The Removal of Pollutants Present in Domestic Wastewater by an Inorganic Medium.

By

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Preface

This thesis contains information regarding a patented process protected under Irish Patent No. S. 58901. The use of this patent and associated intellectual property is entirely reserved and rests with the patent holders. Unauthorised use of any such related material is illegal and may result in prosecution.

Dedication

To John
and
Óonagh.

Declaration

This thesis has not previously been submitted to this or any other college and, with acknowledged exception, is entirely my own work.

Ann Maria Duddy

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Abstract

The removal of polluting parameters present in domestic wastewater, by the Biolat septic tank was investigated. Results obtained indicate that the Biolat media was responsible for the removal of ammonium and phosphate. Biological and physical processes, within the septic tank itself, were responsible for the removal of nitrate, BOD, COD, suspended solids and *E.coli.*

The adsorption capacity of Biolat for both ammonium and phosphate was determined using Biolat columns and pure solutions of ammonium and phosphate. Investigations revealed that the mechanism of phosphate removal was by physical adsorption into the Biolat matrix. The removal of ammonium was by means of cation exchange. Both adsorption phenomena obeyed the Freundlich adsorption isotherm.

Contact time between the Biolat and ammonium or phosphate was important. A retention time of greater than one day was required when influent concentrations exceeded 1000 mg/l of phosphate or ammonium.

Desorption of adsorbed phosphate occurred when water was passed through the saturated Biolat. The desorption process was gradual and necessitated the passage of large quantities of water through the Biolat columns. The desorption of phosphate from Biolat was very efficient because it was merely held in the Biolat matrix by physi-sorption. Some adsorbed ammonium was also desorbed using distilled water. However, the desorption efficiency of ammonium was much lower than for phosphate. The reason for this was due to ammonium being more strongly bound in the Biolat matrix.

The effect of pH and grain size on adsorption were also investigated. The grain size of Biolat was important in adsorption only in the initial stages of contact between Biolat and phosphate or ammonium. The adsorption of phosphate and ammonium by Biolat was relatively unaffected by the the pH of the solution.

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CHAPTER ONE

INTRODUCTION

1.0 Introduction.

In areas without community sewerage schemes the requirement for on-site disposal and treatment of domestic waste water has been largely met by the installation of septic tank systems. Septic tank systems are comprised of a septic tank and a soil absorption system. Septic tank systems have been used in both developed and developing countries for over one hundred years due to their low cost and ease of maintenance. There are over 300,000 septic tank systems in Ireland serving a population in the region of 1.2 million people (Henry, 1990). The septic tank itself can be regarded only as a primary treatment system providing limited attenuation or removal of the pollutants in domestic sewage. The bulk of treatment of domestic waste water therefore occurs in the soil absorption system, provided that the system is functioning properly. Unfortunately, not all soils are capable of effectively treating the waste water emanating from a septic tank due to insufficient or excessive permeability of the soil. If the permeability of the soil is too high then the waste water does not have an adequate contact time with the soil to sufficiently remove the pollutants prior to discharge to groundwater. If there is insufficient permeability then this will result in ponding of effluent on the ground surface with attendant health hazards. It has been reported that only half of the soils used for soil absorption systems in Ireland are actually capable of providing sufficient treatment of the pollutants present in septic tank effluent due to low or high permeability or owing to high water tables (O' Hegarty, 1976 and Daly, 1987). Nevertheless, the widespread use of the septic tank system has continued in the face of a consistent history of failure. Many workers have highlighted septic tanks as one of the major polluters of groundwater supplies (Patterson *et al*, 1971; Viraghavan, 1978; Mc Coy and Hagedorn, 1979 and Bitton and Gerba, 1984). The contamination of surface water by septic tank overflow has also been well documented (De Walle and Scaff, 1980; Chen, 1988 and Patrick, 1988). In particular, the nutrient and bacterial contamination of waters by septic tank effluent is of the greatest concern. The human health risks and environmental significance of such contamination is considerable (Henry, 1990).

In certain situations, such as those described above, the effective use of a conventional septic tank treatment system is precluded and alternative on-site treatments are required. There are many systems currently in use for the treatment of domestic waste water such as those systems which utilise the activated sludge principle e.g. rotating biological filters or trickling filters. These systems are however expensive and require regular maintenance. Many of these systems have been developed specifically for larger scale waste water treatment i.e. municipal waste waters and their alteration to deal with low flow waste water treatment has caused many inherent problems as discussed by Metcalf and Eddie (1991). The septic tank system in comparison is a low technology system and where it operates properly is better suited to private domestic waste water treatment. Therefore the modification or upgrading of the conventional septic tank system to more satisfactorily remove the pollutants in domestic sewage is a better option than the use of other high technology systems.

Alternative septic tank systems currently in use involve the replacement or reinforcement of unsuitable soils in the soil absorption systems with material having more favourable attenuation properties. Many materials have been used to replace the soil in a soil absorption system. Sand, loam, peat and soil mixtures are the most commonly used imported materials. However, bottom ash, strip-mine soils and slags have also been used (Converse *et al*, 1978). Other solid adsorbents such as fly ash, activated alumina, gypsum and powdered aluminium oxides have also been investigated (Shiao *et al*, 1977 and Bhargava and Sheldarkar, 1992). Modifications to the conventional septic tank have also been investigated. These modifications involve the addition of certain materials e.g. coagulants to the septic tank in order to improve the treatment efficiency of the tank and in particular, to enhance the removal of nutrients within the septic tank (Brandes, 1977 and Jones and Lee, 1979). Other modifications to the septic tank include the incorporation of a suitable adsorbent material in a separate compartment from the septic tank as in the Bord na Mona biofiltration unit (Henry, 1990). This system utilises peat for the treatment of pollutants in septic tank effluent with some success. The modified septic tank under investigation in this study is known as the Biolat septic tank. The tank is manufactured by Butler Manufacturing Systems in Co. Longford, Ireland. This system incorporates an extra chamber into the conventional septic tank to house a mineral media trade named 'Biolat'. The

Biolat septic tank is therefore comprised of a three chambered tank, with the third chamber containing the Biolat. The Biolat septic tank was investigated for the removal of pollutants in septic tank effluent and in particular for the removal of nutrients associated with the pollution of surface and groundwater i.e. phosphate, nitrate and ammonia.

1.1 Aims and Objectives

The aim of this study is to assess the performance of the Biolat septic tank for the removal of pollutants in domestic sewage and to compare its efficiency to that of a normal septic tank system. Furthermore the merits of using Biolat for treating septic tank effluent will be investigated and compared to other media which have been used for this purpose. The aims will be achieved by meeting the following objectives

(i) Assessing the performance of a full scale prototype Biolat septic tank which is used to treat domestic waste water from a private residence.

(ii) Determination of the removal of pollutants in domestic sewage at each stage in the Biolat septic tank using pilot scale Biolat septic tanks.

(iii) Assessing whether the removal of pollutants in the pilot scale Biolat septic tanks is influenced by aeration of the second chamber of the tank.

(iv) Assessing the factors which influence the removal of pollutants in septic tank effluent by Biolat using Biolat housed in separate columns

(v) Determination of the mechanism of pollutant removal by Biolat.

1.2 Thesis Layout

This thesis is divided into six separate sections as described below

Section 1 Introduction

Section 2 Literature Review

This section reviews the relevant literature on the performance of the conventional septic tank system and also modified septic tank systems for the removal of pollutants present in domestic sewage. The origin and composition of Biolat used in the Biolat septic tank system is also described.

Section 3 Materials and Methods

The methods and materials used for the analysis of waste water in the Biolat septic tank system are described in this section. Also described are the various experiments undertaken to determine the specific role of Biolat in the removal of pollutants present in domestic waste water.

Section 4 Results and Description of Results

Section 5 Discussion

The results are discussed with reference to previous investigations by other workers. In particular, the usefulness of the Biolat septic tank shall be discussed together with the merits of using Biolat in wastewater renovation.

Section 6 Conclusions

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Waste water produced from concerted human activities is a common purveyor of potentially polluting substances to both groundwater and surface water systems. Each household which is equipped with running water and modern plumbing is faced with the disposal of its waterborne waste. Where distances between houses are great, the installation of public sewer systems is not economic and therefore provision for private waste water treatment systems is required (Goldstein, 1977) There are a number of technologies available for the treatment of the low flow wastes discharged from a household. These are

a) Activated Sludge Treatment Plants.
b) Rotating Biological Contactors.
c) Trickling Filters / Granular Medium Filters.
d) Constructed Wetlands.
e) Septic Tank Systems / Modified Septic Tank Systems.

For the purpose of this study emphasis shall be placed only on (e) above, as a method of treatment of domestic waste water. Other technologies are dealt with elsewhere and are summarised by Metcalf and Eddie (1991).

Septic tank systems, which are comprised of a septic tank and soil absorption system are the most frequently used method of disposing of wastes from private residences. The waste water from a household enters the septic tank where it receives limited treatment to remove the insoluble fractions present in the waste water. The effluent from the septic tank is then discharged into a soil absorption field where it receives further treatment by interaction with the soil colloids. However, the ability of septic tanks and, more importantly the soils ability to renovate waste water is known less precisely than that of other waste water treatment facilities. Failure of either the tank or the soil treatment system can result in inadequately treated sewage reaching ground and surface water causing hazards to health, nuisances and, in many instances, pollution of waterbodies.

In many countries, the effluent that is discharged from septic tanks ranks highest in the total volume of waste water discharged to groundwater systems. In addition, septic tanks are the most frequently reported sources of groundwater contamination (Geraghty and Miller, 1978). Despite the widespread reliance on the septic tank in many countries, they have received much criticism by many workers (Kiker, 1956, Laurence, 1973 and Geraghty and Miller, 1978. Kiker (1956) suggested that, 'at best the septic tank is a poor substitute for centralised sewage collection and should be avoided whenever possible'. The effectiveness of a septic tank depends on many factors, primarily the design, construction and maintenance of the system. The volume and nature of the waste is also important. If the septic tank fails to function properly then the onus is on the soil treatment system entirely to render the waste water harmless before it reaches a surface or groundwater system. However as already stated, more than half the soils in Ireland are unsuitable for septic tank systems due to low permeabilities and high water tables (Daly, 1987), and therefore the degree of treatment which occurs in soil absorption systems is limited. It is imperative then that the septic tank in use should remove as many of the pollutants as possible present in domestic waste water before reaching the soil absorption system.

This section attempts to address the problems associated with septic tank systems by reviewing the available literature on septic tank performance and the performance of soil absorption systems. The pollution of surface and groundwater systems caused by malfunctioning septic tank systems is also reviewed. Modifications to the conventional septic tank system are also investigated in order to determine if improvements in domestic waste water treatment can be achieved prior to discharge to the soil treatment system so that there is less heavy reliance on the soil to treat the waste water before it reaches a surface or groundwater system.

2.2 The requirement for septic tanks

Approximately 35% of development in Ireland is unsewered, i.e. not connected to the public sewer system, which is under the responsibility of the Sanitary Authority. This deficiency in waste water facilities has been met through the installation of over 300,000 septic tank systems for private residences (Henry, 1990). Septic tanks have a number of advantages over other methods of domestic waste water treatment, namely:

(a) The cost of individual or community septic tank systems is less than the cost of central waste water facilities and treatment plants in rural areas.

(b) There is less sludge produced per person through the use of septic tanks than through the use of centralised mechanical plants such as activated sludge plants.

(c) Minimum maintenance is required with septic tanks. Pumping of the septage produced is required every three to five years.

(d) The septic tank is a low technology system, thus the possibility for long term operation without extensive periods of shutdown is enhanced.

(e) Septic tanks have a low energy requirement.

(After Canter and Knox, 1985)

2.2.1 Constituents present in domestic sewage and their pollution potential.

The volume of effluent introduced to a septic tank system from a typical household varies from 150 to 170 litres per person per day (USEPA, 1978). This waste water is comprised of toilet flushings, washbasin and bathtub washings and kitchen waste (Table 2.1 on page 12). Waste emanating from a household is a complex heterogeneous mixture of chemical and biological constituents, which if allowed to enter a waterbody untreated, has the potential to cause serious pollution. This section deals with the identification of the main constituents present in domestic sewage, their origin and their ability to pollute groundwater and surface water systems. The pollutants will be dealt with under three separate headings. These are

- Organic compounds yielding BOD and COD
- Compounds consisting of Nitrogen and Phosphorous
- Micro-organisms.

(Although there are other noteworthy pollutants present in domestic waste water in smaller quantities i.e. metals and other soluble salts, they are outside the scope of this thesis.)

- **Organic compounds yielding BOD and COD.**

Domestic waste water has been shown to contain a variety of natural and synthetic organic compounds collectively expressed in terms of Biochemical and Chemical Oxygen Demand, i.e. BOD and COD. These organic compounds exert a considerable oxygen demand upon entering a surface or groundwater system since they are readily degradable by micro-organisms which use oxygen for the respiration of organic material (Miller and Wolf, 1975). Average values for BOD and COD are shown in Table 2.2. (page 18). Because fully aerated water contains less than 10 mg/l of dissolved oxygen, sewage must be diluted many times to break down the organic components successfully. Raw sewage dumped into a flowing stream will eventually obtain the required oxygen for BOD and COD breakdown, but, in the process, may deplete the oxygen to such an extent that fish and other aquatic life cannot live (Goldstein and Wenk, 1972).

Domestic sewage also contains solid fractions, which are both soluble and insoluble in nature. The majority of these solids are organic in nature and

Source	**Percentage of Total.**
Toilet	28.4%
Toilet leakages	5.5%
Showers	21.2%
Faucets	11.7%
Baths	8.9%
Washing machines	21.2%
Dishwasher	3.1%

(After Metcalf and Eddie, 1991)

Table 2.1 The proportion of wastewater arising from various sources in a domestic household.

will therefore contribute to the overall BOD and COD of the waste water. In addition, if the domestic waste water is released into a river or lake untreated, the solids present may settle on the bottom of the waterbody causing undesirable anaerobic conditions. The solids may also clog spawning beds for fish. If the solids do not settle they may cause an increase in the turbidity of the water, thereby reducing light penetration which will in turn reduce the primary productivity of the system. In addition, waters with high dissolved solids generally are of inferior palatability and may induce an unfavourable physiological reaction in the transient consumer.

- **Compounds consisting of Nitrogen and Phosphorous**

Domestic waste water contains a number of organic and inorganic nutrients the most common of which are nitrogen and phosphorous. Much attention has recently been focused on these nutrients because of their ability to cause eutrophication.

(i) Phosphorous

Phosphorous occurs in natural waters and domestic waste waters almost solely as phosphates. These are classified as orthophosphates, condensed phosphates (pyro-, meta- and other polyphosphates) and organically bound phosphates (*Standard Methods* APHA, 1992). These forms of phosphate arise from a variety of sources. Small amounts of certain condensed phosphates are added to some water supplies during treatment. Larger quantities of the same compounds may be added when the water is used for laundering or other cleaning purposes because these materials are major constituents of many commercial cleaning preparations. Organic phosphates are formed primarily by biological processes. They may be contributed to sewage by body wastes and food residues. Typical values for phosphates in sewage are shown in Table 2.2. (page 18)

Phosphorous is essential to the growth of organisms and can be the nutrient that limits the primary productivity of a body of water. Phosphate is considered to be a major cause of pollution in freshwater and sea water bodies (Patterson *et al*, 1971). Phosphate released from septic tank drainfields affects surface and groundwater quality (Jones and Lee, 1979 and Kerfoot and Skinner, 1981). It has been identified as the key element in controlling the growth of algae and other aquatic plants. (Jones and Lee, 1979). The elimination of phosphate from domestic sewage has proved to be the most important step in the control of eutrophication (Uhlmann et al, 1990) Under favourable conditions phosphate concentrations exceeding 0.05 mg/l may stimulate the growth of algae and other aquatic plants, therefore it is important to maintain the lowest possible level in streams and lakes limiting the amount of same entering a waterbody.

(ii) Nitrogen

The forms of nitrogen of greatest interest in domestic waste waters are, in order of decreasing oxidation state; nitrate, nitrite, ammonia and organic nitrogen. All of these forms of nitrogen as well as nitrogen gas, are biochemically interchangeable (*Standard Methods* APHA, 1992) . Organic nitrogen includes such natural material as proteins and peptides, nucleic acids and urea as well as numerous synthetic nitrogen compounds. Ammonia is present naturally in surface and waste waters. Its concentration is generally low in groundwaters. It is produced largely by deamination of organic nitrogen compounds and by the hydrolysis of urea. The pollution of surface water by ammonia has been well documented (Kiff, 1972 and Lyodd, 1973). Kiff (1972) has reported that ammonia levels of 0.29 to 0.41 mg/l NH_4-N can have lethal consequences for fish and other aquatic organisms, the effect being more pronounced when dissolved oxygen levels are low in the receiving water and temperatures and pHs are high. Where a water is used for the abstraction of drinking water, high levels of ammonia increase the chlorine demand in a water treatment plant but more importantly could possibly give rise to the presence of carcinogenic chloramines. Another indirect effect of ammonia in a receiving water is the exertion of an oxygen demand due to the action of naturally occurring nitrifying organisms who oxidise the ammonia to nitrate. A further consequence of this is that the nitrate acts as a nutrient for plant growth which can lead to the eutrophication of the water body.

Totally oxidised nitrogen is the sum of nitrate and nitrite nitrogen. Nitrate generally occurs as trace quantities in waters and waste waters but may attain high levels in groundwaters. The pollution of groundwaters by nitrates has been well documented (Polkowski and Boyle, 1970; Jones and Lee, 1979; Patterson *et al*, 1971, Lewis *et al,* 1982; Canter and Knox, 1985). In excessive amounts it contributes to the illness known as methaemoglobinaemia (Stewart and Stoleman, 1961; Patterson *et al*, 1971; Bitton and Gerba, 1984 and Keeney, 1986). A limit of 11.3 mg/l NO_3-N has been imposed on drinking water by the World Health Organisation (W.H.O) and the European Union (E.U.) to prevent this disorder. Bitton and Gerba (1984) report that most cases of infantile cyanosis occur when the nitrate concentration in the water consumed is greater than 22.0 mg/l; although cases have been reported where concentrations were less than 10.0 mg/l. A link between high nitrate levels and gastric cancer has also been suggested (Anon, 1985 and Keeney, 1986). In addition, nitrous acid, which is formed from nitrite in acidic solution, can react with secondary amines to form nitrosamines, many of which are known carcinogens. Incidents of livestock poisoning due to high nitrate levels have been reported by Nichols (1965) and Walker (1969).

- **Micro-organisms**

Domestic waste water also contains bacteria, viruses and protozoans that are pathogenic to humans (Burge and Marsh, 1978). The majority of these organisms originate in the human intestine and are discharged to septic tanks via body wastes. Moreover these organisms are usually present in very high numbers and therefore untreated domestic waste embodies a potential health hazard. The proper waste purification and disposal of domestic wastewater is therefore an important concern. Numerous diseases have been linked to the contamination of water by micro-organisms present in domestic waste water, including typhoid fever, infectious hepatitis and gastrointestinal diseases. Although it is difficult to determine the extent of all of these micro-organisms in waste water (laboratory examination of water for pathogens is difficult), their existence is often inferred on the basis of a coliform count test. One type of bacteria called *Escherishia coli* is almost universally present in the mammalian tract. These bacteria are easily identified and counted in water samples and hence they are used to determine the extent of pollution from domestic waste. Typical values of both total and faecal coliforms are presented in Table 2.2. (page 18).

2.3. Septic tank systems

Septic tank systems are comprised of a septic tank and a soil absorption system (Figures. 2.1 and 2.2, pages 24-25). The antecedent of the septic tank can be traced back to about 1860 with the early work of Mouras in France. Since then it has become the most frequently used method of on-site disposal of domestic waste water (Henry, 1990).

Parameter	Average Concentration	Concentration Range.
BOD (mg/l)	300	100 to 450
COD (mg/l)	750	
Total Solids (mg/l)	780	750 to 1200
Suspended Solids (mg/l)	250	100 to 375
Total Organic Nitrogen (mg/l)	38	
Ammonia Nitrogen (mg/l)	12	10 to 40
Nitrate Nitrogen (mg/l)	0.6	0 to 0.1
Nitrite Nitrogen (mg/l)	0.0	
Total Phosphate (mg/l)	25	15 to 30
Orthophosphate (mg/l)	8.8	
Total Coliforms (cfus/100 mls)		1 to 100 million
Faecal Coliforms (cfus/100 mls)	1.3 million	

Table 2.2. Typical values of pollutants present in domestic sewage.

(After Bauer, Conrad and Sherman, 1979 and Council of Environmental Quality, 1974)

2.3.1 The Septic Tank

The septic tank is a buried watertight container designed and constructed to receive waste water from a household. The septic tank should be watertight, structurally sound and reasonably durable. The watertight requirement is to preclude infiltration into the tank at a rate greater than the system design. This would cause hydraulic overloading and lead to poor quality discharges into the soil absorption system. The tank can be prefabricated or built in-situ and can be manufactured from a range of materials, the most common of which are fibreglass and concrete.

The function of the tank is primarily to separate solids from liquids in the influent domestic waste water by gravity separation, and to provide limited anaerobic digestion of the organic matter. The solids are stored on the floor of the tank and the liquid supernatant is allowed to overflow into the surrounding soil for further treatment. The settled solids on the floor of the tank are partially digested by anaerobic micro-organisms, with the liberation of gases, principally carbon dioxide and methane. Oils, fats, greases and soaps in the waste water are floated to the surface by this gas and form a thick scum over the liquid waste, (an indication that the tank is functioning properly). Some anaerobic digestion occurs in the scum layer and to a lesser extent in the intermediate liquid layer.

Design considerations related to septic tanks include determination of the appropriate volume, a choice between single and double compartments, selection of construction material and placement on the site. The septic tank must be designed to ensure removal of almost all settleable solids in the influent waste water from individual housing units (US Environmental Protection Agency.) The design of the tank is important with regard to velocity, flow, circulation, depth of sludge and the amount of the dead space that is available (Henry, 1990). Ideally the tank should have two chambers connected in series. This allows for better settlement of the liquid-solid mass in the incoming effluent (Laak, 1980). It has now been well established that the performance of two chamber septic tanks is superior to that of single chamber septic tanks in the removal of SS and organic colloids (Canter and Knox, 1985). Benefits of the design are largely due to hydraulic isolation and to the reduction or elimination of intercompartmental mixing. Mixing can occur by two means i.e. by water oscillation and through turbulence. Oscillatory mixing can be minimised by making compartments unequal in size. Commonly the second compartment is one third to one half the size of the first chamber (Fig. 2.2, page 25). In the first compartment some mixing of sludge and scum with the liquid always occurs due to the induced turbulence from the entering waste water and the digestive process. The second compartment receives clarified effluent from the first compartment. Most of the time it receives this hydraulic load at a lower rate and with less turbulence than does the first compartment and thus better conditions exist for settling low density solids. These conditions lead to longer working periods before pump out of solids is necessary and they improve the overall performance of the tank.

Most European countries have codes of practice regarding the construction of septic tanks. In Ireland the National Standards Authority of Ireland (NSAI) SR6 of 1991 sets down guidelines for septic tanks and soil absorption fields. The SR6 also provides for the maintenance of the septic tank system.

Since a septic tank functions primarily as a settlement chamber, it only conditions the sewage so that it can percolate more readily through the soil (Cain and Beaty, 1965). The soil purification of waste is required for purification of septic tank effluent before it replenishes groundwater utilised by individual and public water supplies.

2.3.2 Soil absorption systems

Once the effluent leaves the septic tank, it is channelled into a soil treatment system where it receives further treatment by reactions with the soil colloids. There are two treatment systems commonly in use. These are

(a) Soakage pits.

(b) Distribution fields.

The former simply consists of an excavated hole filled with stone or rubble into which the effluent is allowed to flow. Distribution fields on the other hand are designed to distribute the effluent through a large volume of soil via a pipe distribution network. Many countries produce guidelines for the construction and maintenance of these soil distribution systems. In Ireland reference should be made to the NSAI SR6, 1991.

The soil plays an integral part in the process by which the effluent strength is reduced before reaching the saturated zone. Soils have the ability through physical, chemical and microbiological processes to effectively restrict and attenuate the various effluent constituents and reduce their pollution potential. The properties of the soils are such that several mechanisms are available to act on the waste components, thereby effecting at least some degree of renovation. These mechanisms include filtration, sorption, precipitation, oxidation and biological transformation (Ellis, 1973; Miller and Wolf, 1975; Bourma, 1979 and Canter and Knox, 1985). Different soils have different renovation or attenuation capacities depending on many factors including permeability, ion exchange capacity, texture, thickness of the overburden beneath the site, depth to the watertable and slope of the land (Huddleston and Olson, 1967).

2.4 Performance efficiency of the septic tank system

The septic tank may offer several distinct advantages in terms of cost over other methods of domestic waste water treatment. However, the primary objective of waste water treatment is to adequately treat the waste water prior to discharge to a waterbody. This section looks at studies undertaken by various workers on the performance of the septic tank system.

2.4.1. Efficiency of the septic tank

Most authors agree that even the most efficient septic tank can only offer partial treatment of the influent waste water (Patterson *et al*, 1971, Laurence, 1973, Viraghavan, 1978 and Canter and Knox, 1985). Many studies have been conducted on the efficiency of septic tanks. The results obtained are wide and varied in nature, due mainly to the variable nature of the influent waste water. The efficiency of the septic tank for the removal of the various types of pollutants outlined in Section 2.2.1 (page 10) is dealt with separately.

