LEAD REMOVAL FROM WASTEWATER
IN
MOVING MEDIA REACTOR

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
CIVIL ENGINEERING
(With Specialization in Environmental Engineering)

By

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FEBRUARY 1993

In the name of God
the most gracious the most merciful

DEDICATED

To

My Parents and Wife

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled "REMOVAL OF LEAD FROM WASTEWATERS IN A MOVING MEDIA REACTOR" in partial fulfilment of the requirement for the award of the degree of MASTER OF ENGINEERING IN CIVIL ENGINEERING with specialization in ENVIRONMENTAL ENGINEERING submitted in the Department of Civil Engineering, University of Roorkee, Roorkee is an authentic record of my work carried out during a period from July 1992 to Feb. 1993 under the supervision of DR. ARVIND KUMAR, Professor, Department of Civil Engineering and DR. S.C. GUPTA, Professor, Department of Chemical Engineering, University of Roorkee, Roorkee, India.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Dated : Feb.26, 1993

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This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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ACKNOWLEDGEMENTS

It is a matter of privilege for me to work under the supervisor of DR. ARVIND KUMAR *Professor (Environmental), Department of Civil Engineering and Dr. S.C.Gupta, professor, Department of Chemical Engineering, University of Roorkee, for this dissertation. The author takes this opportunity to express his deep sense of gratitude and sincere thanks to Dr. Arvind Kumar and* DR. S.C. GUPTA *for their most valuable guidance, deep involvement and periodic encouragement. The priority given by them to this work inspite of their very busy schedule is gratefully acknowledged.*

Thanks are due to Dr. P.K. Pande, Professor and Head, Department of Civil Engineering, University of Roorkee, for providing various facilities and help during the completion of this work.

The author expresses his sincere thanks to Dr. C.L. Toshniwal, Professor, and Dr. R.P. Mathur, professor and O.C. Environmental Engineering Section. Department of Civil Engineering, University of Roorkee, Roorkee for extending facilities of the laboratory.

I also wish to thank Mr. Zaheer Ahmad and all other laboratory staff for their excellent co-operation during the experimental phase of this work.

Thanks are also due to Laboratory Staff of University Services and Instrumentation Centre for their help time to time.

Thanks are also due to Dr. Saeed AL-Amoodi, professor and chancellor, University of Aden, Aden and Dr. Abdulwali Hadi, Assistant professor and Dean, Faculty of Engineering, University of Aden, Aden, for offering me this great

opportunity to pursue my post graduate study in University of Roorkee, Roorkee.

In the last but not the least, the blessing of my parents and Wife, have all contributed, in no small measure, to the completion of this dissertation.

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ABSTRACT

Lead concentration in watewaters discharges by various industries generally varies from 0.4 mg/l to 400 mg/l. Out of various removal methodoligists, adsorption operation has been seen as a suitable method of treatment of such wastewaters. Therefore, the efficiency of wood charcoal, available locally at Roorkee, in removing lead from wastewaters in a continuous operating adsorption system is studied in this investigation. Locally available charcoal offers advantages over the commercially used adsorbents, which are costly and requires periodic regeneration.

The present investigation has dealt with the adsorptive response of the charcoal particles for lead ions to the changes in operating parameters; the charcoal mass flow rate, the lead ions concentration and the flow rate of influent stream into the reactor. The charcoal mass flow rate ranges from 12.5 g/min to 26.1 g/min, the lead ions concentration in influent stream from 5 mg/l to 15 mg/l and the flow rate of influent stream from 0.25 l/min to 1.00 l/min. Moving media adsorption system using charcoal as adsorbent has succeeded in the removal of lead ions from wastewaters. The percent removal efficiency of lead is found to be 78% to 99% depending upon the values of the above operating parameters.

Based on the experimental data obtained in the present investigation, the correlation relating equilibrium concentration of effluent stream, C_e to the operating parameters, the charcoal mass flow rate, W, the influent flow rate, Q, and the lead ions concentration of influent stream, C_o, has been recommended as hereunder :

$$C_e = 1.3469\ W^{-0.4663}\ Q^{1.1303}\ \exp\ (0.0087\ C_o^{2})$$

The above correlation is a best fit for most of the data points within a maximum deviation of ±20% .

Similarly, the correlation relating the lead removal capacity of charcoal, q, to charcoal mass flow rate, influent flow rate and lead ions concentration of influent stream has been recommended as given below :

$$q = 935.9\ W^{-0.9490}\ Q^{0.9573}\ C_o^{1.0173}$$

This correlation is in excellent agreement with the data points within a maximum deviation of ±10%.

The dynamic system of moving media adsorption has been found to follow the Freundlich isotherm and is given by the following equation :

$$q = 441.842\ C_e^{0.6625}$$

All the data points are well correlated to the above model within a maximum deviation of ±35% .

However, it is important to mention that the above recommended correlations are valid only for the ranges of operating parameters mentioned earlier.

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NOMENCLATURE

SYMBOL	TITLE	UNIT
b	Emperial constant	mg/g
C	Exit effluent concentration	mg/l
C'	Equilibruim effulent concentration by sorbate	moles/l
C_e	Equilibrium lead ion concentration of effluent stream	mg/l
C_o	Lead ion concentration of influent stream	mg/l
C_s	Concentration of solute at struration of all layers	mg/l
Di	Screen aperture	μ
K	Equilibrium constant	cm^3/mg
q	lead removal capacity of charcoal	$\mu g/g$
q_e	removal capacity of sawdus +	$\mu g/g$
q_e'	Phenol removal perunit surface area of charcoal mass input rate permittime	$moles/min/m^2$
Q	influent flow rate	l/min
W	Charcoal mass flow rate	g/min
W_s	Saedust mass input rate	g/min
X_i	mass fractions retained on screen	(-)
θ_c	contact time for adsorption	min
θ_e	Equilibrium time for attaining eqilibrium adsorption	min

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Public concern over heavy metal pollution has grown consistantly since the reported morbidity caused by the mercury in Japan. Man's awareness of the heavy metal hazard now covers a wide spectrum of metals such as lead, cadmium, chromium, silver, copper and zinc. Trace amounts of these heavy metals might be beneficial to microorganisms and plants, but the presence of heavy metals at relatively high concentrations in the environment is detrimental to all living systems. This is further augmented by the fact that most metals are widely dispersed into environment through river water, winds and can persist in the environment for a long time.

Lead is one of the most widely used non-ferrous metals in industry. It is used as a raw material for storage battery manufacture, television tube manufacture, printing, pigments, fuels, electroplating, dying, paints, photographic materials, matches and explosives manufacturing and other processing units. Manufacturing processes in all of these industries produce lead-bearing effluent streams that must be disposed off safely. Normal values of lead in the wastewaters range between 0.40 mg/l to 400 mg/l. Values upto 15 mg/l are available from wastewaters such as :

1. Battery manufacture
2. Plating
3. Glass manufacture

4. Point manufacture
5. Pigment manufacture
6. Textile dying

The removal of lead from effluent streams has been a subject of investigation for the last few decades as its presence in high concentrations is harmful and toxic to the human beings, acquatic life and others. It has been found that small children playing with toys covered with lead-based paints are prone to suffer from lead poisoning. Excess amounts of lead can cause acute abdominal colic syndrome, acute encephalopathy, mental deterioration and other dreadful diseases. Various physical and Chemical methods such as precipitation, coagulation, flocculation, ion exchange, adsorption, cementation etc. have been recommended by various investigators to reduce lead concentration in wastewater. However, recently much interest has been exhibited in the use of Adsorption Technique. This method involves the use of either a sorption media with its recovery and reuse or a low cost adsorption media followed by its destruction. It is interesting to mention here that fixed-bed and fluidised-bed reactors have been employed by various investigators to determine their applicability to remove heavy metals from wastewaters.

However, recent developments have led to a new type of reactor, viz. "Moving Media Reactor". In this type of reactor the solution to be treated flows upward through a downward moving bed of fine adsorbent particles. This is advantageous over others as high adsorption rates are achieved in it due to small particle size and more efficient use of the adsorbent is obtained.

Literature survey clearly indicates that very few investigations are available using the design data for estabilishing the operating and geometrical parameters on the removal capacity of lead through the moving media reactors prior to the application of this type of reactor for the effluent treatment. However, these investigations are inconclusive and need further research work. Keeping the above in view the present investigation has been undertaken for the removal of lead from wastewater in a moving media reactor charcoal as the adsorbent with the following objectives.

1. To carry out experiments for the removal of lead from synthetically prepared wastewater of various initial concentrations of lead in a charcoal adsorbent downword moving bed reactor.
2 To investigate the parametric effects of initial concentration of lead in the wastewater, flow rate of wastewater, and rate of charcoal on the effect of lead removal and thus to develop a correlation amongst these parameters.
3. To determine the lead removal capacity of chorcoal as a function of charcoal mass flowrate, initial concentration of lead in wastewater and the flowrate of wastewater.
4. To develop adsorption isotherm equation for the above situation.

CHAPTER 2

LITERATURE REVIEW

In the field of environmental pollution there are few subjects that, during recent years, have developed as rapidly as the sutdy of toxic metals. A considerable amount of work has been carried out by various investigators to find out on economical and acceptable solution on the treatment of industrial waste effluents, consisting of toxic metals which differ widely in their nature, in order to minimise their harmful and hazardous effects before discharging them to soil and water bodies.

Pollutants, in general, can be in the form of inorganic or biodegradable as well as non-biodegradable organic compounds and metal ions.

In this literature review, lead in particular, has received a great deal of attention related to removal. In fact, acute problems have been due to the presence of lead, particularly, and other toxic elements, in general in wastewaters.

Elevated environmental levels of lead may arise from a variety of sources such as manufacture of photographic materials, storage batteries, pigments, matches, explosives, leaded glass fuels etc. It is one of the most widely used non-ferrous metals in the industry. It is also extensively used in printing, waterpipes, pottery and soldering operations. Besides, it is used as an antiknock agent in gasoline. The major industries which use lead as a raw material in abundance are the storage battery manufacture and the petroleum industry. Lead is also being used as a protective coating on nuts, bolts, bearings and on storage battery parts.

Most lead wastes are in the inorganic form. However, wastewaters of the tetraethyl lead industry contains organic lead compounds.

Table 2.1 Summarizes reported lead levels in industrial wastewaters [8].

Table 2.1 Reported Lead Levels In Industrial Wastewaters [8]

S.No	Industry	lead (mg/l)
1	Battery Manufacture	
	i. Particulate Lead	5 - 48
	ii. Soluble Lead	0.5 - 25
2	Plating	2 - 140
3	Television Tube Manufacture	380 - 400
4	Printed Circuit Board Manufacture	1.65
5	Glass Manufacture	0.43 - 100
6	Porcelain Enameling	2.9
7	Mining Process Water	0.018 - 0.098
8	Tetraethyle Lead Manufacture	45.00
9	Paint Manufacture	1.1 - 10.0
10	Pigment Manufacture	1 - 200
11	Textile Dyeing	8.4
12	Rubber Hose Manufacture, Lead Sheath Process	63
13	Foundry	29 - 170
14	Piston Ring Manufacture	94.6

The sources of lead in a water supply may come from industrial, mine or smelter discharges or from dissolution of oiled lead plumbing. Tap waters that are soft, acidic may contain lead entering from the lead service pipes.

For lead, tolerance limits for industrial effluents discharged into inland surface water[11] is 0.1 mg/l and the same when discharged into public service [12] is 1.0 mg/l. The permissible lead concentration in irrigation water for continuous use is 5.0 mg/l and for short term use in fine textured soil is 20.0 mg/l.

Much interest has been exhibted in the use of numerous techniques for the removal of metal ions from aqueous solutions. These include :

1. Chemical precipitation as insoluble salts
2. Reverse osmosis
3. Solvent extraction
4. Foam flotation
5. Biological purification
6. Ion-Exchange
7. Adsorption

2.1 CHEMICAL PRECIPITATION :

The most widely used method is the lime addition - hydroxide precipitation which have been proved to be effective. Yet this method had several limitations as some of the metals hydroxide are amphoteric over a relatively narrow pH range. The optimum pH differ for minimum solubility for different metals. Also, the solubility is affected by the presence of other constituents in the wastewater particularly complexing agents which inhibit hydroxide precipitation [3,4,14,31]. Soda ash precipitation has received very little attention. Carbonate precipitation has been studied both from theoretical as well as laboratory point of view [23]. Sulphide precipitation has been investigated in recent years, [2,25,28], although it has not yet been widely applied.

2.2. REVERSE OSMOSIS :

This is a technique used by applying sufficient pressure on a concentrated fluid to overcome osmotic pressure and thus force water through a semipermeable membrane. New modifications of cellulose-acetate membranes have greatly increased the efficiency of this process. Some investigators have tried to modify the costing material as well as technique to achieve a high flux density for water [15,20,21,32].

The principal use of reverse osmosis is for purification of brackish water. Research is under way to extend its capability to treat sea water and waste streams having high organic loadings.

In general this technique is applicable for :

i) a reduction in the volume of waste,
ii) recovery of valuable or reusable material,
iii) water treatment for boiler feed and cooling tower, and
iv) getting water of zero hardness.

2.3 SOLVENT EXTRACTION :

It is also known as liquid - liquid extraction. It is considered to be the most versatile and popular method of separation. The main reason for its usefulness is that separation can be carried out on macro level as well as on micro level. One does not need any sophisticated apparatus or instrumentation excepting a separatory funnel. It is based on the principle that a solution distributes itself in a certain ratio between two immiscible solvents. In limiting cases the solute can be more or less transferred into the organic phase.

This technique can be used for the purpose of preparation, purification, enrichment, separation and analysis at all scales of working.

2.4 FOAM FLOTATION :

Foam separation relies upon a surfactant that causes a non-surface-active material to be come surface-active, forming a product that is then removed by bubbling a gas through the bulk solution to form a foam. This technique is well documented [7,16,29.30]. Karger et al. [17] and Pinfold [24] have proposed nomenclature for the entire field of absorptive and bubble separation techniques. Huang and Wilson [10] studied precipitate flotation and absorbing colloid flotation of mercury (II) and cadmium (II) from aqueous systems. Ferguson et al. [6] investigated the foam separation techniques such as ion flotation, precipitate flotation and absorbing collloid flotation to determine if these procedures would be feasible for removing lead (II) and cadmium (II) from highly contaminated wastewaters. Zeitlin et al. [19,27] investigated a host of colloid flotation separations from sea water.

2.5 BIOLOGICAL PURIFICATION :

V.I. Romanenko et al. [26] developed a biological purification process to treat industrial effluents from chromates and dichromates. The efflluents are mixed with domestic sewage and then the chromates and dichromates contained herein are biochemically reduced under anaerobic conditions.

2.6 ION-EXCHANGE :

Ion-exchange is a separation process in which ions, held by electrostatic forces to charged functional groups on the surface of an insoluble solid, are replaced by ions of similar charge in a solution in contact with the solids. In Ion exchange every ion removed from solution is replaced by an equivalent amount of another ionic species of the same sign.

Ion-exchange is used extensively for water and wastewater treatment primarily for the removal of hardness. It is also used for the treatment of a variety of industrial wastes to allow for the recovery of valuable waste materials and by-products. In addition the recovery and removal of radioactive waste material from nuclear reactor, hospital and the laboratory waste is quite well documented.

Historical reviews indicate the early use of clay and other natural materials for demineralization of drinking water. Further work in this direction led to the synthesis and development of a large variety of cross linked organic resins which are commercially available under various trade names. Later on, the specific need of thermally and radiation stable compounds led to the development of inorganic ion exchangers.

Ion exchangers, these days find extttensive use in demineralization of water and treatment of municipal wastes.

2.7 ADSORPTION :

This is the most common widely used method in practice after the precipitation method. Adsorption involves the interphase accumulation of substances at a surface or interphase. This phenomenon takes place when such a surface is placed in contact with a solution. In fact, three steps are involved on the adsorption of solutes from solution by porous adsorbents. The first step is the transport of the adsorbent (film diffusion step); the second is the diffusion of the adsorbate into the pores of the adsorbent (pore diffusion or interparticle transport step) and the last step is the adsorption of solute on the interior surface of the adsorbent (attachment step).

Adsorption by using activated carbon as adsorbent have been tried and results appear to be promising while other adsorbents have also been undertaken in separate studies. Various adsorbents tried for the removal of lead ions are soil, sand, fly ash, hydrous oxides of aluminium and iron, cellulose and activated carbon. In all the investigations carried out in this area, a single theory which can satisfactorily explain even a majority of the observations and the discussion therein not available. Following section review some of the important investigations on the adsorption of heavy metals from wastewater Wentink and Etzel [33] used soil as adsorbent for the removal of copper, chromium and zinc. They found the process to follow a true ion-exchange mechanism. Regeneration of soil was also possilbe. Complete removal of chrome was possible upto concentrations of 300 mg/l with soil. Removal of zinc at application rates as high as 300 mg/l can be accomplished with an efficiencey of no less than 99.7%. Removal of copper was complete after an initial conditioning period.

Netzer et al. [22] studied the adsorption of lead and other heavy metals using activated carbon as a sorbent in a batch studies. The removal efficiency of lead obtained was about 99%. The initial concentration of lead was 8.0 mg/l. They also studied the effect of interference of other heavy metals with lead.

Edward et al. [15] carried out a study for the removal of lead by adsorbing colloid flotation in preliminary batch studies, continuous - flow studies and a pilot - plant studies. In their preliminary batch studies, the initial concentration of lead in influent was 50 mg/l. In these studies the removal efficiency of lead was observed to vary from 62% to 100% at different pH - values and sodium nitrate ionic strength. In the continuous - flow studies, the results obtained were similar to those obtained from the batch studies. In the pilot - plant studies, the removal efficiency of lead was noted to vary from 86% to 99% for pH - values ranging from 5.6 to 7.2.

Isotherm for moving media reactor had been proposed by Bhargava et al. [1] for the removal of phenol from wastewater effluents. The phenol removal efficiency was found to be 40% to 70%. The influent flow rate was varying between 0.25 l/min and 0.75 l/min, the chorcoal mass input rate was varying between 2.00 g/min to 21.66 g/min and the geometric mean diameter of charcoal particles varied between 177 micron to 421 micron with an initial concentration of phenol of 10 mg/l. The study showed that the dynamic system of moving media adsorption has not been found to follow the conventional isotherms. Therefore, they developed the followed correlation :

$$q_e' = 0.21\ C' - 0.27 \qquad (2.1)$$

where,

q_e' is the phenol removal per unit surface area of charcoal mass input rate per. unit time, moles/minute/square meterand

C' is the equilibrium effluent concentration by sorbate, moles per liter.

Gupta [8] has studied the removal of cadmium and lead from effluents in a moving media reactor with residual sawdust as adsorbent. The investigation showed a removal efficiency of lead in the range of 74% to 96%. The various ranges of parameters used in this study were the influent flow rate from 0.25 l/min to 0.625 l/min, the sawdust mass input rate from 11.0 g/min to 23.5 g/min and the initial concentration of lead from 1 mg/l to 50 mg/l at different pH-values and temperatures. He has recommended correlation between the removal capacity of sawdust and sawdust mass input rate, the influent flow rate and the initial concentration of lead as hereunder :

$$q_e = 637.6\ W_s^{-0.907}\ Q^{0.901}\ C^{0.983} \qquad (2.2)$$

Where,

q_e is the removal capacity of sawdust, microgam/gram,

W_s is the sawdust mass input rate, gram/minute,

Q is the influent flow rate, litre/minute

and C_o is the initial concentration of lead ion in the influent, milligram/litre.

He has also developed a correlation between the exit concentration and the sawdust mass input rate, the influent flow rate and the initial concentration of lead in the influent as hereunder :

$$C = 1.18\ W_s^{-0.683}\ Q^{0.680}\ C_o^{1.105} \qquad (2.3)$$

where,

C is the exit effluent concentration, milligram/litre

Inspite of a significant amount of research in this direction, the data appearing in literature is quite incoherent. This is mainly due to the different methods used for the preparation of adsorbents and different conditions set for experimentation.

Table 2.2 indicates the main characteristics of some important techniques used for removal of heavy metals.

TABLE 2.2 Characteristics of Important Techniques Used For Heavy Metals Removal

	Technique	Characteristics
1.	Precipitation	Precipitation from dilute solution is difficult unless a flocculating agent is used, in which case a bulky, very wet sludge must be disposed of.
2.	Ion-Exchange	It is expensive and requires recharge of the resin and disposal of a substantial volume of spent and contaminated regeneration solution.
3.	Foam Flotation	It appears to have some distinct advantages over the other methods when dealing with large volume of waste that are quite dilute in the ions to be removed.
4.	Adsorption	Adsorption on activated carbon requires periodic regeneration of the carbon and, like ion- exchange, is rather expensive because capacity of the carbon to remove heavy metals is very limited. However, this can be overcome by using low cost adsorping materials.

2.8 TYPES OF REACTORS :

There are three common type of reactors used viz. batch, fluidised and moving media reactors.

In a batch type operation, the concentration of adsorbate in contact with a specific quantity of adsorbent decreases steadly as adsorption proceeds and the effectiveness of adsorbent decreases. For a fixed bed continuous flow operation, the adsorbent is continuously in contact with the fresh adsorbate, consequently the concentration in solution in contact with given layer of adsorbent in column is relatively constant. For small particle sizes, expanded bed can be used without the associated problems of excessive head-loss, air binding and fouling with particulate matter.

Many investigators have been worked with fixed bed reactor. Hiester and Vermeulen [9] presented a model for saturation performance of ion-exchange and adsorption columns assuming second order kinetics and using material balance relationship. Keinath et al. [18] presented a predictive model for the design of fluidized bed adsorbers based on Heister et al. [9] suggestion.

The limitations of these reactors forced investigators to develop a reactor having better utilization of adsorbent capacity. Bhargava et al. [1] have attempted the removal of phenol from the effuent in moving media reactor with charcoal as adsorbent. In moving media reactor, the operation is carried out in strictly continuous, steady - state fashion. Steady state conditions require continuous movement of adsorbent and adsorbate throughout the column of constant rate. There should be no change in composition at any point in the system with passage of time.

