.013 +0.009)/ 3 = 0.011 \text{ mg/l} = 0.0011 \text{ mg/ 100 ml} = 0.0014 \text{ mg/gm of sand}$$

$$\% \text{ of organic bound Cd} = 14 \%$$

#### **4) Extraction of Pb by EDTA i.e. carbonate Cd :**

$$\text{Concentration} = (0.004+ 0.004+0.004)/3 = 0.004 \text{ mg/l} = 0.0004 \text{ mg/100 ml} = 0.0005 \text{ mg/gm of sand}$$

$$\% \text{ of carbonate Cd} = 5 \%$$

#### **5) Extraction of Cd by $\text{HNO}_3$ i.e. Sulphide Cd :**

$$\text{Concentration} = ( 0.004+ 0.004 + 0.004) / 3 = 0.004 \text{ mg/l} = 0.0004 \text{ mg/100 ml} = 0.0005 \text{ mg /gm of sand}$$

$$\% \text{ of sulphide Cd} = 5 \%$$

#### **6) Residual Cd :**

$$\text{Concentration} = ( 0.003+ 0.0031 + 0.0028 )/ 3 = 0.003 \text{ mg/l} = 0.0003 \text{ mg/100 ml} = 0.00038 \text{ mg/gm of sand}$$

$$\% \text{ of residual Cd} = 3.8 \%$$

#### **Amount of Cd lost during analysis :**



Total Cd in = 0.01 mg/gm of sand

Total Cd removed = 0.0091 mg/gm of sand. So % lost = 9 %

### **Speciation of Cd at 400 mm of sand bed depth**

#### **Concentration of Cd in the original sample:**

$(0.06+0.06+0.061) / 3 = 0.06 \text{ mg/l} = 0.006 \text{ mg/100 ml} = 0.0075 \text{ mg/gm of sand}$

#### **1) Extraction of Cd by $\text{KNO}_3$ i.e. easily exchangeable Cd :**

Concentration =  $(0.017+0.017 +0.016)/ 3 = 0.017 \text{ mg/l} = 0.0017\text{mg/100 ml} = 0.0021 \text{ mg /gm of sand}$

So % of easily exchangeable Cd = 28 %

#### **2) Extraction of Cd by KF i.e. adsorbed Cd :**

Concentration =  $(0.026 + 0.026 + 0.024) / 3 = 0.025\text{mg/l} = 0.00025 \text{ mg/100 ml} = 0.0032 \text{ mg /gm of sand}$

% of adsorbed Cd = 42 %

#### **3) Extraction of Cd by $\text{Na}_2\text{P}_4\text{O}_7$ i.e. organic-bound Cd :**

Concentration =  $( 0.006 + 0.006 +0.006 )/ 3 = 0.006 \text{ mg/l} = 0.0006 \text{ mg/ 100 ml}$   
 $= 0.00075\text{mg/gm of sand}$

% of organic bound Cd = 10 %

#### **4) Extraction of Cd by EDTA i.e. carbonate Cd :**

Concentration =  $(0.003+ 0.003+0.003)/3 = 0.003 \text{ mg/l} = 0.0003 \text{ mg/100 ml} = 0.00038 \text{ mg/gm of sand}$

% of carbonate Cd = 5 %

#### **5) Extraction of Cd by $\text{HNO}_3$ i.e. Sulphide Cd :**

Concentration =  $(0.003+ 0.003+0.003)/3 = 0.003 \text{ mg/l} = 0.0003 \text{ mg/100 ml} = 0.00038 \text{ mg/gm of sand}$

% of carbonate Cd = 5 %

#### **6) Residual Cd :**



Concentration = ( 0.002+ 0.002 + 0.002 )/ 3 = 0.002 mg/l = 0.0002 mg/100 ml  
=0.00025 mg/gm of sand

% of residual Cd = 3.3 %

**Amount of Cd lost during analysis :**

Total Cd in = 0.0075 mg/gm of sand

Total Cd removed = 0.0071 mg/gm of sand. So % lost = 5.3 %

### **Speciation of Cd at 800 mm of sand bed depth**

**Concentration of Cd in the original sample:**

Concentration = (0.04+0.04+0.04) / 3 =0.04 mg/l =0.004mg/100 ml =0.005 mg/gm of sand