- **Organic compounds yielding BOD and COD**

The majority of studies carried out on the efficiency of septic tanks deal with the removal of suspended solids, BOD and to a lesser degree with COD removal. Suspended solids (SS) are removed from the influent domestic waste water by gravity separation. The solids settle as a sludge on the bottom of the septic tank. Solids which are of a gelatinous nature in fresh sewage become more crystalline in sewage which has been subjected to anaerobic treatment during prolonged storage in a septic tank. The removal of SS is optimised when the design of the septic tank allows quiescent conditions for solids settlement and the tank is maintained properly. Some low density solids are also removed by incorporation into the scum layer. This occurs when the solids are present with oils, fats and grease in the waste water. This fraction is raised to the surface of the liquid level in the septic tank by the gas bubbles that are produced by the anaerobic digestion process occurring within the septic tank. Solids may be lost from the septic tank if the tank is not constructed or maintained properly. In inadequately sized septic tanks there is a danger that

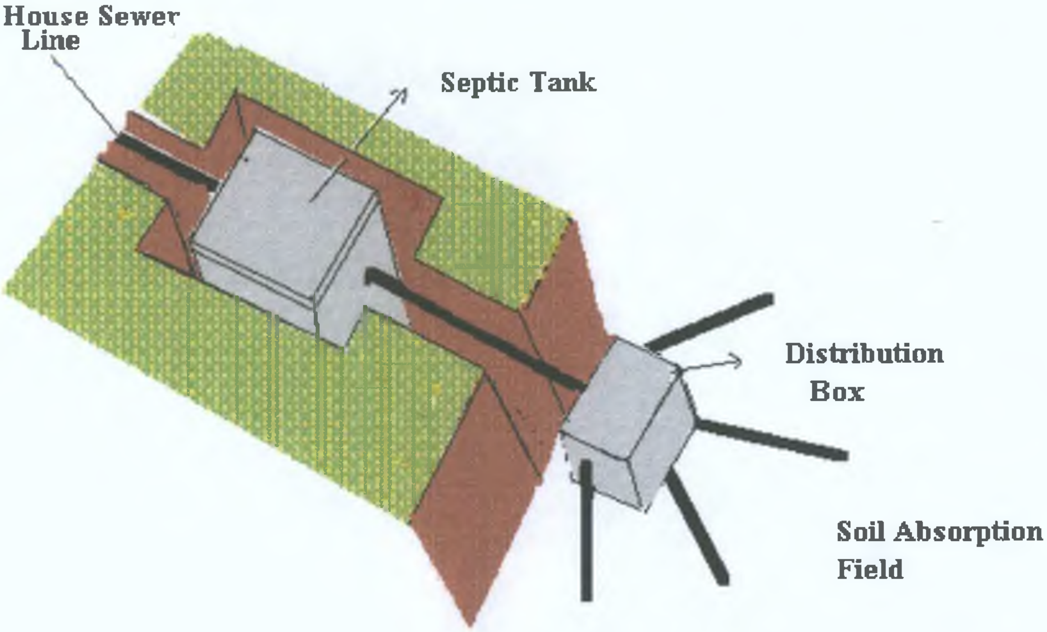

Figure 2.1 Septic Tank and Soil Absorption Field

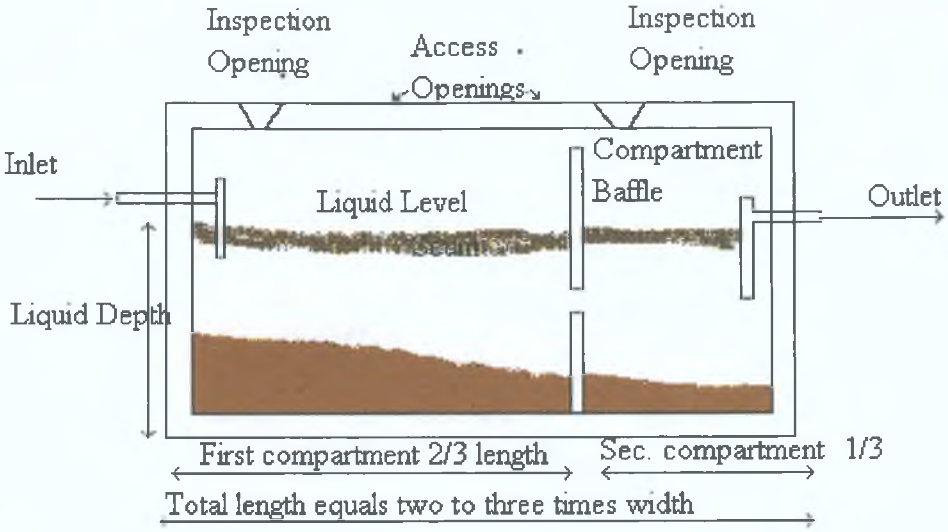

Figure. 2.2. Septic tank.

peak flows will cause short-circuiting or streaming of effluent from inlet to outlet. This causes reentrainment of settled solids and disturbance of the scum layer with subsequent loss of pollutants to the subsoil. In addition, if septic tanks are not desludged at regular intervals, there is a build up of sludge in the tank causing solids to be lost from the tank. BOD and COD removal in the septic tank is achieved primarily by virtue of solids settlement on the floor of the septic tank. A substantial amount of BOD and COD in domestic waste water is present in this solid matter. Anaerobic digestion of these settled solids subsequently occurs thereby reducing the sludge volume. Anaerobic heterotrophs utilise the organic material for growth and energy with carbon dioxide (CO_2), methane (CH_4), hydrogen (H_2), hydrogen sulphide (H_2S), ammonia (NH_4) and water (H_2O) produced as by-products. The remaining BOD and COD is present in the liquid portion of the waste. Anaerobic digestion of this fraction also occurs to a limited extent.

The performance efficiency of the septic tank for the removal of BOD and SS is usually expresses as the percentage removal of each of these parameters. A summary of some of the studies dealing with the removal of BOD and SS in a septic tank are shown in Table 2.3 (page 29). From Table 2.3, the observed results of the efficiency of the septic tank for the removal of BOD and SS are very variable. Values obtained for the removal of BOD in a septic tank range from 7 to 73%, while observed removal rates for SS vary from 0 to 85%. Baumann and Babbit (1953) in studying the operation of six different septic tanks found considerable variation in effluent quality from day to day for any one septic tank and in the average between septic tanks. This exemplifies the difficulty in assessing septic tank performance. Looking at the percentage removal of each of the parameters gives an indication of the percentage removal from influent to effluent in a septic tank and also between removal rates achieved in different septic tanks. A more useful value however, in terms of the pollution capability of the effluent emanating from a septic tank, is the concentration of BOD, COD and SS in the septic tank effluent. Typical values of BOD, COD and SS being discharged to a soil were investigated by Viraghavan and Warnock (1976) and are shown in Table 2.4 (page 30)

- **Compounds containing Nitrogen and Phosphorous**

The removal of nitrogen and phosphorous within a septic tank is less well documented in literature than that of BOD and SS, however, most authors agree that the removal of both within a septic tank is limited (Patterson *et al*, 1971, Canter and Knox, 1985 and Henry, 1990). Canter and Knox (1985) report that anaerobic processes within the tank are largely ineffective in reducing the concentration of both phosphorous and nitrogen in the influent waste water.

(i) Phosphorous

Biological processes within the tank convert most of the influent phosphate in both the organic and condensed forms to soluble orthophosphate.

Bourma (1979) reports on studies by others who found that greater than 85% of the total phosphate in septic tank effluent was in the orthophosphate form. Viraghavan (1976) found that phosphate removal in a septic tank varied from 34 to 56%. However, Henry (1990) found phosphate concentrations actually increased in septic tanks yielding concentrations in effluents as high as 63 mg/l PO_4-P. Doyle and Thorn (1989) found concentrations as high as 52 mg/l PO_4-P while Preul (1965) and Bradley (1981) also found high concentrations of phosphate in septic tank effluent yielding values of 20 and 21 mg/l PO_4-P, respectively. Viraghavan and Warnock (1976) performed a study on the concentrations of phosphate reaching a soil absorption system from a septic tank. Their findings are presented in Table 2.4 (page 30). From these results it can be concluded that the treatment processes within a septic tank are largely ineffective in the removal of phosphate from domestic waste water.

(ii) Nitrogen

Anaerobic conditions within the septic tank result in much of the organic nitrogen being converted to ammonium (Whelan and Barrow, 1984). Canter and Knox (1985) found that the average concentration of total nitrogen in septic tank influent was 38 mg/l, with 12 mg/l (32%) in the ammonium form. Similarly they found that 75% of nitrogen in septic tank effluent occurs as ammonium with only 25% in the organic form. These workers also showed that on passage of domestic sewage through a septic tank, ammonia

Author	**BOD**	**SS**
Gainey and Lord (1952) (cited by Gray, 1989)	25 to 65%	40 to 75%
Baumann and Babbit (1953)	N.A	68.2 to 85%
Bailey and Wallman (1971)	50%	73%
Christoulas and Andreadakis (1989)	35 to 40 %	60 to 65%
Goldstein and Wenk (1972)	25 to 73 %	40 to 75%
Laak (1980)	N.A	80%
Laurence (1973)	7 to 15 %	34 to 35 %
Viraghavan (1973)	48 to 53 %	0 to 22 %
Ziebell et al (1974)	30 to 50 %	N.A.

Table 2.3 The percentage removal of BOD and SS in septic tanks (various authors).

Parameter	**Preul (1965)**	**Polkowski & Boyle (1970)**	**Viraghavan & Warnock (1976)**	**Canter & Knox (1985)**	**Henry (1990)**
BOD (mg/l)	130	102	140- 624	140	140- 822
COD (mg/l)	n.a.	n.a.	240- 2026	300	316- 1800
S.S. (mg/l)	40	70	176	75	68- 708
PO_4-P (mg/l)	20	n.a.	6.2- 30.0	15	13.9- 63.2
NH_3-N (mg/l)	25	14	97	n.a.	13.5- 71.8
NO_3-N (mg/l)	0.150	0.130	0.026	n.a.	0.0- 1.4

Table 2.4 Typical concentrations of pollutants observed in septic tank effluent (various authors).

Author.	**Total Coliforms (cfus / 100 ml)**	**Faecal Coliforms (cfus / 100 ml)**
Robeck *et al* (1964)	n.a.	5.0 million
Bradley *et al* (1971)	4.6 million	2.7 million
Ziebell *et al* (1974)	3.4 million	0.42 million
Thorn et al (1985)	18.0 million	1.2 million
Henry (1990)	16 million	1.3 million

Table 2.5 Typical concentrations of coliforms observed in septic tank effluent (various authors).

Key: n.a. = not available

concentrations increased by an average of 20%. Viraghavan (1973) also found that ammonia levels increased within a septic tank. Nitrate is not removed in septic tanks (Kaplan, 1988 and Perkins, 1989). The nitrate content of septic tank effluent is usually low due to the lack of oxygen present in the treatment process which prevents the conversion of ammonia to nitrate. It is important however to note that under aerobic conditions in soil or surface water, both ammonium and organic nitrogen are readily converted to nitrate and although nitrate concentrations may be low leaving a septic tank, they may quickly reach very high levels in soil absorption systems and in groundwaters. Based on a study by Viraghavan and Warnock (1976) the concentrations of the various forms of nitrogen discharged from a septic tank are outlined in Table 2.4 (page 30)

- **Micro-organisms**

The removal of bacteria within a septic tank system has been widely studied and it has been shown that the removal of these organism within the septic tank is negligible (Robeck *et al*, 1964; Patterson *et al*, 1971, Ziebell *et al*, 1974; and Henry, 1990). Micro-organisms are generally not capable of self propulsion and are carried along by the liquid in which they are suspended (Stead, 1939). However, some bacteria are motile e.g. some species of *E. coli*. The mechanism of removal of bacteria within a septic tank is generally by means of adsorption or attachment of the micro-organisms to the solids present in the domestic waste water and their subsequent sedimentation with these solids. When the solids and bacteria settle to the bottom of the septic tank the bacteria eventually die due to the generally unfavourable environment. Gainey and Lord (1952) report removal rates of 45 to 75% of bacteria in septic tanks due to sedimentation. If the solids pass through the tank and do not settle out then a loss of bacteria will ensue. Polkowski and Boyle (1970) report high coliform numbers in septic tank effluent and cite adsorption to solids which had not settled as the principal causative factor. The natural habitat of coliforms is the human intestine. The environment in fresh raw sewage does not seem to suit the enterics so they tend to die off as the sewage ages. Bacteria of environmental origin, i.e. from soil, tend to predominate at the expense of the coliforms in domestic sewage. Dor *et al* (1976) reported a 99% die-off of coliforms in 44 hours at 20 ^{o}C. Feacham *et al* (1983) suggests that greater than 70 hours may be required for 99% removal at this temperature. The factors that contribute to die-off of bacteria in domestic sewage include the original concentration of coliforms, retention time within the septic tank, ambient temperature, numbers of protozoans present, microbial antagonism, degree of sedimentation of solids and velocity of effluent through the septic tank (Mitchell, 1980 and Mc Cambridge, 1980). A cool anaerobic environment seems to have a protective effect (Hanes *et al*, 1964). Although there is some dispute about the survival of organisms within a septic tank, most authors agree that the number of faecal bacteria in septic tank effluent is very high (Cain and Beaty, 1965, Patterson *et al*, 1971 and Viraghavan,1976). Even with a two or three log reduction in the bacterial numbers, (corresponding to a removal rate of greater than 99 %), the number of coliform bacteria reaching the soil absorption system is still very high, in the order of hundreds of bacteria per ml of effluent. As an example of the minimum purification afforded by passage through the septic tank, Ziebell *et al.* (1974) along with other workers enumerated selected faecal bacteria populations in effluent from five septic tanks. The concentrations obtained are shown in Table 2.5 (page 30).

2.4.2 Efficiency of the soil absorption system

A good soil treatment system for receiving septic tank effluent should be permeable enough to absorb all of the effluent generated and provide a high level of treatment before the effluent reaches a groundwater system (Henry, 1990). The soil acts as a chemical and biological filter in which many organic and inorganic reactions occur when waste water passes through the soil profile. It may also chemically alter the waste contaminants and reduce or in some cases increase their pollution potential (Ellis, 1973).

- **Organic compounds yielding BOD and COD**

The removal of BOD and COD in soils is not well documented in literature, however, it is known that under aerobic conditions good removal rates are achieved. (Pell and Nyberg, 1975). A well drained soil with an adequately designed and installed disposal system is capable of supplying sufficient oxygen for COD and BOD breakdown. Typical concentrations of

BOD, COD and SS reaching groundwater from a soil absorption system are shown in Table 2.6 (page 36)

- **Compounds containing Nitrogen and Phosphorous.**

(i) Phosphorous

Although the treatment process within a septic tank is largely ineffective in reducing the phosphate content of the influent waste water much of the organic phosphate is converted to soluble orthophosphate. Phosphate is restricted from moving through the soil by a combination of adsorption and precipitation reactions. Phosphate can be removed from percolating septic tank effluent at practically all pHs. Phosphate can be sorbed onto aluminium and iron minerals in acid soils and onto calcium minerals in neutral or alkaline soils. Phosphate sorption by soil is usually a rapid process and is 80 to 90 % complete in two to five days (Tofflemire *et al*, 1973). Although Jones and Lee (1979) report that the pollution of groundwater by septic tank systems rarely occurs because of the soils ability to fix and restrict the movement of the phosphate, other workers have shown that under some circumstances phosphate transport from a soil treatment system can occur with subsequent contamination of groundwater (Peavy, 1978; Canter and Knox, 1985 and Henry, 1990). Ellis (1973) and Miller and Wolf (1975) reported that the sorptive capacity of a soil for phosphate can be seriously reduced over a period of time as exchange sites are filled. Based on information obtained by Viraghavan and Warnock (1976) average phosphate concentrations entering groundwater from soil absorption systems are shown in Table 2.6 (page 36).

(ii) Nitrogen

Since the treatment process within a septic tank system is largely ineffective in reducing the nitrogen content of the influent waste water, consequently the effluent discharged into the soil treatment system contains high concentrations of nitrogen mainly in the form of ammonia and to a lesser degree nitrate. Movement of ammonium ions in the soil can be retarded by adsorption, ion exchange, incorporation into the soil biomass or release into the atmosphere in the gaseous form.

Canter and Knox (1985) report that the adsorption process is probably the most efficient in removing ammonium ions from the percolating effluent. However, once the adsorption capacity of the soil is exceeded the ammonium must travel through the saturated soil to find unoccupied sites. The movement of ammonium from the soil treatment system can occur if the effluent is continually added to a saturated soil profile (Miller and Wolf, 1975: Canter and Knox, 1985 and Henry, 1990). Ammonia can be converted to nitrate in soils by the aerobic process of nitrification. Peavy (1978) reported that the rate of nitrification is dependent on the aeration of the soil. Polkowski and Boyle (1970) and Peavy (1978) found that the effectiveness of adsorption of ammonium by soil particles was limited due to its rapid conversion to nitrate. Because nitrate is a negatively charged ion, it is not attracted to negatively

Parameter	**Concentration (mg/l)**
BOD	28 to 84
COD	57 to 142
TSS	18 to 53
Total Phosphate	6 to 9
Ammonia Nitrogen	10 to 78

(After Viraghavan and Warnock, 1976)

Table 2.6. Typical values of pollutants reaching groundwater from a septic tank soil absorption system.

charged soil colloids and as such is much more mobile than the ammonium ion in both saturated and unsaturated soil and its movement to groundwater is well documented (Polkowski and Boyle , 1970; Patterson *et al*, 1971; Jones and Lee, 1979; Lewis *et al,* 1982; Canter and Knox, 1985).

- **Microorganisms**

The removal of bacteria by septic tank soil absorption systems has been well documented (Schaub and Sorber, 1977; Lewis *et al*, 1982 and Canter and Knox, 1985) Several mechanisms combine to remove bacteria from waste water as it percolates through the soil. The physical process of straining and the chemical process of adsorption are the most significant of these (Schaub and Sorber, 1977). Peavy (1978) reports that adsorption of bacteria occurs in soils with high ionic strength and neutral or slightly acidic pH. Cations such as Ca^{2+}, Mg^{2+}, Na^{+}, and H^{+} in the soil water neutralise and sometimes supersaturate the surface of the bacteria and in doing so enable them to be adsorbed to negatively charged soil particles. The clogged layer is highly efficient in trapping and holding bacterial species present in the waste water. However, if the developed mat becomes too thick or dense and restricts the hydraulic functioning of the system the effluent does not enter the soil and becomes ponded on the surface. In a review of the available literature by Hagedorn *et al* (1978) it was found that coliforms were capable of travelling between 1 meter to 830 meters in a septic tank soil absorption field with travel times ranging from 35 hours to 15 days.

2.5. Failure of septic tank systems with subsequent pollution of surface and groundwater

One of the key concerns associated with the design and usage of septic tank systems is the potential for inadvertently polluting groundwater. This concern is increased when considering systems serving multiple house units. Numerous studies have conclusively proven that septic tank failure is a major cause of groundwater pollution (Patterson *et al,* 1971; Viraghaven, 1978; Aldwell *et al*, 1988 Stewart and Reneau, 1981, Mc Coy and Hagedorn, 1979 and Olanrewaju, 1990;). Many incidences of surface water pollution have also been linked to septic tank system failures (Rahe *et al*, 1978; De Walle and Scaff, 1980, Hagedorn *et al*, 1981, Chen, 1988 and Patrick, 1988).

2.5.1 Failure of septic tanks.

Although most incidences of septic tank system failures have been attributed to soil factors some can also be traced to faulty design and improper construction of the septic tank itself (Martin, 1958; Mc Gauhey and Winneberger, 1963; and Anon, 1979). A review of the literature by Hagedorn *et al* (1981) has shown that contamination can easily occur in surface waters and on a watershed basis through the inefficient operation of septic tanks under unsuitable conditions. Almost half of the reported diseases in the US are caused by the consumption of contaminated groundwater (Keswick *et al*, 1982; Yates, 1985), with the overflow from septic tanks being responsible for 42 % of these outbreaks (Craun, 1979). Overland flow from rainfall may carry contaminants directly to a stream or lake or into an inadequately sealed well. In 1971 and 1974, 98 cases of viral hepatitis and 1200 cases of gastrointestinal infections were directly traced to malfunctioning septic tanks (Bitton and Gerba, 1984). In addition, serious nutrient contamination of surface water caused by effluent from septic tanks has been reported (De Walle and Scaff, 1980, Hoare, 1984 and Chen, 1988).

2.5.2 Failure of soil treatment systems.

Several investigators have noted a decline in water quality where septic tanks have been placed in soils inadequate for suitable soil purification (Craun, 1979, Bitton and Gerba, 1984 and Hagedorn *et al*, 1978). It has been estimated that one half of all septic tank soil absorption systems are not operating properly (Scalf, Dunlap and Kreissal, 1977). More than half of the soils in the U.S are unsuitable for septic tank systems with respect to percolation rate. Patterson *et al* (1971) and O' Hegarty (1976) report failure of soil absorption systems in the U.S of between 25 and 50 %. It is estimated that half of these failures may be attributed to the location of absorption fields in soils of low permeability, a characteristic of over 50% of Irish soils (Daly, 1987). Another major reason for failure is the location of absorption fields in areas with high water tables. These factors together can cause the ponding of effluent on the soil surface with resulting health and pollutional hazards. Twenty per cent of Irish soils are waterlogged for at least part of the year which indicates that the incidence of soil failures in Ireland may also be quite high (O' Hegarty, 1976; Daly, 1987). Soils are limited by their percolation rates or the amount of contaminant bearing load to which they are subjected. In addition, Bourma (1979) reports that although a soil may be capable of removing constituents in septic tank effluent, the adsorption and cation exchange capacity of a soil is not infinite and may be exceeded. In such conditions an equilibrium would be reached between the ions in soil and the percolating effluent and eventually the effluent moving to groundwater would remain largely unchanged in terms of its ion content.

In addition, failure can occur if the density of septic tank systems in an area is too high causing the soil to be overloaded insofar as it cannot sufficiently treat the septic tank effluent (Quan *et al*, 1974 and De Walle and Scaff, 1980). The poor microbiological quality of domestic well water in the vicinity of septic tank systems is well documented. Aldwell *et al* (1988) found that 68% of wells tested in Western Ireland were contaminated by faecal coliforms. Daly (1987) reported that in Co. Roscommon, a local authority survey showed that out of a total of 41 group water schemes sampled, 22 were contaminated with *E. coli*. A similar study in the US showed 92% of all groundwater sources tested to be contaminated by coliform bacteria (Bitton and Gerba, 1984). Septic tank effluent was believed to be the main source of contamination in both cases. Many public health workers feel that the most critical effect of malfunction in septic tank systems is the contamination of private water wells. The human health implication of such contamination is considerable. Outbreaks of typhoid fever, infectious hepatitis, gastrointestinal infections and infantile methaemoglobinaemia have all been linked to malfunctioning septic tank systems (Henry, 1990).

2.6 Modifications to the septic tank system

Since the pollution of ground and surface water by septic tank systems has been well documented (Patterson *et al*, 1971; Allen and Geldreich, 1975; Geraghty and Miller, 1978; Aldwell *et al*, 1988; Viraghaven, 1978; Mc Coy and Hagedorn, 1979; Stewart and Reneau, 1981 and Yates, 1985;), there are several concerns relating to septic tanks which should mandate some research effort. One important consideration is the development of alternative septic tank systems which will function in soils where a conventional septic tank and drainfield are not suitable. Research is needed on techniques to upgrade the performance efficiency of conventional septic tank systems.

Laurence (1973) stated that

> ' In spite of the widespread application (of the septic tank) there is a misunderstanding on the part of some sanitarians and most homeowners on the characteristics of septic tank performance. Part of this misunderstanding can be attributed to the long and somewhat colourful history

> of the septic tank which partly results from the lack of study directed to evaluating actual septic tank performance. It is apparent that septic tanks will continue to be used, therefore it is important that septic tank performance be understood and that new innovations be recommended and tested'.

Important changes are now being made with respect to the upgrading of the conventional septic tank. These changes are the result of field research, including studies and evaluation of available field data and actual observations of field installation during normal operation and after failure.

One logical approach has been to import a suitable drainfield material as a substitute for the existing soil (Rock *et al*, 1982). Soil replacement for the soil absorption system has been frequently investigated. Sands, sandy loam and soil mixtures are the most commonly used imported materials, however, bottom ash, strip-mine soil and slags have also been used (Converse *et al*, 1978). Shiao *et al* (1977) cite solid adsorbents such as fly ash, gypsum and activated alumina specifically for the removal of phosphates in septic tank effluent, while Bhargava and Sheldarkar (1992) cite activated alumina, powdered aluminium oxide, blast furnace slag, activated red mud and flyash.

Jones and Lee (1979) and Canter and Knox (1985) suggest that if the phosphate concentration in septic tank effluent becomes a problem, then it is possible to remove the phosphate concentration in the effluent by adding certain chemicals to the tank i.e. aluminium sulphate, lime or ferric chloride.

Brandes (1977) suggested modifications to a septic tank system for the removal of phosphate, where soils cannot remove the phosphate effectively, by adding alum to the septic tank. However the disadvantages of these additives is the production of a sludge. It is reported that the inorganic phosphates which are combined with aluminium, iron and calcium are retained in the sludge in insoluble compounds under aerobic conditions. (Hosomi *et al*, 1979; Hosomi *et al*, 1982). When conditions become anaerobic the iron and aluminium phosphate become resolubilised and are released from the sediment (Joh, 1983).

Many workers have investigated substituting the soil absorption system with filters packed with particular materials (Table 2.7, page 45). Sands, gravel, silt, chalk and peat have been used with varying success. Peat has been used by many workers (Rock *et al*, 1982; Brooks *et al*, 1984 and Viraghavan *et al*, 1987). Bord na Mona, the Irish peat company have devised a peat biofiltration unit for the treatment of septic tank effluent. The system consists of an effluent collecting chamber, a pump and a number of specialised biofibrous peat containing modules. The treatment of sewage within the system is achieved by a combination of physical, biological and chemical interactions between the pollutants and the peat media. Scientific examination of the media has revealed a complex and diverse ecological population ranging from large numbers of aerobic and facultatively aerobic micro-organisms to a wide variety of protozoans, rotifers and higher life forms (Henry, 1990). Rock *et al* (1982) used sphagnum peat as a drainfield material in a septic tank system and found that although COD, SS and ammonia removal was excellent, nitrate concentrations increased by 275%. Initially a removal rate of greater than 70% was obtained for phosphate but in the third year of operation, the removal rate only averaged 30%. Removal rates of greater than 99.99% were achieved for coliforms. However a significant decrease in the pH of the effluent (which fell to a pH of 5) was observed. This drop in pH can have adverse environmental effects, particularly in poorly buffered waters. In addition the effluent from the peat bed was highly coloured, which may also have implications for receiving waters.

Wakatsuki *et al* (1991) investigated a multi-soil layering system (MSL) for the treatment of septic tank effluent. The MSL unit was composed of clay loam soil mixed with 10 to 25% of metal iron, pelletized jute, gravel and zeolite. Wakatsuki *et al* (1991) propose that the metal iron in the soil is oxidised to ferrous iron. This is transferred to the zeolite layers and oxidised further to ferric ions. The iron is deposited on the zeolite particles as hydroxides which can fix phosphate. The organic matter is decomposed in the gravel and zeolite while ammonium ions are predominantly fixed in the zeolite. The zeolite also exerts a buffering capacity, buffering pH change during treatment. Wakatsuki *et al* (1991) reports excellent removal rates in the MSL unit.

It is evident that many workers in the field are developing methods to upgrade the performance of the conventional septic tank. However, problems are inherent with many of these systems. At present there is no widely

Author	**Material used**	**BOD**	**COD**	**SS**	**Indicator organisms**	**TN**	**TP**
Rock *et al* (1982)	Peat	>90%	>80%		45 to 70%		58 to 94%
Brookes *et al* (1984)	Sphagnum Peat	>90%	>80%		99%	58 to 62%	96%
Viraghavan *et al* (1987)	Peat	35 to 50%	35 to 50%	85 to 99%	95%	0 to 90%	0 to 25%
Pell & Nyberg (1990)	Sand		86%			60%	70%
Ebers & Bischofsberger (1990)	Fine grain Sand	98 to 99.2%	88 to 92.8%			90 to 91.3	5.7 to 86%
Ebers & Bischofsberger (1990)	Slightly silty Sand	86 to 99.3%	76%			39 to 68.4 %	86 to 99.3%
Fazio *et al* (1993)	Sand	>90%	>90%			>90%	
Christoulas & Andreadakis (1989)	Gravel	25 to 70%		40%	40 to 45%		
Christoulas & Andreadakis (1989)	Sand	75%			50%		
Yamaura *et al* (1986)	Loam	>90%			>90%	> 50%	>90%

Table 2.7 The percentage removal efficiencies of various media for pollutants.