Investigations related to the application of moving media reactor for the removal of pollutants from their effluents are scarce. Removal of cadmiom and lead from effluents has been tried by Gupta [8] in moving media reactor with residual saw dust as adsorbent.

2.9 ADSORPTION ISOTHERMS :

Positive adsorption in a solid-liquid system results in the removal of solutes from solution and their concentration at the surface of the solid, to such time as the concentration of the solute remaining in solution is in a dynamic equilibrium with that at the surface. At this position of equilibrium, there is a defined distribution of solute between the liquid and solid phases. The distribution ratio is a measure of the position of equilibrium in the adsorption process; it may be a function of the concentration of the solute, the concentration and nature of competing solutes, the nature of the solution, and so on. The preferred form for depicting this distribution is to express the quantity q as a function of C_e at fixed temperature, the quantity q being the amount of solute adsorbed per unit weight of solid adsorbent, and C_e the concentration of solute remaining in solution at equilibrium. An expression of this type is termed an adsorption isotherm. The adsorption isotherm is a functional expression for the variation of adsorption with concentration of adsorbate in bulk solution at constant temperature. Commonly, the amount of adsorbed material per unit weight of adsorbent incrases with increasing concentration, but not in direct proportion.

Several types of isothermal adsorption relations may occur.

2.9.1. LANGMUIR ISOTHERM :

The Langmuir adsorption model is valid for single-layer adsorption. This is the most often used adsorption isotherm, being giving by the relationship :

$$q = \frac{Kb\ C_e}{1 + KC_e} \qquad (2.4)$$

Where K and b are empirical constants

Equation (2.4) is rewritten in linear form by taking the reciprocal of both members

$$\frac{1}{q} = \left(\frac{1}{Kb}\right)\cdot\left(\frac{1}{C_e}\right)+\left(\frac{1}{b}\right) \qquad (2.5)$$

From Equation (2.5) a plot of $1/q$ versus $1/C_e$ yields a straight line, which permits determination of parameters K and b from its slope and ordiante intercept, respectively.

2.9.2 FREUNDLICH ISOTHERM :

The Freundlich isotherm is expressed by the equation

$$q = k\ C_e^{1/n} \qquad (2.6)$$

Where k and n are constants dependent on several environmental factors. Eq. (2.6) is rewritten in linear form by taking logarithms of both members :

$$\log q = (1/n) \log C_e + \log k \qquad (2.7)$$

Equation (2.7) reveals that a logarithmic plot of q versus C_e yields a straight line which permits determination of parameters n and k from its slope and ordinate intercept at $C_e = 1$. The intercept is roughly an indicator of sorption capacity and the slope, $1/n$, of adsorption intensity.

The Freundlich equation generally agrees quite well with the Langmuir equation and experimental data over moderate ranges of concentration, C_e. However, the Freundlich isotherm differs from Langmuir's in that it does not approach a limiting value at high concentration, C_e.

2.9.3 BET ADSORPTION ISOTHERM :

The BET model represents isotherms reflecting apparent multilayer adsorption. Each layer adsorbs according to the Langmuir model. The BET isotherm is expressed by the equation.

$$q = \frac{b\ K\ C_e}{(C_o - C_e)\ [1 + (K-1)\ C_e/C_o]} \qquad (2.8)$$

The constant b has the same meaning as in the Langmuir isotherm, and k is a constant related to energy of adsorption. Co is the concentration of solute at saturation of all layers.

Equations (2.8) can be rewritten in a linear form as below :

$$\frac{C_e}{C_o - C_e).q} = \left[\frac{1}{Kb}\right] + \left[\frac{K-1}{Kb}\right]\left[\frac{C_e}{C_o}\right] \qquad (2.9)$$

Equation (2.9) indicates that a plot of $C_e/q(C_o.C_e)$ versus C_e/C_o should yield a straight line. Constants K and b can be estimated from the slope and ordiante intercept of this line.

2.10 DETERMINATION OF CONCENTRATION OF Pb^{++} IN LIQUID SOLUTION :

Lead (Pb^{++}) is a serious cumulative body poison. Natural waters seldom contain more than 20 µg/l, although values as high as 40µg/l have been reported [34]. Lead in a water supply may come from industrial, mine, and smelter discharges or from the dissolution of old lead plumbing. Tap waters that are soft, acid, and not suitably treated may contain lead resulting from an attack on lead service pipes.

The methods used for the determination of lead concentration as prescribed in Standard Methods are as follows :

i) Atomic Absorption Spectrometric, and
ii) Dithizone method.

2.10.1 ATOMIC ABSORPTION SPECTROMETRIC METHOD :

Atomic absorption spectrophotometry makes use of the fact that neutral or ground state atoms of an element can absorb electromagnetic radiation over a series of very narrow, sharply defined wavelenths. The sample, in solution, is aspirated, as a fine mist into a flame, where, it is converted to an atomic vapour. Most of the atoms remain in the ground state and are therefore capable of absorbing radiation of a suitable wavelength. This discrete radiation is usually supplied by a hollow cathod lamp, which is a sharp line source consisting of a cathod containing an element to be determined along with an anode (usually tungsten).

When a sufficient voltage is impressed across the electrodes, the filter gas is ionised and the ions are accelerated towards the cathod. As these ions bombard the cathod, they cause the cathod material to sputter and form an atomic vapour in which atoms exist in an excited electronic state. In returning to the ground state, the lines characteristics of the elements are emitted and pass through the flame where they may be absorbed by an atomic vapour. Since, gemerally, only the test element can absorbs this radiation, the method becomes very specific in addition to being very sensitive.

In atomic absorption spectrophotometry, the metal is excited from the energy imparted to it thermally by the flame and then as it returns to the ground state, it emits radiation at a characteristic wavelength. This radiation is when isloated by a monochomator and subsequently its intensity is directly proportional to the concentration of the element present.

The atomic absorption spectrometric method is subject to interference in the flame mode and requires an extraction procedure for the low concentrations common in potable water; the electrothermal atomic absorption method does not require extraction.

2.10.2 DITHIZONE METHOD :

The dithizone method is sensitive and is preferred by some analysts for low concentrations.

The principle of this method is that an acidified sample containing microgram quantities of lead is mixed with ammoniacal citrate-cyanide reducing solution and extracted with dithizone in chloroform ($CHCl_3$) to form a cherry-red lead dithizonate. The colour of the mixed colour solution is measured photometrically. Sample volume taken for analysis may be 2l when digestion is used.

In a weakly ammoniacal cyanide solution (pH 8.5 to 9.5) dithizone forms coloured complexes with bismuth, stannous tin, and monovalent thallium. In strongly ammoniacal citrate-cyanide solution (pH 10 to 11.5) the dithizonates of these ions are unstable and are extracted only partially. This method use a high pH, mixed colour, single dithizone extraction. Interference from stannous tin and monovalent thallium is reduced further when these ions are oxidized during preliminary digestion. A modification of the method allows detection and elimination of bismuth interference. Excessive quantities of bismuth, thallium, and tin may be removed.

Dithizone in $CHCl_3$ absoprbs at 510 nm; coontrol its interference by using nearly equal concentrations of excess dithizone in samples, standards, and blank.

This method can be used for the determination of Pb^{++} content upto 30 µg in the presence of 20 µg Tl^{+}, 100 µg Sn^{2+}, 200 µg In^{3+},and 1000 µg each of Ba^{2+}, Cd^{2+}, Co^{2+}, Cu^{2+}, Mg^{2+}, Mn^{2+}, Hg^{2+}, Sr^{2+}, Zn^{2+}, Al^{3+}, Sb^{3+}, As^{3+}, Cr^{3+}, Fe^{3+}, V^{3+}, PO_4^{3-}, and SO_4^{2-}. Alkali metals do not interfere.

The method employed for the determination of concentration of lead in this study is as given in theOperational Manual Model IL 751 Atomic Absorption/Atomic Emission Spectrophotometer of University Service and Instrumentation Centre, University of Roorkee, Roorkee.

CHAPTER 3

EXPERIMENTAL INVESTIGATION

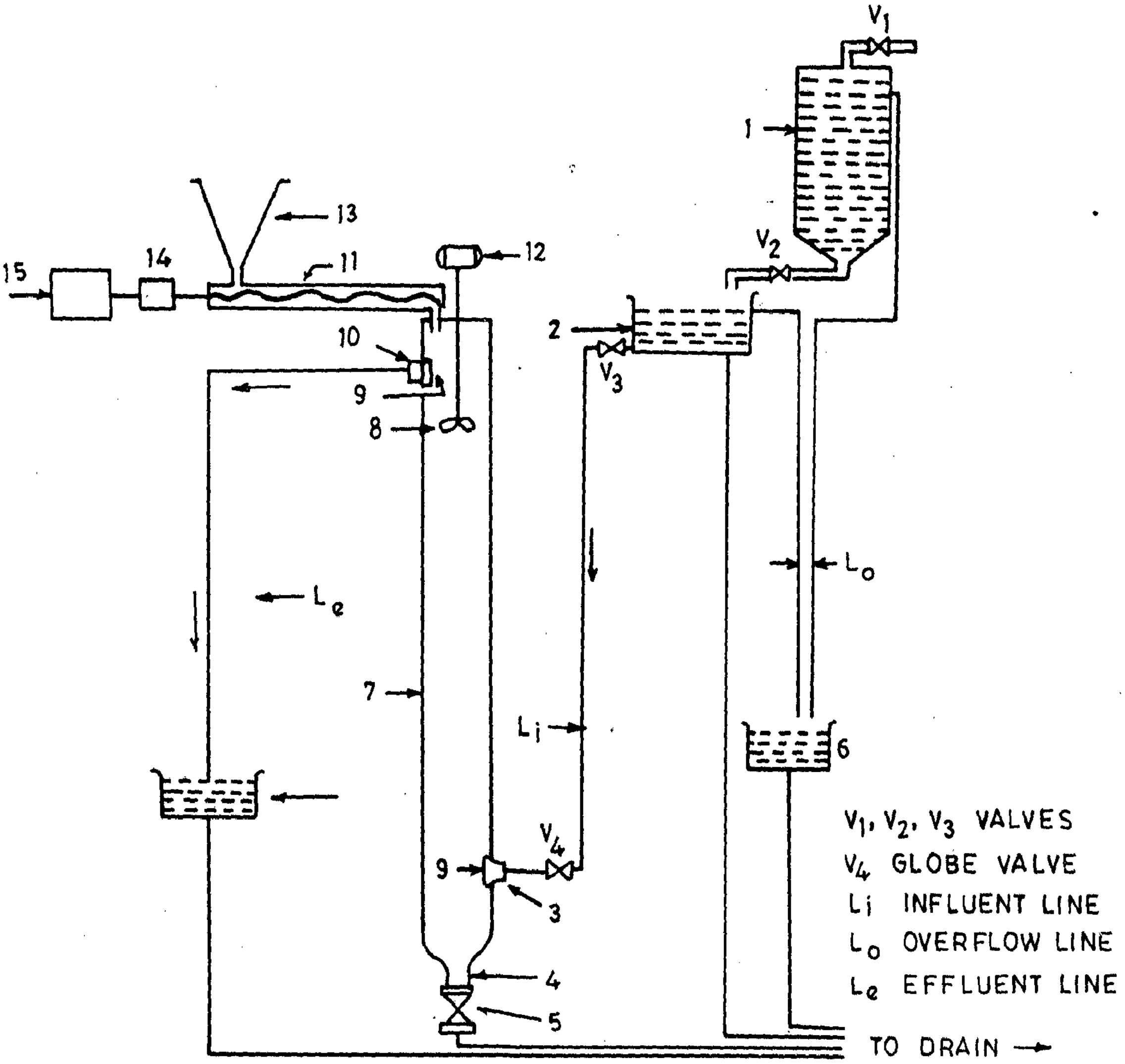
To meet the objectives of the present investigation an experimental set-up was designed, fabricated and commissioned. It has been shown estimatically in Figure 3.1.

3.1 DESIGN CONSIDERATIONS :

The following important design considerations were taken into account while erecting the experimental set-up so that the experimental data are reliable and reproducible :

a) Replacement of exhausted charcoal with fresh material is of paramount importance. For this purpose, an inlet nozzle for the influent was provided at a height of 150 mm from the bottom of the reactor. Besides, it is necessary that the upward velocity of the influent in the reactor is equal to the terminal settling velocity of the charcoal particles. To realise this, the terminal settling velocity of charcoal was theoretically calculated and accordingly the range of the velocity of the influent was selected.

b) Complete exhaustion of charcoal particles is necessary so that the whole surface area is utilized for adsorption during their residence time. This condition in the present investigation has been obtained by selecting appropriate values of mass flow rate of the charcoal, liquid flow rate and the initial concentration of lead. It may be mentioned at this junction that laboratory bench scale experiments were carried out to determine the range



1 OVERHEAD RESERVOIR
2 CONSTANT HEAD TANK
3 INFLUENT FLOW INLET
4 COLLECTION CHAMBER
5 GATE VALVE
6 OVERFLOW COLLECTION TANK
7 MOVING MEDIA REACTOR
8 STIRRER

9 WIREMESH
10 EFFLUENT OUTLET
11 SCREW CONVEYOR
12 AC MOTOR
13 HOPPER
14 DC MOTOR
15 ELECRONIC SPEED REGULATOR
16 EFFLUENT COLLECTION TANK

FIG. 3.1 – SCHEMATIC DIAGRAM OF THE EXPERIMENTAL SET-UP

of the above parameters.

c) Possibility of arch formation of charcoal particles in the hopper was eliminated by installing a vibrator near the hopper. This was essential to maintain the free flow of solid particles in the reactors.

3.2 EXPERIMENTAL SET-UP :

The experimental set-up for a continuous operating moving media adsorption system includes an overhead reservoir (1), a constant head tank (2), a column of perspex material (moving media reactor) (7), a charcoal feeding conveyor and other measuring instruments.

3.2.1 OVERHEAD RESERVOIR :

The overhead reservoir (1) was a mild steel cylindrical basin having dimensions of 520 mm x 1100 mm. The basin had a lid at the top and conical at the botttom for the discharge of influent in a constant head tank (2). The possibility of rust formation during the course of experimentation was eliminated by applying an anticorrosive synthetic enamel paint on the inner surface of the basin.

3.2.2 CONSTANT HEAD TANK :

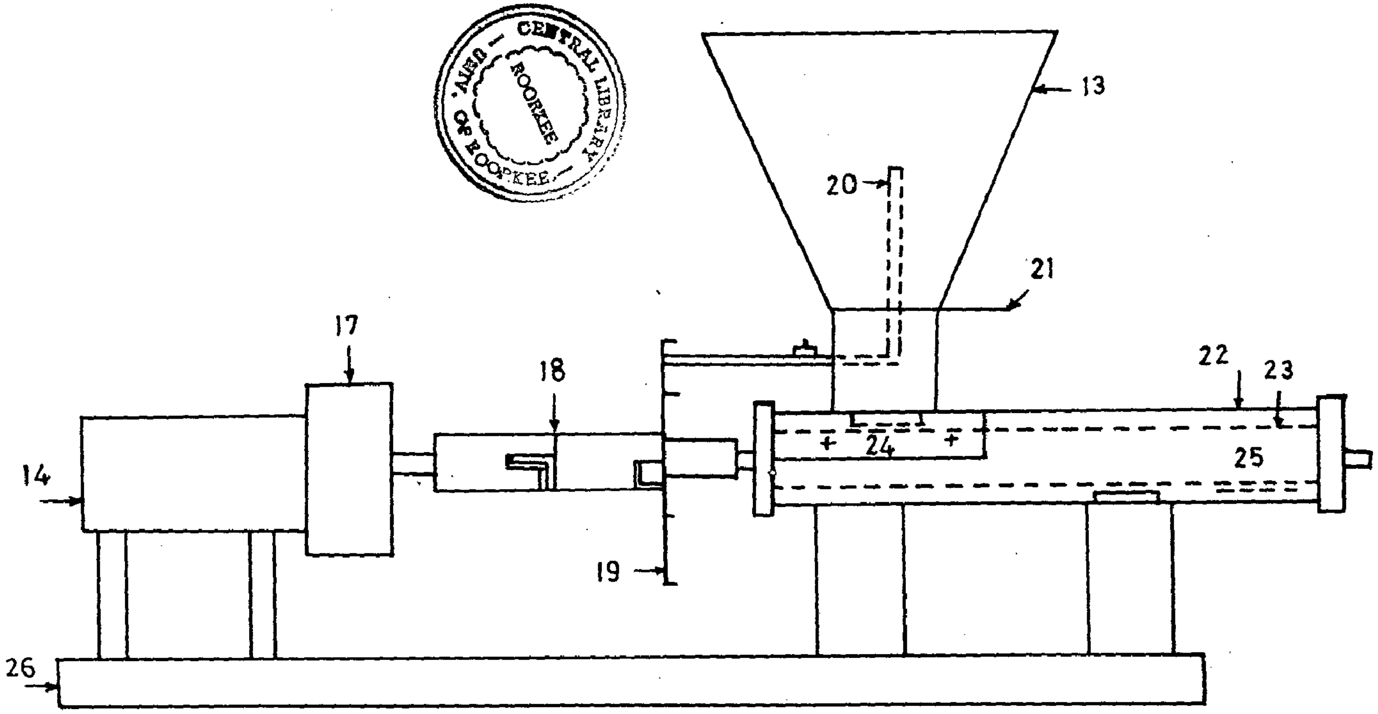
It is a rectangular vessel having an opening at one of its sides so that the influent may flow to the reactor from it. An overflow pipe (L_0) was provided near the top of the tank (2) so that the level of the influent in the tank maintained at a constant head. The overflow liquid was collected in an overflow tank (6) from where it was drained.

3.2.3 MOVING MEDIA REACTOR :

The reactor involved a cylindrical column of 100 mm inside diameter, 114 mm outside diameter and 1150 mm height. The bottom of it had a conical socket which in turn was connected to a collection chamber (4) for the collection of exhausted charcaol from the column. The periodical removal of the charcoal from the column was carried out with the help of a gate valve (5) provided at the end of the collection chamber. At a height of 150 mm from the top of the collection chamber an inlet nozzle (3) of about 15 mm diameter was provided. Paste of perspex powder and araldite was used to make the joint leakproof. The top of the column had an arrangement for the installation of a stirrer (8) and a hopper (13) through which charcoal particles flow downward into the column (7). At a distance of about 150 mm a nozzle (10) similar to the inlet nozzle was provided for the flow of treated water from the reactor. The possibility of any charcoal particle passing into the inlet and the outlet pipelines was elimianted by installing copper wire mesh (9) at the mouth of both the inlet and outlet nozzles. The size of wire mesh was selected to be less than the finest particle in the charcoal bed. In the present investigation the wire mesh size was 100 micron. The mechanical stirrer (8) was used for the uniform dispersion of charcoal particles in the reactor. It was rotated by an A.C. electric motor (12) of 0.05 H.P. and its speed was controlled by means of virial.

3.2.4 CHARCOAL FEEDING CONVEYOR :

The details of charcoal feed conveyor system is shown in Figure 3.2. Its main parts were screw conveyor (11), feed



13	HOPPER
14	D.C. MOTOR
17	SPEED REDUCTION GEAR AND TACHOMETER
18	COUPLING GEAR
19	WHEEL WITH TEETH
20	VIBRATOR
21	FEED RATE CONTROLLER PLATE
22	BARREL
23	SCREW
24	INLET
25	OUTLET
26	BASE

FIG.3.2 — CHARCOAL FEEDING CONVEYOR

hopper (13) and a vibrator (20). Screw conveyor had a barrel (22) in which a screw was laid axially (23). Both the ends of the barrel were closed. However, it had provision for their openings for maintenance and operational difficulties. Two rectangular slots at the two ends of the barrel were used as the inlet and outlet of the screw conveyor. Vibrator (20) eliminated the possibility of any arch formation of the charcoal particles in the hopper. The screw in the barrel was rotated by a D.C. motor (14) whose speed was regulated by an electronic timer (15).

3.3 TESTING OF EXPERIMENTAL SET-UP :

Before conducting the series of experimental runs the experimental set-up was tested against any mechanical and electrical leakage. For this purpose, water was circulated in the unit for a prolonged period at different intervals of times. The mechanical leakages were detected and plugged there off. Similarly, the unit was examined for electrical short circuiting and made trouble-free.

3.4 OPERATING PROCEDURE :

In order to conduct the experimental runs, it was necessary to consider the important points related to the selection of adsorbent and its characteristics, preparation of synthetically wastewater solution, calibration of charcoal feeding conveyor at different speeds of the electronic speed regulator, and the determination of concentration of lead in the influent and effluent streams. These are discussed in details hereunder :

3.4.1 SELECTION OF ADSORBENT :

Wood charcoal was selected as the adsorbent in the present investigation. It was procured from the local market at Roorkee. It was washed by tap water in order to remove any dirt, dust or any foreign solvent materials present in it. Then, it was sun dried for about one day and finally in an electrical oven at a temperature of 110 ^{o}C for about 48 hours. This treatment made the charcoal free from any mositure.

Washing is likely to affect charcoal characteristics considerably. Therefore, experiments were carried out to determine its adsorption capacity. For this purpose, a 5 gm of charcoal sample was washed and dispersed in 1 litre of synthetically prepared solution of lead having a concentration of 1 mg/l. It was stirred on a magnetic stirrer for 3 hours to determine lead concentration in the resulting solution. Experiments were repeated same as in the above manner by taking 5 gm of unwashed charcoal sample. The adsorption of the washed and unwashed charcoal was observed 98.92% and 98.96% respectively indicating no effect of washing on charcoal particles. The details procedure to determine the equilibrium concentration of lead on charcoal particles has been given in Appendix A.