**1) Extraction of Cd by KNO<sub>3</sub> i.e. easily exchangeable Cd :**

Concentration = (0.014+0.014 +0.014)/ 3 =0.014 mg/l = 0.0014mg/100 ml =0.00175 mg /gm of sand

So % of easily exchangeable Cd = 35 %

**2) Extraction of Cd by KF i.e. adsorbed Cd :**

Concentration = ( 0.02 + 0.02 + 0.02 ) / 3 =0.02 mg/l =0.002 mg/100 ml =0.0025mg /gm of sand

% of adsorbed Cd = 50 %

**3) Extraction of Cd by Na<sub>2</sub>P<sub>4</sub>O<sub>7</sub> i.e. organic-bound Cd :**

Concentration = ( 0.004 + 0.004 +0.004 )/ 3 = 0.004 mg/l = 0.0004 mg/ 100 ml  
=0.0005 mg/gm of sand

% of organic bound Cd = 10 %

**4) Extraction of Cd by EDTA i.e. carbonate Cd :**

Concentration = (0.001+ 0.001+0.001)/3 = 0.001 mg/l =0.0001 mg/100 ml =0.000125 mg/gm of sand

% of carbonate Cd = 2.5 %

**5) Extraction of Cd by HNO<sub>3</sub> i.e. Sulphide Cd :**



Concentration =  $(0.001 + 0.001 + 0.001) / 3 = 0.001 \text{ mg/l} = 0.0001 \text{ mg/100 ml} = 0.000125 \text{ mg/gm of sand}$

% of carbonate Cd = 2.5 %

#### **6) Residual Cd :**

Concentration =  $(0.00 + 0.00 + 0.00) / 3 = 0.00 \text{ mg/l} = 0.00 \text{ mg/100 ml} = 0.00 \text{ mg/gm of sand}$

% of residual Cd = 0 %

#### **Amount of Cd lost during analysis :**

Total Cd in = 0.005 mg/gm of sand

Total Pb removed =  $0.00175 + 0.0025 + 0.0005 + 0.000125 + 0.000125 = 0.004875$

mg/gm of sand. So % lost = 2.5 %

#### **Speciation of Cd at 1200 mm of sand bed depth**

##### **Concentration of Cd in the original sample:**

$(0.03 + 0.03 + 0.03) / 3 = 0.03 \text{ mg/l} = 0.003 \text{ mg/100 ml} = 0.00375 \text{ mg/gm of sand}$

##### **1) Extraction of Cd by $\text{KNO}_3$ i.e. easily exchangeable Cd :**

Concentration =  $(0.015 + 0.015 + 0.015) / 3 = 0.015 \text{ mg/l} = 0.0015 \text{ mg/100 ml} = 0.001875 \text{ mg /gm of sand}$

So % of easily exchangeable Cd = 50 %

##### **2) Extraction of Cd by KF i.e. adsorbed Cd :**

Concentration =  $(0.015 + 0.015 + 0.015) / 3 = 0.015 \text{ mg/l} = 0.0015 \text{ mg/100 ml} = 0.001875 \text{ mg /gm of sand}$

% of adsorbed Cd = 50 %

##### **3) Extraction of Cd by $\text{Na}_2\text{P}_4\text{O}_7$ i.e. organic-bound Cd :**

Concentration = 0 mg/l

% of organic bound Cd = 0 %

##### **4) Extraction of Cd by EDTA i.e. carbonate Cd :**



Concentration = 0 mg/l

% of carbonate Cd = 0 %

**5) Extraction of Cd by HNO<sub>3</sub> i.e. Sulphide Cd :**

Concentration = 0 mg/l

% of carbonate Cd = 0 %

**6) Residual Cd**

Concentration = ( 0.00+ 0.00 + 0.00 )/ 3 = 0.00 mg/l = 0.00 mg/100 ml =0.00 mg/gm of sand

% of residual Cd = 0 %

**Amount of Cd lost during analysis :**

Total Cd in = 0.00375 mg/gm of sand

Total Cd removed = 0.00375 mg/gm of sand. So % lost = 0 %