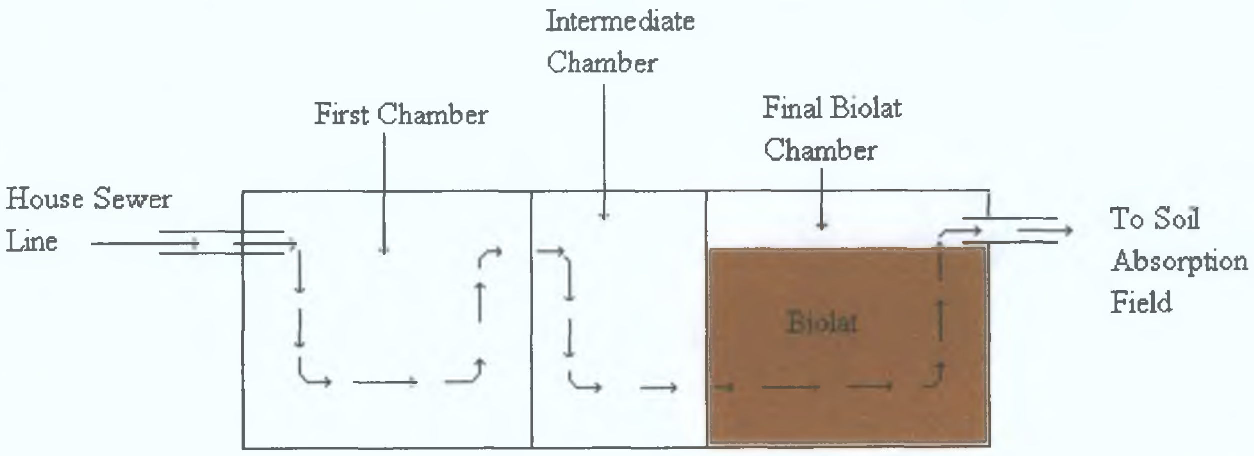

Figure 2.3 BMS Biolat Septic Tank

acceptable modification to the septic tank that would effectively remove all the pollutants present in domestic waste water to such as extent that the requirement for soil purification would be eradicated.

2.7 The BMS Biolat Septic Tank

The BMS septic tank has been developed to remove pollutants present in domestic sewage. The tank has been designed in accordance with the NSAI SR6 of 1991. However, in addition to the two chambers provided for in the SR6, the BMS tank also contains an extra chamber containing an inorganic media trade named Biolat. The effluent that is discharged from a household enters the septic tank in the normal fashion entering chambers one and two. It is then diverted through the third chamber containing the Biolat media. The Biolat is used in order to further treat the effluent before it percolates through to the subsoil. The third chamber is designed so that the effluent flows in an upward direction through the Biolat. This prevents channelling of the effluent in discrete conduits which would seriously limit the contact time between the effluent and the Biolat (Fig 2.3, page 46 and Plate 3.1, page 101).

2.7.1. Biolat

Biolat is essentially comprised of the mineral rock called laterite. Laterite has been defined as 'a hydrated mixture of oxides of aluminium, iron and titanium, of extremely varied composition, and showing every gradation from ferruginous laterite almost free from alumina to aluminous laterite almost free from iron' (Fermor, 1912). Laterites are the products of intensive weathering called laterisation under tropical and subtropical climatic conditions. Laterisation involves the leaching out of silica and alkali and the accumulation of hydrated iron and aluminium oxides (sequioxides). Alexander and Cady (1962) state that

> 'laterite is a highly weathered material rich in secondary oxides of iron, aluminium or both. It is nearly void of bases and primary silicates but it may contain large amounts of quartz and kaolinites. It is either hard or being capable of hardening on exposure to wetting and drying'.

Many authors have revealed, through petrographic studies, that laterites often possess a porous granular structure consisting of iron- impregnated clayey material in minute (1-10 micron) spherical aggregations (Humbert, 1948; Terzaghi, 1985; Alexander and Cady, 1962 and Iyer and Williams, 1990).

The Irish laterites occur between a particular horizon, the Interbasaltic horizon among the Tertiary lava flows of County Antrim. The occurrence of a zone of an apparently stratified rock in the midst of the basaltic series of Northern Ireland is fully apparent in the famous Giant's Causeway in County Antrim. This zone can be traced over a wide area from west of the Giant's causeway to Glenarm and Island Magee. The bright red colouring of the laterite band halfway up these cliffs is in stark contrast to the brown and black joint faces of the basaltic series. These seams of red or ochreous clay were mainly developed during a particular epoch where the volcanic activity that gave rise to the basalts of Northern Ireland died down for a time and a broad surface of lavas became exposed to weathering (Cole, 1912). The period in which conditions favourable for the formation of laterite existed is known as the Interbasaltic period. At an early stage in this period there was a temporary recrudescence of volcanic activity marked by the extrusion of highly acidic lavas, mainly rhyolites, accompanied, probably by the deposition of volcanic ash. Conditions favourable for the formation of laterite then existed until almost the end of the Interbasaltic period. As a consequence of the deposition of the sediments derived from rhyolite on the plateau formed by the lower basalts, the Irish laterites vary considerably in composition. Some are formed solely from basalt lava; others from rhyolitic sediments (and perhaps in some localities from uneroded rhyolite); others again appear to be formed in part from rhyolitic debris but were subsequently modified by the addition of material derived in solution from the underlying basalts or basaltic lithomarge. Field work supported by chemical analysis indicated that the Irish laterites were formed by the alteration of the parent rock in two distinct stages (Eyles, 1952). The two stages are as follows

(a) Kaolinisation. i.e. the alteration of the parent material to lithomarge.

(b) Lateritisation. i.e. the formation of laterite from lithomarge.

Lithomarge is quite a distinct rock type and can exist independently of laterite. The formation of lithomarge is brought about by the breaking up of complex silicate minerals such as feldspar, pyroxene and olivine into their constituent oxides. When the process follows its normal course some of these oxides notably magnesia, lime and the alkali earth metals, are more or less completely eliminated in solution. The silica and alumina thus freed combine with water to form kaolinite or halloysite. There is also, apparently, a not inconsiderable loss of silica by elimination, during kaolinisation, the ratio of silica to alumina being appreciably reduced by the time kaolinisation is complete. The oxides of iron and titanium remain to form an integral part of the lithomarge, but ferrous iron is largely oxidised to the ferric state. The resultant rock consists essentially of hydrated silicate of alumina plus an admixture of oxides of iron and titanium in amounts dependent, at any rate in the case of iron, on the composition of the parent rock (Eyles, 1952).

The alteration of lithomarge to laterite is essentially a desilication process, formed by the decomposition of the hydrated silicate of alumina and accompanied by the elimination in solution of the silica thus freed. The residual alumina takes up as much additional water as is necessary to form the tri-hydrate of alumina, gibbsite ($Al_2O_3.3H_2O$). Normally if this process continues to completion, a rock consisting essentially of gibbsite, together with the oxides of iron and titanium is formed. Concurrent with the chemical changes, segregative and concretionary processes operate that tend to effect a separation of the aluminous from the ferruginous oxide, so that ultimately, if the lateritisation process continues long enough, two discrete rock types result. The aluminous oxide forms a layer or bed of predominantly aluminous laterite, or bauxite, and the iron oxide tends to move upwards towards the surface where it forms a layer of highly ferruginous laterite, sometimes termed a cuirasse de fer, overlying the bauxite. The process of lateritisation is a slow one in terms of geological time and, in Ireland, it seems generally not to have continued sufficiently long to have effected either complete desilication of the previously formed lithomarge or complete separation of the aluminous from the ferruginous laterite. Rocks intermediate in composition between lithomarge and laterite i.e. lateritic lithomarges , or highly ferruginous or siliceous laterites are thus the prevailing types. Broadly speaking, the laterites of Northern Ireland can be divided into three groups

(i) Highly ferruginous red bauxites, in which iron oxide is usually present to the extent of 20 to 30%, but silica seldom exceeds 10% and may be less than 5%. These have been formed from basalt.

(ii) Siliceous grey bauxites, in which the iron oxide seldom reaches 10% and is often less than 5%, but silica occurs in amounts often exceeding 20% and often reaching 40%. These have been formed from parent rocks consisting largely or entirely of rhyolitic debris (i.e. highly acidic lavas).

(iii) Bauxites of mixed origin, and variable in colour. These are intermediate in composition between (i) and (ii), and derive their substance in part from rhyolitic material and in part from the underlying basalt.

Tables 2.8 and 2.9 (pages 67 and 68) show the laterisation process in both basalt and rhyolitic debris and the difference in compounds present in the resulting laterite. The laterite used in the BMS Biolat septic tank is found in the Skerry bauxite mine, near Newtown Cromellin, Co. Antrim and is more correctly called a laterised basaltic lithomarge and has the typical composition shown in Table 2.11 (page 70).

The properties of laterites are influenced by climate, geology and the degree of weathering or lateritisation (Gidigasu, 1972 and 1976). It has been found that the geotechnical properties of these soils in different tropical climates are also different (Gidigasu, 1976), and that lateritic soils formed on the same parent rock in the same tropical country, but under different climatic conditions, have different geotechnical properties (Gidigasu, 1972 and Lin Zongyuan, 1986). In addition, various horizons are often found in lateritic soil profiles (Terzaghi, 1985; Moh and Mazhar, 1969; Gidigasu and Yeboa, 1972). This is true of the laterite used in the BMS septic tank where a layer of this laterite is sandwiched between other laterite types.

Iyer and Williams (1990) stress the importance of carrying out mineralogical analysis of laterites, since the mineral constituent affects the properties of the laterites. The presence of these minerals depends on the mineralogical composition of the parent rock and on the climatic conditions prevalent during the laterisation process. Determination of the exact mineralogical composition of 'Biolat' could not be undertaken in this study, rather the compounds present in the 'Biolat' were determined (Table 2.11, page

70). Field work undertaken by Bannister (1946) on laterite extracted from the Skerry Bauxite mine at Newtown Crommelin (where 'Biolat' is extracted) has shown it to contain elements in very similar quantities as are present in 'Biolat' (Tables 2.11 and 2.12, page 70). This field work shall provide information as to the mineralogical make-up of 'Biolat'.

In general, laterites are broadly composed of three main types of soil colloids . (Bannister,1946; Newill, 1961; Wallace, 1973; Gidigasu, 1976; and Iyer and Williams, 1990). These are

(a) Silicate clays

(b) Hydrous oxides of iron and aluminum.

(c) Allophane.

(a) Silicate clays

Most silicate clays are aluminosilicates, that is, there are both aluminium and silicon components of the clay structure. An interlocking plane of a series of silica tetrahedra tied together by shared oxygen atoms gives a sheetlike tetrahedral layer. Similarly large numbers of alumina octrahedra bound to each other by shared oxygen atoms in an octrahedral layer are arranged in a plane. These two basic layers in different stacking arrangements and combinations provide the fundamental structural units of silicate clays. The layers are bound to each other within the clay crystals by shared oxygen atoms. Classification of the aluminosilicates is based on the arrangement of the silica layer, $SiO_4{}^{4-}$ and the aluminium layer $Al_4(OH)_6$. On the basis of the number and arrangement of these layers the minerals can be classified into three major groups. A summary of each of these groups is provided in Table 2.10 (page 69), using the main member of each group for illustrative purposes.

The most important properties of the silicate clays, for the purpose of this study, are those of surface area and charge associated with the clay surfaces. All clay particles have a large amount of external surfaces because of their fineness of division. In some clays there are extensive internal surfaces as well. This internal surface occurs between the plate-like crystals that make up each particle. Thus, the tremendous surface area that characterises the silicate minerals is accounted for not only by the fineness of division but also by the plate-like structure of the fine particles.

The minute silicate clay colloid particles, referred to as micelles, ordinarily carry net negative charges and consequently thousands of positively charged cations are attracted to each colloidal crystal. This gives rise to what is known as an ionic double layer. The colloidal particle which constitutes the inner ionic layer being essentially a huge anion, the surface of which is highly negative in charge. The outer ionic layer is made up of a swarm of rather loosely held cations which surround and in some cases penetrate the particle. Thus a clay particle is accompanied by an enormous amount of adsorbed cations. Although all cations may be adsorbed by the clay micelle, certain ones are especially prominent under natural conditions. For humid region colloids these are in the order of H^+, Al^{3+} and Ca^{2+} first, Mg^{2+} second and K^+ and Na^+ third. For well drained arid and semi-arid regions the order of exchangeable ions is usually Ca^{2+} and Mg^{2+} first, K^+ and Na^+ next and H^+ last. When drainage is impeded and alkaline salts accumulate adsorbed Na^+ ions are likely to become prominent and may equal or even exceed those of adsorbed calcium.

There are at least two sources of negative charges associated with silicate clay particles. The first involves unsatisfied valences at the broken edges of the silica and alumina sheets. Also the flat external surfaces of the 1:1 type minerals, such as kaolinite, have some exposed oxygen and hydroxyl groups which act as negatively charged sites. At high pHs especially the hydrogen of the hydroxyls dissociates slightly and the colloidal surface is left with a negative charge carried by the oxygen. The loosely held hydrogen is readily exchangeable. The presence of thousands of such groups gives clay particles like kaolinite a definite electronegativity. Consequently they are surrounded by cations that may have replaced such hydrogen. This phenomenon apparently accounts for most of the adsorbing capacity of a 1:1 type colloidal clay. It is also of some significance in the 2:1 type clays.

Isomorphic substitution of one ion for another in a crystal lattice may result in a second source of negative charge in a clay crystal. It occurs when ions undergoing exchange reactions do not have an equal charge to those in the clay mineral. This results in an imbalance giving rise most commonly to a net electronegativity. The 2:1 type clays exhibit isomorphic substitution to a marked degree. It is not common in the 1:1 type clays.

It should be noted that some clay minerals exhibit both positive and negative charges. This makes possible anion exchange between surface hydroxyl units and anions. These positive charges arise from the protonation or adding of H^+ ions to the hydroxyl groups on the edges of the mineral crystals and the exchange of the hydroxyl groups for other ions such as phosphate. The reactions are most significant for phosphate since these ions tend to be quite tightly adsorbed (Brady, 1974).

- Silicate clays in laterite

Bannister (1946) found that the laterite from the Skerry mine comprised of approximately 50 % of a silicate clay named kaolin. Kaolin-type silicate minerals are built from a common structural unit, the kaolin layer, of ideal composition $Al_2O_3.2SiO_2.2H_2O$ or $Al2(Si_2O_5)(OH_4)$. Different members of the group can be distinguished, which correspond to different combinations of the stacking of the aluminium and silicate layers. These members are kaolinite, halloysite, dicktite and anauxite/ nacrite (Read, 1947). Anauxite and dicktite are rare in nature. Kaolinite is the clay mineral that characterises kaolins and therefore the greatest amount of information is available for this mineral. The characteristics of kaolinite can be extended to the other members of the kaolin group (Lefond, 1983).

All members of the kaolin group have essentially the same composition. The tetrahedral silicate and octahedral aluminium sheets in a layer of kaolin crystal are held tightly together by strong bonding. The structure of all kaolin type minerals is therefore somewhat fixed and no expansion between the layers ordinarily occurs to allow the entry of cations and water into the structure. The effective surface of the kaolin group is thus restricted to it's outer faces or external surfaces area. The surface of kaolin as with all silicate clays hold small but significant quantities of cations such as calcium, magnesium, potassium, hydrogen, sodium, ammonium and aluminium. These cations are exchangeable with other cations in solution however, due to the limited surface area, the kaolin type minerals have a low cation exchange capacity of around 8 meq/100g ranging from 3- 15 meq/ 100g (Brady, 1974)). The surface charge of kaolin as well as other associated properties is determined by the chemical composition and internal arrangement of atoms in the colloidal crystal. As stated previously, kaolin minerals are, in general, highly electronegative affording them the ability to adsorb cations. Brady (1974) cites many investigators to have shown that kaolin also exhibits positive charges making possible the exchange of anions in particular; phosphate.

The specific kaolin type mineral identified in laterite by Bannister (1946) was halloysite or more specifically meta-halloysite. Halloysite occurs in two forms. These are halloysite $(OH)_8Si_4\ AL_4O_{10}.4H_2O$ and meta-halloysite $(OH)_8Si_4\ AL_4O_{10}$. Halloysite is so similar to kaolinite that the two cannot be distinguished without very careful mineralogical work (Brindler *et al*, 1948). The difference in hydration states between halloysite and meta-halloysite causes a difference in the basal spacing between the layers of the different minerals. The basal spacing of halloysite is approximately 10 angstrom units. This is converted irreversibly to 7 angstrom units upon dehydration of the mineral leaving the basal spacing of meta-halloysite essentially the same as for kaolinite (Lefond, 1983). Bannister (1946) suggested that this form of meta-halloysite was present in laterite due to the dehydration of halloysite by the heat engendered by the emplacement of the Upper Basalt lavas. Brindler *et al* (1948) states that partial transformation of halloysite to meta-halloysite has been achieved by the application of pressure alone, and probably under specific geological conditions, pressure alone would be sufficient to effect the transformation. The rocks on the Interbasaltic horizon were originally buried under several hundred feet of Upper Basalt lavas, so that contemporary geological conditions certainly favoured the development of meta-halloysite at the expense of halloysite.

(b) Hydrous oxides of iron and aluminium

In general the hydrous oxides of iron and aluminium are formed primarily in temperate regions where they are intermixed with clay minerals. As their name suggests, hydrous oxides are oxides containing associated water molecules with general formulas $Fe_2O_3.x\ H_20$ and $Al_2O_3.xH_2O$. The x indicates that the quantity of associated water of hydration is different for different minerals. For simplicity, the hydrous oxides are often shown as actual iron and aluminium hydroxides, $Al(OH)_3$ and $Fe(OH)_3$. In soils, gibbsite ($Al_2O_3.3H_2O$) is probably the most dominant aluminium oxide; geothite ($Fe_2O_3.\ H_20$) and limonite ($Fe_2O_3.x\ H_20$) are the most prominent iron hydrous oxides.. Although relatively less is known about the hydrous oxide clays, they seem to have at least some properties in common with the silicates. For example, at least some of them are thought to have a definite crystalline structure. The small particles may carry negative charges and thus serve as a central micelle around which a swarm of cations are attracted. The same general constitution described for the silicates may be visualised. Because of the much smaller number of negative charges per micelle, however, cation adsorption is even lower than for kaolinite (approx 4 meq /100g). In very acid soils some iron and aluminium oxides are positively charged due to the attachment of the H^+ to the OH^- groups on the surface of minerals (Brady, 1974).

- Hydrous oxides of iron and aluminium in laterites

Many workers have found that hydrous oxides of iron and aluminium are present in laterites. (Bannister, 1946; Newill, 1961; Townsend, 1971; Wallace, 1973; Gidigasu, 1976 and Iyer and Williams, 1990). The specific iron oxides noted in laterite by Bannister (1946) were haematite (αFe_2O_3) and geothite ($\alpha Fe_2O_3 . H_2O$). Gibbsite ($\gamma Al_2O_3 . 3H_2O$) was the aluminium oxide present.

Haematite is obtained on heating the iron hydrous oxides to 200 ^oC. It has a structure where the oxide ions form a close packed array and the Fe^{3+} ions are distributed among the octahedral interstices (Cotton and Wilkinson, 1988). The Fe^{3+} ions have been found to enter into compounds with some ions e.g. phosphate, and so can adsorb very large quantities of this ion (Parfitt *et a,l* 1975). Geothite is the hydrated form of haematite. Geothite has also been found to adsorb phosphate. Fixation of phosphate on geothite occurs over a relatively wide pH (Sanchez and Uehara, 1980).

Gibbsite is sometimes regarded as a defect spinel structure, that is having the structure of spinel, with a deficit of cations (Laidler and Miller, 1995 and Cotton and Wilkinson 1988). The spinel structure is of variable composition with the general formula AB_2O_4 which form octahedral crystals. A may be magnesium, zinc, manganese, iron or nickel whereas B may be aluminium, iron or chromium. The corrundums (Al_2O_3) which are the dehydrated form of gibbsite are formed in this system. These have a high aluminium oxide content that form hexagonal crystals. The phosphate ion reacts with gibbsite producing hydroxyphosphates.

(c) Allophane

Allophane is an amorphous mineral with somewhat poorly defined combinations of silica and aluminium sesquioxides. Having a composition approximating $Al_2O_3.2SiO_2.H_2O$, this material is found as a constituent in many soils. It is most prevalent in soils developed from volcanic ash. The presence of allophane in soils is important because it has a high cation exchange capacity. This capacity is pH dependent. Allophane also has a considerable anion exchange capacity.

Allophane has also been documented as being common in laterites (Iyer and Williams, 1990) however it has not been reported by Bannister (1946) in the laterites from the Skerry mines.

A concentration of titanium dioxide in laterite is a well recognised feature of these rocks wherever they are found (Bannister, 1946). Investigations into the mineralogical composition on laterite from the Skerry mine by the author has shown that titanium dioxide was present (Table 2.11, page 70). Bannister (1946) noted the possibility that titanium may be present with aluminium as the mineral ilmenite, however there is a lack of evidence to support this theory. Ilmenite may alter to anatase under lateritic conditions. Eyles (1952) states that anatase appears to be the normal form in which titanium occurs in the majority of laterites. He states that the occurrence of ilmenite in laterites may be regarded as exceptional and its presence probably accounted for as residual from the parent rock.

2.7.2 The use of Biolat in effluent treatment

Due to the mineralogical make up and structure of Biolat it has the capability for the removal of materials from domestic sewage by a number of means. From the perspective of this study, the most important mechanisms are

(a) Adsorption.

(b) Ion exchange.

(a) Adsorption

Adsorption may generally be described as the process whereby a molecule from a gas or liquid phase is deposited onto the surface of a support material. There are two main types of adsorption phenomena i.e. physical adsorption (physisorption) and chemical adsorption (chemisorption).

In the case of chemisorption molecules are tightly bound to the support material by covalent bonds and as a direct result of this, the maximum coverage of the surface attainable, is a monolayer. In physisorption, the force which holds molecules on the surface of a support are much weaker Van der Waals forces and therefore multiple layers of adsorbed molecules may be formed. This gives rise to a condensed phase on the surface of a solid support.

Studies of adsorption of gas phase molecules onto solid supports have been widely studied and there are numerous examples of adsorption isotherms can be utilised to explain this behaviour (Barrow, 1988). Adsorption from solution is however a much more complicated phenomenon and has not been treated in as rigorous a theoretical manner. One of the most commonly used treatments of this situation is an empirical adsorption isotherm called the Freundlich isotherm (Barrow, 1988). The Freundlich equation is in the form

$$y = kc^{1/n} \quad \text{or} \; \log y = \log k + 1/n \log c$$

where y = weight of solute adsorbed per gram of adsorbent

c = concentration of solute in solution

k and n are empirical constants.

This equation does not correspond to saturation of the surface. The amount adsorbed keeps increasing as c increases. If the above equation holds for a system, a plot of log y against log c will give a straight line of slope $1/n$ and intercept log k.

(b) Cation/ Anion exchange

Ion exchange is a process whereby counter ions which are associated with a support structure may be reversibly exchanged with other ions of the same charge without altering the matrix. This electrostatic process enables the ionic composition of the liquid to be treated or modified without changing the total number of ions in the solution before the exchange. The cation or anion exchange capacity of a given colloidal micelle is determined by the relative amounts of different colloids and by the ion exchange of each of these colloids. The site of positive or negative charges on a soil colloid are the seats of exchange between two cations or anions. This is because the positive or negative sites adsorb ions of opposite charge. These adsorbed ions can therefore be exchanged with other ions of similar charge. It is for this reason the adsorption of ions must be a precursor to the exchange of ions. Although anion exchange does occur in soil colloids, cation exchange is more prevalent in soils with a net electronegative charge such as the silicate clays and hydrous oxides of iron and aluminium. For this reason attention will be focused mainly on cation exchange.

Several factors operate to expedite the exchange of ions on the colloidal micelle (Brady, 1974). First, there is the percentage saturation of the exchange complex with a particular ion. For example if the percentage calcium saturation of a colloid (with respect to the total cation saturation) is high then the displacement of this ion and exchange for other ions is relatively rapid and easy. If the percentage calcium saturation is low then the displacement of this ion and therefore it's exchange is low. A second factor influencing the exchange of an ion is the complementary ions held on the colloids. For example the strength of adsorption of different cations is in the order

$Al^{3+} > Ca^{2+} > Mg^{2+} > K^{+} = NH_4^{+} > Na^{+}$

Consequently a nutrient cation such as K^{+} is less tightly held on the colloidal micelle than Al^{3+}. The loosely held K^{+} ions are more readily exchanged than the more tightly bound Al^{3+}. A third factor is the tenacity with which several types of colloidal micelles hold specific ions and the ease with which they exchange the ions. This is known as charge density. Members of the kaolin group, for example have a low charge density and so hold cations less tightly than a colloid like smectite which has a high charge density. The cation exchange capacity of a soil is also influenced by pH. At very low pH values the cation exchange capacity is generally very low. Under these conditions only a small proportion of the pH dependent charges of organic colloids, allophane and 1:1 type silicate minerals hold exchangeable ions. As the pH is increased the negative charges on 1:1 type silicate clays (such as kaolin), allophane and iron and aluminium oxides increases, thereby increasing the cation exchange capacity of the colloid.

Kaolin is a 1:1 type silicate mineral and therefore the layers in the colloidal crystals are somewhat fixed and expansion does not normally occur. For this reason the entry of ions to the interlayer spaces is somewhat restricted. West (1984) reports however that kaolin and titanium dioxide (found to be present in Biolat) are capable of intercalation. Intercalation is the incorporation of guest molecules or ions into the structure of a material. Intercalation requires that there is a certain structural openness in the structure of a material which permits foreign atoms and ions to diffuse in and out of the structure. The host crystal posses a layer or lamellar structure and the layers are pushed apart as the foreign atoms or ions penetrate the interlayer space. The layers move back together if the atoms or ions subsequently move out of the structure. Although the layers in kaolin are somewhat fixed, the basal spacing between the layer of meta-halloysite is approximately 7 angstrom units and therefore this would allow the entry of some ions into its structure. The advantage of intercalation is that it allows an increase in the number of active sites in a mineral crystal by virtue of allowing processes to occur in interlayer spaces in addition to those which occur at the edge of the crystallites.

Smith *et al* (1980) has cited laterites as being capable of removing phosphate. However, no mechanism of removal or adsorption capacity data was provided. Laterite has already been used for the production of coagulants for the treatment of waste water in Northern Ireland although this work is hitherto unpublished. The laterite is activated by adding concentrated sulphuric acid. This serves to release the aluminium, iron, silica and titanium which provide the basis for the coagulant, known as FAS. It is then added to waste water where it serves to coagulate and flocculate the solids present. Previous unpublished work reputes that the coagulant is capable of removal of 75% of nitrates, 95% of phosphates and >90% of SS in domestic sewage. The coagulant has been successfully used in Northern Ireland for over ten years for the treatment of septic tank effluent prior to discharge to lake catchments.

Compound	**Lower Basalt**	**Early Kaolinisation**	**Lithomarge**	**Laterised Lithomarge**	**True Laterite**	**Ferruginous Bauxite**
SiO_2	45.80	35.20	35.00	23.30	6.90	0.80
Al_2O_3	16.90	23.20	27.00	32.00	39.80	44.10
Fe_2O_3	3.70	23.20	27.60	24.60	26.70	27.10
FeO	5.90	2.30	1.30	0.70	n.d.	n.d.
TiO_2	2.80	2.00	2.70	2.90	3.60	3.50
MgO	6.30	5.50	0.90	0.38	*	n.a.
CaO	7.90	1.10	0.94	tr.	0.08	n.a.
Na_2O	2.00	0.50	0.07	tr.	n.d.	n.a.
K_2O	0.30	0.20	0.20	0.20	n.d.	n.a.
H_2O +105°C	3.70	12.60	11.00	11.00	21.40	24.10
H_2O -105°C	4.20	8.20	5.80	5.70	n.a.	n.a.