3.4.2 CHARACTERISTICS OF CHARCOAL :

Characteristics of charcoal include sieve anlaysis, proximate analysis, density and porosity. To carry out sieve analysis a sample of the dried charcoal particles was taken and kept on the top most sieve of the deck of screens in a sieve shaker. The detailed method and results are given in Appendix B. The solid fraction, passing through 0.70 mm mesh and retained on 0.15 mm mesh was selected for experiments. Its mean size is 425 micron.

Proximate analysis (moisture content, volatile matter, ash content, and fixed carbon), density and porosity have been determined in accordance with the method described by I.S. The method of anlaysis is given in Appendix C. The results of analysis are tabulated in Table 3.1.

Table 3.1 Characteristics of Chorcoal particles

1.	Moisture content	1.461
2.	Volatile	13.467 %
3.	Ash content	14.015 %
4.	Fixed carbon	71.057%
5	Density	0.8386 g/cc
6.	Porosity	49.860 %

3.4.3 CALIBRATION OF CHARCOAL FEEDING CONVEYOR :

The charcoal feeding conveyor was calibrated against the electronic speed regulator. The results of calibration are shown in Appendix D.

3.4.4 PREPARATION OF SYNTHETICALLY WASTEWATER SOLUTION OF LEAD:

Wastewater solution of lead-ions (Pb^{++}) was prepared synthetically in accordance to the method described in Appendix E.

3.4.5 DETERMINATION OF THE CONCENTRATION OF LEAD ION IN WASTEWATER SOLUTION :

The method used for the determination of lead concentration was as described in the Operational Manual IL 751

Atomic Absorption/Atomic Emission Spectrophotometer Centre, University of Roorkee, Roorkee. It is given in Chapter 2, Sbusection 2.10.1.

3.5 EXPERIMENTATION :

Initially, the overhead reservoir (1) was filled with the wastewater solution having the desired concentration of lead. Samples at different depths of the tank were collected and concentration of lead was measured. The concentration of lead was found to be the same throughout the depth of the tank. Liquid was then allowed to pass from the bottom of the overhead reservoir through a control valve (V_4) into the constant head tank (2). It then passed to the column (7) through the inlet nozzle (3). The flow rate of solution to the column was maintained at a pre-determined rate. The level of solution into column gradually increased and ultimately it passed through the outlet nozzle (10). Samples were drawn to determine lead content in outgoing stream. It may be mentioned that no difference in the lead content in inlet- and outlet - streams was detected at any time. Charcoal particles were introduced in a hopper (13) placed at the top of the column (7) and was allowed to fall freely and continuously through the inlet of the screw conveyor (24) at a pre-set constant rate. The mechanical stirrer (8) was driven at a speed of 100 r.p.m. to achieve uninterrupted flow of charcoal particles from the hopper and uniform dispersion of the charcoal particles at the top of the column. The stirrer was extended slightly into the water surface to ensure wetting and subsequent free fall of the charcoal particles. Thus, solid and liquid passed counter-currently to each other in the reactor. Samples of the treated wastewater were drawn from the outlet nozzle (10) and analaysed for Pb^{++} concentration. The exhausted charcoal was collected in the collection chamber (16).

Experiments were repeated for the removal of lead from wastewater by charcoal particls using various influent flow rate, Q, initial concentration of Pb^{++} in wastewater, C_o, and charcoal mass input rate, W.

The influent flow rate of wastewater solution varied from 0.25 l/min to 1.00 l/min, the initial concentration of Pb^{++} in the watewater solution from 5.0 mg/l to 15.0 mg/l and the charcoal flow rate from 12.5 g/min to 26.1 g/min. The range of operating variables is given in Table 3.2.

Table 3.2 Range of Operating Parameters

S. No.	Operating Parameters	Values
1.	Lead ions concentration in influent stream (mg/l)	5.0,7.5,10.0,12.5 and 15.0
2.	Flow rate of influent stream (l/min)	0.25, 0.50,0.75 and 1.00
3.	Charcoal mass flow rate (g/min)	12.5, 16.0,20.3 and 26.1

The experimental runs were discontinued at the end of each run to allow discharging of exhausted charcoal particles from the collected chamber (4) in the reactor.

The experimental data of the various sets of runs are tabulated in Appendix F.

3.6 REPRODUCIBILITY AND CONSISTENCY OF EXPERIMENTAL DATA :

The reproducibility and consitency of the experimental data is an important feature of the present investigation. Therefore, experiments under identical conditions were conducted at different times. The results obtained were found to be reproducible and not to be erratic in nature.

CHAPTER - 4

RESULTS AND DISCUSSION

This chapter discusses the results of the experiments conducted to carry out the removal of lead ions from wastewater by adsorption on charcoal particles. Basically, it deals with the determination of equilibrium time, the quilibrium concentration, and the percent removal of lead ions and charcoal adsorption capacity for the wastewater at various influent flow rates, initial Pb^{++} concentrations and with varying mass flow rates of charcoal particles in a moving media reactor. Following sections deal with these aspects:

4.1 EQUILIBRIUM CONCENTRATION OF LEAD IONS IN INFLUENT STREAM :

The experimentally-determined values of effluent lead ion concentration, tabulated in Tables F.1 through F.20 of Appendix F have been plotted as a function of contact time for various values of operating variables of this investigation. Figures 4.1 through 4.4 show some of the typical plots between effluent lead ion concentration, C, and contact time, θ, with effluent flow rate, Q, as a parameter. Each of these plots is for a given value of effluent Pb^{++} concentration and charcoal mass flow rate. An inspection of these plots reveals the following important features :

(a) For a given influent flow rate, an increase in contact time leads to decrease the concentration of Pb^{++} in effluent stream. This trend continues till the effluent concentration becomes constant irrespective of contact time. This constant value of concentration is called equilibrium concentration and the time equilibrium time.

(b) At a given contact time, the value of effluent Pb^{++}

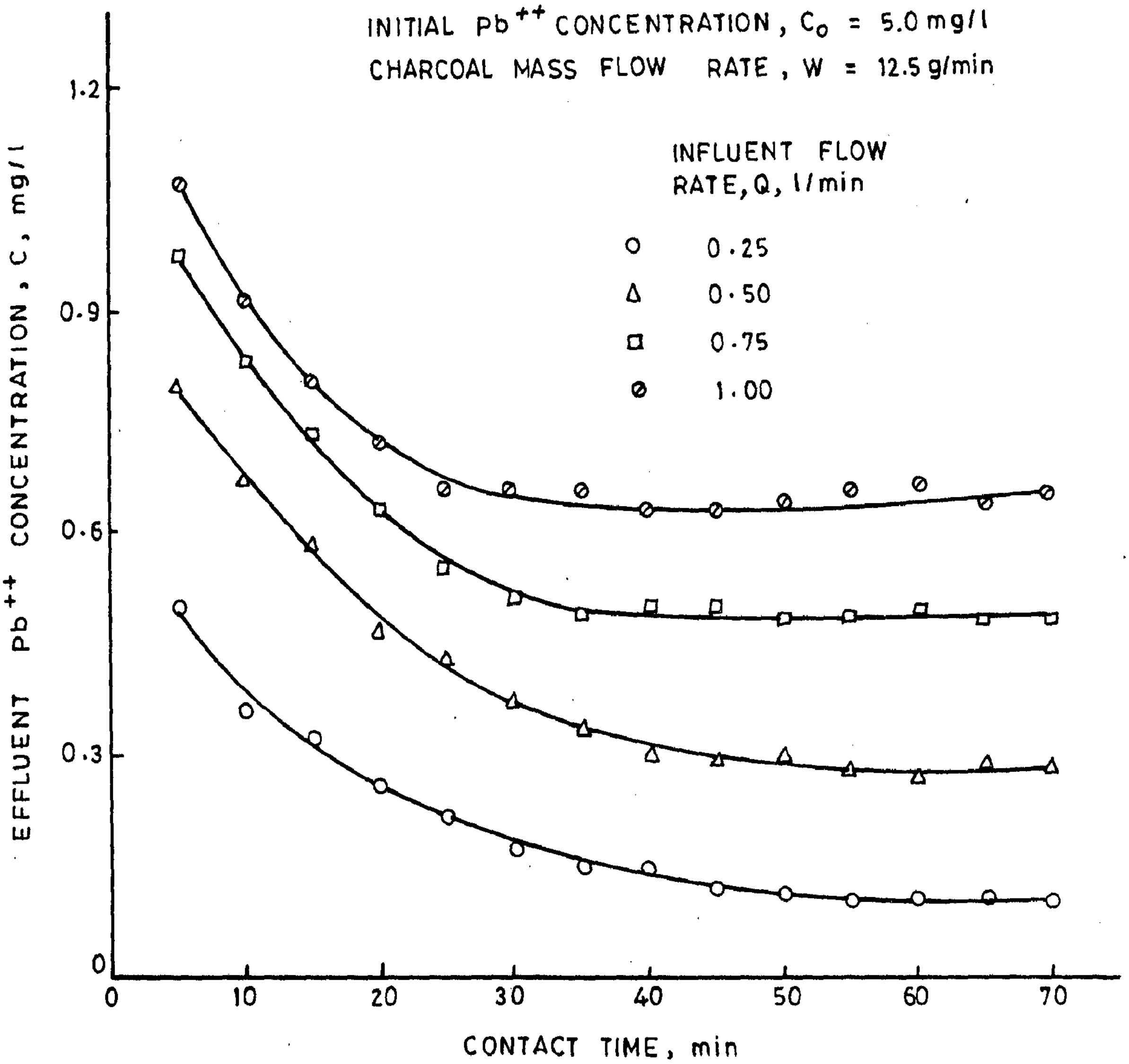


FIG.4.1 - A PLOT BETWEEN EFFLUENT Pb^{++} CONCENTRATION AND CONTACT TIME WITH INFLUENT FLOW RATE AS A PARAMETER

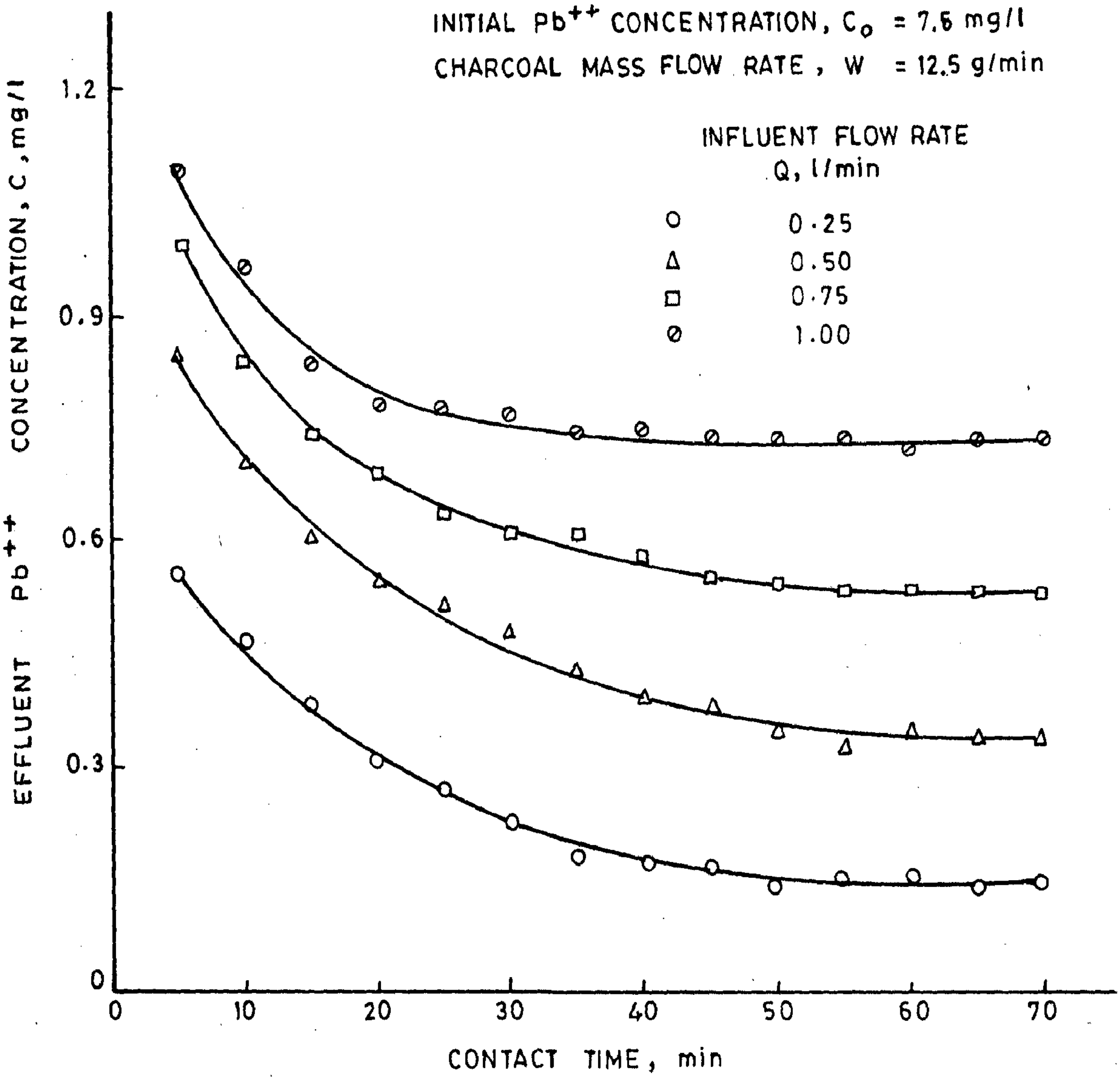


FIG. 4.2 – A PLOT BETWEEN EFFLUENT Pb^{++} CONCENTRATION AND CONTACT TIME WITH INFLUENT FLOW RATE AS A PARAMETER

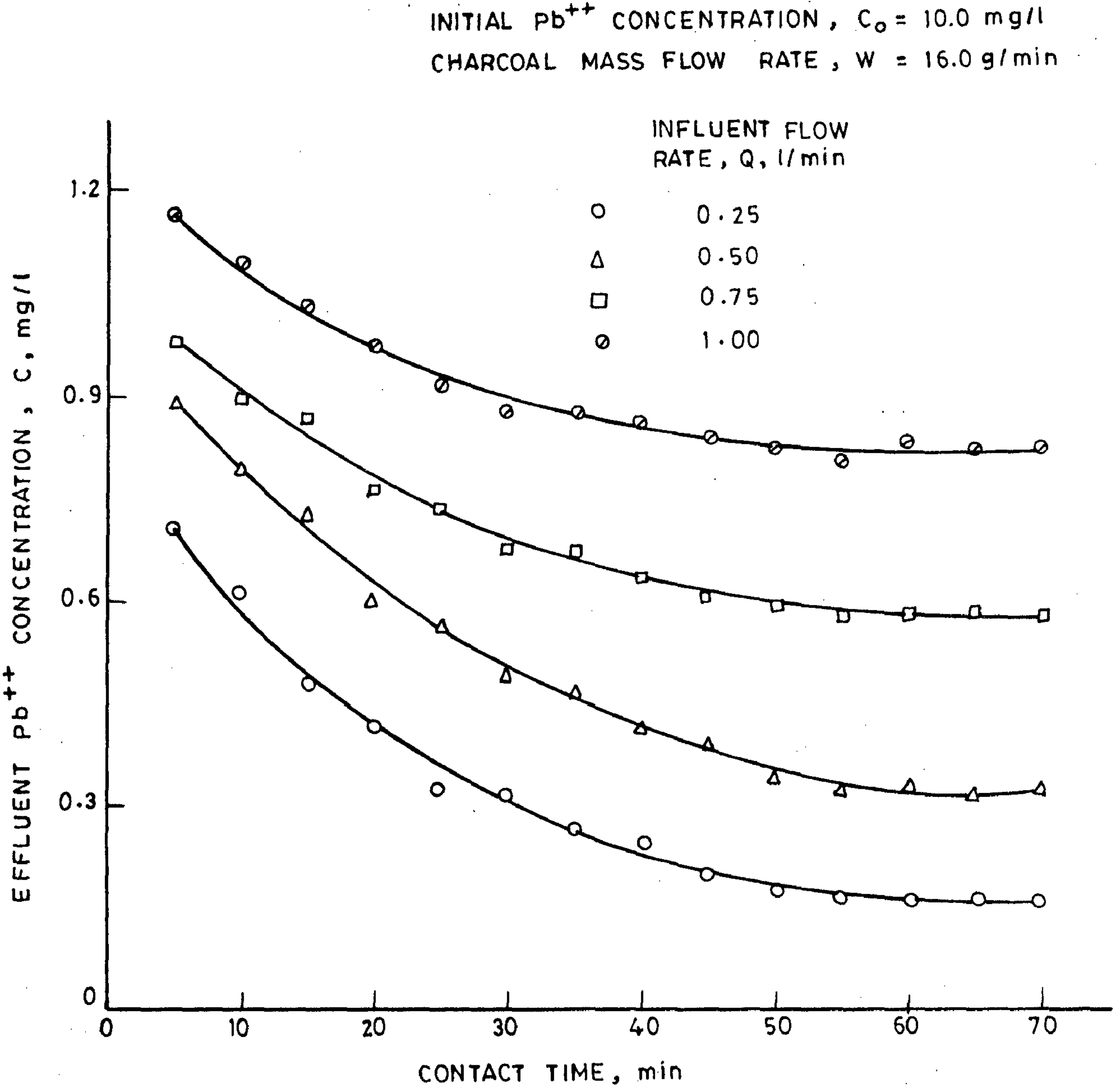


FIG.4.3 – A PLOT BETWEEN EFFLUENT Pb^{++} CONCENTRATION AND CONTACT TIME WITH INFLUENT FLOW RATE AS A PARAMETER

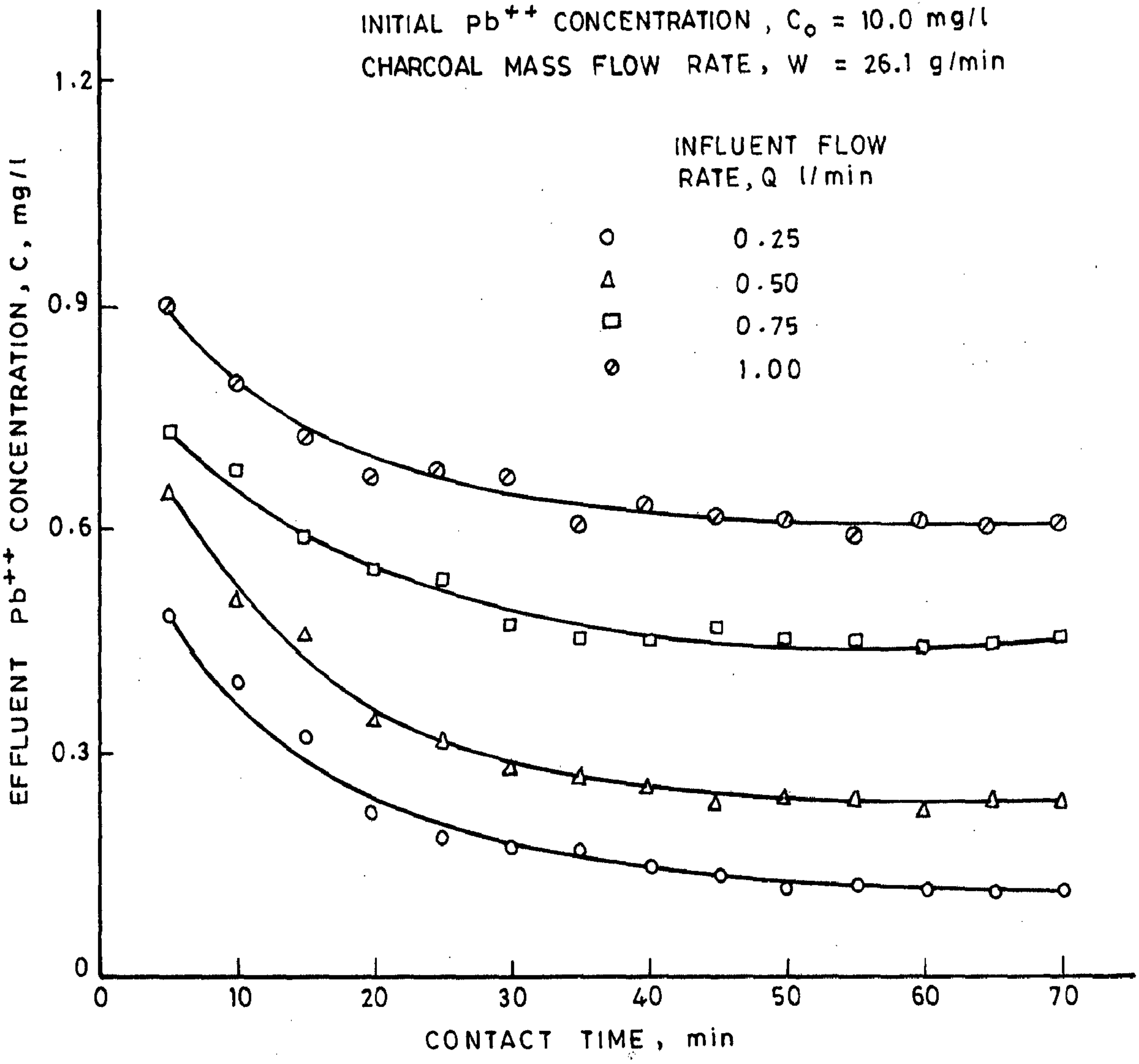


FIG.4.4 - A PLOT BETWEEN EFFLUENT Pb^{++} CONCENTRATION AND CONTACT TIME WITH INFLUENT FLOW RATE AS A PARAMETER

concentration rises with the increase in influent flow rate.

The above features have also been found in other plots. These features can be attributed to the following :

At a given flow rate of influent as time passes in the reactor, more and more surface area of charcoal comes into contact with the influent and therefore adsorption of Pb^{++} increases continuously. Thus, Pb^{++} concentration in effluent stream is found to decrease with the contact time. However, at a certain point of time whole of the surface gets exhausted and now no more adsorption of lead ion is possible. Thus, quilibrium concentration is attained.

Increase in influent flow rate leads to increase adsorption of Pb^{++} on charcoal. This, in turn, causes the effluent Pb^{++} concentration to increase with rise in influent flow rate.

The values of equilibrium time, θ_e, and equilibrium concentration, C_e, for all the systems of this investigation are tabulated in Table 4.1.

4.2 IEAD REMOVAL EQUILIBRIUM CONCENTRATION:

An inspection of the aforesaid Table 4.1 clearly shows that equilibrium concentration of lead ions in effluent streams is a strong function of influent concentration, influent flow rate and the mass flow rate of charcoal in the reactor. Therefore, i't is essential to determine the functional relationship between the equilibrium effulent Pb^{++} concentration and other variables.

Following subsection discusses the effect of influent Pb^{++} concentration, influent flow rate and charcoal mass flow rate on the equilibrium concentration of Pb^{++} in the reactor and thereby a correlation amongst them.

TABLE 4.1 EQUILIBRIUM CONCENTRATION, TIME, PERCENT REMOVAL OF Pb^{++} AND LEAD REMOVAL CAPACITY IN THE MOVING MEDIA REACTOR

S.No.	Influent flow rate Q l/min	Charcoal mass flow rate W g/min	Equilibrium time θ_e min	Equilibrium Pb^{++} concentration C_e mg/l	Percent removal of Pb^{++} P_r %	Lead Removal capacity of charcoal q μg/g

Initial concentration of lead , C_o = 5.0 mg/l

1	0.25	12.5	55	0.102	97.96	97.96
2	0.25	16.0	40	0.105	97.90	76.48
3	0.25	20.3	40	0.053	98.94	60.92
4	0.25	26.1	40	0.041	99.18	47.50
5	0.50	12.5	50	0.302	93.96	187.92
6	0.50	16.0	45	0.248	95.04	148.50
7	0.50	20.3	50	0.182	96.36	118.67
8	0.50	26.1	40	0.171	96.58	092.51
9	0.75	12.5	45	0.493	90.14	270.42
10	0.75	16.0	40	0.398	92.04	215.72
11	0.75	20.3	50	0.350	93.00	171.80
12	0.75	26.1	45	0.306	93.88	134.89
13	1.00	12.5	40	0.665	86.70	346.80
14	1.00	16.0	30	0.595	88.10	275.31
15	1.00	20.3	40	0.477	90.46	222.81
16	1.00	26.1	40	0.461	90.78	173.91

TABLE 4.1 Contd.

S.No.	Q	W	θ_e	C_e	P_r	q

Initial concentration of lead , C_o= 7.5 mg/l

1	0.25	12.5	50	0.145	98.067	147.10
2	0.25	16.0	60	0.135	98.200	115.08
3	0.25	20.3	55	0.112	98.507	90.99
4	0.25	26.1	50	0.089	98.810	70.99
5	0.50	12.5	50	0.314	95.810	287.44
6	0.50	16.0	55	0.261	96.520	226.22
7	0.50	20.3	55	0.224	97.013	179.21
8	0.50	26.1	45	0.211	97.187	139.64
9	0.75	12.5	55	0.524	93.013	418.52
10	0.75	16.0	55	0.480	93.600	329.06
11	0.75	20.3	55	0.375	95.000	263.24
12	0.75	26.1	55	0.351	95320	205.43
13	1.00	12.5	55	0.726	90.320	541.92
14	1.00	16.0	55	0.666	91.120	527.13
15	1.00	20.3	50	0.561	92.520	341.82
16	1.00	26.1	55	0.452	93.973	270.04

S.No.	Q	W	θ_e	C_e	P_r	q
Initial concentration of lead, C_o = 10.0 mg/l						
1	0.25	12.5	55	0.185	98.150	196.30
2	0.25	16.0	55	0.159	98.410	155.77
3	0.25	20.3	55	0.143	98.450	121.39
4	0.25	26.1	60	0.118	98.820	94.66
5	0.50	12.5	55	0.381	96.190	384.76
6	0.50	16.0	55	0.326	96.740	302.31
7	0.50	20.3	55	0.292	97.080	239.11
8	0.50	26.1	45	0.235	97.650	187.07
9	0.75	12.5	55	0.655	93.450	560.70
10	0.75	16.0	55	0.582	94.180	441.47
11	0.75	20.3	55	0.540	94.600	349.51
12	0.75	26.1	55	0.449	95.510	274.45
13	1.00	12.5	55	0.959	90.290	723.28
14	1.00	16.0	55	0.808	91.920	574.50
15	1.00	20.3	50	0.684	93.160	458.92
16	1.00	26.1	55	0.586	94.140	360.69

TABLE 4.1 Contd.

Initial concentration of lead , C = 12.5 mg/l

S.No.	Q	W	θ_e	C_e	P_r	q
1	0.25	12.5	55	0.321	97.432	243.58
2	0.25	16.0	55	0.307	97.544	190.52
3	0.25	20.3	50	0.250	98.000	150.86
4	0.25	26.1	55	0.223	98.152	117.60
5	0.50	12.5	55	0.685	94.520	472.60
6	0.50	16.0	55	0.621	95.032	371.22
7	0.50	20.3	55	0.525	95.800	294.95
8	0.50	26.1	55	0.494	96.048	230.00
9	0.75	12.5	55	1.215	90.280	677.10
10	0.75	16.0	45	1.047	91.624	541.34
11	0.75	20.3	50	0.951	92.392	427.02
12	0.75	26.1	55	0.793	93.656	336.41
13	1.00	12.5	55	1.576	87.392	873.92
14	1.00	16.0	55	1.375	89.000	695.31
15	1.00	20.3	55	1.261	89.616	553.65
16	1.00	26.1	45	1.201	90.392	432.91

TABLE 4.1 Contd.

Initial concentration of lead , $C_o = 15.0$ mg/l

S.No.	Q	W	θ_E	C_e	P_r	q
1	0.25	12.5	55	0.664	95.573	286.72
2	0.25	16.0	55	0.593	96.047	225.11
3	0.25	20.3	50	0.541	96.393	178.07
4	0.25	26.1	55	0.482	96.787	139.06
5	0.50	12.5	55	1.325	91.167	547.00
6	0.50	16.0	50	1.254	91.640	429.56
7	0.50	20.3	50	1.106	92.627	342.22
8	0.50	26.1	45	1.014	93.240	267.93
9	0.75	12.5	40	2.159	85.607	770.46
10	0.75	16.0	45	1.982	86.787	610.22
11	0.75	20.3	50	1.797	88.020	487.80
12	0.75	26.1	50	1.510	89.933	387.64
13	1.00	12.5	45	3.218	78.547	942.56
14	1.00	16.0	40	2.831	81.127	760.56
15	1.00	20.3	50	2.762	81.587	602.86
16	1.00	26.1	50	2.395	84.033	482.95

4.2.1 VARIATION OF CHARCOAL FLOW RATE WITH EQUILIBRIUM CONCENTRATION OF LEAD IONS :

Figure 4.5 represents a plot to demonstrate the variation of equilibrium Pb^{++} concentration with charcoal mass flow rate, keeping influent flow rate as a parameter. This plot is for a given value of lead ion concentration in influent stream. From this plot the following noteworthy features emerge out:

(a) The equilibrium Pb^{++} concentration decreases continuously with the increase in charcoal mass flow rate for a specified influent flow rate. The variation between the two can be represented by a power law, given below :

$$C_e = K_1 W^{-0.4663} \qquad (4.1)$$

Where K_1 is a constant whose value depends upon the influent flow rate and its lead ion concentration. The values of K_1 for various influent flow rates are given in Table 4.2.

(b) Value of equilibrium Pb^{++} concentration rises with the increase in flow rate of influent stream for a given mass flow rate of charcoal in the reactor. These features are consistent and can be explained as below :

An increase in mass flow rate of charcoal in the reactor augments the availability of surface area for adsorption. Consequently, larger amount of lead ions are found to be removed from the influent stream. Therefore, the equilibrium concentration of lead ions in effluent stream is found to decrease with the increase in mass flow rate of charcoal.

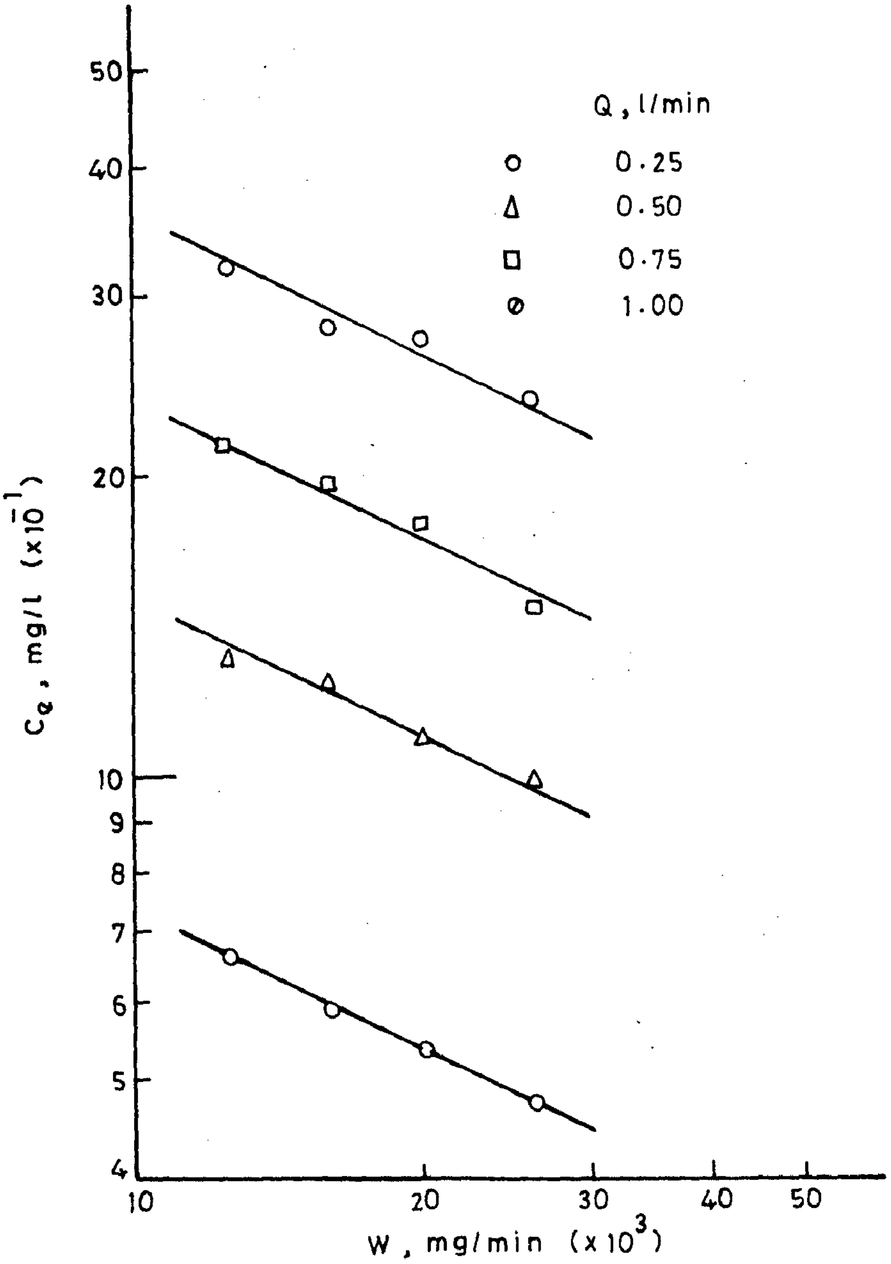


FIG.4.5 — A PLOT BETWEEN C_e AND W (C_o = 15.0 mg/l)

As regards the variation of equilibrium Pb^{++} concentration with influent flow rate, the explanation for above-noted behaviour has already been discussed in Section 4.1.

Table 4.2 Values of K_1 When Pb^{++} concentration of influent stream , C_o is 15.0 mg/l

Q , l/min	K_1
0.25	2.13
0.50	4.41
0.75	7.05
1.00	11.50

From Table 4.2, it is noted that the value of K_1 increases with the rise in influent flow rate. Similarly the values of the constant K_1 were calculated for other values of influent Pb^{++} concentration, and they were also found to depend on influent flow rate.

In order to represent the varitation of constant K_1 of Eq.(4.1) with influent flow rate, Q, quantitatively, plots of $K_1 (=C_e/W^{-0.4663})$ against Q were drawn on a log-log graph paper. Such a plot is shown in Figure 4.6. This plot has influent lead ion concentration as a parameter. An examination of this plot indicates that all the data points are well represented by straight lines, each representing a particular value of influent lead ion concentration. The equation of this line is as follows:

$$\frac{C_e}{W^{-0.4663}} = K_2 \quad Q^{1.1303}$$

$$\text{or} \quad C_e = K_2 \, W^{-0.4663} \, Q^{1.1303} \qquad (4.2)$$

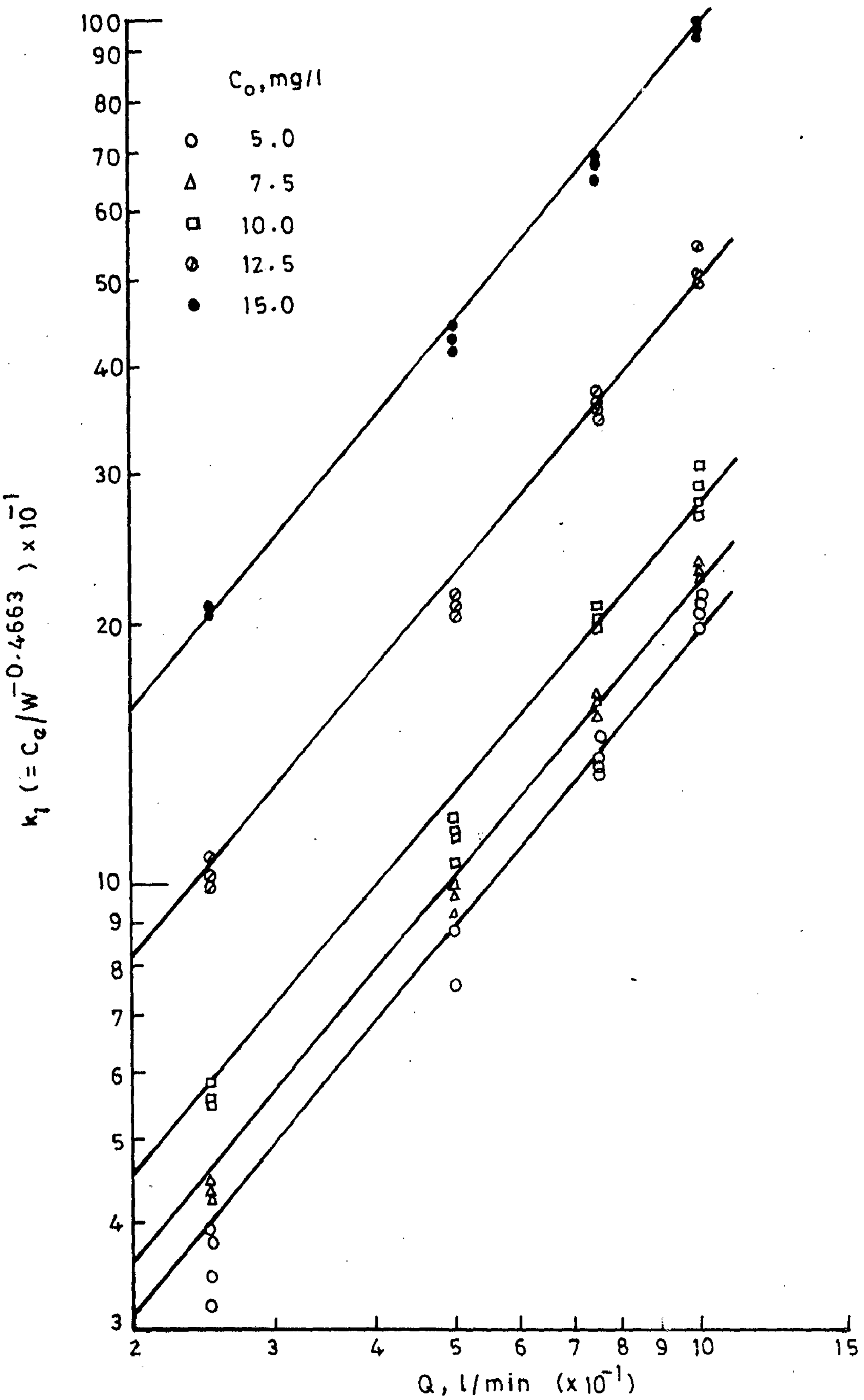


FIG. 4.6 — A PLOT BETWEEN k_1 (= $C_e/W^{-0.4663}$) AND Q

Where K_2 is a constant whose value differs from one set to another depending upon the Pb^{++} concentration in influent stream. The values of constant, K_2 for influent stream having different lead ion concentration are listed in Table 4.3.

Above discussion clearly shows that value of K_2 increases with the rise in flow rate of influent stream for a specified Pb^{++} concentration of influent stream. This observation is understandable in view of the fact that as the flow rate of influent stream is increased, opportunity for adsorption of Pb^{++} on charcoal surface becomes less and thereby the equilibrium concentration of lead ions in the effluent stream increases. This, as a matter of fact, is responsible to increase the value of $C_e/W^{-0.4663}$ with Q.

Table 4.3 values of K_2 at various Pb^{++} concentration of influent stream, C_o.

C_o, mg/l	K_2
5.00	1.98
7.50	2.25
10.00	2.69
12.50	5.00
15.00	9.83

Values of Table 4.3 clearly point out that K_2 differs with the lead ion concentration in influent stream. Therefore, it is necessary to know the functional relationship between K_2 which is equal to $C_e/(W^{-0.4663}\ Q^{1.1303})$ and the influent lead ion concentration, C_o. For this purpose, plots between $C_e/(W^{-0.4663}\ Q^{1.1303})$ and C_o were drawn on log-log scale as well as semi-log scale. But such plots always had a wide scattering of data points. In other words, the plots did not represent the desired relationship between the two. Then it was thought intuitively to draw a plot between $C_e/(W^{-0.4663}$ $Q^{1.1303})$ and C_o^2 on a semi-log graph paper. Fortunately, the plot correlated all the data points with less scattrering. Such a plot is shown in Figure 4.7. As can be seen from this plot, all the data points are correlated by the straight line whose equation is as follows :

$$\frac{C_e}{W^{-0.4663}\ Q^{1.1303}} = 1.3469\ \exp(0.0087C_o^2)$$

$$\text{or } C_e = 1.3469\ W^{-0.4663}\ Q^{1.1303}\ \exp(0.0087C_o^2) \qquad (4.3)$$

The maximum deviation of Eq. (4.3) from most of the data points is ±20%.

Eq(4.3) is a correlation of equilibrium concentration for removal of lead ions from wastewater in moving media reactor with charcoal mass flow rate, influent flow rate and the Pb^{++} concentration in influent stream. Therefore, one can determine the equilibrium Pb^{++} concentration by use of Eq.(4.3) from the knowledge of charcoal mass feed rate, Pb^{++} concentration and flow rate of influent stream.

At this junction it is important to mention that the correlation, Eq.(4.3) has been developed on the bases of experimental data obtained in the present investigation. It, therefore, means that the present correlation is valid on the range of operating parameters given in Table 3.2. Hence no attempt should be made to extend the applicability of Eq.(4.3) beyond the operating parameters of this investigation.