Table 2.8 Sequence of formation of laterite from basalt (after Eyles, 1952)
Note; All values are expressed as percentages

Legend; n.d. = not detected n.a. = not available tr. = trace amounts detected

Compound	Rhyolite	Lithomarge	Slightly laterised Lithomarge	Grey laterised Lithomarge	Grey Bauxite	Ferruginous Bauxite
SiO_2	75.80	49.70	35.60	32.30	24.90	22.80
Al_2O_3	12.50	33.90	37.30	39.50	32.70	29.80
Fe_2O_3	1.50	1.40	n.a.	n.a.	16.30	25.70
FeO	0.40	0.70	n.a.	4.10	0.60	0.90
TiO_2	tr.	0.90	13.40	5.50	2.40	4.00
MgO	< 0.10	0.20	n.d.	n.a.	tr.	0.40
Na_2O	2.30	tr.	n.d.	n.a.	0.04	tr.
H_2O +105°C	1.30	13.10	13.70	17.40	18.00	8.00
H_2O -105°C	0.80	n.a	n.a.	n.a.	4.70	8.60

Table 2.9 Sequence of formation of laterite from rhyolite (after Eyles, 1952)
Note; All values are expressed as percentages

Legend; n.d. = not detected n.a. = not available tr. = trace amounts detected

	1:1 Type Clay	**2:1 Type Clay (Expanding)**	**2:1 Type Clay (Non Expanding)**
	kaolinite	montmorillonite	illite
Main Stacking Arrangment	One silica layer alternating with one alumina layer.	An alumina layer sandwiched between two silica layers.	As for 2:1 Expanding except k ions serve to bind the layers together.
Shape	Hexagonal crystal.	Irregular flakes.	Irregular flakes.
Size (ums)	0.10- 5.00	0.01- 1.00	0.10- 2.00
Specific Surface (m^2/g)	5- 20	700- 800	100- 120
CEC (meq/100g)	3- 15	80- 100	3- 15

Table 2.10 Classification and characteristics of the three main silicate clay groups (Brady, 1974)

Compound	Typical Composition
SiO_2	25.3%
TiO_2	2.9%
Al_2O_3	30.2%
Fe_2O_3	23.2%
FeO	0.5%
H_2O +105°C	17.5%

Table 2.11. Typical composition of Biolat.
(Analysis performed by OMAC laboratories)

Compound	Typical Composition
SiO_2	23.2%
TiO_2	2.9%
Al_2O_3	32.0%
Fe_2O_3	24.6%
FeO	0.7%
H_2O +105°C	15.9%.

Table 2.12. Typical composition of laterite investigated by Bannister (1946).

CHAPTER THREE

METHODS & MATERIALS

3.1 Introduction.

The basis for using laterite as a medium for the removal of pollutants in domestic waste water arose from early unpublished work carried out in Northern Ireland by Molloy and Forde. These workers had investigated the use of laterite for the tertiary treatment of effluents prior to their release to waterways and found that some laterites had promising phosphate removal capabilities. These early workers believed that the phosphate removal capabilities of certain laterites would be useful in the treatment of domestic waste water since the eutrophication of waterways in Northern Ireland with phosphate had become a serious environmental problem. To this end, a waste water treatment plant design company, called Butler Manufacturing Services (BMS) from Co. Longford, Ireland, designed a three chambered septic tank which incorporated the laterite into the treatment unit (Plate 3.1, page 101). The company obtained the rights to the particular laterite mines of interest and tradenamed the laterite "Biolat". The septic tank which incorporated the Biolat media was tradenamed the BMS Biolat septic tank. The BMS Biolat septic tank is a three chambered septic tank designed in accordance with the NSAI (National Standards Authority of Ireland) SR6 of 1991, with the addition of an extra chamber which contains the Biolat media. The unit was designed to remove pollutants, and in particular phosphate, from domestic sewage. The functioning of the BMS Biolat septic tank is described in Section 2.7 (page 47). The usefulness of the unit for the removal of pollutants in domestic sewage required investigation in-situ and therefore, a prototype BMS Biolat septic tank was installed at a domestic dwelling house in February, 1993. The prototype BMS Biolat septic tank served as the sole method of waste water treatment for the waste arising from the household which was comprised of four people. In March, 1993, the author, funded by BMS, began sampling and analysis of the effluent to and from the BMS Biolat septic tank for a range of problematic pollutants normally present in domestic waste water (Table 3.1, page 78). Following repeated sampling and analysis of the effluents, it became apparent that the BMS Biolat unit was much more successful in the removal of phosphates from domestic sewage than was usual in a conventional septic tank. In addition, a range of other pollutants, namely ammonium, nitrate and the faecal coliform, *E. coli* appeared to be removed to a greater extent than was usual in a conventional septic tank. Following this, it was decided that pilot scale septic BMS Biolat septic tanks would also be set up to investigate the removal of pollutants in domestic sewage. Using pilot scale septic tanks, as opposed to the prototype Biolat septic tanks, it was possible to determine more accurately the removal of pollutants at each stage within the BMS Biolat septic tanks and assess more closely the processes which were occurring. The retention times within the tank could also be more easily controlled.

Four pilot scale BMS Biolat septic tanks were used for the trials. The pilot scale septic tanks were scaled down versions of the prototype Biolat septic tank and had a capacity of 6.1 litres (plate 3.2, page 101). In order to achieve the three day hydraulic retention time (HRT) for the domestic sewage within the tank, as specified in the NSAI SR6 of 1991, 2.03 litres of the sewage was pumped through the tanks daily. Samples were taken daily of the influent and final effluent in each of the tanks, together with samples from the intermediate chambers. The samples from the intermediate chambers were taken so as to determine the removal of the various parameters under investigation at each stage in the septic tank. The samples were tested for each of the parameters listed in Table 3.1 (page 78). From the results generated in the pilot scale septic tanks a number of observations were made which categorised the various parameters under investigation into two main groups;

1. Those parameters which were being removed predominantly in chambers one and two of the septic tanks. These included BOD, COD, SS and the faecal coliform, *Escherishia coli.*
2. Those parameters which were being removed to a significant extent in the Biolat section of the septic tanks. These included phosphate, ammonia and nitrate and to a lesser degree, *E. coli.*

Separate columns were therefore constructed which housed the Biolat media alone in order to investigate its efficiency for the removal of phosphate, ammonia, nitrate and *E.coli.* The Biolat columns were designed to be upward flow columns and held 600g of Biolat. Various concentrations of the individual parameters under investigation were prepared and passed through the Biolat by means of a peristaltic pump. Samples were taken of the effluent which had passed through the Biolat and these were subsequently analysed for each of the parameters of interest. Using the known influent concentrations and the determined effluent concentrations it was possible to assess the removal efficiency of the Biolat for each of the parameters under investigation. However, as results emerged it appeared that Biolat was capable of removing phosphate and ammonium only and the removal of nitrate and *E. coli* was attributable to other physical and biological processes occurring within the third chamber of the tanks. Hence adsorption tests were performed for ammonium and phosphate only.

The adsorptive capacity of Biolat for ammonium and phosphate was determined by passing solutions of same through the Biolat columns and observing the removal of the ions in the Biolat until the Biolat became saturated i.e. it was unable to remove any more phosphate or ammonium ions from solution.

The adsorption tests were performed under varying conditions i.e. of concentration, retention time, pH and grain size, to assess the influence, if any, of these on the adsorption process. Experiments were also performed on the saturated Biolat in order to assess the ease of desorption of phosphate and ammonium from Biolat. These desorption tests were undertaken primarily to gain further insight into the mechanism of phosphate and ammonium removal by Biolat and to a lesser extent to assess the possibility of regeneration and subsequent reuse of the Biolat (i.e. Biolat has to be removed from the BMS Biolat septic tank once it has exceeded its useful lifespan so that it may be replaced with new Biolat. The spent Biolat may be capable of being recycled if adsorbed ammonium or phosphate can be easily removed).

Finally, numerous experiments were performed in an attempt to investigate the exact mechanism of removal of phosphate and ammonium by Biolat and to ascertain if the adsorption process could be fitted to an adsorption isotherm.

3.2 Analysis of prototype BMS septic tank

Domestic sewage effluent discharged from a household comprised of four people entered the BMS septic tank at a rate of approximately 0.85 m^3 per day. The effluent entered the first and then the second chamber of the tank after which it flowed upwardly into a final media section containing the Biolat. The effluent then left the tank and was discharged to the soil via a percolation field.

A flow recorder was installed on the outlet pipe from the dwelling house to assess the retention time of the effluent in the septic tank, given that the tank had a capacity of approximately 6.1 m^3. A HRT of approximately one week dictated that the efficiency of removal of pollutants present in the influent could not be assessed in the effluent until one week later. Sampling of the domestic effluent occurred in the first chamber containing the raw sewage and from the pipe leaving the third chamber containing the treated effluent. The influent and effluent were analysed for a range of parameters listed in Table 3.1(page 78). The methods of analysis are also listed in Table 3.1.

The initial sampling period was bi-weekly for a period of three months.

Schematic of Experimental Procedure.

1. Removal of the pollutants present in domestic sewage by the prototype BMS septic tank.

↓

2. Removal of the pollutants present in domestic sewage by the pilot scale BMS septic tanks.

↙ ↘

3. Pollutants removed predominantly in chambers 1 and 2 | Pollutants removed predominantly in the Biolat chamber.

↙ ↘

4. Pollutants removed by Biolat. | Pollutants removed by other processes occurring in domestic sewage.

↓

5. Factors controlling the removal of pollutants by Biolat.

↙ ↓ ↓ ↘

Retention time | Concentration | pH | Grain size

6. Desorption of pollutants from Biolat.

7. Investigation into the mechanism of phosphate and ammonium removal by Biolat.

Sampling was then carried out periodically over a period of four years. The removal of pollutants in the BMS prototype septic tank was determined by comparing the influent and effluent concentrations for each of the parameters of interest.

3.3 Pilot Scale Biolat Septic Tanks

Four pilot septic tanks were constructed from fibreglass. By reducing all of the dimensions of the BMS Biolat unit by one tenth, the overall volume of the tanks was reduced by one thousandth, hence the pilot scale septic tanks held 6.1 litres. The pilot scale tanks were compartmentalised in accordance with the Biolat septic tank dimensions. The third media chamber contained 3 KGs of Biolat, (i.e. 1/1000th of that used in the normal Biolat unit), through which the effluent flowed in an upward direction (Fig. 3.2, page 80).

In order to achieve the three day HRT, as specified by the SR6 (1991) 2.03 litres of sewage effluent were fed through each tank daily. The effluent was fed from a holding container, which was continually stirred (to prevent solids settlement and so that the tanks would receive a homogenous effluent) via a peristaltic pump which was primed to deliver 1.45 mls/min (2.03 l/day). When the effluent had passed through the septic tanks it was collected in an acid washed plastic container (or for microbiological analysis, a sterile container) which was placed at the outlet pipe from the third chamber of the tanks. The sewage effluent was obtained from the inlet of a sewage treatment

Parameter	**Method of determination**
BOD	D.O electrode
COD	Digestion/ Spectrophotometric
Suspended solids	Gravimetric.
Ammonia Nitrogen	Phenol Nitroprusside.*
Nitrate Nitrogen	Chromotrophic Acid.
Phosphorous (PO4- P)	Vanadomolybdophosphoric acid.
pH	Electrometric.
E.coli.	Membrane filtration.

Table 3.1. Methods of analysis of the various pollutants in domestic sewage.

All methods were obtained from *Standard Methods* (APHA, 1992).

*Phenol Nitroprusside method according to Scheiner (1976).

Isolation and Identification of *E. coli* from domestic sewage.

Take samples & prepare serial dilutions in 1/4 strength Ringers solution.

↓

Perform membrane filtration through a 0.47 µm membrane filter using 100 ml aliquots.

↓

Place filter on adsorbent pad saturated with M. Endo broth.

↓

Incubate at 44.5 ^{o} C for 24 hrs.

↓

Count all typical colonies and record as cfus of E. coli /100 ml

↓

Subculture typical colony into 10 mls of lactose bile broth (e.g. Mac Conkey Purple).

↓

Incubate at 44.5 ^{o} C for 24 hours.

↓

Growth with gas and acid production in positive tubes.

↓

Subculture positive tubes onto

(a) Differential media (Eosin Methylene Blue) or (b) Selective media (Mac Conkey agar)

↓

Incubate at 44.5 ^{o} C for 24 hours.

↓

Further identification by gram staining and biochemical tests.

Fig. 3.1 Flow diagram for the isolation and identification of *E. coli* from domestic sewage.

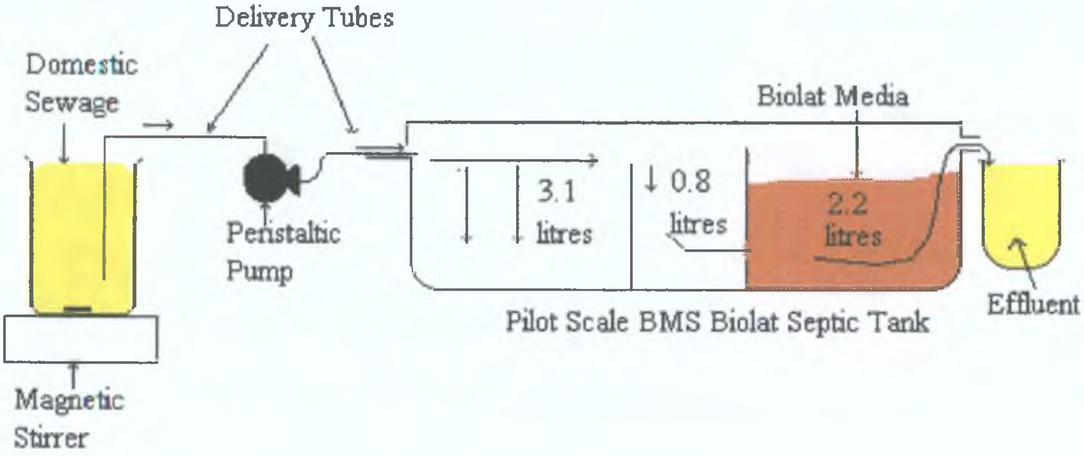

Fig. 3.2 Diagrammatic set-up of pilot scale tanks.

plant, which serves a 1,000 population equivalent. Following repeated analysis of the pollutional strength of the effluent it was considered to be representative of normal domestic sewage entering a septic tank.

Of the four pilot scale septic tanks used, two of the tanks were aerated and two were unaerated. This was to determine the influence, if any, of aeration on the removal of pollutants by Biolat. Aeration was achieved by means of a pump and diffuser stone which was placed in the second chamber of two of the tanks (i.e. Tanks three and four). The second chamber was chosen to be aerated since aerating the first chamber would interfere with the settlement of larger solids in the influent.

3.3.1 Sampling and analysis of effluent

An initial start up period of three weeks was required in order to achieve an adequate scum layer of grease and solids on the surface of the septic tanks. This layer (which achieved a thickness of approximately 2.0 cm) was required so as to resemble conditions in a normal septic tank. The layer forms due to the oil, fat and grease (OFG) content of domestic sewage. The OFG's float to the surface of the liquid level, bringing with it attached solids.

Samples were taken daily of;

(a) The influent (collected in the holding container)

(b) Intermediate chamber (collected 5 cm below the liquid level)

(c) Final effluent (collected from the outlet pipe)

Samples were taken in the intermediate chamber so as to determine the removal of the various pollutants at each stage of the treatment process i.e. following settlement and the various biological processes occurring in chambers one and two prior to reaching the Biolat chamber and subsequently following passage through the Biolat chamber. The influent, effluent and intermediate samples were analysed for the range of parameters listed in Table 3.1 (page 78). The initial sampling period was for eight weeks in order to build up a clear picture of processes occurring within the tank. Hereafter sampling and analysis was carried out for two weeks of every two months over a period of six months.

3.3.2. Calculation of the percentage removal of the various parameters at each stage in the pilot septic tanks

Due to the three day HRT in the pilot scale tanks, effluent entering the tank on day one, left the intermediate chamber on day three and left the final chamber on day four. Hence the results yielded from day one were compared to results obtained on days three and four in order to determine the removal of the pollutants at each stage in the septic tanks.

i.e. (Concentration on Day 1) minus (Concentration on Day 3)

= Removal in the first and second chamber

and (Concentration on Day 4) minus (Concentration on Day 3)

= Removal owing to Biolat

The percentage removal achieved at each stage in the pilot scale septic tanks was calculated and compared both for the aerated and unaerated septic tanks

3.4 Biolat Columns

These were constructed using 5cm diameter PVC pipe. They were constructed so that the effluent would flow upwardly through the Biolat contained in the column. A circular 0.5 mm mesh was placed above the inflow pipe at the base of the column to prevent the Biolat from clogging the perforations in the inflow pipe (Fig 3.3, page 84). For standardisation purposes a particle size of between 2 and 4 mm was chosen to be used in the columns for the trials. This particle size was obtained by sieving through the appropriate sieves. The Biolat columns held 600g of Biolat (1/5000 th of that used in the BMS Biolat unit) and had a capacity of 0.5 litres when the Biolat was present. Preliminary results obtained from the pilot scale septic tank trials had indicated that phosphate, ammonia, nitrate and *E. coli* were removed to varying degrees in the third chamber of the septic tank. Hence it was necessary to determine whether the removal of these parameters was due to the Biolat media itself housed in the third chamber of the septic tank or to other processes occurring within the third chamber.

3.4.1. The removal of phosphate by Biolat

In order to investigate how phosphate was being removed in the Biolat chamber, experiments were set up whereby phosphate in solution was passed through the Biolat columns. Various concentrations of phosphate, namely 50, 100 and 200 mg/l were prepared using potassium dihydrogen orthophosphate (as per *Standard Methods*, APHA, 1992). The phosphate was prepared both in

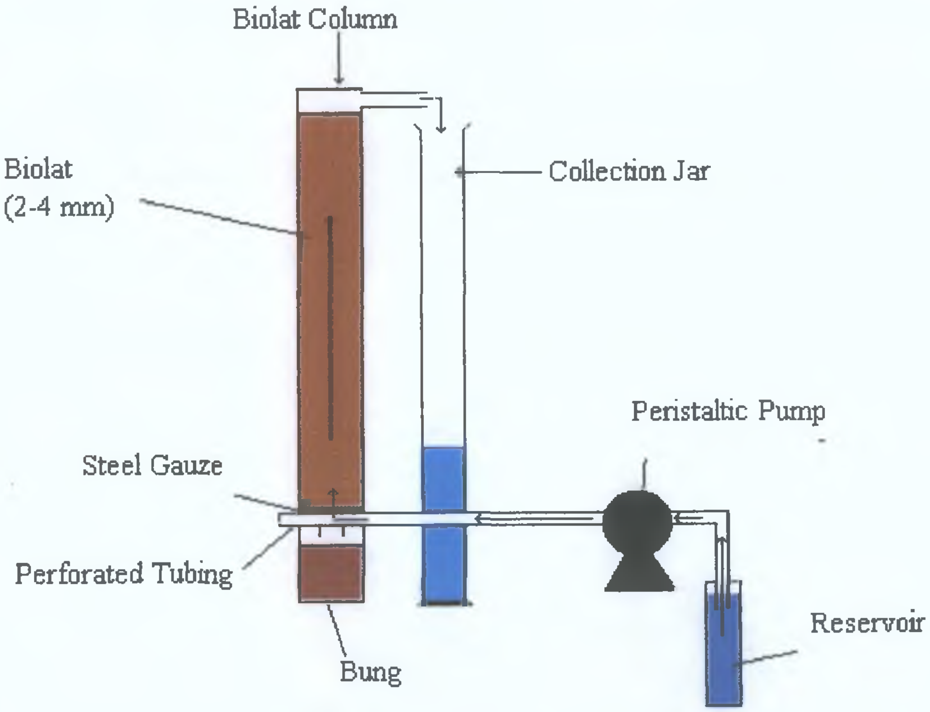

Fig. 3.3 Diagrammatic set up for the Biolat columns.

distilled water and in domestic sewage. The solutions were then run through the columns at a rate of 0.35 mls min.$^{-1}$. This allowed a one day HRT between the Biolat and the phosphate. The tests were carried out in triplicate over a five day test period. Samples were collected at the overflow from the columns and analysed for phosphate as per Table 3.1, page 78. The percentage removal rate of phosphate by Biolat was calculated and compared for both the distilled water and domestic sewage samples. Mean values were calculated for removal rates achieved at each of the phosphate concentrations.

3.4.2 The removal of ammonium by Biolat.

Investigations into the removal of ammonium by Biolat were performed as per 3.4.1. Again similar concentrations of ammonium were prepared as per *Standard Methods*(APHA, 1992) using ammonium sulphate. The solutions were prepared in both distilled water and domestic sewage. Experiments were performed in triplicate for each of the various concentrations over the five day test period. Analysis of the ammonium present in the samples collected at the overflow of the Biolat columns was by the phenol nitroprusside method.

3.4.3. The removal of nitrate by Biolat.

Investigations into the removal of nitrate by Biolat were as per 3.4.1. Nitrate of various concentrations was prepared using potassium nitrate (as per *Standard Methods*, APHA, 1992). Experiments were performed in triplicate for each of the various concentrations over the five day test period. Analysis of the nitrate present in the samples collected at the overflow of the Biolat columns was by the chromotrophic acid method.

3.4.4 The removal of *E. coli* by Biolat.

The removal of *E. coli* by Biolat was investigated by feeding various concentrations of the bacteria through the Biolat media. Concentrations of 1.6 x 10^6, 1.9 x 10^8 and 2.0 x 10^{10} cfus/ 100 mls were prepared from a pure culture of *E. coli* using 1/4 strength Ringer's solution. Colony counts were performed prior to and following passage of the cultures through the Biolat. Enumeration of *E.coli* was as per Fig. 3.1, page 79.

The removal of *E. coli* indigenous to domestic sewage by Biolat was also investigated by passing raw domestic sewage through the Biolat columns. Colony counts were performed on the influent and effluent to determine the removal rate of *E.coli* in the Biolat. Fresh samples of domestic sewage were used each day over the five day test period. The percentage removal rates achieved for *E. coli* in both the domestic sewage and Ringer's solution by the Biolat media were calculated and compared.

3.5 Adsorptive capacity of Biolat

3.5.1 Adsorptive capacity of Biolat for phosphate.

Various concentrations of phosphate (50, 100, and 200 mg/l PO_4-P) were prepared using potassium dihydrogen orthophosphate as per *Standard*

Methods (APHA, 1992). Nine columns were filled with 600g quantities of Biolat (i.e. three columns were required for each of the concentrations so as to triplicate the results). 500 ml quantities of PO_4-P, at the various concentrations, were passed daily through separate Biolat columns. This provided a one day HRT within the columns and was achieved by means of a peristaltic pump and delivery tubes calibrated to deliver 0.35 mls min. $^{-1}$. Since the Biolat column were constructed to provide an upward flow, samples were collected at the overflow from the columns. These samples were then analysed for phosphate using the vanadomolybdophosphoric acid method. The trials were performed daily until the Biolat columns were saturated with respect to phosphate i.e. influent concentration equalled effluent concentration.

The total phosphate removed /adsorbed by the Biolat was calculated by the formula $\Sigma (x - y)$

where x = mg of phosphate added daily

y = mg of phosphate remaining in effluent daily

The results were calculated as mg of phosphate adsorbed per 100g of Biolat.

3.5.2 Adsorptive capacity of Biolat for ammonium

The adsorptive capacity of Biolat for ammonium was investigated and calculated as per 3.5.1. Again concentrations of 50, 100 and 200 mg/l NH_4-N were used. The various concentrations were prepared using ammonium sulphate as per *Standard Methods*, (APHA, 1992). The experiments were performed in triplicate. The experiments ceased when the Biolat became saturated with ammonium. Analysis of the ammonium present in the overflow from the Biolat columns was by means of the phenol nitroprusside method.

3.6. Factors controlling the removal of ammonium and phosphate by Biolat.

A number of factors were investigated in an effort to determine the conditions of removal of ammonium and phosphate by Biolat and also to determine the limitations, if any, on the Biolat's efficiency in their removal. The following factors were investigated

- Concentration of ions in solution.
- Retention / Contact time between the ions and Biolat.
- pH of the influent solution.
- Grain size of Biolat.

Concentration and retention time experiments were dealt with together in order to investigate the removal of various influent concentrations at specific time intervals.

- **Concentration / Retention time.**

(i) Phosphate

One hundred gram quantities of Biolat, of grain size between 2 and 4 mm were placed in six erlenmeyer flasks. Various concentrations of phosphate were prepared using potassium dihydrogen orthophosphate as per *Standard*

Methods (APHA, 1992). The concentrations used were 10, 50, 100, 500, 1,000, 5,000 and 10,000 mg/l PO_4-P. To each of the flasks containing the Biolat, 100 mls of the phosphate solution at a particular concentration was added and allowed to stand, following an initial 10 second gentle mixing. Samples of the supernatant in each of the flasks were then taken at various time intervals over a 24 hour period. Samples were initially taken after one hour contact time and subsequently after 2, 4, 6, 8 and 24 hours contact. The experiments were performed in triplicate. The supernatant was analysed for phosphate using the vanadomolybdophosphoric acid method. The percentage removal rate achieved at each concentration and at various time intervals was determined.

(ii) Ammonium

The effect of concentration / retention time on ammonium removal was determined as per phosphate above. Concentrations of 10, 50, 100, 500, 1,000, and 5,000 mg/l NH_4-N were used in the experiments. These were prepared using ammonium sulphate as per *Standard Methods* (APHA, 1992). The concentration of ammonium present in the supernatant was determined using the phenol nitroprusside method.

The effect of retention time on the total adsorptive capacity of Biolat was also investigated by running the experiments outlined in 3.5.1 (page 86) for a two and three day HRT for both ammonium and phosphate. These HRTs were achieved by means of setting the peristaltic pump to deliver 10.4 mls hr^{-1} and 6.25 mls hr^{-1}, respectively.

- **pH of influent solution.**

In order to investigate if pH was influential in the removal of phosphate by Biolat, standard concentrations of 100 mg /l PO_4-P were prepared using potassium dihydrogen orthophosphate and distilled water which had been pH adjusted to pH 2, 4, 6, 8, 10 and 12. The pHs of the resulting phosphate solutions were then rechecked and adjusted if necessary to achieve the appropriate pH. Concentrated sulphuric acid and a 40% sodium hydroxide solution were used for pH adjustment. One hundred gram quantities of Biolat were placed in six erlenmeyer flasks. One hundred ml volumes of phosphate solutions at the various pHs were added to each of the flasks. A HRT of eight hours was allowed, following which the concentration of phosphate remaining in the supernatant was determined using the vanadomolybdophosphoric acid method. The effect of pH was determined by comparing the percentage removal rate obtained at each pH. All tests were performed in triplicate.

The above procedure was then repeated for ammonium using 100 mg/l NH_4-N concentrations which were prepared using ammonium sulphate and distilled water which had been pH adjusted to pHs 2, 4, 6, 8, 10 and 12. One hundred ml volumes of the ammonium solutions were added to 100 g quantities of Biolat. A HRT of eight hours was allowed following which the concentration of ammonium remaining in the supernatant was determined using the phenol nitroprusside method.

- **Grain size of Biolat.**

Biolat was sieved in order to obtain the following grain sizes, 0.25- 0.50, 0.50 to 1.00, 1.00-2.00 and 2.00- 4.00 mm grain sizes. A fifty gram quantity of each of the various grain sizes of Biolat were placed in four separate erlenmeyer flasks. A standard 50mg/l concentration of phosphate was prepared using potassium dihydrogen orthophosphate and 150 ml volumes of same were added to each of the four flasks. The larger volumes of solution were required since these experiments involved shaking the flasks containing Biolat. The shaking action had the effect of producing a more viscous sample which was difficult to filter and thus larger volumes of the phosphate solution were required in these experiments than in previous experiments. The supernatant was sampled and analysed for phosphate concentration following a 15 minute contact time and thereafter at intervals of 30 mins, 1 hour, 2 hours, 4 hours, 12 hours and 24 hours. Phosphate analysis was by means of the vanadomolybdophosphoric acid method. Due to the fact that the smaller grain sizes i.e. < 0.25 mm, became suspended in solution, the samples required filtration through a 0.45 micron filter paper prior to analysis. The experiments were performed under conditions whereby one set of flasks was shaken and the other set was unshaken. The reason for this being that the unshaken flasks represented conditions in the Biolat septic tank, whereas the shaken flasks allowed more contact between the Biolat and the phosphate thereby reflecting the true effect of grain size on phosphate removal. All tests were carried out in triplicate. The effect of grain size was determined by comparing the removal rate obtained at each of the various grain sizes. The above procedure was then repeated for ammonium using a 50 mg/l NH_4-N concentration which was prepared using ammonium sulphate as per *Standard Methods*, APHA, 1992. Analysis of the ammonium concentration in the supernatant was by the phenol nitroprusside method.