4.3 LEAD REMOVAL CAPACITY OF CHARCOAL :

One of the important objectives of this investigation

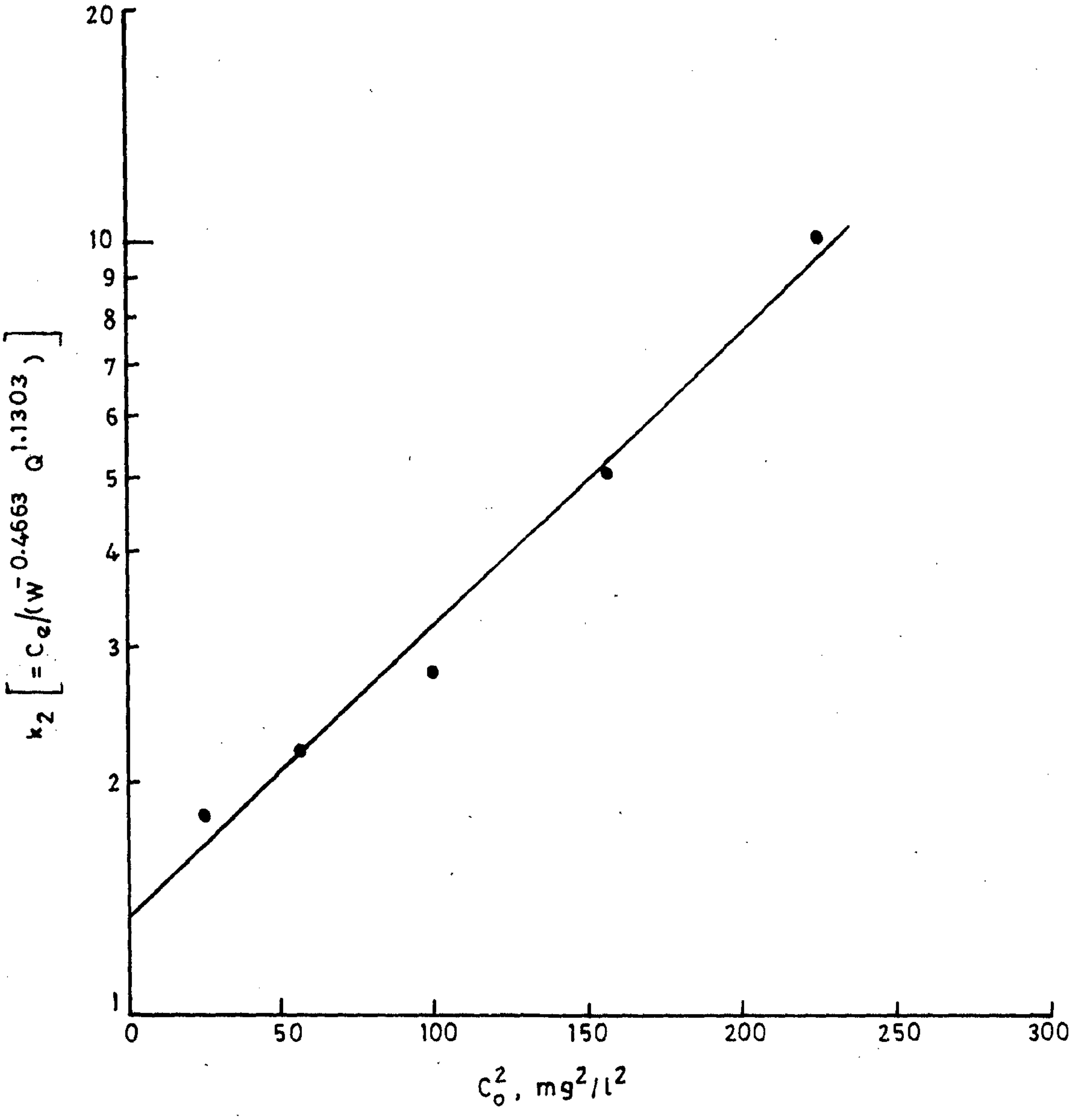


FIG. 4.7 — A PLOT BETWEEN $k_2 \left[= C_e/(W^{-0.4663}\ Q^{1.1303}) \right]$ AND C_o^2

is to determine the adsorption capacity of charcoal for the removal of lead ions from wastewater and itsfunctional relationship with the operating parameters. The lead removal capacity of charcoal is defined as the ratio of experimentally-determined lead ions removed during the residence time in the reactor to the amount of Pb^{++} adsorbed by charcoal. Mathematically, is defined as :

$$\text{lead removal capacity of charcoal, } q = \frac{(C_o - C_e)\ Q\ \theta_e}{W\ \theta_e} \qquad (4.4)$$

Eq.(4.4) assumes that entire surface area of charcoal is available for adsorption. Using Eq.(4.4), value of lead removal capacity of charcoal have been computed for all the operating parameters. The values, so obtained, are listed in Table 4.3.

A persual of Table 4.3 brings out the fact that lead removal capacity of charcoal is a strong function of the Pb^{++}concentration in influent stream, flow rate of influent stream and charcoal mass flow rate to the reactor. So it is essential to find out the functional relationship between these variables and lead removal capacity of charcoal. Such an exercise has been attempted in the following paragraphs :

Figure 4.8 is a plot to demonstrate the variation of lead removal capacity of charcoal with charcoal mass flow rate. In this plot the influen flow rate is a parameter. This plot is for a given value of lead ions concentration in the influent stream. From the plot the following salient features are noted:

(a) At a given flow rate of influent, the lead removal capacity of charcoal decreases with the increase in charcoal mass flow rate in the reactor. The variation between q and W

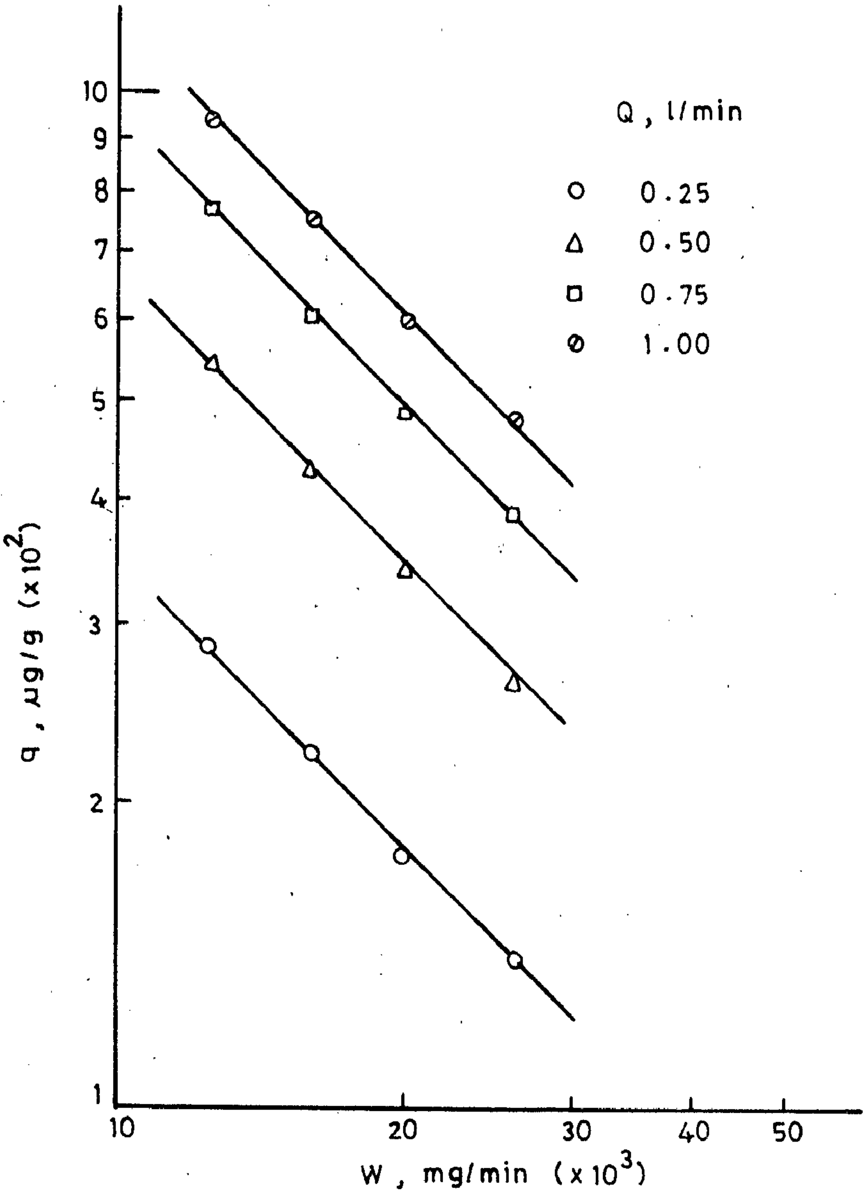


FIG.4.8—A PLOT BETWEEN q AND W (C_o= 15.0 mg/l)

can be repersented by a straight line of the following equation :

$$q = K_1' W^{-0.9490} \qquad (4.5)$$

Where K_1' is a constant. The value of constant K_1' depends upon the flow rate and Pb^{++} concentration of influent stream passing to the reactor. The values of K_1' have been calculated for all the experimental data and are listed in Table (4.4).

(b) The lead removal capacity of charcoal rises with the increase in the flow rate influent for a given mass flow rate of charcoal in the reactor.

These observations have been found with all the sets of this investigation. Therefore, they are consistent and can be explained as given hereunder:

An increase in the flow rate of charcoal decreases the lead removal capacity of charcoal due to the fact that rise in the flow rate of charcoal to reactor decreases the equilibruim concentration of lead ions in influent stream. The reason for this feature has already been explained in detailes in Section 4.2. As a result of it, the removal of lead per unit volume expressed by (C_o-C_e) increases. However, increasein (C_o-C_e) is compratively smaller then that in the flow rate of charcoal. All this couses the lead removal capcity of charcoal to decrease.

An increase in the flow rate of influent stream, for a given charcoal feed rate, raises the equilibrium concentration of Pb^{++}in effluent stream. This, in turn, causes the value of (C_o-C_e) to decrease. However, the amount of lead removed in the reactor increases due to rise in the flow rate of influent stream. All this causes the lead removal capacity of charcoal to be higher when the reactor is fed with larger flow rate of influent stream.

Table 4.4 Values of K_1' when Pb^{++} concentration of influent stream C_o, is 15.0 mg/l.

Q , l/min	K_1'
0.25	3150
0.50	6015
0.75	8465
1.00	10360

Values of Table 4.4 make it amply clear that the lead ion concentration and the flow rate of influent stream strongly affect the value of constant, K_1'. In order to establish the functional relationship between K_1' and other variables, plots are drawn between K_1' $(=\frac{q}{W^{-0.9490}})$ and the flow rate of influent stream, Q.

One such a typical plot is shown in Figure. 4.9. The concentration of lead ions in influent stream is a parameter in this plot. The plot clearly indicates a family of parallel straight lines, each representing a given value of Pb^{++} concentration in influent stream. The equation of straight line is as follows:

$$\frac{q}{W^{-0.9490}} = K_2' \; Q^{0.9573} \qquad (4.6)$$

Where K_2' is a constant whose value depends upon the Pb^{++} concentration of influent stream. Values of K_2' for various Pb^{++} concentration of influent stream are given in table (4.5).

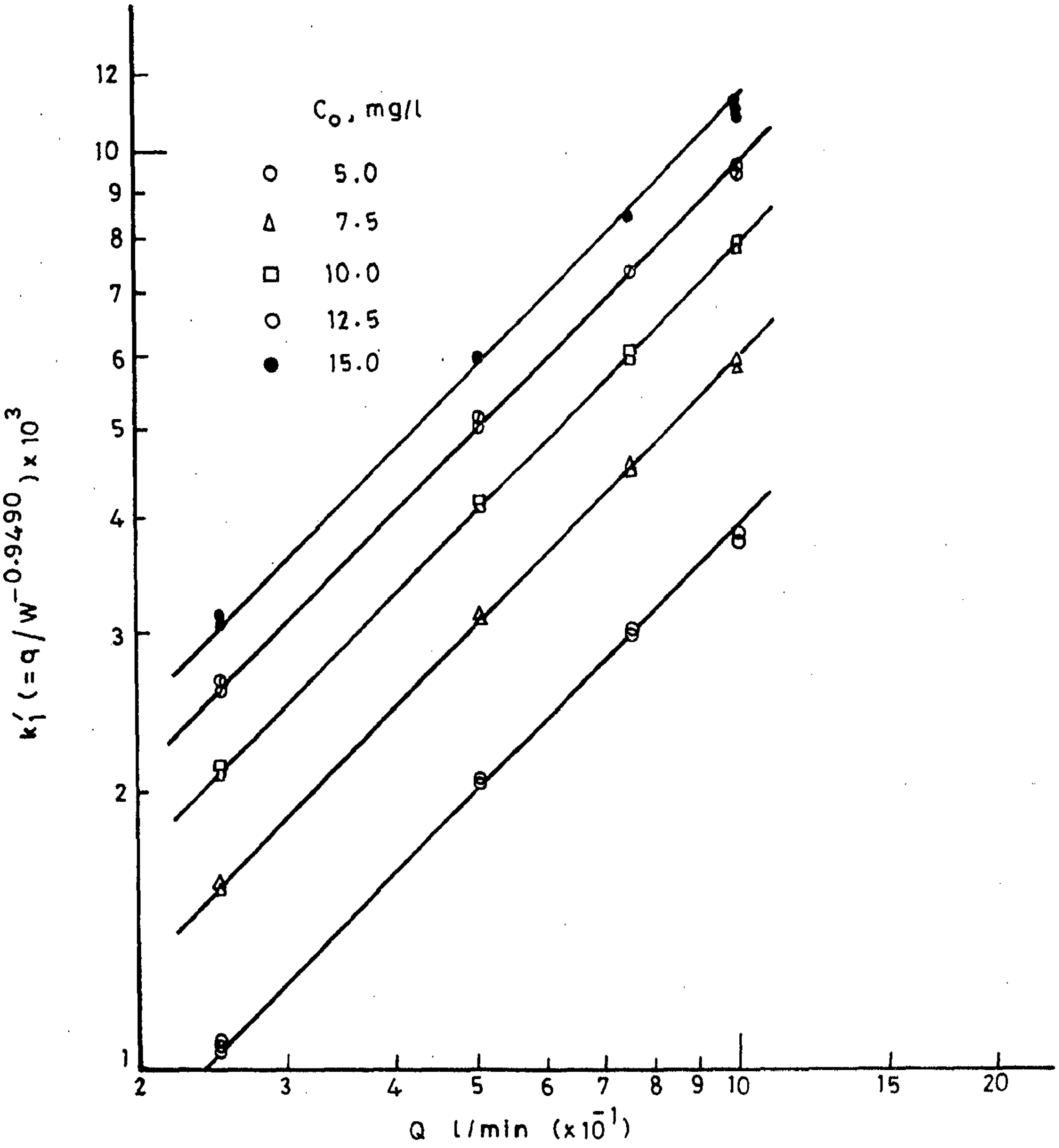


FIG.4.9– A PLOT BETWEEN k'_1 (= q / $W^{-0.9490}$) AND Q

The above observation can also be expressed by stating that $(q/W^{-0.9490})$ varies directly with Q. This is an expected behaviour in the light of above discussion.

Table 4.5 Values of K_2' at various Pb^{++} concentration of influent stream, C_o.

C_o, mg/l	$K_2' \times 10^3$
5.00	38.40
7.50	59.60
10.00	79.70
12.50	96.10
15.00	111.00

It is seen from Table 4.5 that the value of K_2' increases with the rise in C_o. To obtain the relationship between K_2' and the Pb^{++} concentration of influent stream, a plot between these two quantities is drawn. This plot is shown in Figure 4.10. The ordinate of this plot represent $K_2' \left[= q/(W^{-0.9490} Q^{0.9573})\right]$ and the abscissa C_o. The plot clearly shows all the data points to be well correlated by the following equation within a maximum deviation of ±10% .

$$\frac{q}{W^{0.9490}\ Q^{.9573}} = 935.9\ C_o^{1.0173}$$

$$\text{or} \quad q = 935.9\ W^{-0.9490}\ Q^{0.9573}\ C_o^{1.0173} \qquad (4.7)$$

Eq.(4.7) is a simple and convenient correlation to determine lead removal capacity of charcoal from the known values of charcoal feed rate, Pb^{++} concentration and flow rate of influent stream. Eq. (4.7) holds true only for the range of operating parameters given in Table (3.2). Therefore, the above correlation should not be used for those situations which

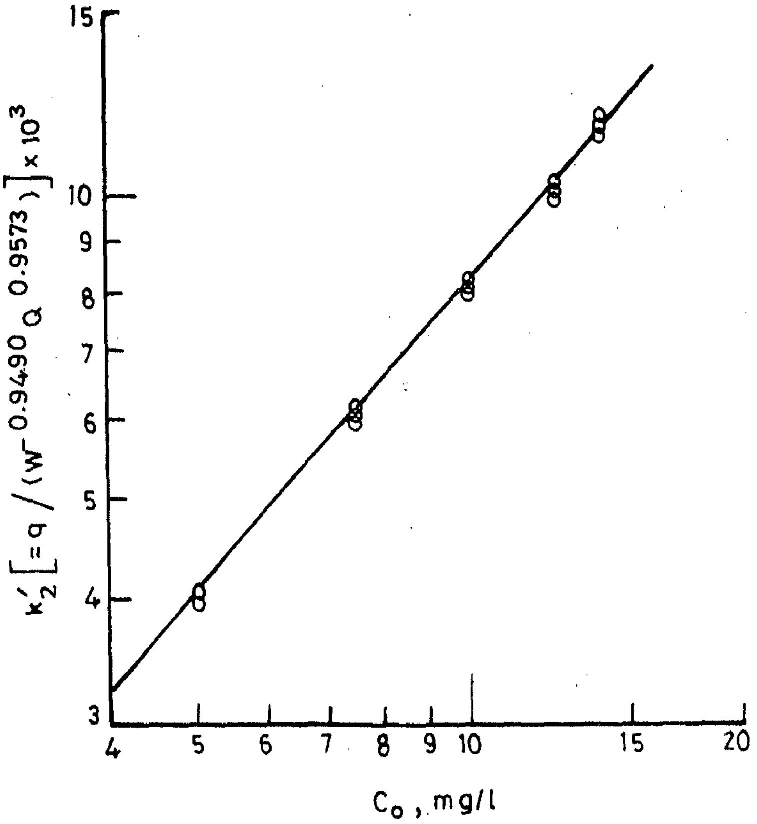


FIG.4.10—A PLOT BETWEEN $k_2' \left[= q/(W^{-0.9490} Q^{0.9573})\right]$ AND C_o

deviateion from the present investigation.

4.4 ADSORPTION ISOTHERM :

Adsorption isotherm is simple and convenient means of expressing the behaviour of the reactor for the removal of solids from effluent stream. As mentioned in Chapter 2, Section 2.9, there are generally three measure types of adsorption isotherms-the Freundlich, the Langmuir and the Braunauer-Emmett-Taller (BET) isotherms. The type of isotherm depends upon the adsorbent concentration, its characteristics, and the adsorbate. Therefore, each of them is represented by different relationship between the solid removal capacity of adsorbate and equilibrium concentration of adsorbent. As a matter of fact, the determination of adsorption isotherm reveals the underlying principle involved in adsorption process and also helps in the design of multi-stage adsorption columns. Keeping this in view, the present investigation has been extended for the determination of isotherm.

Figure 4.11 is a plot to show the adsorption isotherm for moving media reactor. In this plot, lead ion removal capacity of charcoal is on ordinate whereas, the equilibrium lead ion concentration on abscissa. The plot clearly reveals that all the data points are well correlated by the following equation within a maximum deviation of $\pm 35\%$.

$$q = 441.842\, C_e^{0.6625} \qquad (4.8)$$

Equation (4.8) represents the Freundlich isotherm. Thus, it can be said that moving media reactor follows the Freundlich isotherm when lead ions are removed from effluent stream by using charcoal as an adsorbate.

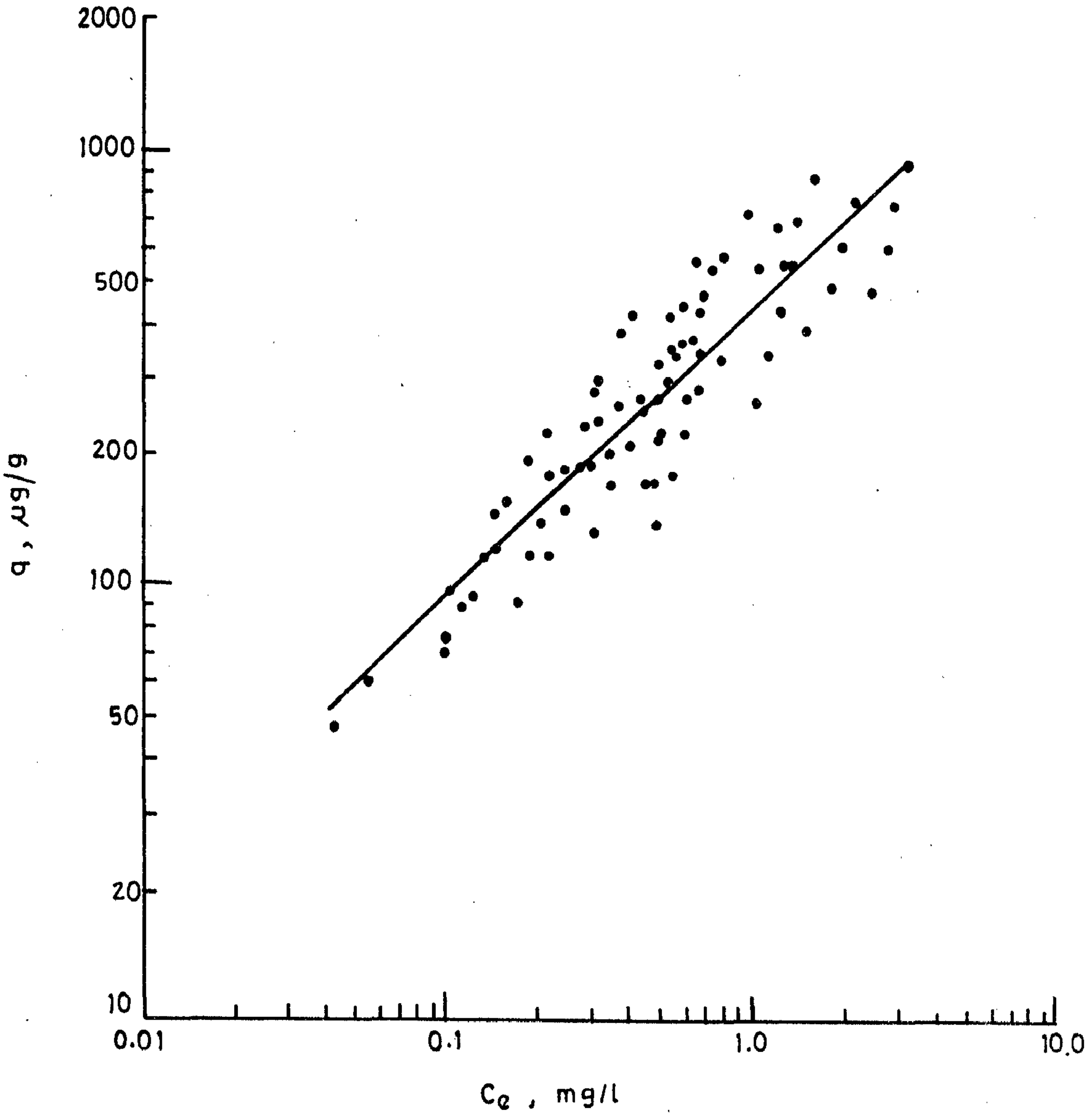


FIG. 4.11 — ISOTHERM FOR MOVING MEDIA REACTOR

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The locally available charcoal is found to be an excellent low cost absorbent for the removal of lead ions from wastewaters in the present moving media reactor. For the ranges of operating parameters of the present investigation, the lead removal efficiency is found to be 78% to 99% depending upon the values of the operating parameters. The counter-current operation of the adopted moving media's dynamic system provides maximum opportunity for sorbate-sorbent contact. The capacity of the sorbent material is utilized to its fullest possible extent.