3.7 Desorption of phosphate and ammonium from Biolat

Investigations into the desorption of phosphate and ammonium from previously saturated Biolat was initially attempted using distilled water. The Biolat had been previously saturated with phosphate or ammonium at various concentrations, namely 100, 200 and 400 mg/l (Section 3.5.1 and 3.5.2, pages 86 and 87). Thereafter experiments were performed using distilled water which had been pH adjusted in the pH range 2 to 12. This was in order to investigate if pH would affect the desorption process.

3.7.1 Desorption of phosphate and ammonium with distilled water

Distilled water was initiallyintroduced into Biolat which had previously been saturated with phosphate at the various concentrations. The water was initially introduced in 150 ml quantities and analysed for phosphate (using the vanadomolybdophosphoric acid method) following passage through the saturated columns. Subsequently larger volumes were used. Passage of water through the Biolat continued until no phosphate was detectable in the water passed through. The passage of water was continuous at a rate of 1.6 mls min^{-1}. The total quantity of water passed through the columns was calculated, together with the amount of phosphate desorbed. This was then expressed as a percentage of that amount of phosphate which had been previously adsorbed.

The experiments were then repeated to investigate the desorption of ammonium from ammonium saturated Biolat. Analysis of ammonium was by the phenol nitroprusside method.

3.7.2 Desorption of phosphate and ammonium from Biolat using distilled water of varying pHs

Due to the fact that the delivery tubes could not withstand the extreme pHs used in the experiments, investigations into the effect on desorption of raising and lowering the pH was performed by means of placing 100g quantities of Biolat (previously saturated with phosphate or ammonium) into erlenmeyer flasks. In the case of phosphate 100g of Biolat which had been previously saturated with phosphate as outlined in section 3.5.1, page 86 was used. One hundred ml portions of distilled water were pH adjusted to the appropriate pH values namely 2, 4, 6, 8, 10 and 12 and added to the Biolat. A contact time of 24 hours was allowed following which the supernatant was sampled and analysed for phosphate using the vanadomolybdophosphoric acid method. The concentration of phosphate desorbed by the distilled water at the various pHs was calculated and expressed as a percentage of that amount which had previously been adsorbed by the Biolat.

The above procedure was then repeated to investigate the desorption of ammonium at varying pHs. The Biolat used in the desorption trials had been previously saturated with a 50 mg/l concentration of ammonium as outlined in section 3.5.2 (page 87). Analysis of ammonium was by the phenol nitroprusside method.

3.8 Investigation into the mechanism of phosphate and ammonium removal by Biolat.

In an effort to determine the mechanism of phosphate and ammonium removal by Biolat, a number of experiments were undertaken which involved contacting various concentrations of ammonium or phosphate with Biolat over a period of time and determining the concentration of these ions in the supernatant. The experiments also attempted to determine the concentration of other cations and anions which were present in the supernatant when the Biolat was contacted with phosphate and ammonium solutions. The ions of interest in the supernatant when Biolat was contacted with phosphate were chloride, nitrate, nitrite and sulphate. The ions of interest in the supernatant when Biolat was contacted with ammonium were calcium, potassium, magnesium and sodium. The ammonium and phosphate solutions were prepared using analar grade reagents and hence did not contain the ions of interest as impurities prior to contact with Biolat.

In previous experiments (pages 88- 89) which investigated the removal of phosphate and ammonium by Biolat, flasks containing the Biolat and phosphate or ammonium solutions were not shaken but allowed to stand. This was in order to be representative of conditions in the Biolat septic tank. However, for the purpose of determining the mode of removal of phosphate and ammonium by Biolat all experiments were undertaken in flasks which were shaken. This was in order to provide as much contact as possible between the phosphate and ammonium solutions with the Biolat and to allow the development of equilibrium conditions. Determination of the concentration of the various ions present in the supernatant when phosphate or ammonium was contacted with Biolat was by means of ion chromatography.

3.8.1 Validation of the ion chromatographic method

Prior to experiments, the ion chromatograph (Dionex DX100) had to be validated for both the anions and cations of interest. This was in order to determine

(a) Retention times for each of the ions on the cation or anion columns.

(b) The linearity of the instrument response over various concentration ranges for a particular ion.

(c) The relative standard deviation of the instrument response for each ion.

The anions of interest found to be present were chloride, nitrate, nitrite, sulphate and phosphate. The cations of interest were sodium, potassium, calcium and magnesium. Various concentrations of each of these ions as well as those of ammonium and phosphate were prepared in isolation in ultra-pure water (of conductivity less than 1 μS) according to *Standard Methods* (APHA, 1992). The concentrations prepared were 0.5, 1.0, 2.5, 5.0, 7.5, 10.0, 15.0, 20.0, 25.0, 30.0, 35.0 and 40.0 mg/l. A 0.7 ml volume of each of the concentrations of a particular ion was injected into the ion chromatograph five times and the area under the peaks was recorded each time. The eluent used for the anions was a sodium carbonate buffer which flowed through the column at a rate of 2.0 mls/ min. The eluent used for the cations was a 22 mN solution of sulphuric acid which flowed through the column at a rate of 1.0 mls/ min. Calculation of the area of the peaks was performed by the integrator (Spectra Physics 4270). For a particular concentration, the average area obtained from each of the five injections was calculated together with the RSD value. When all of the concentrations for a particular ion had been run through the ion chromatograph, a graph was drawn of concentration versus average peak area using the Cricket Graph application of the Apple Machintosh SE30. This was in order to test the linearity of the instrument response over the concentrations used.

3.8.2 Investigation into the presence of anions in the supernatant when phosphate solutions of various concentrations were contacted with Biolat.

50g quantities of Biolat (of grain size between 2 and 4 mm) were placed in five erlenmeyer flasks. Various concentrations of phosphate were prepared in ultra-pure water using potassium dihydrogen orthophosphate as per *Standard Methods* (APHA, 1992). The concentrations used were 0, 10, 50, 100 and 500 mg/l PO_4-P. 150 mls of ultra-pure water was added to the first flask and 150 mls of each of the other phosphate concentrations were added to the other flasks. The flasks were placed on a shaker table and shaken for the required investigation period i.e. 48 hours. The experiment was performed in triplicate. Samples of the supernatant in each of the flasks were taken at various time intervals over a 48 hour period. Samples were initially taken after 15 and 30 minute intervals and subsequently after, 1, 2, 4, 6, 8, 16, 24 and 48 hours. The samples taken were filtered through a 54 μm filter paper so as not to damage the column on the ion chromatograph with suspended particles. A sample volume of 0.7 mls was injected into the ion chromatograph for each sample. A number of samples required dilution in order to bring them within the linear range. Dilution of all samples was with ultra-pure water. The concentrations of chloride, nitrate, nitrite and sulphatepresent after a particular time interval were calculated and compared for each of the phosphate concentrations used.

3.8.3 Investigation into the presence of cations in the supernatant when ammonium solutions of various concentrations were contacted with Biolat.

Investigation into the presence of cations in the supernatant when ammonium solutions of various concentrations were contacted with Biolat was determined as per phosphate above. The concentrations of ammonium used were 0, 10, 50, 100 and 500 mg/l NH_4-N. These were prepared using ammonium sulphate as per *Standard Methods* (APHA, 1992) in ultra-pure water. The concentrations of sodium, potassium, magnesium and calcium present following a particular time interval was calculated and compared for each of the ammonium concentrations used.

3.8.4 Determination of the cation exchange capacity of Biolat.

Determination of the cation exchange capacity of Biolat (expressed as meq/100g of Biolat) was by means of the ammonium saturation method. This method involved leaching a 10g quantity of Biolat with an excess of ammonium acetate to remove the exchangeable cations and saturate the exchange material with ammonium. Determination of the quantity of adsorbed ammonium then gave the cation exchange capacity.

A 10g quantity of 2 mm air dried Biolat was placed in a 500 ml erlenmeyer flask which contained 200 mls of neutral 1N ammonium acetate. The flask was shaken and allowed to stand overnight following which the Biolat was filtered with light suction using a Buchner funnel and flask until no calcium was detected in the leachate. The Biolat was then leached four times with neutral 1N NH_4Cl and once with a 0.25N NH_4Cl. The electrolyte was washed out of the Biolat with 99% isopropyl alcohol until no chloride appeared in the filtrate (chloride and calcium determinations were by means of ion chromatography). The amount of ammonium which was adsorbed by the Biolat was determined by the acid-NaCl method. This method involved leaching the ammonium saturated Biolat with 225 mls of 10% acidified NaCl. The leachate was then transferred to a kjeldahl flask which contained 25 mls of 1N NaOH. 60 mls of solution was distilled into 50 mls of 2% H_3BO_3. The boric acid solution was titrated with a standard 0.1N H_2SO_4 solution using bromocresol green as an indicator. Since only 10g of Biolat was used in the determination, the calculated amount of ammonium adsorbed was multiplied by 10 in order to express the CEC as meq/100g of Biolat.

3.8.5 Application of results to the Freundlich adsorption isotherm.

Using the same experimental set up and analysis outlined in 3.8.2 and 3.8.3, the removal of phosphate or ammonium achieved by Biolat after each of the time intervals was determined. The experiments in 3.8.2 and 3.8.3 were continued over a period of time until either all of the phosphate or ammonium was removed by the Biolat or the Biolat was incapable of removing any more phosphate or ammonium and an equilibrium situation had been reached. The equilibrium value was determined by obtaining the average amount of phosphate or ammonium removed at each concentration. The data generated were then applied to the Freundlich adsorption isotherm in order to determine if the removal of phosphate or ammonium by Biolat obeyed this mode of adsorption. If the data fitted the Freundlich adsorption isotherm, then a straight line graph would be obtained when the log of the concentration was plotted against the log of the amount of phosphate or ammonium removed. Furthermore, one should be able to predict mathematically the amount of phosphate and ammonium removed at a particular solution concentration by means of the equation of the line generated from the data. An equation for the line was determined for both phosphate and ammonium using the Cricket Graph application of the Apple Machintosh SE30 computer. The correlation co-efficient achieved from the data generated for both ions was 1.000. From the equation of the lines, the amount of phosphate and ammonium which would be removed at arbitrary concentrations of 75, 300 and 700 mg/l was predicted.

In order to validate the predictive results, experiments were set up whereby concentrations of 75, 300 and 700 mg/l of phosphate were contacted with Biolat. Similar concentrations were used for the experiments with ammonium. 50g quantities of Biolat (2-4 mm grain size) was added to three erlenmeyer flasks. The various concentrations of phosphate were prepared in ultra-pure water using potassium dihydrogen orthophosphate as per *Standard Methods* (APHA, 1992). To each of the flasks containing the Biolat, 150 mls of the phosphate solution at a particular concentration was added. The flasks were then covered and shaken on a shaker table. The experiments were performed in triplicate. The supernatant was analysed daily for phosphate using the ion chromatograph. Sampling and analysis continued until such a time as an equilibrium situation was achieved. The equilibrium value was then compared to the value which had been predicted.

The above experiment was then repeated for ammonium. The 75, 300 and 750 mg/l ammonium solutions were prepared in ultra-pure water using ammonium sulphate as per *Standard Methods* (APHA, 1992).

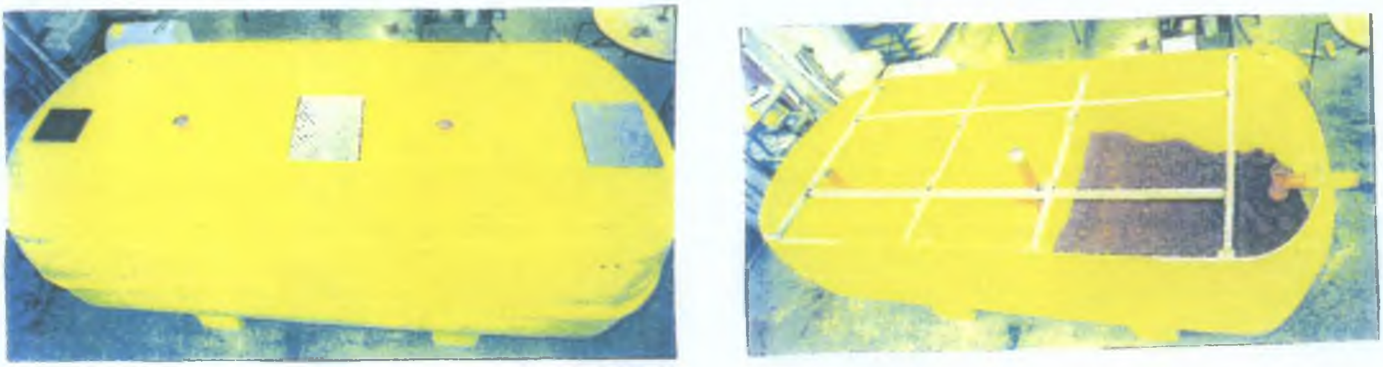

Plate 3.1 Prototype BMS Septic Tank.

Plate 3.2 Pilot Scale BMS Septic Tank.

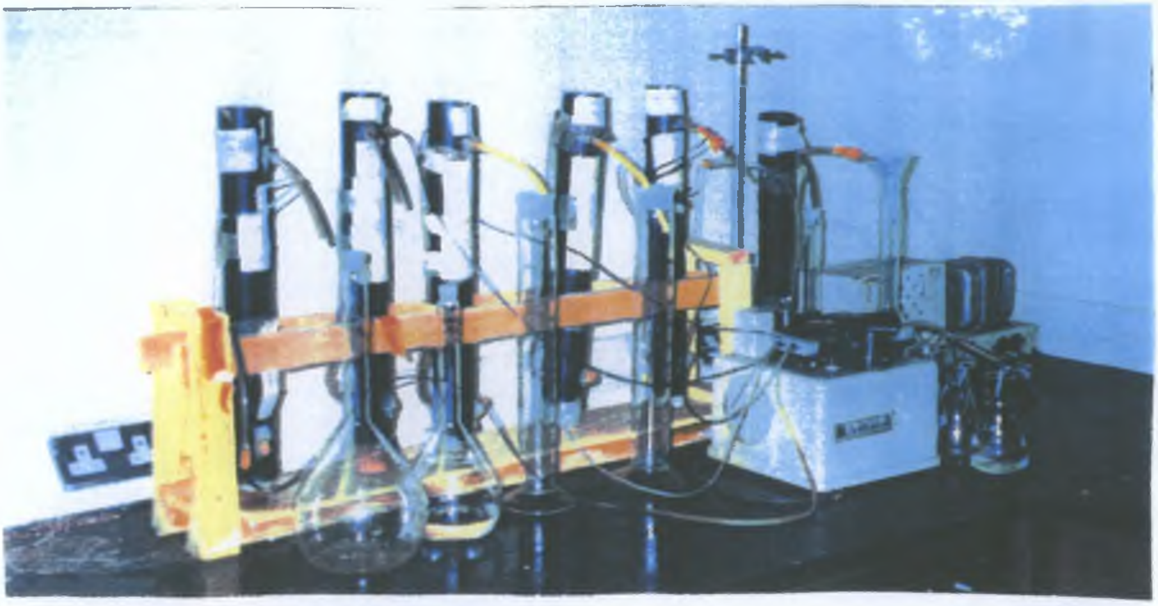

Plate 3.3 Biolat Columns

CHAPTER FOUR

RESULTS

4.0 Results and Description of Results.

4.1 Prototype BMS Septic Tank.

Table 4.1 (page 105) and Figure 4.4 (page 107) demonstrate that the range of influent BOD to the BMS prototype septic tank was variable, ranging from 30 to 570 mg/l BOD ($x = 228$ mg/l). The removal rate achieved for this influent BOD varied from to 21.6 to 83.0% (Figure 4.1, page 106 and Table 4.1, page 105). The average removal rate achieved over the four year test period was 59.3%. The BOD concentrations leaving the prototype septic tank and entering the percolation field varied from a concentration of less than 5 to 268 mg/l BOD ($x = 93$ mg/l BOD).

It is important to note that all of the average values obtained for BOD and also the other parameters under investigation have been calculated using data obtained over the four year investigation period. However, sampling was not carried out between months 26 and 47. This is indicated by the broken line in Figures 4.1 to 4.10.

The removal of COD in the BMS prototype septic tank followed the same general pattern as that of BOD (Figure 4.1, page 106 and Table 4.1, page 105). The influent concentrations were however much higher for COD than for BOD, ranging from <50 to 603 mg/l COD and with a mean influent concentration of 357 mg/l COD (Table 4.1, page 105 and Figure 4.5, page 108). The corresponding effluent values were also higher ranging from < 50 to 385 mg/l COD. Figure 4.1 (page 106) and Table 4.1 (page 105) demonstrate the variation in COD removal rates. Values varied between 23.0 and 73.0% (x = 54.0%) over the four year test period.

Table 4.1 (page 105) and Figure 4.6 (page 108) show the suspended solids concentration in the influent to vary between 11 and 210 mg/l SS (x = 112 mg/l SS). The average percentage removal rate achieved in the prototype septic tank over the four year test period was 63.6%, with values ranging from 15.8 to 87.0 % (Figure 4.3, page 107 and Table 4.1, page 105). The concentration of suspended solids in the final effluent and subsequently reaching the percolation field ranged from 3 to 88 mg/l (x = 39 mg/l SS).

The removal rate of phosphate within the BMS prototype septic tank averaged at 73.1% and ranged from 22.3 to 99.0% (Figure 4.2, page 106 and Table 4.1, page 105). The mean influent concentration of phosphate in the domestic sewage reaching the septic tank was 11.8 mg/l PO_4-P, ranging from 3.2 to 37.8 mg/l. Figure 4.7 (page 109) and Table 4.1 (page 105) portray the concentration of phosphate in the final effluent which varied from 0.03 to 8.0 mg/l PO_4-P (x =2.8 mg/l).

The average influent ammonia concentration to the septic tank was 44.0 mg/l NH_3-N, however the concentrations varied over a wide range i.e. from 2.9 to 129 mg/l NH_3-N. The effluent concentrations were somewhat lower, but were equally varied (Figure 4.8, page 109 and Table 4.1, page 105). Effluent ammonia concentrations ranged from 0.5 to 96.1 mg/l NH_3-N (x =28.3 mg/l NH_3-N). The removal rates achieved for ammonia in the BMS prototype septic tank were variable ranging from 13.0 to 83.0 %, with a mean value of 41.6%

observed over the four year test period (Figure 4.2, page 106 and Table 4.1, page 105).

Influent nitrate concentrations to the prototype septic tank were quite low, i.e. the average influent nitrate concentration was 1.7 mg/l NO_3-N, ranging from 0 to 4.2 mg/l NO_3-N (Table 4.1, page 105 and Figure 4.9, page 110). From Figure 4.2 (page 106) and Table 4.1 (page 105), the removal rate achieved within the tank was variable, ranging from -190.0 to +100.0% (x = 23.5%). Effluent concentrations values were subsequently only a little lower than influent concentrations with a mean nitrate concentration of 1.3 mg/l NO_3-N, with values ranging from 0 to 6.1 mg/l NO_3-N over the four year test period (Table 4.1 page 105, and Figure 4.9, page 110).

The average concentrations obtained for the faecal bacteria, *E. coli* in influent domestic sewage over the investigation period was 3.2×10^6 cfus/100 mls. The number of *E. coli* ranged from 3.0×10^4 to 2.0×10^7 cfus /100 mls (Figure 4.10, page 110 and Table 4.1, page 105). The percentage reduction achieved ranged from 31.0 to 100.0% with an average removal rate of 89.6% observed over the four year test period (Figure 4.3, page 107 and Table 4.1, page 105). The numbers of *E. coli* in the septic tank effluent were quite variable and ranged from 1.1×10^1 to 1.8×10^6 cfus/100 mls (x =2.7×10^5 cfus/100 mls).

Parameter	**Influent conc. (mean)**	**Influent conc. (range)**	**Effluent conc. (mean)**	**Effluent conc. (range)**	**% Removal (mean)**	**% Removal (range)**
BOD (mg/l)	228.0	30.0 to 570.0	93.0	< 5 to 268.0	59.3	21.6 to 83.0
COD (mg/l)	357.0	< 50.0 to 603.0	168.0	< 50 to 385	54.0	23.0 to 73.0
SS (mg/l)	112.0	11.0 to 210.0	39.0	3.0 to 88.0	63.6	15.8 to 87.0
NO_3-N (mg/l)	1.7	0.0 to 4.2	1.3	0.0 to 6.1	23.5	- 190 to +100
NH_3-N (mg/l)	44.0	2.9 to 129.0	28.3	0.5 to 96.1	41.6	13.0 to 83.0
PO_4-P (mg/l)	11.8	3.2 to 37.8	2.8	0.03 to 8.0	73.1	22.3 to 99.0
***E. coli* (cfus/100ml)**	3.2×10^6	3.4×10^4 to 2.0×10^7	2.7×10^5	1.1×10^1 to 5.5×10^6	89.6	31.0 to 100.0

Table 4.1 The influent and effluent concentrations obtained for pollutants under investigation in the BMS prototype septic tank. Also shown are the percentage removal rates achieved for the pollutants within the tank.
Note: Percentage removal rates were calculated using data obtained over the four year investigation period.

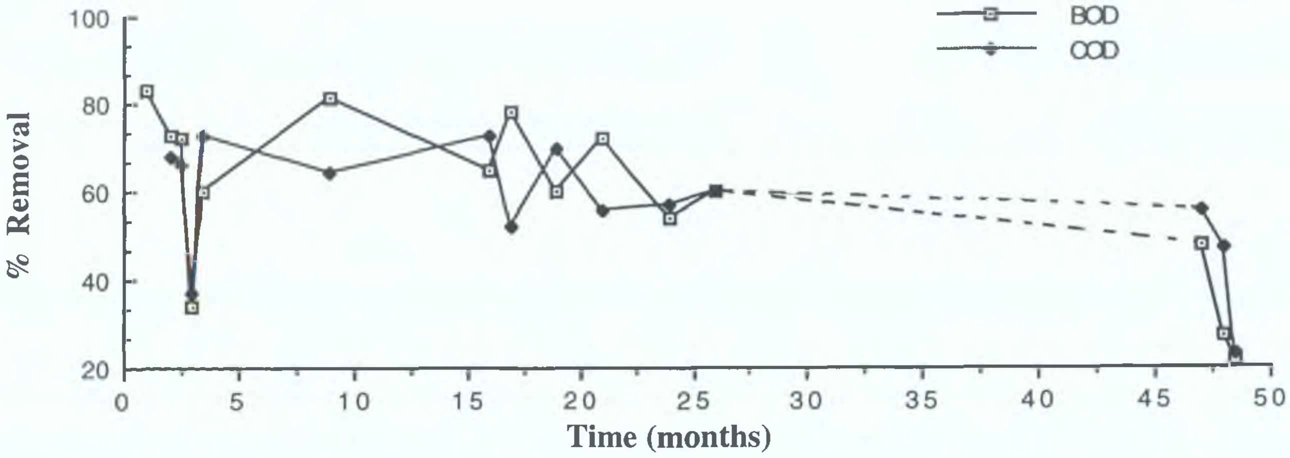

Fig 4.1 The percentage removal rate of BOD and COD over time in the BMS prototype septic tank.

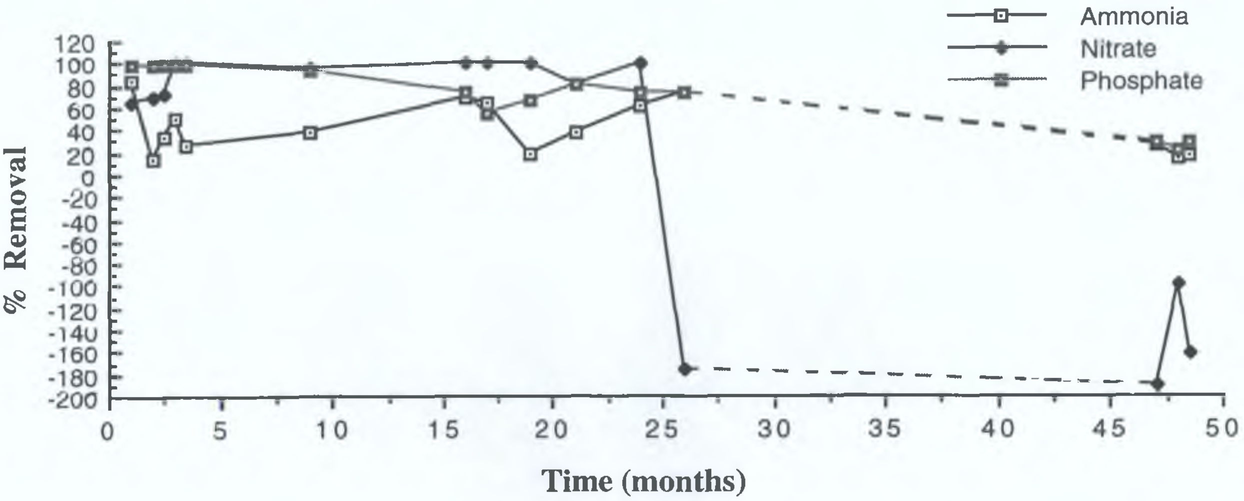

Fig 4.2 The percentage removal rate of ammonia, nitrate and phosphate over time in the BMS prototype septic tank.

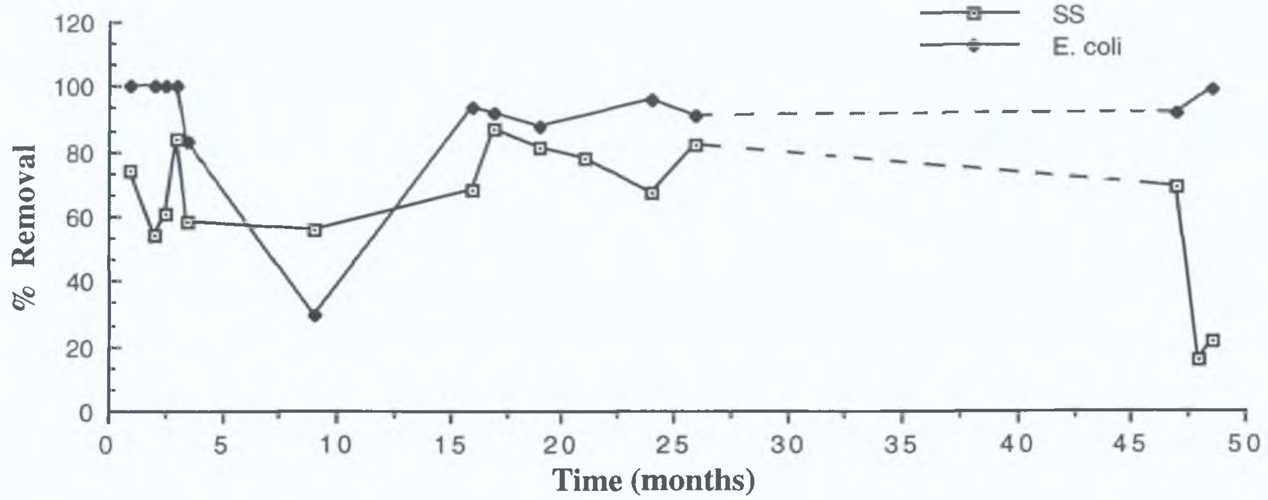

Fig 4.3 The percentage removal rate of *E. coli* and SS over time in the BMS prototype septic tank.