From the various results of this investigation, for the removal of lead ions from influent steam by charcoal particles for varying influent flowrate, Q, and lead ions concentration of influent stream, C_o in a given media reactor, the following note-worthy conclusions emerge out:

1. For the range of charcoal mass flow rate, W, from 12.5 g/min to 26.1 g/min to the moving media reactor, the charcoal particles remain in their individual entities. This is implied from the fact that with increase in the value of W, there is a proportional increase in the effective surface area of the particles which is amply supported by the proportional increase of lead ions adsorbed on the charcoal particles. Both the values of lead removal capacity of charcoal, q, and the equilibrium lead ion concentration of effluent stream, C_e, decreases

consistently with the increase in the charcoal mass flow rate, W, for the specified values of influent flow rate, Q, and lead ion concentration of influent stream, C_o.

2. As the flow rate of influent stream, Q, increased, the opportunity for adsorption of Pb^{++} on charcoal surface area becomes less and, in turn, resulting in increase in the equilibrium lead ion concentration of effluent stream, C_e.

3. The correlation relating the equilibrium lead ion concentration of effluent stream, C_e, to charcoal mass flow rate, W, influent flow rate, Q, and lead ions concentration of influent stream, C_o, is recommended as follows :

$$C_e = 1.3469\, W^{-0.4663}\, Q^{1.1303} \exp\,(0.0087\, C_o^{2})$$

most of the experimental data are correlated within a maximum deviation of ± 20%

4. The correlation relating the lead removal capacity of charcoal, q, to charcoal mass flow rate, influent flow rate, and lead ions concentration of influent stream is recommended as given below :

$$q = 935.9\, W^{-0.9490}\, Q^{0.9573}\, C_o^{1.0173}$$

This correlation is in excellent agreement with the experimental data of the present investigation within a maximum deviation of ±10 %.

5. The adsorption isotherm for the moving media adsorption

system has been found to follow the Freundlich isotherm and its equation is recommended as given hereunder.

$$q = 441.842 \ C_e^{0.6625}$$

All data points are correlated within a maximum deviation of ±35 %.

At this junction, it is important to mention that the above recommended equations are only valid for the operating parameters given in this investigation.

However, this investigation has much to offer as scope for future work.

1. A detailed study of adsorption in the pores of charcoal particles by diffusional mass transfer is important and consequently a dimensionless correlation for all operating parameters of this investigation seems to be of paramount importance to generalize the problem.
2. The determination of the effect of coalescence on the adsorption of lead ions on charcoal particles is important. In view of this, it is felt that the experiments could be planned to find out the value of charcoal mass flow rate at which the charcoal particles coalesce and thus impair the performance of the reactor. Consequently, it is recommended also to carry out experiments for the adsorption of lead ions by charcoal particles in columns of reactors having lesser diameters than the adopted one in this investigation.
3. Regeneration and disposal of the charcoal including the adsorbed media may be examined because of dangers of leaching if land disposal is planned.

APPENDIX A

CHARCOAL ADSORBTIVE BEHAVIOUR ON LEAD SOLUTION IN A BATCH STUDY

The adsorption of lead on charcoal was studied by preparing a synthetic wastewater containing leadions. Dried charcoal in its natural form having size particles of 425 micron i.e. passing 700 micron mesh size screen and retaining on 150 micron mesh size screen was used as a sorbent material. 10.0 gm of charcoal was added to a beaker containing 1 litre of wastewater having lead concentration of 5 mg/kl. The mixture was stirred at a speed of 50 r.p.m. in the breaker for about six hours continuously. Samples were drawn at an interval of 5 minutes, 30 minutes, 1 hour, 4 hours and 6 hours duration. The concentration of lead in the sample was determined on the atomic absorption spectrophotometer, as per procedure, laid down in the Operational Manual Model IL 751. pH of the sample was measured before and after the experiment, which are listed in Table A.1.

The experimental data, so obtained, were analysed to find out adsorptive capacity of charcoal on wastewater behaviour containing Pb^{++}. Figure A.1 is a plot between percent removal of lead from the solution versus contact time when charcoal is allowed to contact wastewater having initial lead concentration of 5 mg/l. From the plot, it is observed that as the contact time increases, percent removal is found to increase and after a maximum value it decreases. However, the change in percent removal is marginal only. The percent removal is 94.12 for a contact time of 4 hours. The above observation is due to the fact that as time passes, more and more surface area of charcoal particles becomes available for adsorption and thus percent removal of lead is found to increase with time. But after a period, when whole of the surface area has been completely exhausted, no more adsorption occurs. Thus in the present investigation the optimum contact time is 4 hours and the removal of lead corresponding to this period is 94.12% .

Further, it is also seen from Table A-1 that the value of pH does not undergo alteration during the course of experimentation.

TABLE A-1 EXPERIMENTAL DATA FOR THE STUDY OF CHARCOAL ADSORPTIVE CAPACITY ON LEAD ION

Initial Pb^{++} concentration = 5 mg/l
Charcoal added for a batch = 10 gm

Residual concentration of Pb^{++} in solution mg/l					Percent removel of lead on charcoal %					Adsorption on charcoal mg/g %					pH	
5 min	30 min	1 hr	4 hr	6 hr	5 min	30 min	1 hr	4 hr	6 hr	5 min	30 min	1 hr	4 hr	6 hr	Before	After
0:577	0.439	0.426	0.294	0.585	88.46	91.22	91.48	94.12	88.30	44.23	45.61	45.74	47.66	44.15	6.23	6.28

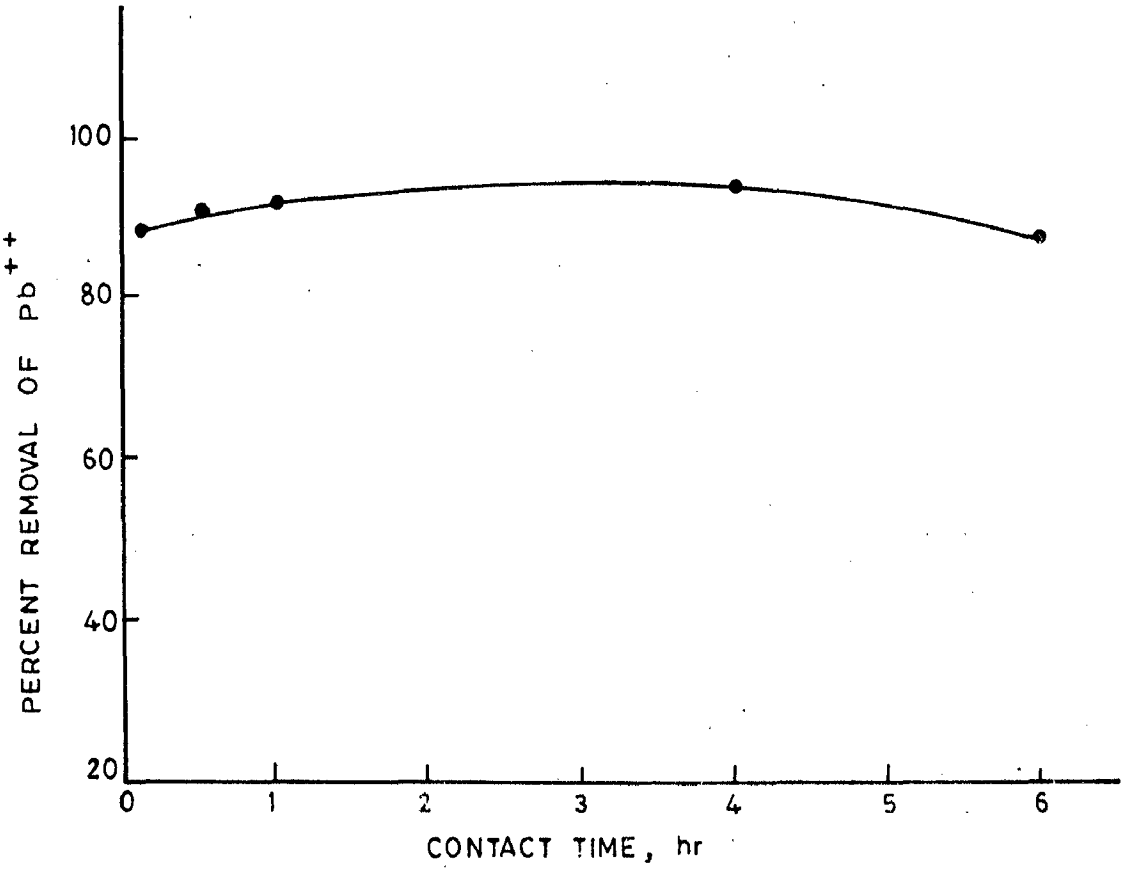


FIG. A.1 — PERCENT REMOVAL OF Pb^{++} IN WASTEWATER VERSUS CONTACT TIME

APPENDIX B

SIEVE ANALYSIS

The particle size of the adsorbent (carcoal) strongly affects the adsorption phenomena, therefore it is very important to have a knowledge about the particle size distribution of the charcoal. The method of analysis is clearly described as follows:

Before undertaking sieve analysis of the material under investigation, screens are arranged in their increasing mesh number or decreasing screen openings to form a deck of screens. The bottom most screen is kept on pan and the top most screen is covered with a lid. Now, a sample of charcoal was weighed and kept on the top most screen in a deck of screens. The deck was transferred to a Rotap Sieve Shaker machine. The time was adjusted for about 30 minutes and the machine was started. At the end of 30 minutes, the deck was removed from the shaker and the materials retained on various screens was weighed to determine its size. The results are given in Table B.1.

The average diameter of the charcoal as shown in the Sample Calculations (Appendix G) was 425 micron.

Table B.1 Sieve Analysis of Charcoal

S.No.	Screen aperture μ	Mean diameter of the particle μ	Mass fractions retained on screen
1	-700	700.00	0.0000
2	-700 + 600	650.00	0.1115
3	-600 + 425	512.05	0.3838
4	-425 + 355	390.00	0.1972
5	-355 + 250	302.50	0.1701
6	-250 + 150	200.00	0.1374

APPENDIX C

ANALYSIS OF CHARCOAL

This Appendix describes the following methods used for the analysis of charcoal i.e. for the determination of moisture content, volatile content, ash content and fixed carbon and also the determination of density and porosity of charcoal particles.

C.1 MOISTURE CONTENT [13] :

A measured weight of charcoal was kept in an oven for one hour at a temperature of about 100 ± 5°C. The loss in its weight was determined. It represents the moisture present in the sample. Following are the results:

1. Weight of watch glass = 39.645 g
2. Weight of watch glass + charcoal = 43.546 g
3. Weight of charcoal = 3.901 g
4. Weight of watch glass + charcoal = 43.489 g
   (after one hour, kept at 100 ± 5°C)
5. Weight of dried charcoal = 3.844 g
6. Total loss in weight of charcoal = 0.057 g

$$\text{Moisture content} = \frac{0.057 \times 100}{3.901} = 1.461\%$$

C.2 VOLATILE MATTER [13]

A measured weight of charcoal was kept in an oven for seven minutes at 900 ± 25 C°. The loss in weight was determined. It represented the volatile matter and moisture content in the sample. Following are the results :

1. Weight of crucible = 39.318 g
2. Weight of crucible + charcoal = 43.719 g
3. Weight of charcoal = 4.401 g
4. Weight of crucible + charcoal = 43.062 g
   (Kept for 7 minutes at 900 $\pm 25^{o}C$)
5. Total loss in charcoal = 0.657 g

$$\text{(Volatile matter + moisture) of charcoal} = \frac{0.657 \times 100}{4.401} = 14.928\%$$

Moisture content = 1.461%

∴ Volatile matter = (14.928 − 1.461) %
= 13.467%

C.3 ASH CONTENT [13] :

A measured weight of charcoal was kept in an oven for one hour at 700 $\pm 50^{o}C$. The loss in its weight was determined. It represented the ash content of the sample. Following are the results :

1. Weight of ash dish = 39.326 g
2. Weight of ash dish + charcoal = 44.606 g
3. Weight of charcoal = 5.28 g
4. Weight of ash dish + charcoal = 43.866 g
   (kept for 1 hr at 700 $\pm 50^{o}C$)
5. Total loss in weight of charcoal = 0.74 g

$$\text{Ash content of charcoal} = \frac{0.74 \times 100}{5.28} = 14.015\%$$

C.4 FIXED CARBON [13] :

Fixed carbon of charcoal was calculated by subtracting the summation of percent of moisture, volatile matter, and ash content from 100.

Fixed carbon of charcoal = 100 − (Moisture content + volatile matter + Ash content)
= 100 − (1.461 + 13.467 + 14.015)
= 71.057 %

C.5 DENSITY [13] :

A calibrated container of volume 1000 cc was weighed. It was filled with charcoal, loosely upto the brim. The container filled with charcoal was measured. The difference in the two weights provided the weight of loose charcoal in the container. From this the density of loose charcoal was determined. Now, the calibrated container was again filled with charcoal, compact as much as possible upto its brim. The weight of compact mass of charcoal was calculated. This provided the density of compact mass. Average of these two densities represented the true density of charcoal. The results of this test are as follows :

a. When Filled With Loose Charcoal :

1. Weight of calibrated container = 262.0 g
2. Weight of container + loose charcoal = 1070.8 g
3. Weight of loose charcoal = 808.8 g

$$\text{Density of loose charcoal} = \frac{\text{Mass}}{\text{Volume}} = \frac{808.8}{1000} = 0.8088 \text{ g/cc}$$

b. When Filled With Compact Charcoal :

1. Weight of calibrated container = 262.0 g
2. Weight of container + compact charcoal =1130.4 g
3. Weight of compact charcoal = 868.4 g

Density of compact charcoal $= \frac{868.4}{1000} = 0.8684$ g/cc

Average density of charcoal $= \frac{0.8088+0.8684}{2}$

$= 0.8386$ g/cc

C.6 POROSITY [13] :

A known amount of charcoal was taken and kept in a beaker. The beaker was then filled with water. It was kept about 15 minutes so that the pores present in charcoal particles were filled with water. The wet charcoal was transferred to a filter paper to remove extra water, without applying any pressure. The wet charcoal was then dried in an oven at a temperature of 60°C for about an hour. The difference in the weights of wet and dry charcoal gives the amount of water absorbed. The porosity of charcoal was determined by using the density calculated in Section C.5. Following are the results obtained :

1. Weight of watch glass = 39.645 g
2. Weight of watch glass + dry charcoal = 48.201 g
3. Weight of dry charcoal = 11.416 g
4. Weight of watch glass + wet charcoal = 57.849 g
5. Weight of wet charcaol = 18.204 g
6. Weight of water in voids = 6.788 g

7. Volume of charcoal $= \frac{\text{Mass}}{\text{Density}} = \frac{11.416}{0.8386} = 13.613$ cc

8. Porosity of charcoal $= \frac{6.788}{13.613} \times 100 = 49.86\%$

APPENDIX D

CALIBRATION OF ELECTRONIC SPEED REGULATOR CHARCOAL FEEDING CONVEYOR

The dried charcoal was introduced in the hopper and allowed to fall freely via screw conveyor at pre-determined speeds of 10, 15, 20, 25 and 30 r.p.m. for 1,5 and 10 minutes. Charcoal, thus dropped, was then collected and weighed. Three sets of readings were taken to ensure the regular dropping of charcoal through the screw conveyor. The readings are tabulated in Table D.1.

TABLE D-1 CHARCOAL MASS FLOW RATE FOR DIFFERENT R.P.M. OF THE ELECTRONIC SPEED REGULATOR

R.P.M. of E.S.R.	Charcoal mass flow rate (gram) for different time interval										
	For 1 min			For 5 min			For 10 min			Average	Adopted W
	I	II	III	I	II	III	I	II	III		
10.0	12.176	11.921	13.406	61.215	63.210	63.081	125.361	126.013	123.631	12.501	12.5
15.0	16.121	15.141	17.231	81.211	77.216	83.712	162.130	158.301	161.428	16.096	16.0
20.0	19.231	20.317	22.513	101.294	98.731	104.216	201.314	203.363	199.371	20.368	20.3
25.0	23.267	21.962	20.913	116.217	113.713	118.013	231.377	228.441	230.073	22.747	22.7
30.0	27.316	26.308	25.016	131.214	128.022	134.261	261.114	258.201	260.334	26.145	26.1

APPENDIX E

PREPARATION OF WASTEWATER SOLUTION OF LEAD IONS (Pb^{++})

Lead nitrate $Pb(NO_3)_2$ was used as solute material for preparing synthetic solution of lead as described in the Standard Methods [34].

1.598 gm Lead Nitrate was dissolved in approximately 200 ml of triple distilled water. 1.5 ml of concentrated nitric acid was added to it and the resulting solution was diluted to 1 litre with triple distilled water to give a concentration of 1000 µg of lead per ml. A polyethylene container was used to store stock solution of lead.

APPENDIX F

EXPERIMENTAL DATA

Table F.1 Initial Pb^{++} concentration, C_o = 5.0 mg/l
Charcoal mass flow rate, W = 12.5 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
Influent flow rate, Q = 0.25 l/min				
1	5	05	0.501	89.98
2	5	10	0.363	92.74
3	5	15	0.322	93.56
4	5	20	0.264	94.72
5	5	25	0.212	95.76
6	5	30	0.180	96.40
7	5	35	0.156	96.88
8	5	40	0.155	96.90
9	5	45	0.117	97.66
10	5	50	0.118	97.64
11	5	55	0.102	97.96
12	5	60	0.106	97.88
13	5	65	0.107	97.86
14	5	70	0.101	97.98
Influent flow rate, Q = 0.50 l/min				
1	5	05	0.802	83.96
2	5	10	0.679	86.42
3	5	15	0.586	88.28
4	5	20	0.464	90.72
5	5	25	0.438	91.24
6	5	30	0.371	92.58
7	5	35	0.336	93.28
8	5	40	0.301	93.98
9	5	45	0.298	94.04
10	5	50	0.302	93.96
11	5	55	0.280	93.98
12	5	60	0.275	93.70
13	5	65	0.300	94.00
14	5	70	0.295	94.10

Table F.1 contd.

S. No.	θ	θ_c	C	P_r
Influent flow rate, Q = 0.75 l/min				
1	5	05	0.976	80.48
2	5	10	0.827	83.46
3	5	15	0.734	85.32
4	5	20	0.623	87.54
5	5	25	0.550	89.00
6	5	30	0.512	89.76
7	5	35	0.490	90.20
8	5	40	0.492	90.16
9	5	45	0.493	90.14
10	5	50	0.480	90.40
11	5	55	0.488	90.24
12	5	60	0.501	89.98
13	5	65	0.481	90.38
14	5	70	0.484	90.32
Influent flow rate, Q = 1.00 l/min				
1	5	05	1.069	78.62
2	5	10	0.910	81.80
3	5	15	0.802	83.96
4	5	20	0.721	85.58
5	5	25	0.655	86.90
6	5	30	0.665	86.70
7	5	35	0.666	86.68
8	5	40	0.665	86.70
9	5	45	0.666	86.78
10	5	50	0.664	86.72
11	5	55	0.665	86.70
12	5	60	0.663	86.74
13	5	65	0.664	86.72
14	5	70	0.666	86.68

EXPERIMENTAL DATA

Table F.2 Initial Pb^{++} concentration, C_o = 5.0 mg/l
Charcoal mass flow rate, W = 16.0 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %

Influent flow rate, Q = 0.25 l/min

1	5	05	0.460	90.80
2	5	10	0.301	93.98
3	5	15	0.255	94.90
4	5	20	0.226	95.48
5	5	25	0.169	96.62
6	5	30	0.138	97.24
7	5	35	0.127	97.46
8	5	40	0.105	97.90
9	5	45	0.092	98.16
10	5	50	0.102	97.96
11	5	55	0.099	98.02
12	5	60	0.096	98.08
13	5	65	0.098	98.04
14	5	70	0.095	98.10

Influent flow rate, Q = 0.50 l/min

1	5	05	0.735	85.30
2	5	10	0.602	87.96
3	5	15	0.524	89.52
4	5	20	0.427	91.46
5	5	25	0.379	92.42
6	5	30	0.342	93.16
7	5	35	0.286	94.28
8	5	40	0.264	94.72
9	5	45	0.248	95.04
10	5	50	0.252	94.96
11	5	55	0.251	94.98
12	5	60	0.253	94.94
13	5	65	0.258	94.84
14	5	70	0.250	95.00

Table F.2 contd.

S. No.	θ	θ_c	C	P_r

Influent flow rate, Q = 0.75 l/min

1	5	05	0.895	82.10
2	5	10	0.778	84.44
3	5	15	0.655	86.90
4	5	20	0.564	88.72
5	5	25	0.505	89.90
6	5	30	0.457	80.86
7	5	35	0.424	91.52
8	5	40	0.398	92.04
9	5	45	0.406	91.88
10	5	50	0.403	91.94
11	5	55	0.409	91.82
12	5	60	0.405	91.90
13	5	65	0.407	91.86
14	5	70	0.402	91.96

Influent flow rate, Q = 1.00 l/min

1	5	05	0.975	80.50
2	5	10	0.877	82.46
3	5	15	0.751	84.98
4	5	20	0.652	86.96
5	5	25	0.591	88.18
6	5	30	0.595	88.10
7	5	35	0.601	87.98
8	5	40	0.596	88.08
9	5	45	0.594	88.12
10	5	50	0.593	88.14
11	5	55	0.596	88.08
12	5	60	0.599	88.02
13	5	65	0.600	88.00
14	5	70	0.595	88.10

EXPERIMENTAL DATA

Table F.3 Initial Pb^{++} concentration, C_o = 5.0 mg/l
Charcoal mass flow rate, W = 20.3 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
Influent flow rate, Q = 0.25 l/min				
1	5	05	0.402	91.96
2	5	10	0.258	94.84
3	5	15	0.229	95.42
4	5	20	0.187	96.26
5	5	25	0.132	97.36
6	5	30	0.116	97.68
7	5	35	0.084	98.32
8	5	40	0.053	98.94
9	5	45	0.054	98.92
10	5	50	0.052	98.76
11	5	55	0.053	98.94
12	5	60	0.067	98.66
13	5	65	0.063	98.74
14	5	70	0.062	98.76
Influent flow rate, Q = 0.50 l/min				
1	5	05	0.673	86.54
2	5	10	0.559	88.82
3	5	15	0.450	91.00
4	5	20	0.361	92.78
5	5	25	0.336	93.28
6	5	30	0.280	94.40
7	5	35	0.272	94.56
8	5	40	0.208	95.84
9	5	45	0.201	95.98
10	5	50	0.182	96.36
11	5	55	0.192	96.16
12	5	60	0.198	96.04
13	5	65	0.189	96.22
14	5	70	0.190	96.20

Table F.3 contd.

S. No.	θ	θ_c	C	P_r

Influent flow rate, Q = 0.75 l/min

1	5	05	0.789	84.22
2	5	10	0.731	85.38
~~3~~	~~5~~	~~15~~	~~0.708~~	~~85.84~~
4	5	20	0.559	88.82
5	5	25	0.550	89.00
6	5	30	0.441	81.18
7	5	35	0.438	91.24
8	5	40	0.395	92.10
9	5	45	0.372	92.56
10	5	50	0.350	93.00
11	5	55	0.354	92.92
12	5	60	0.357	82.86
13	5	65	0.345	93.08
14	5	70	0.347	93.06

Influent flow rate, Q = 1.00 l/min

1	5	05	0.882	82.36
2	5	10	0.829	83.42
3	5	15	0.705	85.90
4	5	20	0.616	87.68
5	5	25	0.575	88.50
6	5	30	0.506	89.88
7	5	35	0.511	89.78
8	5	40	0.477	90.46
9	5	45	0.481	90.38
10	5	50	0.512	89.76
11	5	55	0.490	90.20
12	5	60	0.464	90.72
13	5	65	0.491	90.18
14	5	70	0.494	90.12

EXPERIMENTAL DATA

Table F.4 Initial Pb^{++} concentration, C_o = 5.0 mg/l
Charcoal mass flow rate, W = 26.1 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %

Influent flow rate, Q = 0.25 l/min

1	5	05	0.347	93.06
2	5	10	0.229	95.42
3	5	15	0.199	96.02
4	5	20	0.148	97.04
5	5	25	0.098	98.04
6	5	30	0.087	98.26
7	5	35	0.079	98.42
8	5	40	0.041	99.18
9	5	45	0.051	98.98
10	5	50	0.050	99.00
11	5	55	0.041	99.18
12	5	60	0.051	98.98
13	5	65	0.049	99.02
14	5	70	0.051	98.98

Influent flow rate, Q = 0.50 l/min

1	5	05	0.626	83.96
2	5	10	0.524	86.42
3	5	15	0.418	88.28
4	5	20	0.279	90.72
5	5	25	0.236	91.24
6	5	30	0.215	92.58
7	5	35	0.201	93.28
8	5	40	0.171	93.98
9	5	45	0.176	94.04
10	5	50	0.172	93.96
11	5	55	0.171	93.98
12	5	60	0.162	93.70
13	5	65	0.152	94.00
14	5	70	0.150	94.10

Table F.4 contd.

Influent flow rate, Q = 0.75 l/min

S. No.	θ	θ_c	C	P_r
1	5	05	0.742	85.16
2	5	10	0.648	87.04
3	5	15	0.539	89.22
4	5	20	0.439	91.22
5	5	25	0.406	91.88
6	5	30	0.376	92.48
7	5	35	0.334	93.32
8	5	40	0.350	93.00
9	5	45	0.306	93.88
10	5	50	0.335	93.30
11	5	55	0.310	93.80
12	5	60	0.311	83.78
13	5	65	0.288	94.24
14	5	70	0.306	93.88

Influent flow rate, Q = 1.00 l/min

S. No.	θ	θ_c	C	P_r
1	5	05	0.841	87.48
2	5	10	0.750	89.52
3	5	15	0.671	91.64
4	5	20	0.576	94.42
5	5	25	0.511	95.28
6	5	30	0.454	95.70
7	5	35	0.451	95.98
8	5	40	0.461	96.58
9	5	45	0.419	96.48
10	5	50	0.415	96.56
11	5	55	0.460	96.58
12	5	60	0.452	96.76
13	5	65	0.448	96.96
14	5	70	0.447	97.00

EXPERIMENTAL DATA

Table F.5 Initial Pb^{++} concentration, C_o = 7.5 mg/l
Charcoal mass flow rate, W = 12.5 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
Influent flow rate, Q = 0.25 l/min				
1	5	05	0.551	92.653
2	5	10	0.462	93.840
3	5	15	0.372	95.040
4	5	20	0.307	95.907
5	5	25	0.271	96.387
6	5	30	0.234	96.880
7	5	35	0.173	97.693
8	5	40	0.165	97.800
9	5	45	0.174	97.680
10	5	50	0.145	98.070
11	5	55	0.144	98.080
12	5	60	0.156	97.920
13	5	65	0.138	98.160
14	5	70	0.151	97.987
Influent flow rate, Q = 0.50 l/min				
1	5	05	0.851	88.653
2	5	10	0.702	90.640
3	5	15	0.604	91.947
4	5	20	0.545	92.733
5	5	25	0.519	93.080
6	5	30	0.488	93.493
7	5	35	0.443	94.093
8	5	40	0.390	94.800
9	5	45	0.382	94.907
10	5	50	0.314	95.810
11	5	55	0.317	95.773
12	5	60	0.350	95.333
13	5	65	0.341	95.453
14	5	70	0.344	95.413

Table F.5 contd.

S. No.	θ	θ_c	C	P_r
Influent flow rate, Q = 0.75 l/min				
1	5	05	1.001	86.653
2	5	10	0.842	88.773
3	5	15	0.748	90.027
4	5	20	0.693	90.760
5	5	25	0.642	91.440
6	5	30	0.610	91.867
7	5	35	0.612	91.840
8	5	40	0.581	92.253
9	5	45	0.553	92.627
10	5	50	0.547	92.707
11	5	55	0.524	93.013
12	5	60	0.539	92.813
13	5	65	0.530	92.933
14	5	70	0.531	92.920
Influent flow rate, Q = 1.00 l/min				
1	5	05	1.094	85.413
2	5	10	0.976	86.987
3	5	15	0.838	88.827
4	5	20	0.784	89.547
5	5	25	0.786	89.520
6	5	30	0.761	89.853
7	5	35	0.760	89.867
8	5	40	0.750	90.000
9	5	45	0.741	90.120
10	5	50	0.732	90.240
11	5	55	0.726	90.320
12	5	60	0.719	90.413
13	5	65	0.735	90.200
14	5	70	0.733	90.227

EXPERIMENTAL DATA

Table F.6 Initial Pb^{++} concentration, C_o = 7.5 mg/l
Charcoal mass flow rate, W = 16.0 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
Influent flow rate, Q = 0.25 l/min				
1	5	05	0.505	93.267
2	5	10	0.421	94.387
3	5	15	0.324	95.680
4	5	20	0.272	96.373
5	5	25	0.246	96.720
6	5	30	0.213	97.160
7	5	35	0.164	97.813
8	5	40	0.170	97.733
9	5	45	0.153	97.960
10	5	50	0.114	98.480
11	5	55	0.131	98.147
12	5	60	0.135	98.200
13	5	65	0.124	98.347
14	5	70	0.141	98.120
Influent flow rate, Q = 0.50 l/min				
1	5	05	0.748	90.027
2	5	10	0.665	91.133
3	5	15	0.564	92.480
4	5	20	0.514	93.147
5	5	25	0.458	93.893
6	5	30	0.444	94.080
7	5	35	0.402	94.640
8	5	40	0.336	95.520
9	5	45	0.324	95.680
10	5	50	0.283	96.227
11	5	55	0.261	96.520
12	5	60	0.271	96.387
13	5	65	0.273	96.360
14	5	70	0.262	96.507

Table F.6 contd.

Influent flow rate, Q = 0.75 l/min

S. No.	θ	θ_c	C	P_r
~~1~~	~~5~~	~~05~~	~~0.884~~	~~88.213~~
2	5	10	0.801	89.320
3	5	15	0.705	90.600
4	5	20	0.656	91.253
5	5	25	0.609	91.880
6	5	30	0.568	92.427
7	5	35	0.550	92.667
8	5	40	0.524	93.013
9	5	45	0.516	93.120
10	5	50	0.491	93.453
11	5	55	0.480	93.600
12	5	60	0.461	93.853
13	5	65	0.487	93.507
14	5	70	0.486	93.516

Influent flow rate, Q = 1.00 l/min

S. No.	θ	θ_c	C	P_r
1	5	05	0.966	87.120
2	5	10	0.865	88.467
3	5	15	0.821	89.053
4	5	20	0.777	89.640
5	5	25	0.769	89.747
6	5	30	0.731	90.253
7	5	35	0.680	90.933
8	5	40	0.688	90.827
9	5	45	0.686	90.853
10	5	50	0.662	91.173
11	5	55	0.666	91.120
12	5	60	0.658	91.227
13	5	65	0.664	91.147
14	5	70	0.648	91.360

EXPERIMENTAL DATA

Table F.7 Initial Pb^{++} concentration, C_o = 7.5 mg/l
Charcoal mass flow rate, W = 20.3 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
Influent flow rate, Q = 0.25 l/min				
1	5	05	0.418	94.427
2	5	10	0.364	95.147
3	5	15	0.305	95.933
4	5	20	0.257	96.573
5	5	25	0.221	97.053
6	5	30	0.177	97.640
7	5	35	0.142	98.107
8	5	40	0.150	98.000
9	5	45	0.147	98.040
10	5	50	0.101	98.653
11	5	55	0.112	98.507
12	5	60	0.102	98.640
13	5	65	0.107	98.573
14	5	70	0.095	98.733
Influent flow rate, Q = 0.50 l/min				
1	5	05	0.623	91.693
2	5	10	0.580	92.267
3	5	15	0.527	92.973
4	5	20	0.455	93.933
5	5	25	0.398	94.693
6	5	30	0.356	95.253
7	5	35	0.305	95.933
8	5	40	0.268	96.247
9	5	45	0.269	96.413
10	5	50	0.241	96.787
11	5	55	0.224	97.013
12	5	60	0.235	96.687
13	5	65	0.236	96.853
14	5	70	0.239	96.813

Table F.7 contd.

S. No.	θ	θ_c	C	P_r
Influent flow rate, Q = 0.75 l/min				
1	5	05	0.738	90.160
2	5	10	0.676	90.987
3	5	15	0.570	92.400
4	5	20	0.536	92.853
5	5	25	0.491	93.543
6	5	30	0.472	93.707
7	5	35	0.410	94.533
8	5	40	0.386	94.853
9	5	45	0.411	94.520
10	5	50	0.392	94.773
11	5	55	0.375	95.000
12	5	60	0.359	95.213
13	5	65	0.331	95.587
14	5	70	0.351	95.320
Influent flow rate, Q = 1.00 l/min				
1	5	05	0.798	89.360
2	5	10	0.734	90.213
3	5	15	0.718	90.427
4	5	20	0.660	91.200
5	5	25	0.612	91.840
6	5	30	0.604	91.947
7	5	35	0.607	92.907
8	5	40	0.584	92.213
9	5	45	0.576	92.320
10	5	50	0.561	92.520
11	5	55	0.553	92.627
12	5	60	0.577	92.307
13	5	65	0.561	92.520
14	5	70	0.552	92.640

EXPERIMENTAL DATA

Table F.8 Initial Pb^{++} concentration, C_o = 7.5 mg/l
Charcoal mass flow rate, W = 26.1 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
Influent flow rate, Q = 0.25 l/min				
1	5	05	0.361	95.187
2	5	10	0.276	96.320
3	5	15	0.174	97.680
4	5	20	0.185	97.533
5	5	25	0.136	98.187
6	5	30	0.110	98.533
7	5	35	0.107	98.573
8	5	40	0.101	98.653
9	5	45	0.099	98.680
10	5	50	0.089	98.810
11	5	55	0.096	98.720
12	5	60	0.071	99.053
13	5	65	0.072	99.040
14	5	70	0.085	98.867
Influent flow rate, Q = 0.50 l/min				
1	5	05	0.556	92.587
2	5	10	0.488	93.493
3	5	15	0.364	95.080
4	5	20	0.338	95.493
5	5	25	0.296	96.053
6	5	30	0.240	96.800
7	5	35	0.261	96.520
8	5	40	0.241	96.787
9	5	45	0.211	97.187
10	5	50	0.208	97.227
11	5	55	0.205	97.267
12	5	60	0.219	97.080
13	5	65	0.216	97.120
14	5	70	0.214	97.147

Table F.8 contd.

S. No.	θ	θ_c	C	P_r
Influent flow rate, Q = 0.75 l/min				
1	5	05	0.659	91.213
2	5	10	0.531	92.920
3	5	15	0.490	93.467
4	5	20	0.412	94.507
5	5	25	0.385	94.867
6	5	30	0.401	94.653
7	5	35	0.376	94.987
8	5	40	0.359	95.213
9	5	45	0.361	95.187
10	5	50	0.360	95.200
11	5	55	0.351	95.320
12	5	60	0.349	95.347
13	5	65	0.338	95.493
14	5	70	0.350	95.333
Influent flow rate, Q = 1.00 l/min				
1	5	05	0.745	90.067
2	5	10	0.638	91.493
3	5	15	0.632	91.573
4	5	20	0.555	92.600
5	5	25	0.541	92.787
6	5	30	0.524	93.013
7	5	35	0.497	93.373
8	5	40	0.469	93.747
9	5	45	0.478	93.627
10	5	50	0.460	93.867
11	5	55	0.452	93.973
12	5	60	0.453	93.960
13	5	65	0.464	93.813
14	5	70	0.457	93.907

EXPERIMENTAL DATA

Table F.9 Initial Pb^{++} concentration, C_o = 10.0 mg/l
Charcoal mass flow rate, W = 12.5 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
Influent flow rate, Q = 0.25 l/min				
1	5	05	0.765	92.35
2	5	10	0.635	93.65
3	5	15	0.535	94.65
4	5	20	0.470	95.30
5	5	25	0.435	95.68
6	5	30	0.369	96.31
7	5	35	0.337	96.63
8	5	40	0.286	97.14
9	5	45	0.265	97.35
10	5	50	0.219	97.81
11	5	55	0.185	98.15
12	5	60	0.192	98.08
13	5	65	0.195	98.05
14	5	70	0.191	98.09
Influent flow rate, Q = 0.50 l/min				
1	5	05	1.209	87.91
2	5	10	1.052	89.48
3	5	15	0.884	91.16
4	5	20	0.796	92.04
5	5	25	0.731	92.69
6	5	30	0.607	93.93
7	5	35	0.543	94.57
8	5	40	0.498	95.02
9	5	45	0.450	95.50
10	5	50	0.411	95.89
11	5	55	0.381	96.19
12	5	60	0.392	96.08
13	5	65	0.384	96.16
14	5	70	0.386	96.14

Table F.9 contd.

Influent flow rate, Q = 0.75 l/min

S. No.	θ	θ_c	C	P_r
1	5	05	1.422	85.78
2	5	10	1.221	87.79
3	5	15	1.102	88.98
4	5	20	1.004	89.96
5	5	25	0.926	90.74
6	5	30	0.853	91.47
7	5	35	0.782	92.18
8	5	40	0.734	92.66
9	5	45	0.690	93.10
10	5	50	0.695	93.05
11	5	55	0.655	93.45
12	5	60	0.658	93.42
13	5	65	0.659	93.41
14	5	70	0.651	93.49

Influent flow rate, Q = 1.00 l/min

1	5	05	1.564	84.36
2	5	10	1.338	86.62
3	5	15	1.281	87.19
4	5	20	1.187	88.13
5	5	25	1.150	88.50
6	5	30	1.051	89.49
7	5	35	1.042	89.58
8	5	40	1.002	89.98
9	5	45	0.965	90.35
10	5	50	0.971	90.29
11	5	55	0.959	90.41
12	5	60	0.960	90.40
13	5	65	0.953	90.47
14	5	70	0.948	90.52

EXPERIMENTAL DATA

Table F.10 Initial Pb^{++} concentration, C_o = 10.0 mg/l
Charcoal mass flow rate, W = 16.0 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
Influent flow rate, Q = 0.25 l/min				
1	5	05	0.709	92.91
2	5	10	0.615	93.85
3	5	15	0.477	95.23
4	5	20	0.421	95.79
5	5	25	0.325	96.75
6	5	30	0.327	96.73
7	5	35	0.266	97.34
8	5	40	0.247	97.53
9	5	45	0.202	97.98
10	5	50	0.173	98.27
11	5	55	0.159	98.41
12	5	60	0.158	98.42
13	5	65	0.164	98.36
14	5	70	0.166	98.34
Influent flow rate, Q = 0.50 l/min				
1	5	05	0.904	90.96
2	5	10	0.801	91.99
3	5	15	0.731	92.69
4	5	20	0.601	93.99
5	5	25	0.566	94.34
6	5	30	0.495	95.05
7	5	35	0.473	95.27
8	5	40	0.420	95.80
9	5	45	0.398	96.02
10	5	50	0.344	96.56
11	5	55	0.326	96.74
12	5	60	0.334	96.66
13	5	65	0.325	96.75
14	5	70	0.328	96.72

Table F.10 contd.

S. No.	θ	θ_c	C	P_r
Influent flow rate, Q = 0.75 l/min				
1	5	05	0.981	90.19
2	5	10	0.904	90.96
3	5	15	0.871	91.29
4	5	20	0.764	92.36
5	5	25	0.735	92.65
6	5	30	0.682	93.18
7	5	35	0.681	93.19
8	5	40	0.640	93.60
9	5	45	0.608	93.92
10	5	50	0.594	94.06
11	5	55	0.582	94.18
12	5	60	0.591	94.09
13	5	65	0.590	94.10
14	5	70	0.585	94.15
Influent flow rate, Q = 1.00 l/min				
1	5	05	1.169	88.31
2	5	10	1.104	88.96
3	5	15	1.032	89.68
4	5	20	0.974	90.26
5	5	25	0.916	90.84
6	5	30	0.880	91.20
7	5	35	0.874	91.26
8	5	40	0.869	91.31
9	5	45	0.844	91.56
10	5	50	0.827	91.73
11	5	55	0.808	91.92
12	5	60	0.837	91.63
13	5	65	0.827	91.73
14	5	70	0.832	91.68

EXPERIMENTAL DATA

Table F.11 Initial Pb^{++} concentration, C_o = 10.0 mg/l
Charcoal mass flow rate, W = 20.3 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
Influent flow rate, Q = 0.25 l/min				
1	5	05	0.597	94.03
2	5	10	0.521	94.79
3	5	15	0.388	96.12
4	5	20	0.356	96.44
5	5	25	0.290	97.10
6	5	30	0.241	97.59
7	5	35	0.256	97.44
8	5	40	0.239	97.61
9	5	45	0.194	98.06
10	5	50	0.191	98.09
11	5	55	0.143	98.57
12	5	60	0.155	98.45
13	5	65	0.144	98.56
14	5	70	0.152	98.48
Influent flow rate, Q = 0.50 l/min				
1	5	05	0.735	92.65
2	5	10	0.618	93.82
3	5	15	0.585	94.15
4	5	20	0.539	94.61
5	5	25	0.441	95.59
6	5	30	0.375	96.25
7	5	35	0.388	96.12
8	5	40	0.335	96.65
9	5	45	0.312	96.88
10	5	50	0.306	96.94
11	5	55	0.292	97.08
12	5	60	0.304	96.96
13	5	65	0.296	97.04
14	5	70	0.295	97.05

Table F.11 contd.

S. No.	θ	θ_c	C	P_r

Influent flow rate, Q = 0.75 l/min

1	5	05	0.814	91.86
2	5	10	0.752	92.48
3	5	15	0.690	93.10
4	5	20	0.634	93.66
5	5	25	0.595	94.05
6	5	30	0.562	94.38
7	5	35	0.574	94.26
8	5	40	0.573	94.27
9	5	45	0.539	94.61
10	5	50	0.542	94.58
11	5	55	0.540	94.60
12	5	60	0.533	94.67
13	5	65	0.541	94.59
14	5	70	0.532	94.68

Influent flow rate, Q = 1.00 l/min

1	5	05	0.997	90.03
2	5	10	0.931	90.69
3	5	15	0.868	91.32
4	5	20	0.794	92.06
5	5	25	0.736	92.64
6	5	30	0.701	92.99
7	5	35	0.710	92.90
8	5	40	0.702	92.98
9	5	45	0.708	92.92
10	5	50	0.684	93.16
11	5	55	0.691	93.09
12	5	60	0.687	93.13
13	5	65	0.687	93.13
14	5	70	0.686	93.14

EXPERIMENTAL DATA

Table F.12 Initial Pb^{++} concentration, C_o = 10.0 mg/l
Charcoal mass flow rate, W = 26.1 g/min

Influent flow rate, Q = 0.25 l/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
1	5	05	0.487	95.13
2	5	10	0.399	96.01
3	5	15	0.326	96.74
4	5	20	0.220	97.80
5	5	25	0.189	98.11
6	5	30	0.177	98.23
7	5	35	0.176	98.24
8	5	40	0.151	98.49
9	5	45	0.138	98.62
10	5	50	0.121	98.79
11	5	55	0.124	98.76
12	5	60	0.118	98.82
13	5	65	0.114	98.86
14	5	70	0.116	98.84

Influent flow rate, Q = 0.50 l/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
1	5	05	0.651	93.49
2	5	10	0.505	94.95
3	5	15	0.458	95.42
4	5	20	0.341	96.59
5	5	25	0.315	96.85
6	5	30	0.280	97.20
7	5	35	0.272	97.28
8	5	40	0.251	97.49
9	5	45	0.235	97.65
10	5	50	0.247	97.53
11	5	55	0.246	97.84
12	5	60	0.218	97.82
13	5	65	0.244	97.56
14	5	70	0.233	97.67

Table F.12 contd.