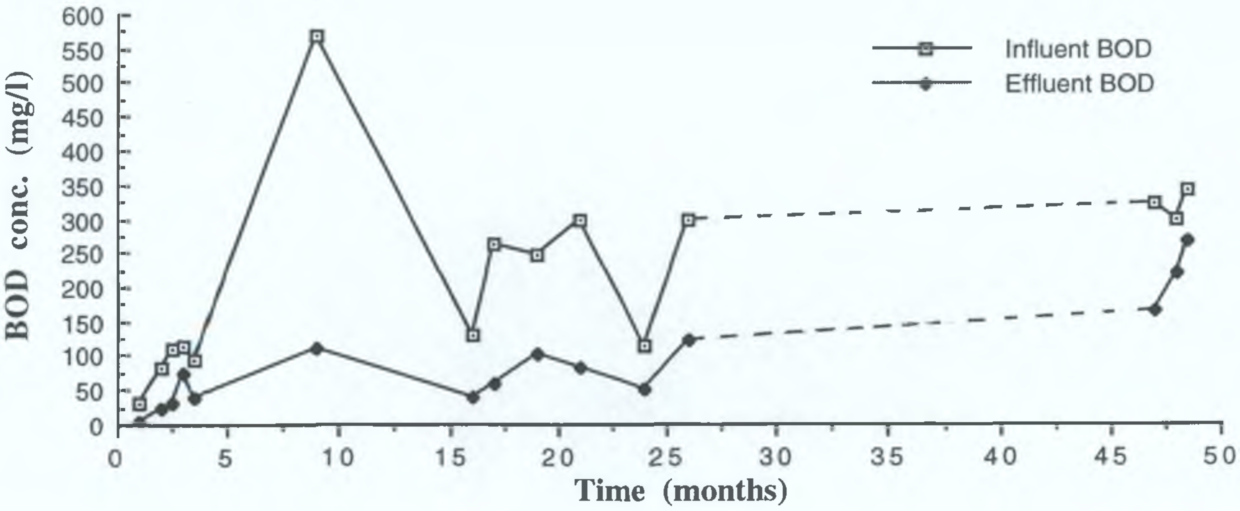

Fig 4.4. The variation in influent and effluent BOD concentrations over time in the BMS prototype septic tank

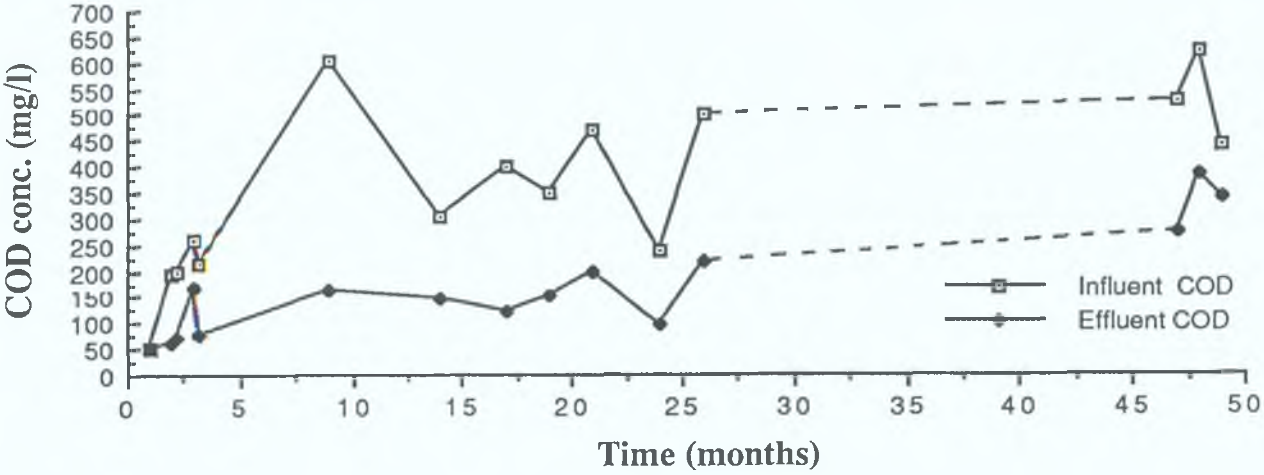

Fig 4.5. The variation in influent and effluent COD concentrations over time in the BMS prototype septic tank.

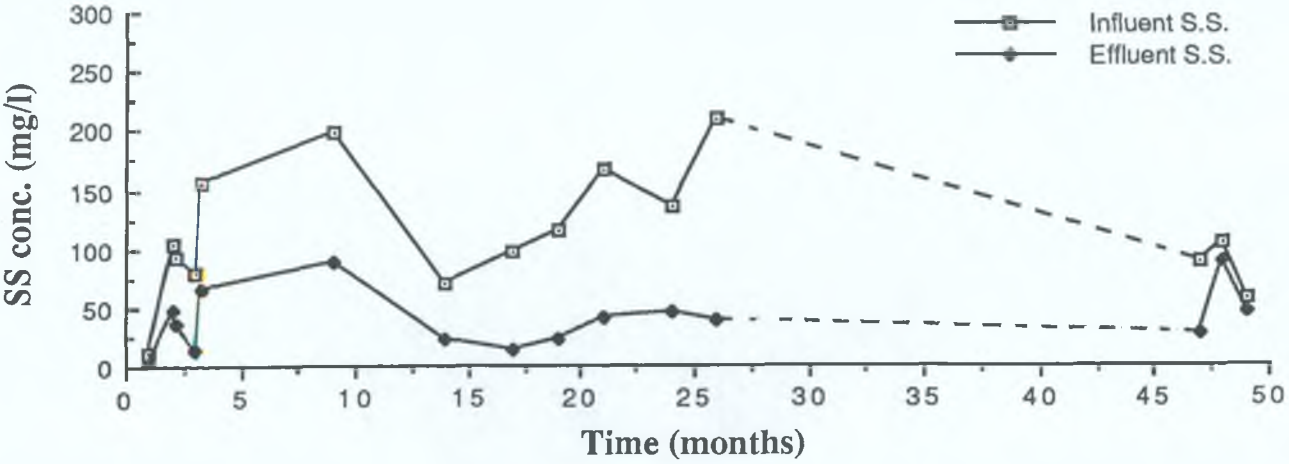

Fig 4.6 The variation in influent and effluent SS. concentrations over time in the BMS prototype septic tank.

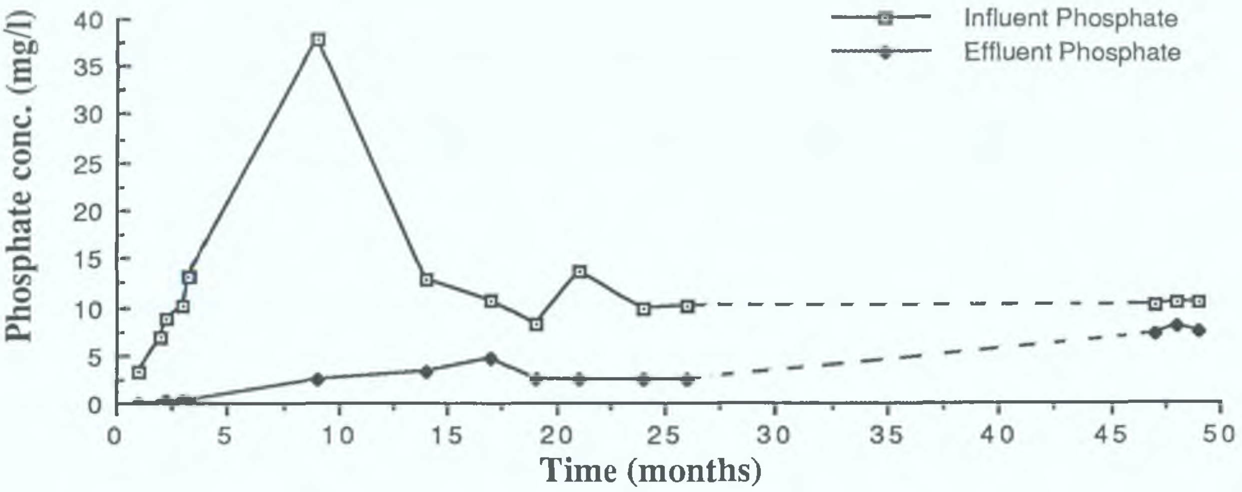

Fig 4.7. The variation in influent and effluent concentrations phosphate over time in the BMS prototype septic tank.

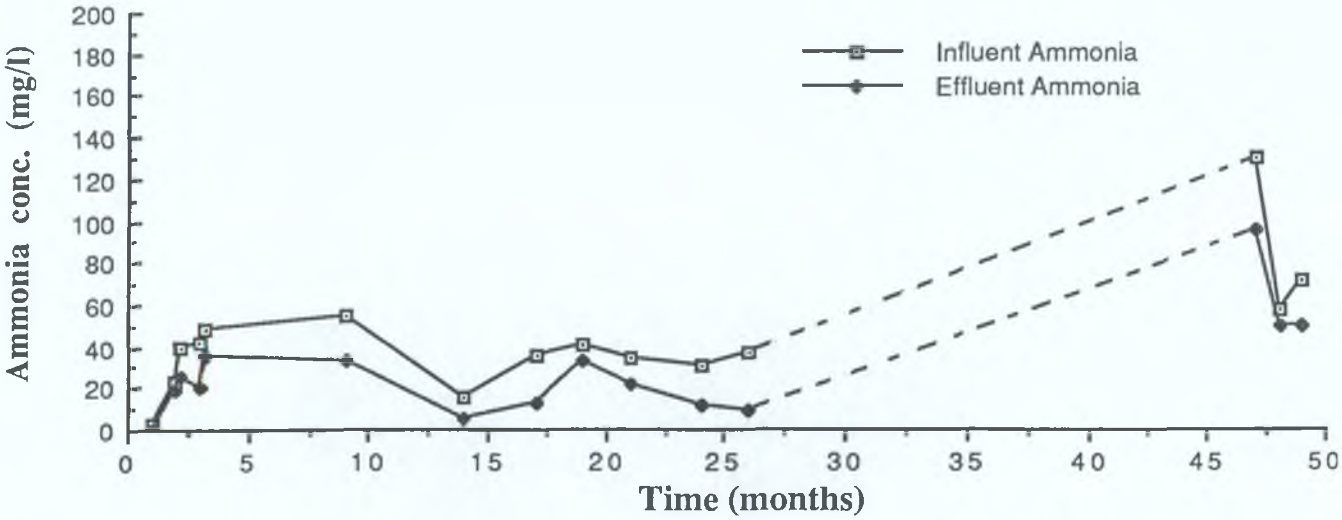

Fig 4.8 The variation in influent and effluent ammonia concentrations over time in the BMS prototype septic tank.

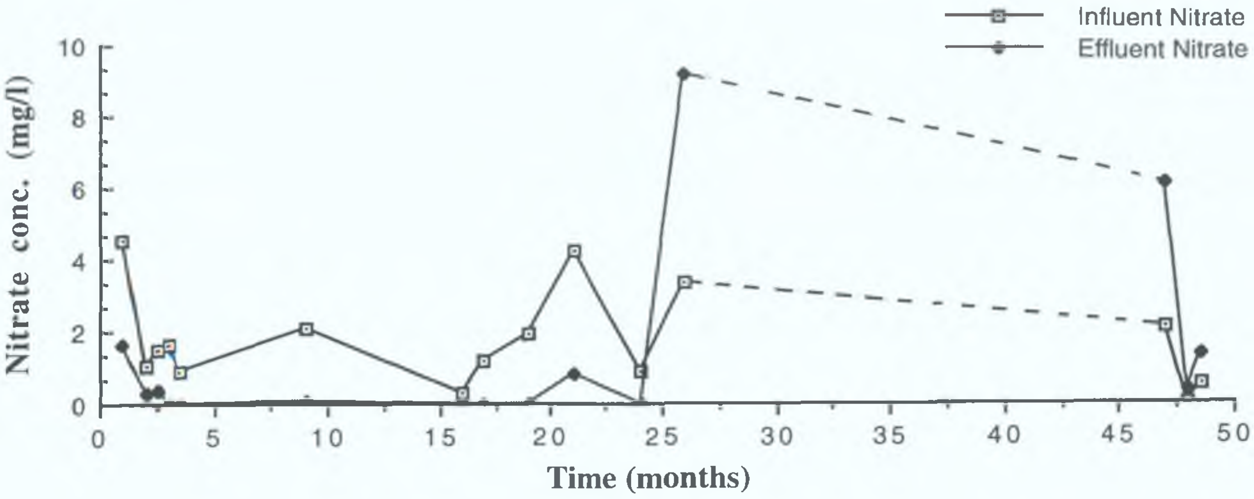

Fig 4.9. The variation in influent and effluent nitrate concentrations over time in the BMS prototype septic tank.

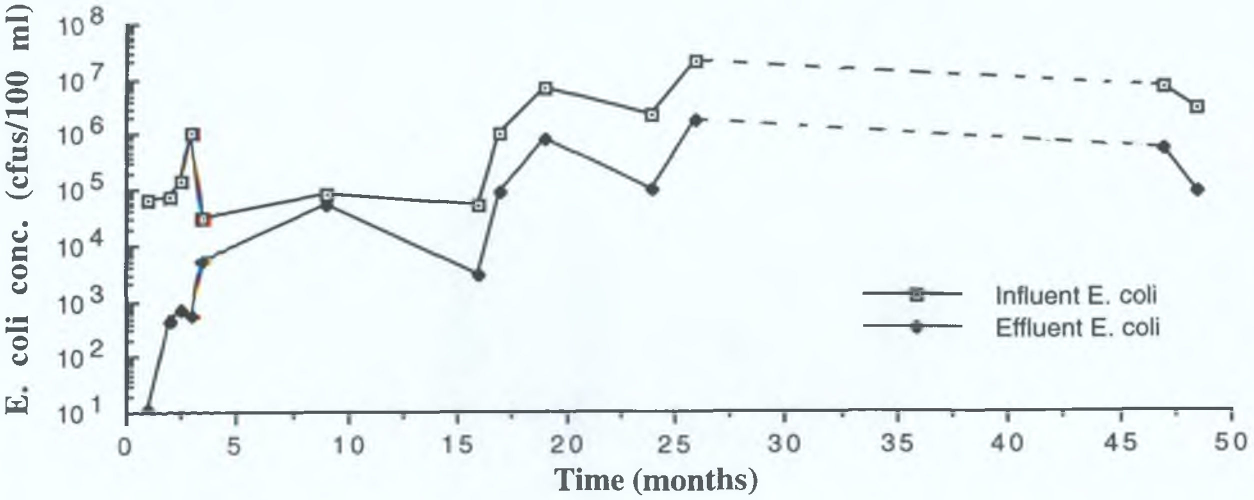

Fig 4.10. The variation in influent and effluent *E.coli* concentrations over time in the BMS prototype septic tank.

4.2 Pilot scale BMS septic tanks.

The variations in influent BOD, effluent BOD and BOD concentration in the second chamber of the pilot scale septic tanks are shown in Table 4.2 (page 118) and Figures 4.11 and 4.12 (page 120). The influent BOD concentration was variable and fluctuated between 66 and 200 mg/l BOD (x = 150 mg/l BOD). The bulk of BOD removal was achieved in chambers one and two of the pilot scale septic tanks (Figures 4.25 and 4.26, page 127). The average value obtained for total reduction of BOD in the pilot scale septic tanks over the 25 week test period was 56% in the unaerated tanks and 65% in the aerated tanks (Table 4.2, page 118). From Table 4.2 and Figures 4.11 and 4.12 (page 120), the BOD concentration in the effluent generated in the unaerated septic tanks varied from 37 to 110 mg/l BOD (x = 63 mg/l BOD). In the aerated pilot plant septic tanks, the concentration range was 19 to 74 mg/l BOD (x = 50 mg/l). BOD removal was therefore greatest in the aerated septic tanks.

Table 4.2 (page 118) and Figures 4.13 and 4.14 (page 121) demonstrate the variation in influent COD concentration to the pilot scale septic tanks. The influent COD concentration ranged from 120 to 456 mg/l COD. An average concentration value of 240 mg/l COD was obtained over the 25 week test period. The bulk of COD removal occurred in the first two chambers with little removal occurring within the Biolat chamber (Table 4.2, page 118 and Figures 4.27 and 4.28, page 128). An average value of 53% was obtained for total reduction of COD within the unaerated septic tank over the test period. Of this value, 50% removal was achieved within chambers 1 and 2, while only 3% removal occurred in the Biolat chamber. Similarly, in the aerated tanks, a corresponding value of 56% removal was obtained, 50% of influent COD being removed in the first two chambers with only 6% of this value contributed by the Biolat chamber. Again, as with BOD, greater removal of COD occurred in the aerated septic tanks, although the difference in removal rates obtained was slight i.e. 3%. Table 4.2 (page 118) and Figures 4.13 and 4.14 (page 121) show the variability in COD concentration in the effluent leaving the unaerated septic tanks. The concentrations varied from 64 to 288 mg/l COD (x = 107 mg/l COD). The corresponding COD concentration in the effluent generated in the aerated septic tanks ranged from 68 to 134 mg/l COD (x = 96 mg/l COD).

The removal of SS present in the influent domestic sewage also occurred predominantly in chambers 1 and 2 of the pilot scale septic tanks (Figures 4.29 and 4.30, page 129). Table 4.2 (page 118) and Figures 4.15 and 4.16 (page 122) illustrate the variability in influent SS concentration in domestic sewage entering the pilot scale septic tanks. The concentration of SS in the influent domestic sewage ranged from 46 to 117 mg/l SS (x = 71 mg/l SS). The average values obtained for the total removal of SS within both the aerated and unaerated tanks ranged from 95 to 99% (x = 98%) over the 26 week test period. The concentration of SS in the effluent leaving the septic tanks was very low and ranged from 1.0 to 3.0 mg/l SS for both the aerated and unaerated tanks over the test period. The effect of aeration on suspended solids removal in the pilot scale septic tanks was to prevent the normal settlement of solids in the second chamber of the tanks i.e. the average percentage removal obtained from the influent domestic sewage to chamber two of the septic tanks was 94% for the unaerated tanks and only 87% for the aerated tanks. In general in the pilot scale septic tanks it was observed that while most of the solids were removed in the first chamber of the tanks there was nevertheless some carry over of solids to the second chamber. In the unaerated tanks these solids settled to the floor of the tanks. However, in the aerated tanks the bubbles of air produced by aeration held them in suspension and so they were carried over to the Biolat chamber. Here, they were predominantly removed by filtration. Since the Biolat was effective in removing solids carried over from chamber two, the average final removal rates achieved in both the aerated and unaerated pilot scale septic tanks were the same i.e. 98%..

Table 4.2 (page 118) and Figures 4.17 and 4.18 (page 123) demonstrate the variation in the concentration of phosphate present in the influent to the septic tanks. The influent concentration varied between 2.0 and 14.6 mg/l PO_4-P (x = 4.9 mg/l PO_4-P). From Figures 4.31 and 4.32 (page 130), it is evident that the bulk of phosphate removal occurred in the Biolat chamber (i.e. of the mean value of 69% achieved for total removal in the unaerated tanks over the test period, 16% removal occurred in the first two chambers while 53% removal was achieved in the Biolat chamber). Also, in the aerated tanks 49% of the total 70% removal was achieved in the Biolat chamber while only 21% removal occurred in chambers 1 and 2. Table 4.2 (page 118) and Figures 4.17 and 4.18 (page 123) demonstrate that the phosphate concentration in the effluent from the unaerated septic tanks ranged from 0.2 to 4.4 mg/l PO_4-P (x = 1.6 mg/l PO_4-P), while the corresponding concentrations of phosphate in effluent from the aerated tanks varied between 0.0 and 4.7 mg/l (x = 1.6 mg/l PO_4-P). The average total removal rates were approximately the same i.e. 70% in both aerated and unaerated pilot scale septic tanks. The percentage reduction from influent domestic sewage to chamber two was slightly greater in the aerated pilot scale septic tanks i.e. yielding a value of 21% removal as opposed to 16% in the unaerated pilot scale septic tanks.

Figures 4.19 and 4.20 (page 124) show the variation in the influent concentration of ammonia to the pilot scale septic tanks over the 25 week test period. Influent ammonia concentrations were between 15.6 and 34.5 mg/l NH_3-N over that period (x = 27.1 mg/l NH_3-N). The removal of ammonia occurred in both chambers 1 and 2 and in the Biolat chamber of the septic tanks (Table 4.2, page 118 and Figures 4.33 and 4.34, page 131). An average value of 70% removal was achieved for ammonia removal in the unaerated tanks over the investigation period. Of this value, 40% occurred in the first two chambers while 30% removal was observed in the Biolat chamber. Similarly a corresponding value of 78% was achieved for ammonia removal in the aerated tanks, with 48% removal occurring in chambers 1 and 2 and 30% occurring in the Biolat chamber. Figures 4.33 and 4.34 (page 131) show the concentration of ammonia in the final effluent from the unaerated septic tanks varied between 0.7 and 16.3 mg/l NH_3-N (x =6.7 mg/l NH_3-N), while the concentration of ammonia in effluent from the aerated tanks ranged from 0.9 to 15.4 mg/l NH_3-

N (x = 5.2 mg/l NH_3-N). The removal of ammonia was greatest in the aerated septic tanks i.e. an average of 78% removal was observed in the aerated pilot scale septic tanks as opposed to 70% removal in the unaerated septic tanks. Ammonia concentrations were on average lower in chamber two of the aerated septic tanks than in the unaerated septic tanks (Figures 4.19 and 4.20, page 124 and Table 4.2, page 118). An average concentration of 17.6 mg/l NH_3-N was observed in chamber two of the unaerated pilot scale septic tanks over the 25 week test period, while a corresponding value of 13.5 mg/l NH_3-N was observed in the aerated tanks.

As shown in Table 4.2 (page 118) and Figures 4.21 and 4.22 (page 125), the concentration of nitrate in the influent to the pilot scale septic tanks was quite low in comparison to ammonia concentrations, ranging from 0.8 to 6.6 mg/l NO_3-N (x = 3.2 mg/l NO_3-N). Increases in nitrate concentration over influent concentration were observed in chamber 2 of the aerated pilot scale septic tanks during practically all of the investigation period. The average increase in chamber 2 concentrations over influent concentration during the 25 week test period was 88%. Increases in nitrate concentration over influent concentration was observed in chamber 2 of the unaerated septic tanks over only two of the sampling weeks, therefore a net overall decrease in nitrate concentration was observed (i.e. 1%) upon passage of the domestic sewage through the tanks. The values shown in Table 4.2 (page 118) for total removal of nitrate in the pilot scale septic tanks over the 25 week test period were calculated from the difference between influent and effluent nitrate concentration. An average value of 63% was calculated for the unaerated tanks while a value of 42% was determined for the aerated tanks. However, taking into account that nitrate concentrations increased in chambers 1 and 2 of the aerated septic tanks by an average of 88%, a more accurate value for total removal in the Biolat chamber of the aerated septic tanks would be 130%. Figures 4.35 and 4.36 (page 132) demonstrate that nitrate removal occurred predominantly in the Biolat chamber of the septic tank. The concentration of nitrate in effluent leaving the unaerated septic tanks ranged from 0 to 2.5 mg/l NO_3-N (x = 1.3 mg/l NO_3-N), while the nitrate concentration in the effluent arising from the aerated tanks varied between 0.1 and 5.9 mg/l NO_3-N (x = 2.0 mg/l NO_3-N). Aeration of the pilot scale septic tanks served to increase the nitrate content of the domestic sewage in chambers 2 therefore, higher concentrations of nitrate were observed in the effluent from the aerated tanks.

Table 4.2 (page 118) and Figures 4.23 and 4.24 (page 126) show the concentration of *E. coli* in the influent to the pilot scale septic tank. Influent *E. coli* numbers ranged between 1.1×10^6 and 3.1×10^7 cfus/100 mls (x = 8.05×10^6 cfus /100 mls). Figures 4.37 and 4.38 (page 133) illustrate that the majority of *E. coli* were removed in chambers 1 and 2 of the pilot scale septic tanks. An average value of 97% was achieved for the total removal of *E. coli* in the unaerated tanks over the 25 week sampling period. Of this value, 73% removal occurred in the first two chambers, while 24% removal was observed in the Biolat chamber. The corresponding value observed for total removal in the aerated tanks was 96%, of which 84% was achieved in chambers 1 and 2 and 12% removal was due to the Biolat chamber. Table 4.2 (page 118) and Figures 4.23 and 4.24 (page 126) show that the concentration of *E. coli* in the final effluent varied between 1.5 x 10^4 and 7.2 x10^5 for the unaerated tanks (x = 2.1 x 10 ^{5}), and from 3.6 x 10^3 to 9.4 x 10^5 in the aerated tanks (x = 2.4 x 10^5). The influence of aeration on the removal of *E. coli* served to increase their removal rate in chambers one and two as compared to chambers one and two of the unaerated pilot scale septic tanks. However, the final removal rates achieved in both the aerated and unaerated pilot scale septic tanks were similar.

	BOD		COD		SS		Phosphate	
	Tanks 1 &2	**Tanks 3&4**	**Tanks 1 &2**	**Tanks 3&4**	**Tanks 1 &2**	**Tanks 3&4**	**Tanks 1 &2**	**Tanks 3&4**
Influent conc. (mean)	150	150	240	240	71	71	4.9	4.9
Influent conc. (range)	66 to 200	66 to 200	120 to 456	120 to 456	46 to 117	46 to 117	2.0 to 14.6	2.0 to 14.6
Chamber 2 conc.(mean)	71	52	116	116	4	9	4.4	4.1
Chamber 2 conc. (Range)	39 to 116	25 to 83	69 to 264	67 to 218	2 to 6	2 to 7	1.7 to 13.6	1.6 to 11.5
Effluent conc. (Mean)	63	50	107	96	1.0	1.0	1.6	1.6
Effluent conc. (range)	37 to 110	19 to 74	64 to 228	68 to 134	1 to 3.	1 to 3	0.2 to 4.4	0.0 to 4.7
% Reduction Infl. to C2 (mean)	50.	64	50	50	94	87	16	21
% Reduction Infl. to C2 (range)	34 to 77	45 to 82	35 to 78	33 to 73	88 to 98	78 to 93	-14. to 53	-10 to 53
% Reduction in Biolat (mean)	6	1	3	6	4	11	53	49
% Reduction in Biolat (range)	0 to 18	0 to 8	0 to 8	0 to 21	1 to 12	6 to 17	22 to 100	15 to 68
% Reduction Total (mean)	56	65	53	56	98	98	69	70
% Reduction Total (range)	44 to 80	46 to 82	38 to 79	43 to 74	95 to 99	95 to 99	35 to 94	35 to 100

ctd. overleaf

	Ammonia		Nitrate		*E. Coli*	
ctd.	**Tanks 1 &2**	**Tanks 3&4**	**Tanks 1 &2**	**Tanks 3&4**	**Tanks 1 &2**	**Tanks 3&4**
Influent conc. (mean)	27.1	27.1	3.2	3.2	8.05 E+6	8.05 E+6
Influent conc. (range)	15.6 to 34.5	15.6 to 34.5	0.8 to 6.6	0.8 to 6.6	1.1 E+6 to 3.1 E+7	1.1 E+6 to 3.1 E+7
Chamber 2 conc.(mean)	17.6	13.5	3.1	5.9	1.6 E+6	1.3 E+6
Chamber 2 conc. (range)	8.8 to 21.1	1.7 to 26.3	0.6 to 6.1	1.0 to 9.0	7.3 E+4 to 3.7 E+6	3.5 E+4 to 5.2 E+6
Effluent conc. (mean)	6.7	5.2	1.3	2.0	2.1 E+5	2.4 E+5
Effluent conc. (range)	0.7 to 16.3	0.9 to 15.4	0.0 to 2.5	0.1 to 5.9	1.5 E+4 to 7.2 E+5	3.6 E+3 to 9.4 E+5
% Reduction Infl. to C2 (mean)	40	48	1	-88	73	84
% Reduction Infl. to C2 (range)	11 to 64	8 to 92	-60 to 33	-262 to 5	-38 to 93	66 to 98
% Reduction in Biolat (mean)	30	30	62	130	24	12
% Reduction in Biolat (range)	10 to 50	4 to 72	23 to 130	47 to 270	5 to 127	2 to 23
% Reduction Total (mean)	70	78	63	42	97	96
% Reduction Total (range)	35 to 98	34 to 96	30 to 100	8 to 94	89 to 100	89 to 100

Table 4.2. Summary table of the results obtained in the analysis of various pollutants entering the pilot scale BMS septic tanks. Included in the table are the concentrations of each of the pollutants observed and the level of treatment afforded at each stage in the tanks

Note; *E. Coli* concentrations expressed as cfus/100 mls. All other values are expressed as mg/l except where otherwise stated.

Key: Tanks 3 &4 were aerated while Tanks 1&2 were not aerated

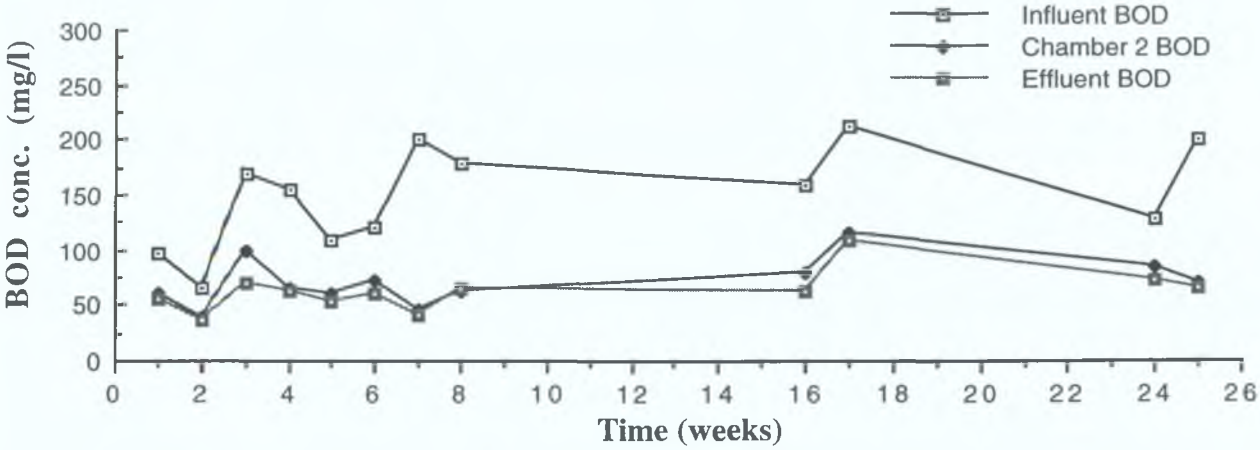

Fig 4.11. The variation in influent, effluent and chamber two BOD concentration in the pilot scale BMS septic tanks (Tanks 1 & 2) over a 25 week period.

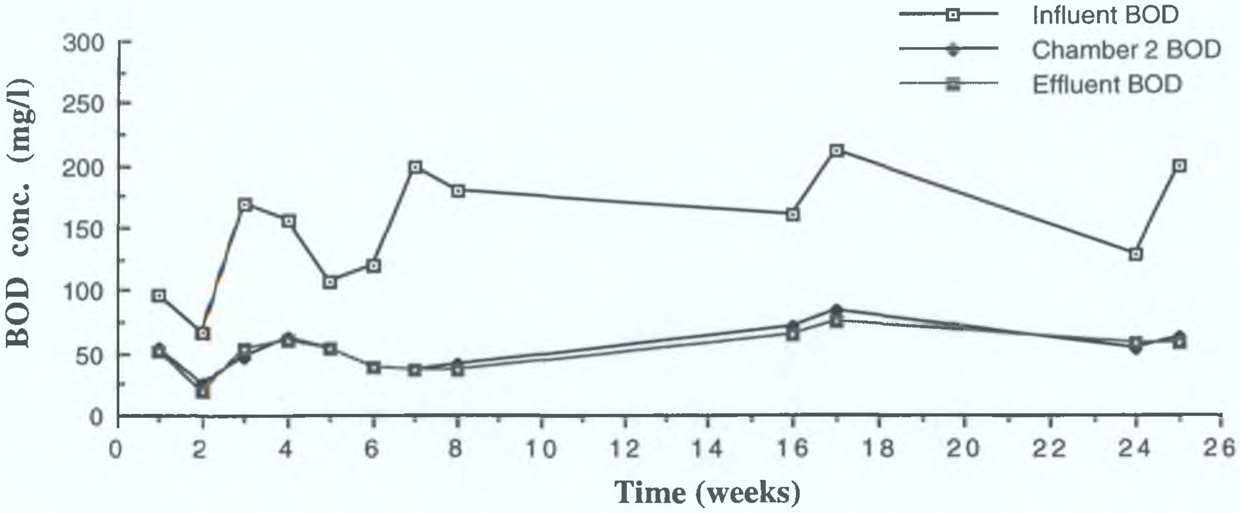

Fig 4.12. The variation in influent, effluent and chamber two BOD concentration in the pilot scale BMS septic tanks (Tanks 3 & 4) over a 25 week period.

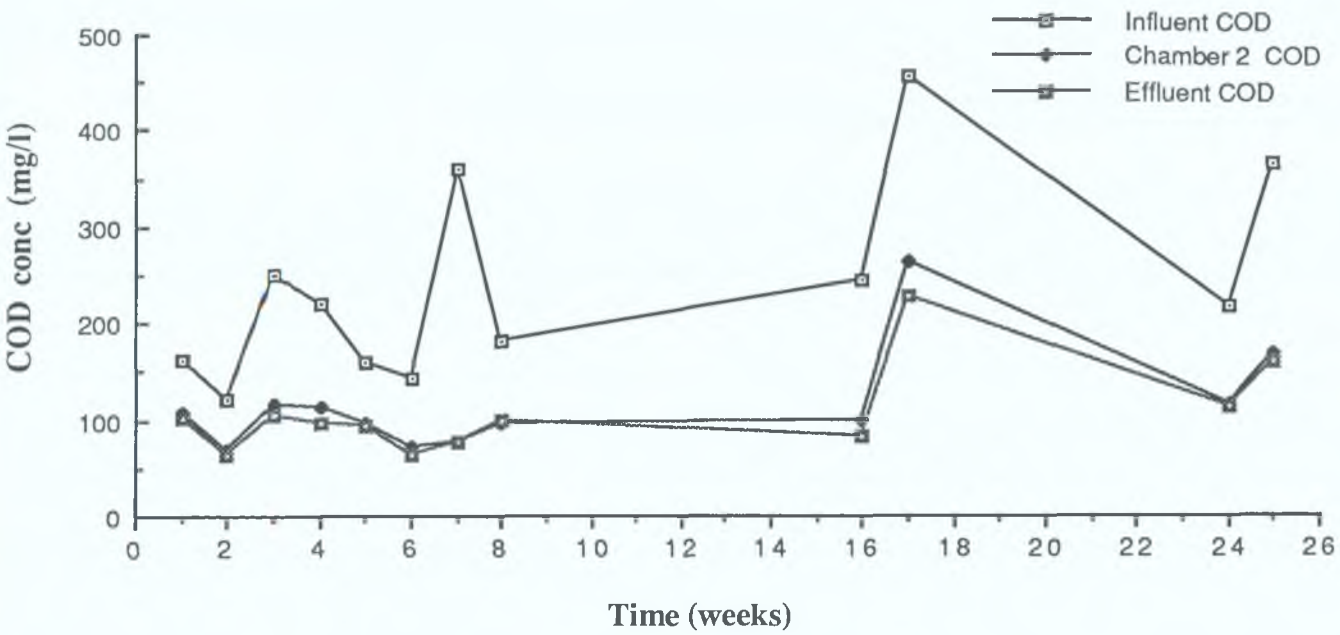

Fig 4.13. The variation in influent, effluent and chamber two COD concentration in the pilot scale BMS septic tanks (Tanks 1 & 2) over a 25 week period.

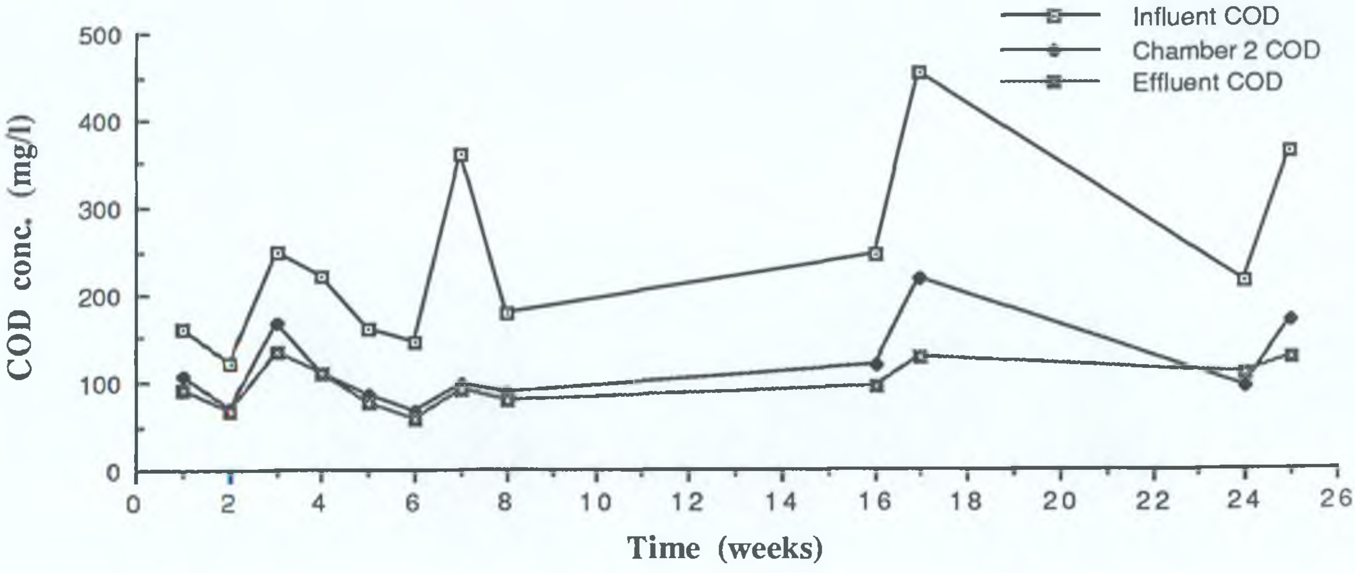

Fig 4.14. The variation in influent, effluent and chamber two COD concentration in the pilot scale BMS septic tanks (Tanks 3 & 4) over a 25 week period.

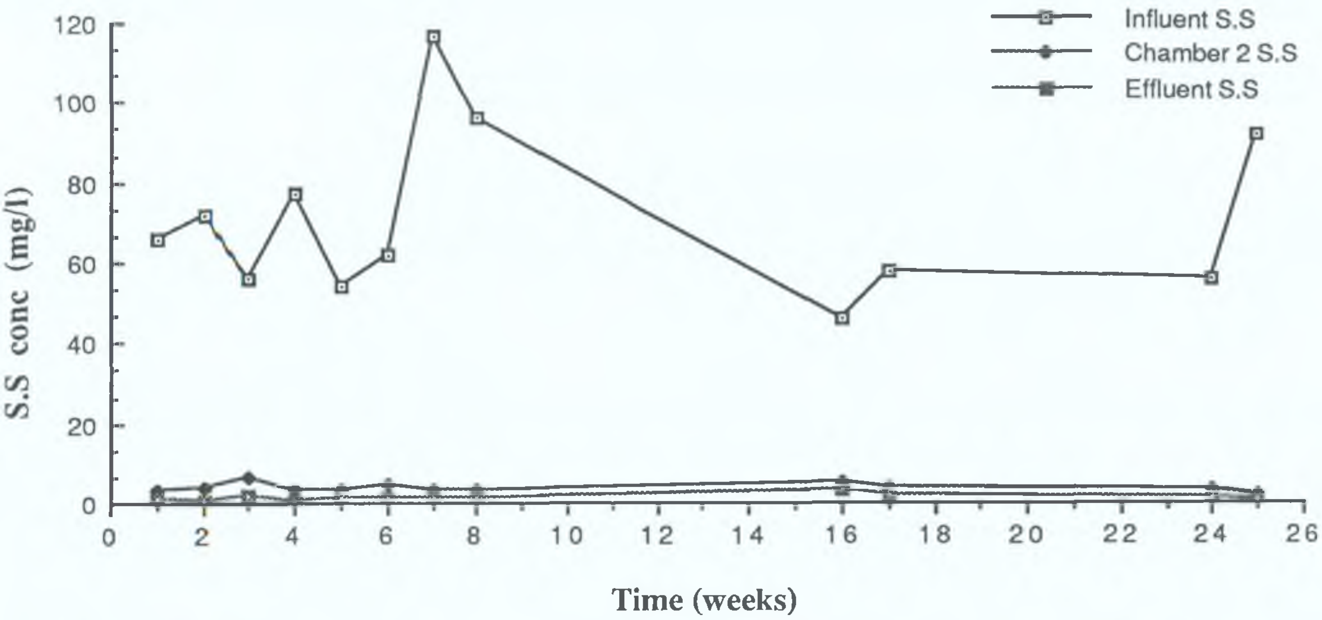

Fig 4.15. The variation in influent, effluent and chamber two SS concentration in the pilot scale BMS septic tanks (Tanks 1 & 2) over a 25 week period.

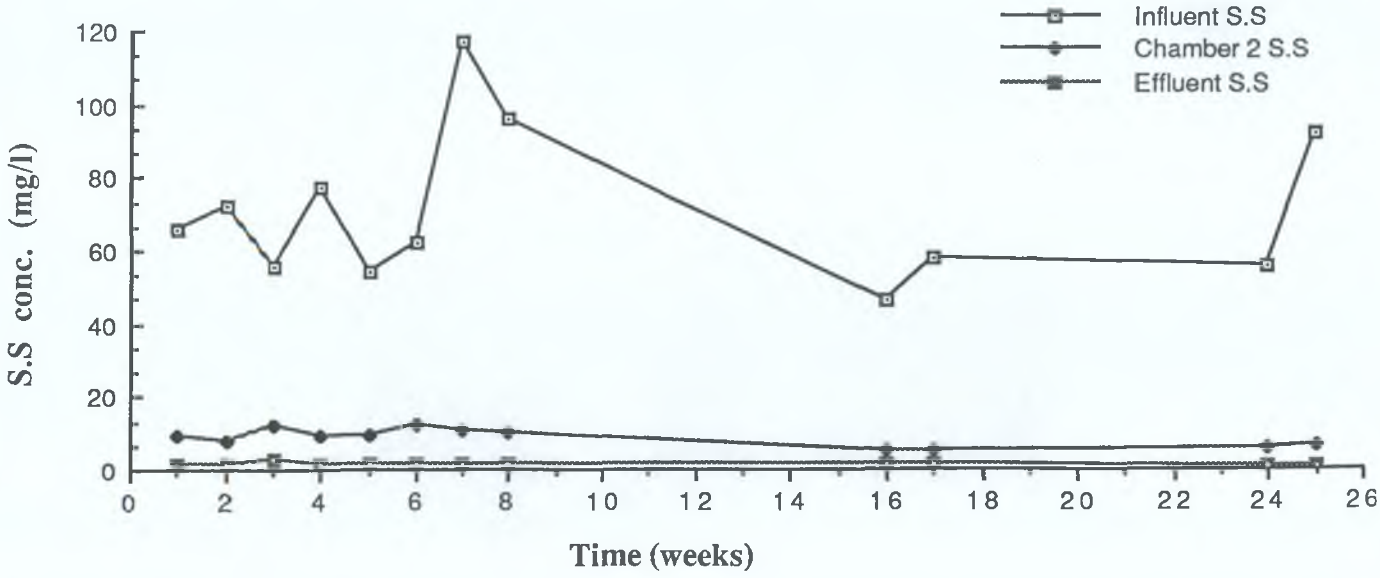

Fig 4.16. The variation in influent, effluent and chamber two SS concentration in the pilot scale BMS septic tanks (Tanks 3 & 4) over a 25 week period.

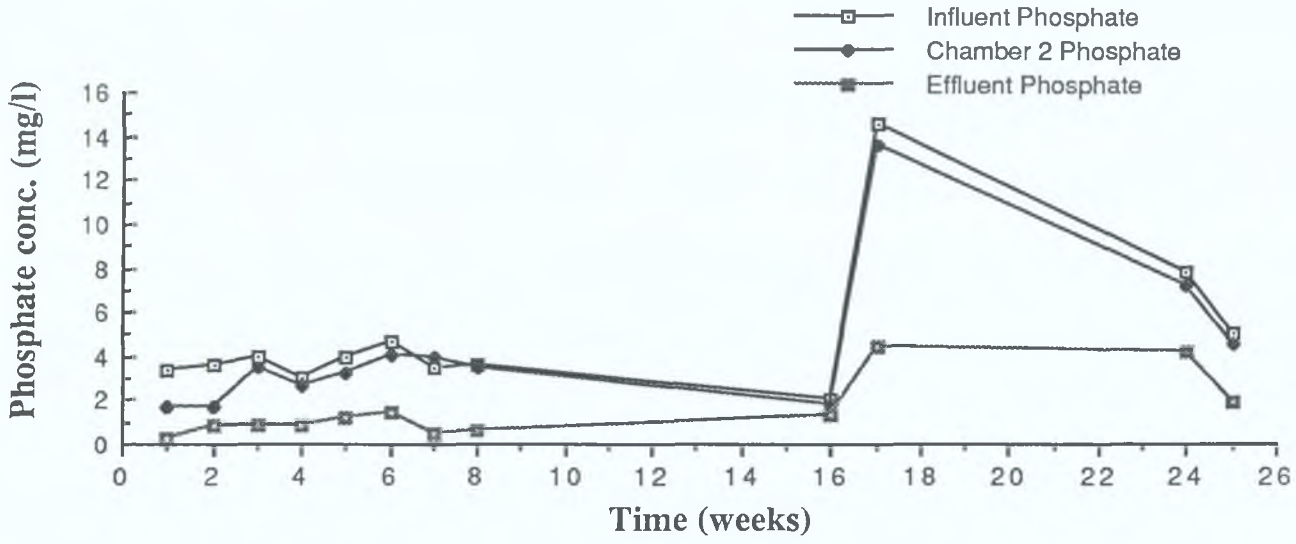

Fig 4.17. The variation in influent, effluent and chamber two phosphate concentration in the pilot scale BMS septic tanks (Tanks 1 & 2) over a 25 week period.

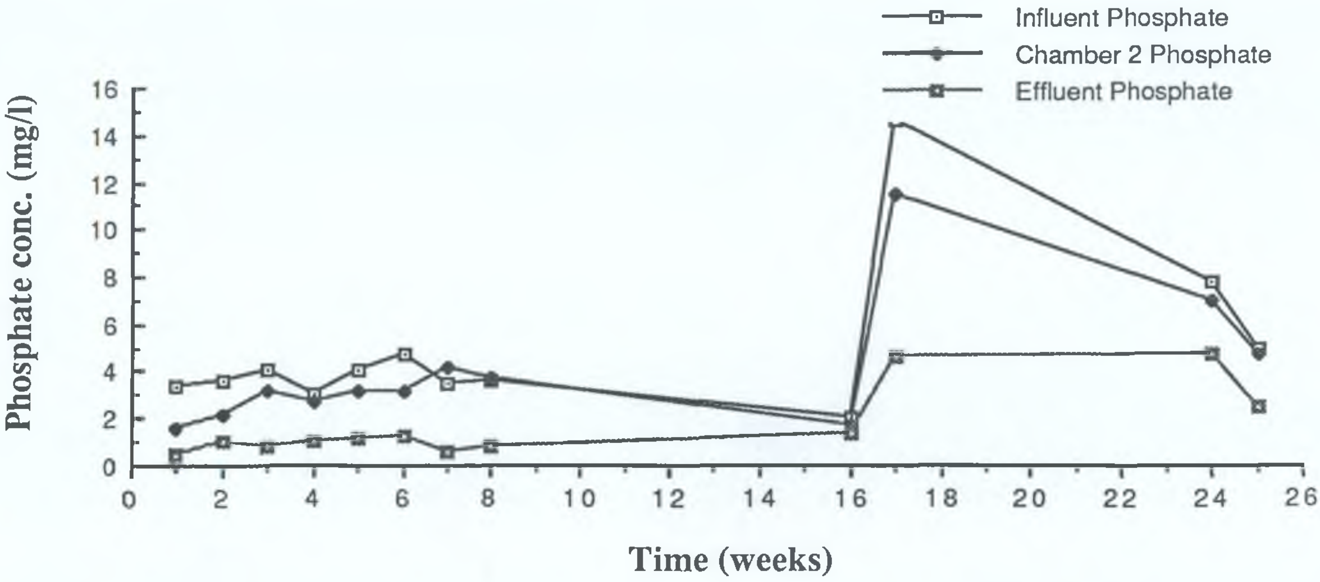

Fig 4.18. The variation in influent, effluent and chamber two phosphate concentration in the pilot scale BMS septic tanks (Tanks 3 & 4) over a 25 week period.

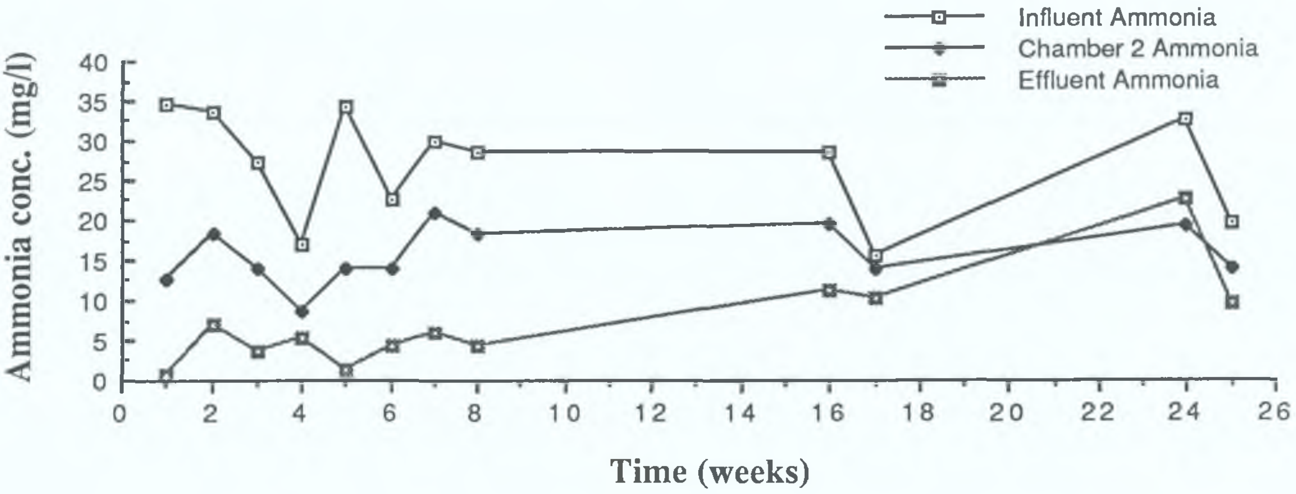

Fig 4.19 The variation in influent, effluent and chamber two ammonia concentration in the pilot scale BMS septic tanks (Tanks 1 & 2) over a 25 week period.

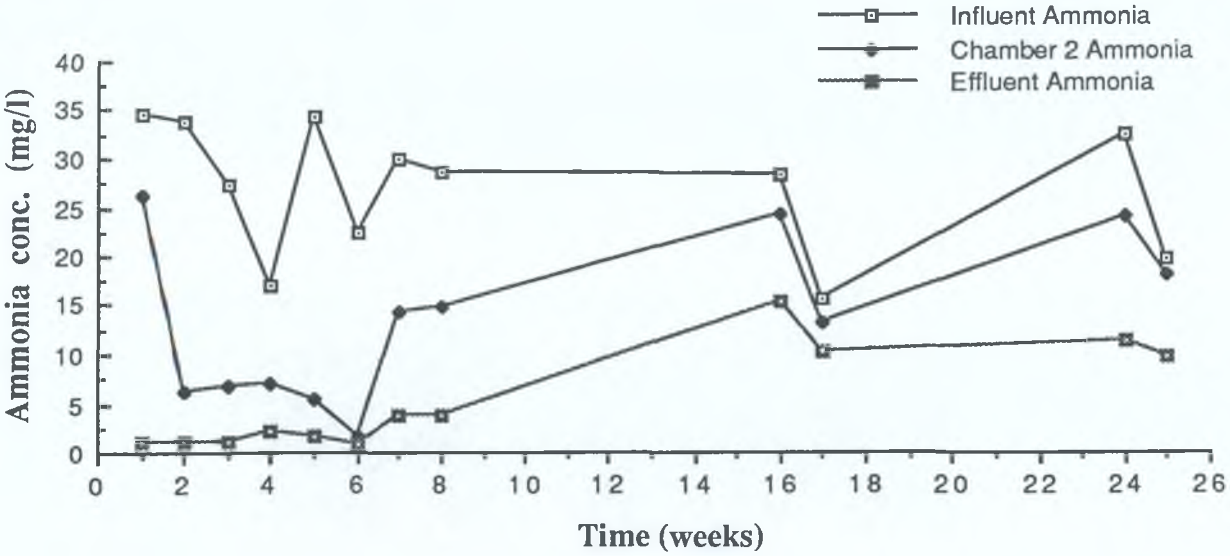

Fig 4.20 The variation in influent, effluent and chamber two ammonia concentration in the pilot scale BMS septic tanks (Tanks 3 & 4) over a 25 week period.