S. No.	θ	θ_c	C	P_r
Influent flow rate, Q = 0.75 l/min				
1	5	05	0.732	92.68
2	5	10	0.677	93.23
3	5	15	0.590	94.10
4	5	20	0.548	94.52
5	5	25	0.531	94.69
6	5	30	0.473	95.27
7	5	35	0.452	95.48
8	5	40	0.450	95.50
9	5	45	0.464	95.36
10	5	50	0.451	95.49
11	5	55	0.449	95.51
12	5	60	0.440	95.60
13	5	65	0.445	95.55
14	5	70	0.451	95.49
Influent flow rate, Q = 1.00 l/min				
1	5	05	0.902	90.98
2	5	10	0.798	92.02
3	5	15	0.722	92.78
4	5	20	0.667	93.33
5	5	25	0.681	93.19
6	5	30	0.672	93.28
7	5	35	0.604	93.96
8	5	40	0.636	93.64
9	5	45	0.614	93.86
10	5	50	0.618	93.82
11	5	55	0.586	94.14
12	5	60	0.611	93.89
13	5	65	0.601	93.99
14	5	70	0.604	93.96

ECPERIMENTAL DATA

Table F.13 Initial Pb^{++} concentration, C_o = 12.5 mg/l
Charcoal mass flow rate, W = 12.5 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
		Influent flow rate, Q = 0.25 l/min		
1	5	05	1.001	91.992
2	5	10	0.855	93.160
3	5	15	0.764	93.888
4	5	20	0.691	94.472
5	5	25	0.623	95.016
6	5	30	0.560	95.520
7	5	35	0.497	96.024
8	5	40	0.428	96.576
9	5	45	0.419	96.648
10	5	50	0.371	97.032
11	5	55	0.321	97.432
12	5	60	0.336	97.312
13	5	65	0.320	97.440
14	5	70	0.324	97.408
		Influent flow rate, Q = 0.50 l/min		
1	5	05	1.301	89.592
2	5	10	1.142	90.864
3	5	15	1.036	91.712
4	5	20	0.994	92.048
5	5	25	0.946	92.432
6	5	30	0.877	92.984
7	5	35	0.840	93.280
8	5	40	0.802	93.584
9	5	45	0.756	93.952
10	5	50	0.724	94.208
11	5	55	0.685	94.520
12	5	60	0.694	94.448
13	5	65	0.691	94.472
14	5	70	0.689	94.488

Table F.13 contd.

S. No.	θ	θ_c	C	P_r
Influent flow rate, Q = 0.75 l/min				
1	5	05	1.886	84.912
2	5	10	1.651	86.792
3	5	15	1.502	87.984
4	5	20	1.454	88.368
5	5	25	1.382	88.944
6	5	30	1.335	89.320
7	5	35	1.269	89.848
8	5	40	1.258	89.936
9	5	45	1.231	90.152
10	5	50	1.224	90.208
11	5	55	1.215	90.280
12	5	60	1.221	90.232
13	5	65	1.217	90.264
14	5	70	1.208	90.336
Influent flow rate, Q = 1.00 l/min				
1	5	05	2.060	83.520
2	5	10	1.923	84.616
3	5	15	1.801	85.592
4	5	20	1.695	86.440
5	5	25	1.649	86.808
6	5	30	1.618	87.056
7	5	35	1.572	87.424
8	5	40	1.612	87.104
9	5	45	1.604	87.168
10	5	50	1.603	87.176
11	5	55	1.576	87.392
12	5	60	1.580	87.360
13	5	65	1.577	87.384
14	5	70	1.579	87.368

EXPERIMENTAL DATA

Table F.14 Initial Pb^{++} concentration, C_o = 12.5 mg/l
Charcoal mass flow rate, W = 16.0 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %

Influent flow rate, Q = 0.25 l/min

1	5	05	0.951	92.392
2	5	10	0.798	93.616
3	5	15	0.696	94.432
4	5	20	0.657	94.744
5	5	25	0.582	94.344
6	5	30	0.501	95.992
7	5	35	0.453	96.376
8	5	40	0.388	96.896
9	5	45	0.364	97.088
10	5	50	0.333	97.336
11	5	55	0.307	97.544
12	5	60	0.312	97.504
13	5	65	0.314	97.488
14	5	70	0.308	97.536

Influent flow rate, Q = 0.50 l/min

1	5	05	1.199	90.408
2	5	10	1.116	91.072
3	5	15	0.966	92.272
4	5	20	0.887	92.904
5	5	25	0.846	93.232
6	5	30	0.775	93.800
7	5	35	0.739	94.088
8	5	40	0.695	94.440
9	5	45	0.663	94.696
10	5	50	0.641	94.872
11	5	55	0.621	95.032
12	5	60	0.630	94.960
13	5	65	0.631	94.952
14	5	70	0.623	95.016

Table F.14 contd.

S. No.	θ	θ_c	C	P_r
Influent flow rate, Q = 0.75 l/min				
1	5	05	1.360	89.120
2	5	10	1.236	90.112
3	5	15	1.210	90.320
4	5	20	1.142	90.864
5	5	25	1.096	91.232
6	5	30	1.081	91.352
7	5	35	1.063	91.496
8	5	40	1.061	91.512
9	5	45	1.047	91.624
10	5	50	1.058	91.536
11	5	55	1.051	91.592
12	5	60	1.052	91.584
13	5	65	1.054	91.568
14	5	70	1.053	91.576
Influent flow rate, Q = 1.00 l/min				
1	5	05	1.829	85.368
2	5	10	1.716	86.272
3	5	15	1.652	86.784
4	5	20	1.588	87.296
5	5	25	1.498	88.016
6	5	30	1.486	88.112
7	5	35	1.424	88.608
8	5	40	1.406	88.752
9	5	45	1.387	88.904
10	5	50	1.380	88.960
11	5	55	1.375	89.000
12	5	60	1.381	88.952
13	5	65	1.377	88.984
14	5	70	1.382	88.944

EXPERIMENTAL DATA

Table F.15 Initial Pb^{++} concentration, C_o = 12.5 mg/l
Charcoal mass flow rate, W = 20.3 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
Influent flow rate, Q = 0.25 l/min				
1	5	05	0.754	93.928
2	5	10	0.613	95.096
3	5	15	0.542	95.664
4	5	20	0.476	96.192
5	5	25	0.385	96.920
6	5	30	0.329	97.368
7	5	35	0.304	97.568
8	5	40	0.261	97.912
9	5	45	0.257	97.944
10	5	50	0.250	98.000
11	5	55	0.247	98.024
12	5	60	0.249	98.008
13	5	65	0.238	98.096
14	5	70	0.245	98.040
Influent flow rate, Q = 0.50 l/min				
1	5	05	0.984	92.128
2	5	10	0.874	93.008
3	5	15	0.839	93.288
4	5	20	0.738	94.096
5	5	25	0.702	94.384
6	5	30	0.636	94.912
7	5	35	0.624	95.008
8	5	40	0.577	95.384
9	5	45	0.574	95.408
10	5	50	0.501	95.992
11	5	55	0.525	95.800
12	5	60	0.540	95.680
13	5	65	0.536	95.712
14	5	70	0.526	95.792

Table F.15 contd.

S. No.	θ	θ_c	C	P_r
Influent flow rate, Q = 0.75 l/min				
1	5	05	1.244	89.648
2	5	10	1.171	90.632
3	5	15	1.126	90.992
4	5	20	1.058	91.536
5	5	25	1.010	91.920
6	5	30	0.985	92.120
7	5	35	0.983	92.136
8	5	40	0.953	92.376
9	5	45	0.958	92.336
10	5	50	0.951	92.392
11	5	55	0.942	92.464
12	5	60	0.945	92.440
13	5	65	0.941	92.472
14	5	70	0.940	92.480
Influent flow rate, Q = 1.00 l/min				
1	5	05	1.690	86.480
2	5	10	1.574	87.408
3	5	15	1.461	88.312
4	5	20	1.401	88.792
5	5	25	1.391	88.872
6	5	30	1.347	89.224
7	5	35	1.321	89.432
8	5	40	1.294	89.648
9	5	45	1.290	86.680
10	5	50	1.298	89.616
11	5	55	1.261	89.912
12	5	60	1.261	89.912
13	5	65	1.269	89.848
14	5	70	1.266	83.872

EXPERIMENTAL DATA

Table F.16 Initial Pb^{++} concentration, C_o = 12.5 mg/l
Charcoal mass flow rate, W = 26.1 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
Influent flow rate, Q = 0.25 l/min				
1	5	05	0.664	94.688
2	5	10	0.542	95.664
3	5	15	0.516	95.872
4	5	20	0.433	96.536
5	5	25	0.367	97.064
6	5	30	0.348	97.216
7	5	35	0.283	97.736
8	5	40	0.259	97.928
9	5	45	0.247	98.024
10	5	50	0.241	98.072
11	5	55	0.223	98.216
12	5	60	0.231	98.152
13	5	65	0.229	98.168
14	5	70	0.226	98.192
Influent flow rate, Q = 0.50 l/min				
1	5	05	0.996	92.032
2	5	10	0.871	93.032
3	5	15	0.832	93.344
4	5	20	0.736	94.112
5	5	25	0.645	94.840
6	5	30	0.619	95.048
7	5	35	0.552	95.584
8	5	40	0.538	95.696
9	5	45	0.527	95.784
10	5	50	0.504	95.968
11	5	55	0.494	96.048
12	5	60	0.506	95.952
13	5	65	0.498	96.016
14	5	70	0.495	96.040

Table F.16 contd.

S. No.	θ	θ_c	C	P_r
Influent flow rate, Q = 0.75 l/min				
1	5	05	1.205	93.360
2	5	10	1.092	91.264
3	5	15	1.031	91.752
4	5	20	0.950	92.400
5	5	25	0.924	92.608
6	5	30	0.888	92.896
7	5	35	0.864	93.088
8	5	40	0.834	93.328
9	5	45	0.806	93.552
10	5	50	0.802	93.584
11	5	55	0.793	93.656
12	5	60	0.801	93.592
13	5	65	0.803	93.576
14	5	70	0.796	93.632
Influent flow rate, Q = 1.00 l/min				
1	5	05	1.579	87.368
2	5	10	1.402	88.784
3	5	15	1.331	89.352
4	5	20	1.329	89.368
5	5	25	1.285	89.720
6	5	30	1.255	89.960
7	5	35	1.234	90.128
8	5	40	1.239	90.088
9	5	45	1.201	90.392
10	5	50	1.222	90.224
11	5	55	1.221	90.232
12	5	60	1.227	90.184
13	5	65	1.206	90.352
14	5	70	1.229	90.168

EXPERIMENTAL DATA

Table F.17 Initial Pb^{++} concentration, C_o = 15.0 mg/l
Charcoal mass flow rate, W = 12.5 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
Influent flow rate, Q = 0.25 l/min				
1	5	05	1.280	91.467
2	5	10	1.103	92.647
3	5	15	1.018	93.213
4	5	20	0.963	93.580
5	5	25	0.875	94.167
6	5	30	0.818	94.547
7	5	35	0.774	94.840
8	5	40	0.719	95.207
9	5	45	0.703	95.313
10	5	50	0.678	95.480
11	5	55	0.664	95.573
12	5	60	0.672	95.520
13	5	65	0.663	95.580
14	5	70	0.673	95.513
Influent flow rate, Q = 0.50 l/min				
1	5	05	1.895	87.367
2	5	10	1.681	88.793
3	5	15	1.634	89.107
4	5	20	1.539	89.740
5	5	25	1.472	90.187
6	5	30	1.379	90.807
7	5	35	1.377	90.820
8	5	40	1.342	91.053
9	5	45	1.345	91.033
10	5	50	1.351	90.993
11	5	55	1.325	91.167
12	5	60	1.349	91.007
13	5	65	1.348	91.013
14	5	70	1.346	91.027

Table F.17 contd.

S. No.	θ	θ_c	C	P_r
Influent flow rate, Q = 0.75 l/min				
1	5	05	2.945	80.367
2	5	10	2.669	82.207
3	5	15	2.564	82.907
4	5	20	2.375	84.167
5	5	25	2.288	84.747
6	5	30	2.221	85.193
7	5	35	2.167	85.553
8	5	40	2.159	85.607
9	5	45	2.166	85.560
10	5	50	2.167	85.553
11	5	55	2.162	85.587
12	5	60	2.163	85.580
13	5	65	2.174	85.507
14	5	70	2.169	85.540
Influent flow rate, Q = 1.00 l/min				
1	5	05	3.796	74.693
2	5	10	3.611	75.927
3	5	15	3.435	77.100
4	5	20	3.394	77.373
5	5	25	3.328	77.813
6	5	30	3.314	77.907
7	5	35	3.264	78.240
8	5	40	3.268	78.213
9	5	45	3.218	78.547
10	5	50	3.230	78.467
11	5	55	3.214	78.573
12	5	60	3.231	78.460
13	5	65	3.219	78.54
14	5	70	3.217	78.553

EXPERIMENTAL DATA

Table F.18 Initial Pb^{++} concentration, C_o = 15.0 mg/l
Charcoal mass flow rate, W = 16.0 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %

Influent flow rate, Q = 0.25 l/min

1	5	05	1.219	91.873
2	5	10	1.016	93.227
3	5	15	0.947	93.687
4	5	20	0.834	94.440
5	5	25	0.749	95.007
6	5	30	0.733	95.113
7	5	35	0.688	95.413
8	5	40	0.674	95.507
9	5	45	0.640	95.733
10	5	50	0.601	95.993
11	5	55	0.593	96.047
12	5	60	0.598	96.013
13	5	65	0.597	96.020
14	5	70	0.594	96.040

Influent flow rate, Q = 0.50 l/min

1	5	05	1.041	86.393
2	5	10	1.772	88.187
3	5	15	1.661	88.927
4	5	20	1.560	89.600
5	5	25	1.387	90.753
6	5	30	1.359	90.940
7	5	35	1.267	91.553
8	5	40	1.273	91.513
9	5	45	1.260	91.600
10	5	50	1.254	91.640
11	5	55	1.246	91.693
12	5	60	1.251	91.660
13	5	65	1.259	91.607
14	5	70	1.256	91.627

Table F.18 contd.

S. No.	θ	θ_c	C	P_r
Influent flow rate, Q = 0.75 l/min				
1	5	05	2.753	81.647
2	5	10	2.495	83.367
3	5	15	2.352	84.320
4	5	20	2.165	85.567
5	5	25	2.101	85.993
6	5	30	2.064	86.240
7	5	35	1.980	86.800
8	5	40	1.991	86.727
9	5	45	1.982	86.787
10	5	50	1.977	86.82
11	5	55	1.972	86.853
12	5	60	1.969	86.873
13	5	65	1.980	86.800
14	5	70	1.989	86.740
Influent flow rate, Q = 1.00 l/min				
1	5	05	3.697	75.353
2	5	10	3.448	77.013
3	5	15	3.294	78.040
4	5	20	3.112	79.253
5	5	25	2.901	80.660
6	5	30	2.875	80.833
7	5	35	2.884	80.773
8	5	40	2.831	81.127
9	5	45	2.865	80.900
10	5	50	2.854	80.973
11	5	55	2.883	80.780
12	5	60	2.864	80.907
13	5	65	2.891	80.727
14	5	70	2.888	83.747

EXPERIMENTAL DATA

Table F.19 Initial Pb^{++} concentration, C_o = 15.0 mg/l
Charcoal mass flow rate, W = 20.3 g/min

Influent flow rate, Q = 0.25 l/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
1	5	05	0.981	93.460
2	5	10	0.854	94.307
3	5	15	0.776	94.827
4	5	20	0.725	95.167
5	5	25	0.674	95.507
6	5	30	0.631	95.793
7	5	35	0.612	95.920
8	5	40	0.575	96.167
9	5	45	0.556	96.293
10	5	50	0.541	96.393
11	5	55	0.537	96.420
12	5	60	0.542	96.387
13	5	65	0.551	96.327
14	5	70	0.548	96.347

Influent flow rate, Q = 0.50 l/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
1	5	05	1.745	88.367
2	5	10	1.491	90.060
3	5	15	1.369	90.873
4	5	20	1.296	91.360
5	5	25	1.193	92.047
6	5	30	1.177	92.153
7	5	35	1.175	92.167
8	5	40	1.153	92.313
9	5	45	1.108	92.613
10	5	50	1.106	92.627
11	5	55	1.102	92.653
12	5	60	1.105	92.633
13	5	65	1.106	92.627
14	5	70	1.103	92.647

Table F.19 contd.

S. No.	θ	θ_c	C	P_r
Influent flow rate, Q = 0.75 l/min				
1	5	05	2.347	84.353
2	5	10	2.357	84.287
3	5	15	2.135	85.767
4	5	20	1.976	86.827
5	5	25	1.939	87.073
6	5	30	1.893	87.380
7	5	35	1.834	87.773
8	5	40	1.816	87.893
9	5	45	1.824	87.840
10	5	50	1.797	88.020
11	5	55	1.802	87.987
12	5	60	1.804	87.973
13	5	65	1.784	88.107
14	5	70	1.806	87.960
Influent flow rate, Q = 1.00 l/min				
1	5	05	3.395	77.365
2	5	10	3.129	79.140
3	5	15	2.954	80.307
4	5	20	2.910	80.600
5	5	25	2.841	81.060
6	5	30	2.812	81.253
7	5	35	2.813	81.247
8	5	40	2.774	81.507
9	5	45	2.781	81.460
10	5	50	2.762	81.587
11	5	55	2.751	81.660
12	5	60	2.762	81.587
13	5	65	2.754	81.640
14	5	70	2.755	81.633

EXPERIMENTAL DATA

Table F.20 Initial Pb^{++} concentration, C_o = 15.0 mg/l
Charcoal mass flow rate, W = 26.1 g/min

S. No.	Time interval θ min	Cumulative time θ_c min	Effluent Pb^{++} Concentration C, mg/l	Percent removal P_r %
Influent flow rate, Q = 0.25 l/min				
1	5	05	1.145	92.367
2	5	10	0.961	93.593
3	5	15	0.857	94.287
4	5	20	0.734	95.107
5	5	25	0.694	95.373
6	5	30	0.595	96.033
7	5	35	0.573	96.180
8	5	40	0.551	96.237
9	5	45	0.550	96.333
10	5	50	0.506	96.627
11	5	55	0.482	96.787
12	5	60	0.484	96.773
13	5	65	0.506	96.627
14	5	70	0.488	96.747
Influent flow rate, Q = 0.50 l/min				
1	5	05	1.820	87.864
2	5	10	1.584	89.440
3	5	15	1.308	91.280
4	5	20	1.191	92.060
5	5	25	1.143	92.380
6	5	30	1.079	92.807
7	5	35	1.071	92.860
8	5	40	1.032	93.120
9	5	45	1.014	93.240
10	5	50	1.009	93.273
11	5	55	1.023	93.180
12	5	60	1.027	93.153
13	5	65	1.994	93.373
14	5	70	1.013	93.247

Table F.20 contd.

S. No.	θ	θ_c	C	P_r
Influent flow rate, Q = 0.75 l/min				
1	5	05	2.363	84.247
2	5	10	2.074	86.173
3	5	15	1.954	86.973
4	5	20	1.775	88.167
5	5	25	1.695	88.700
6	5	30	1.591	89.393
7	5	35	1.573	89.513
8	5	40	1.552	89.653
9	5	45	1.505	89.967
10	5	50	1.510	89.933
11	5	55	1.485	90.100
12	5	60	1.508	89.947
13	5	65	1.511	89.927
14	5	70	1.506	89.960
Influent flow rate, Q = 1.00 l/min				
1	5	05	3.545	76.367
2	5	10	3.104	79.307
3	5	15	2.902	80.653
4	5	20	2.751	81.660
5	5	25	2.560	82.933
6	5	30	2.466	83.560
7	5	35	2.451	83.660
8	5	40	2.410	83.933
9	5	45	2.428	83.813
10	5	50	2.395	84.033
11	5	55	2.403	83.980
12	5	60	2.406	83.960
13	5	65	2.399	84.007
14	5	70	2.401	83.993

APPENDIX G

SAMPLE CALCULATIONS

Run no. 1 of Table F.1 has been selected to demonstrate the calculation procedure used in this investigation. The data corresponding to this run number are as follows :

Initial concentration of Pb^{++} in influent, $Co = 5$ mg/l

Charcoal mass flow rate, $W = 12.5$ g/min.

Influent flow rate, $Q = 0.25$ l/min

Cumulative contact time, $\theta_c = 5$ min.

Effluent leadion concentration, $C = 0.501$ mg/l

G-1 PERCENT REMOVAL OF Pb^{++} IN THE REACTOR

$$\text{Percent removal} = \frac{C_o - C}{C_o} \times 100$$

$$= \frac{5.0 - 0.501}{5.0} \times 100$$

$$= 89.98 \%$$

G.2 LEAD REMOVAL CAPACITY OF CHARCOAL :

For run no. 1 of Table 4.1.

$$q = \frac{(C_o - C)\ Q\ \theta_e}{W\ \ \theta_e}$$

$$= \frac{(5 - 0.102) \times 0.25 \times 55}{12.5 \times 55} = 0.09796 \text{ mg/g}$$

G.3 SIZE OF CHARCOAL PARTICLE

Average diameter of particle

$$= \frac{\text{mass fractions retained} \times \text{mean size of particles retained}}{\text{Total mass}}$$

$$\sum_i x_i D_i = \frac{\sum_i x_i D_i}{\sum_i x_i}$$

$$= \frac{(650 \times 0.1115) + (512.5 \times 0.3838) + (390 \times 0.1972) + (302.5 \times 0.1701) + (200 \times 0.1374)}{1.00}$$

$= 425.0 \ \mu$

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