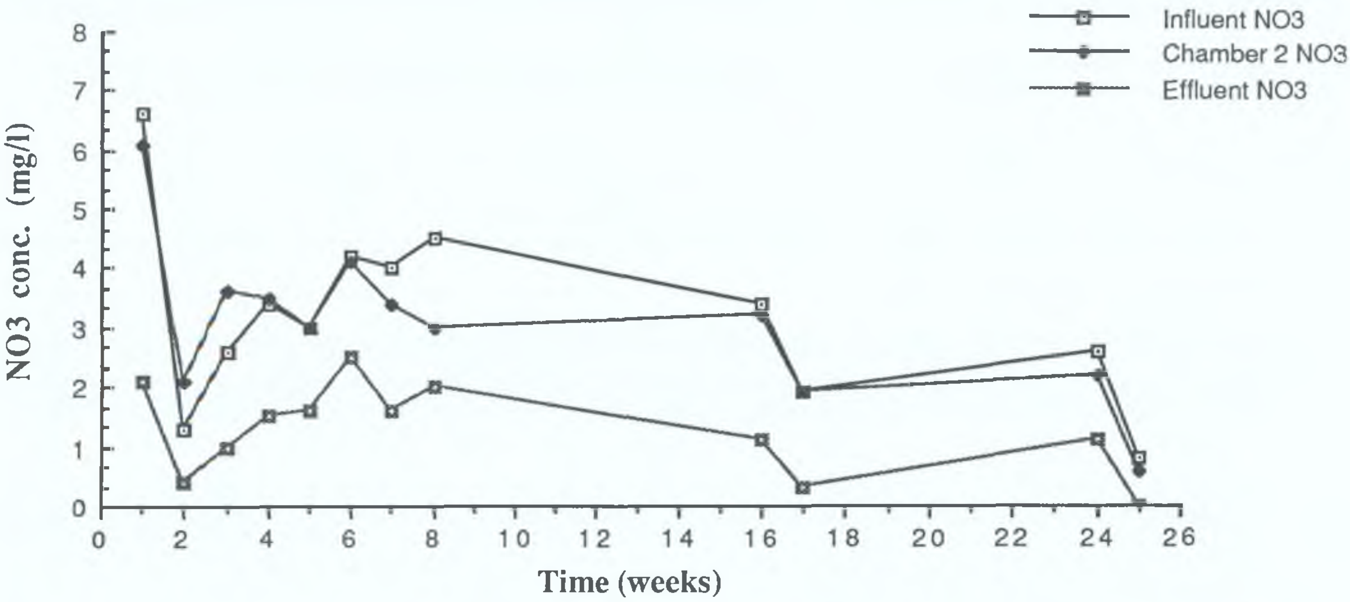

Fig 4.21. The variation in influent, effluent and chamber two nitrate concentration in the pilot scale BMS septic tanks (Tanks 1 & 2) over a 25 week period.

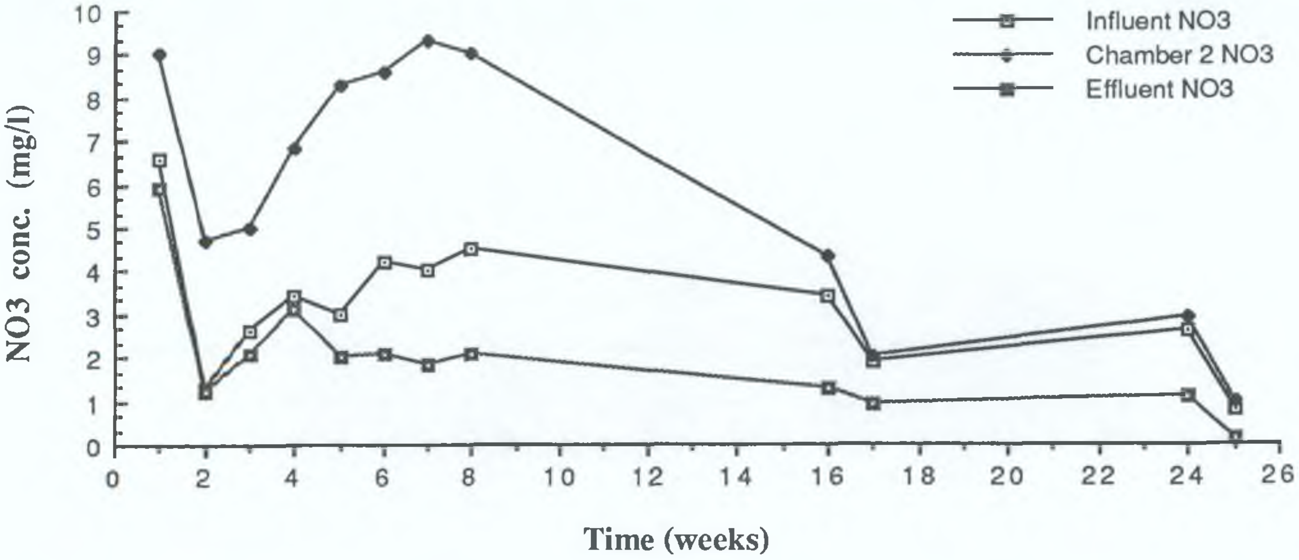

Fig 4.22.The variation in influent, effluent and chamber two nitrate concentration in the pilot scale BMS septic tanks (Tanks 3 & 4) over a 25 week period.

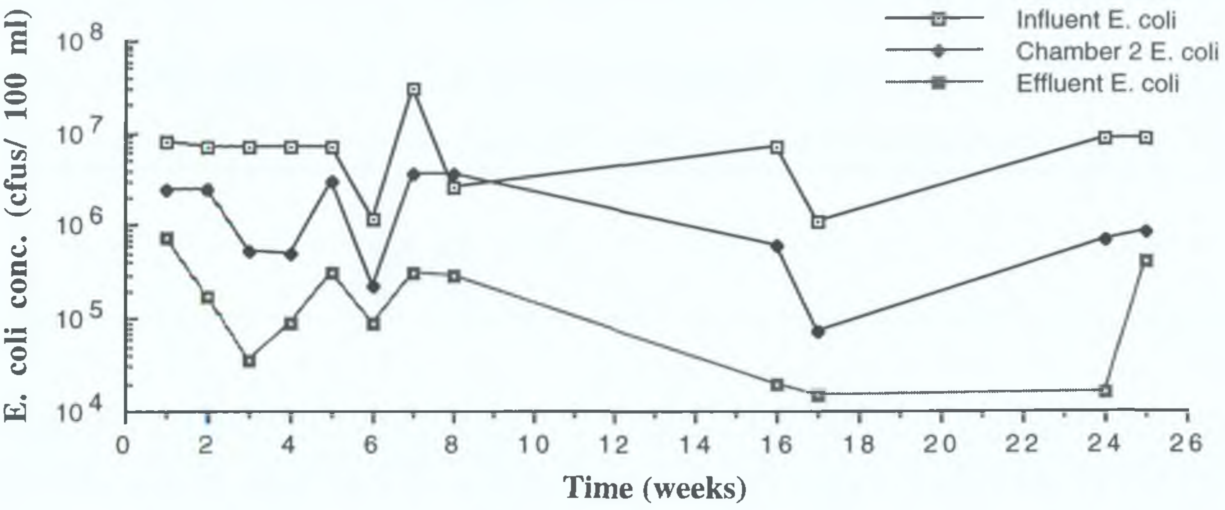

Fig 4.23 The variation in influent, effluent and chamber two *E. coli* concentrations in the pilot scale BMS septic tanks (Tanks 1 & 2) over a 25 week period.

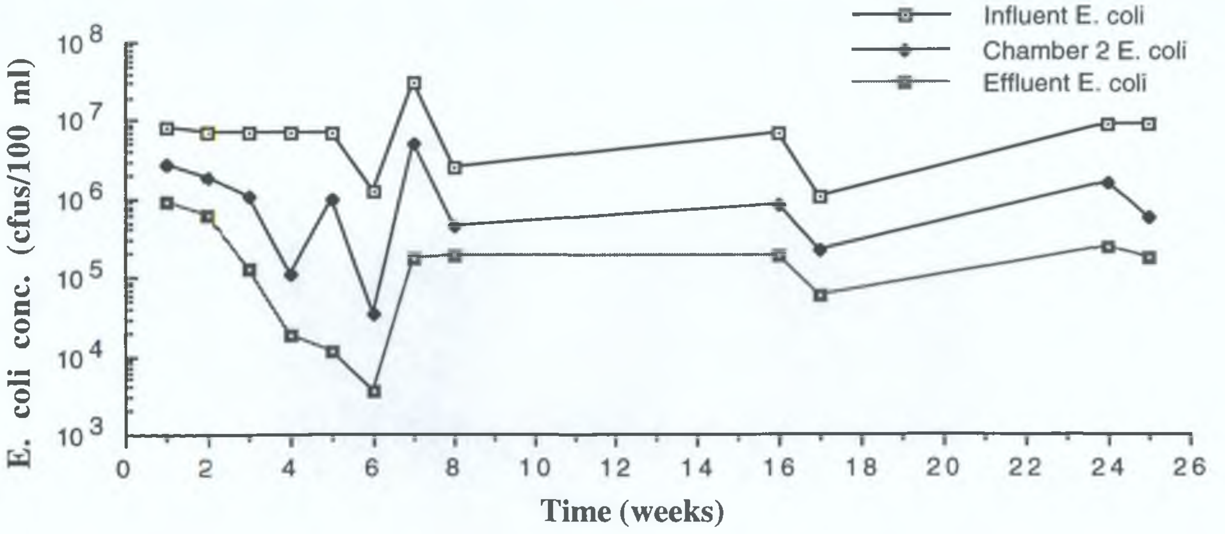

Fig 4.24. The variation in influent, effluent and chamber two *E. coli* concentrations in the pilot scale BMS septic tanks (Tanks 3 & 4) over a 25 week period.

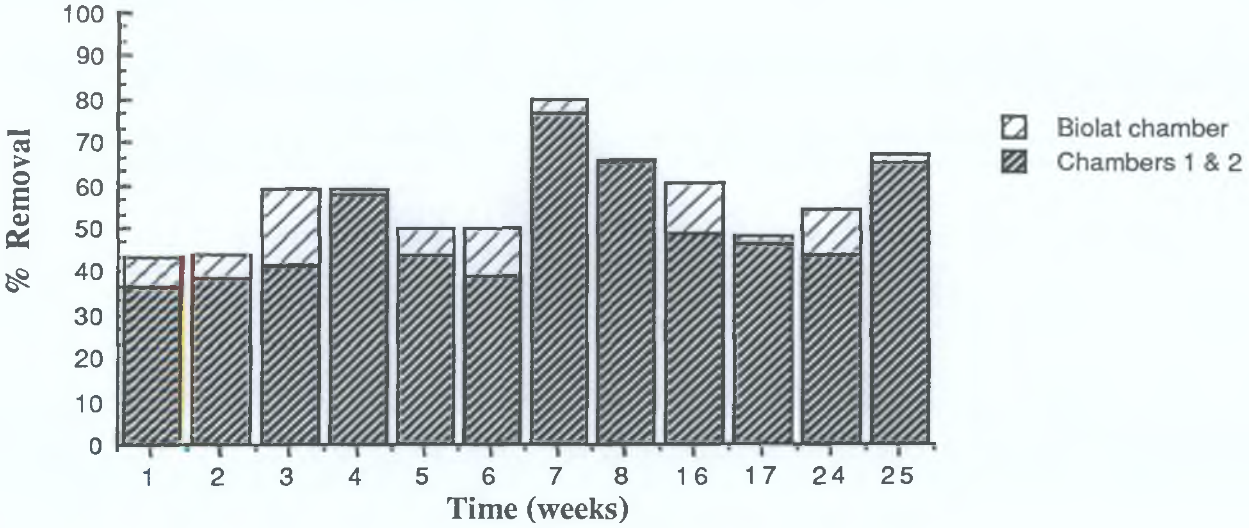

Fig. 4.25 Comparison of the average removal rates achieved for BOD in chambers one and two and in the Biolat chamber of the pilot scale BMS Biolat septic tanks (i.e. Tanks one and two) over a 25 week period.

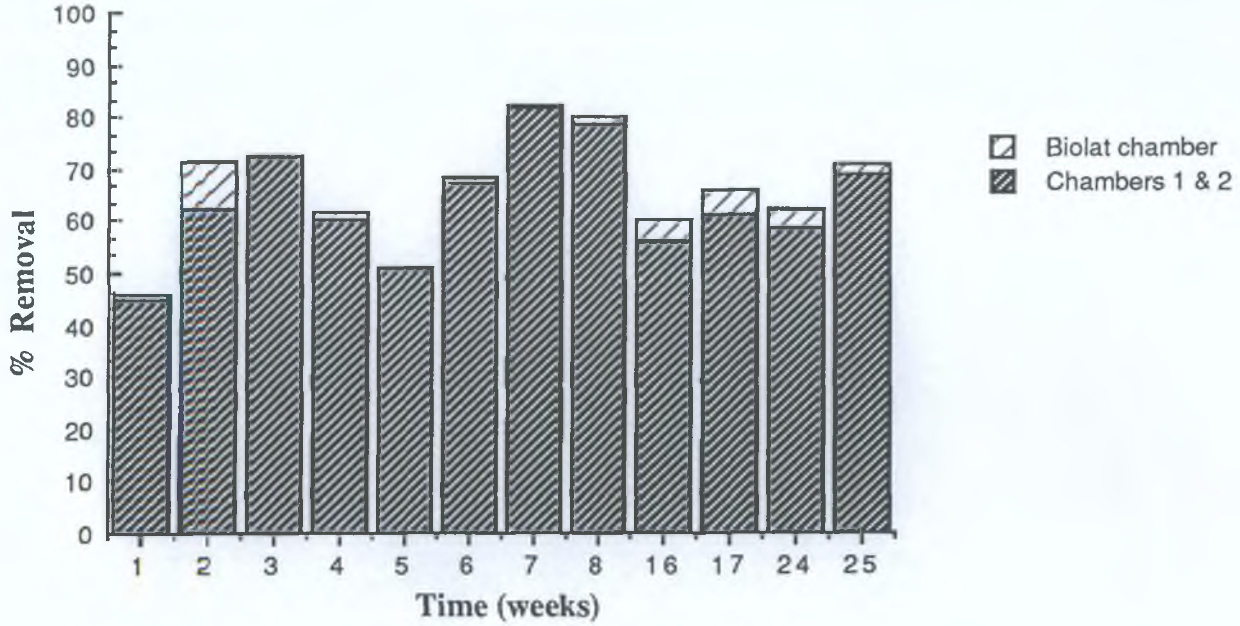

Fig. 4.26 Comparison of the average removal rates achieved for BOD in chambers one and two and in the Biolat chamber of the pilot scale BMS Biolat septic tanks (i.e. Tanks three and four) over a 25 week period.

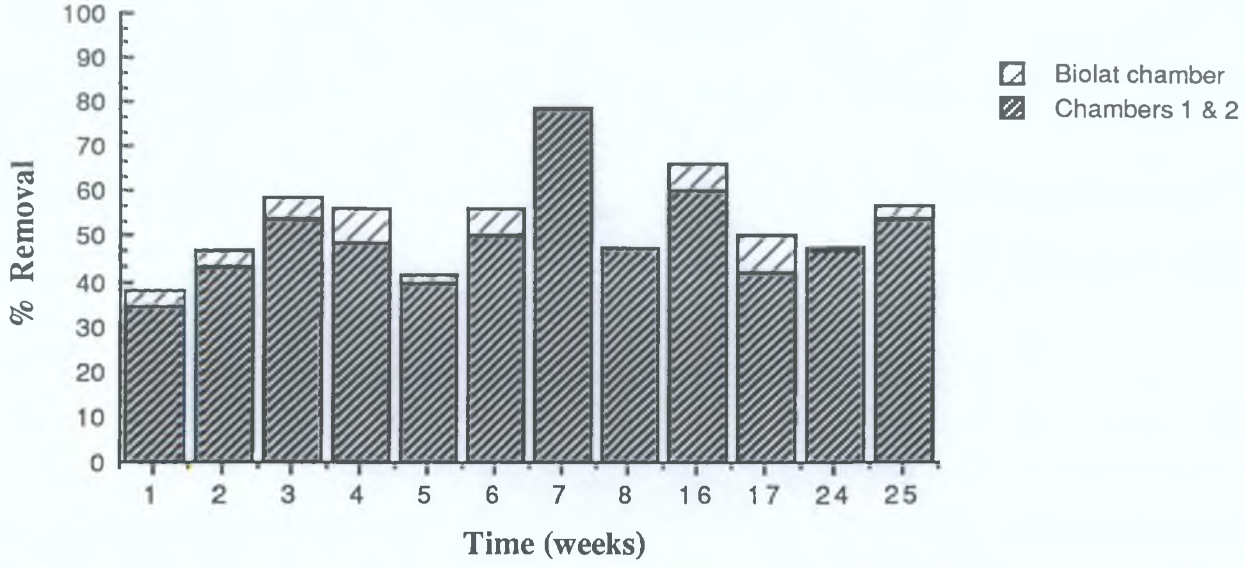

Fig. 4.27 Comparison of the average removal rates achieved for COD in chambers one and two and in the Biolat chamber of the pilot scale BMS Biolat septic tanks (i.e. Tanks one and two) over a 25 week period.

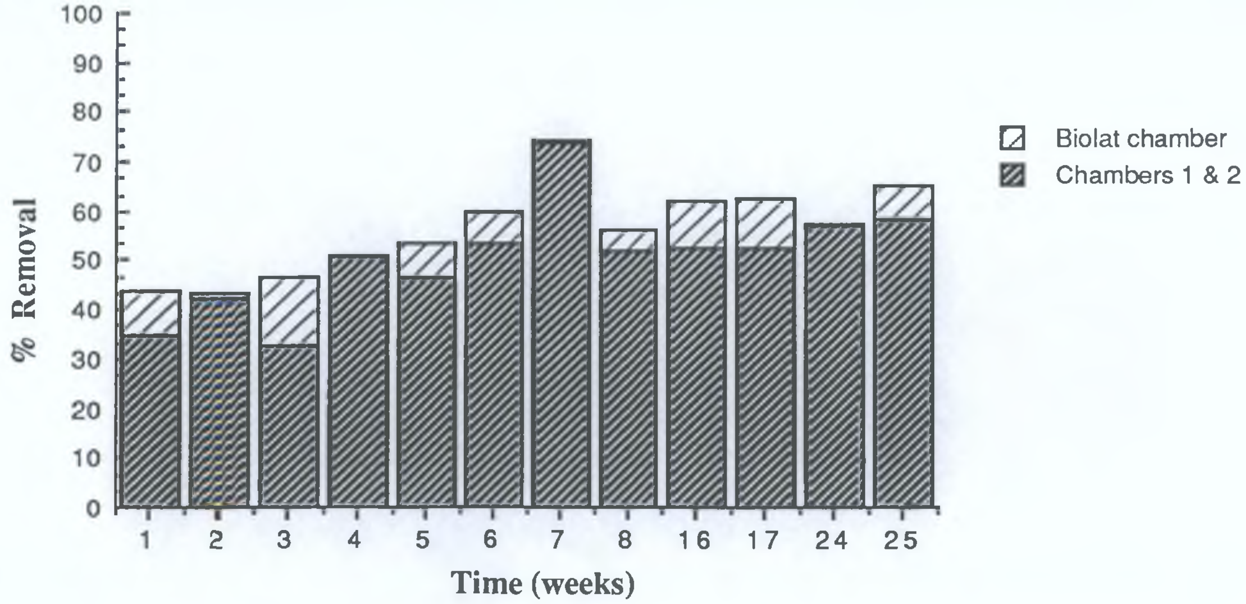

Fig. 4.28 Comparison of the average removal rates achieved for COD in chambers one and two and in the Biolat chamber of the pilot scale BMS Biolat septic tanks (i.e. Tanks three and four) over a 25 week period.

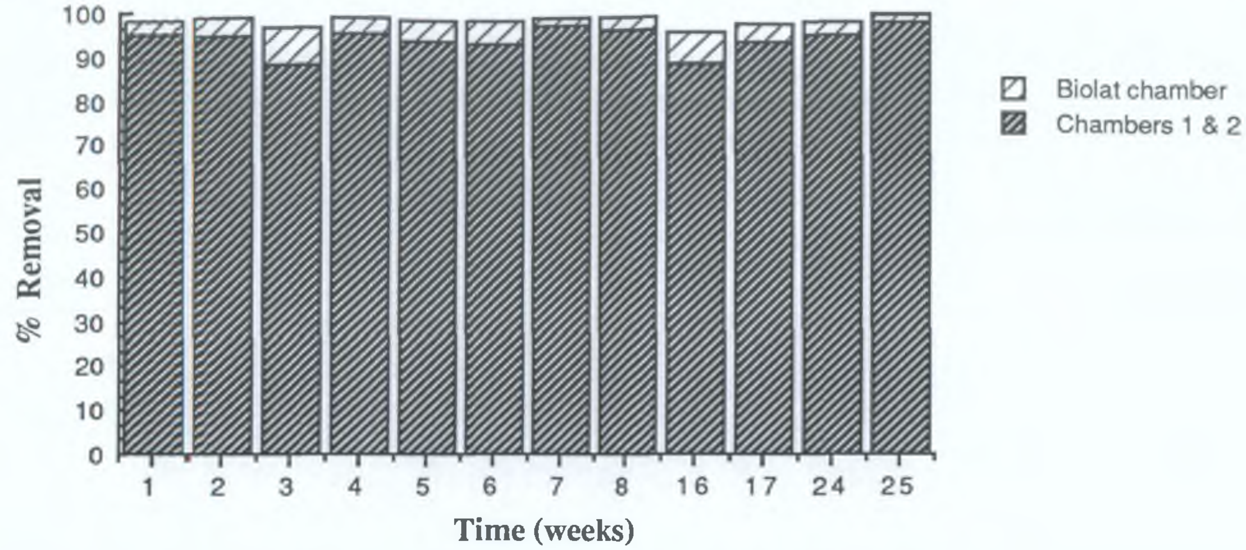

Fig. 4.29 Comparison of the average removal rates achieved for SS in chambers one and two and in the Biolat chamber of the pilot scale BMS Biolat septic tanks (i.e. Tanks one and two) over a 25 week period.

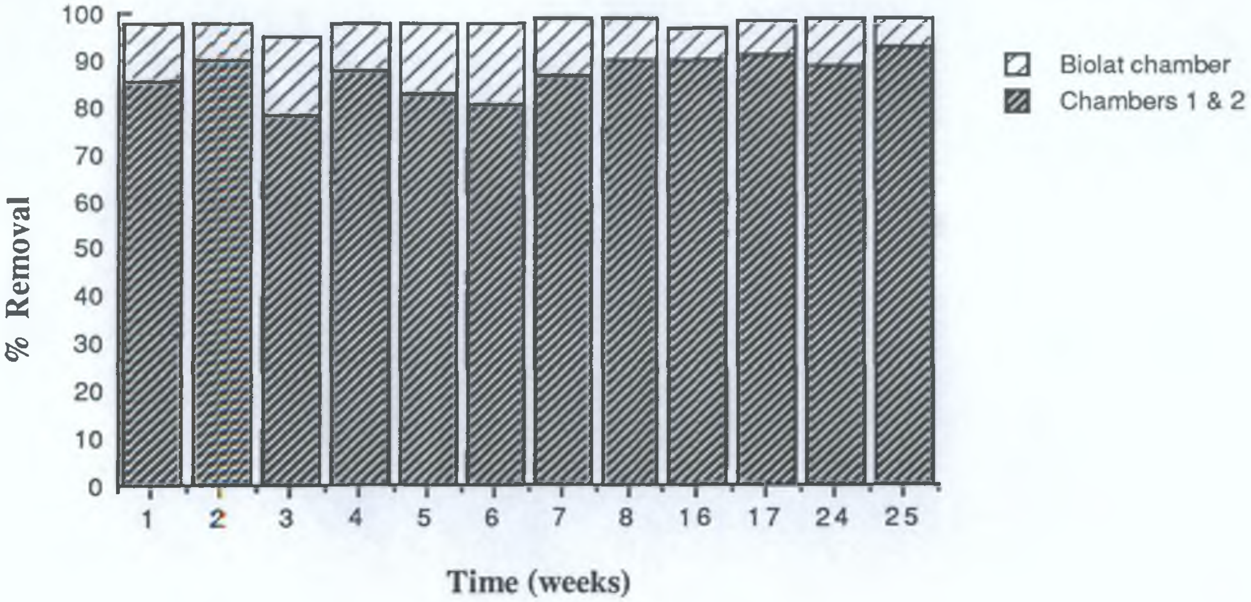

Fig. 4.30 Comparison of the average removal rates achieved for SS in chambers one and two and in the Biolat chamber of the pilot scale BMS Biolat septic tanks (i.e. Tanks three and four) over a 25 week period.

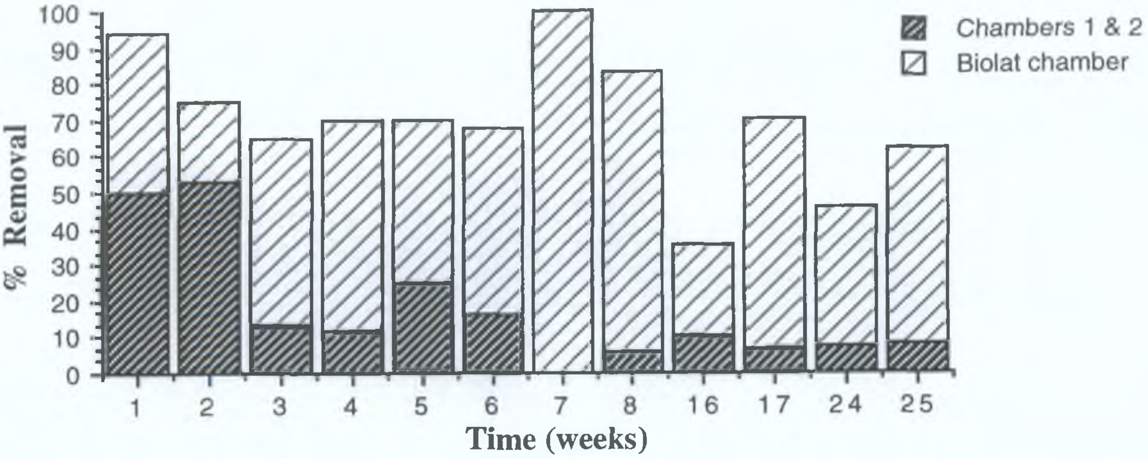

Fig. 4.31 Comparison of the average removal rates achieved for phosphate in chambers one and two and in the Biolat chamber of the pilot scale BMS Biolat septic tanks (i.e. Tanks one and two) over a 25 week period.

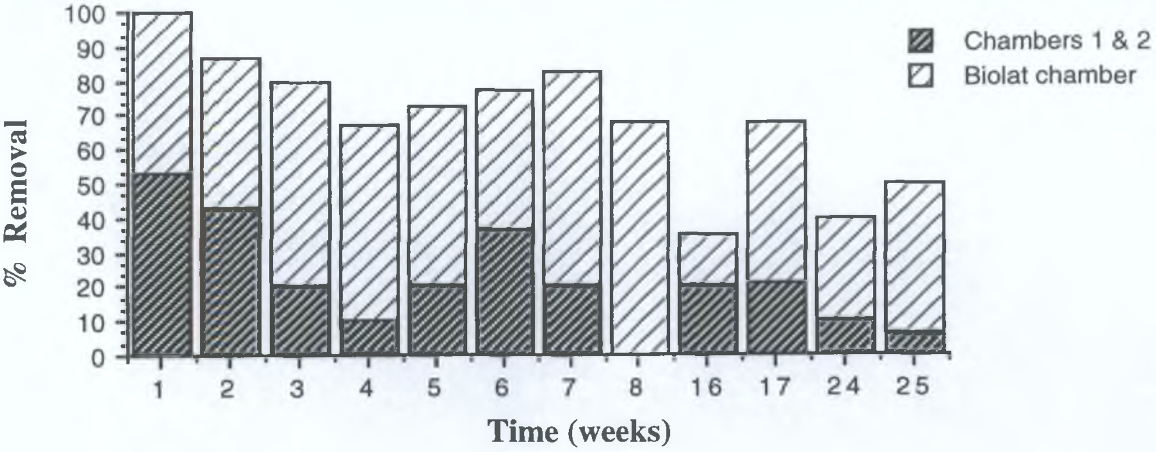

Fig. 4.32 Comparison of the average removal rates achieved for phosphate in chambers one and two and in the Biolat chamber of the pilot scale BMS Biolat septic tanks (i.e. Tanks three and four) over a 25 week period.

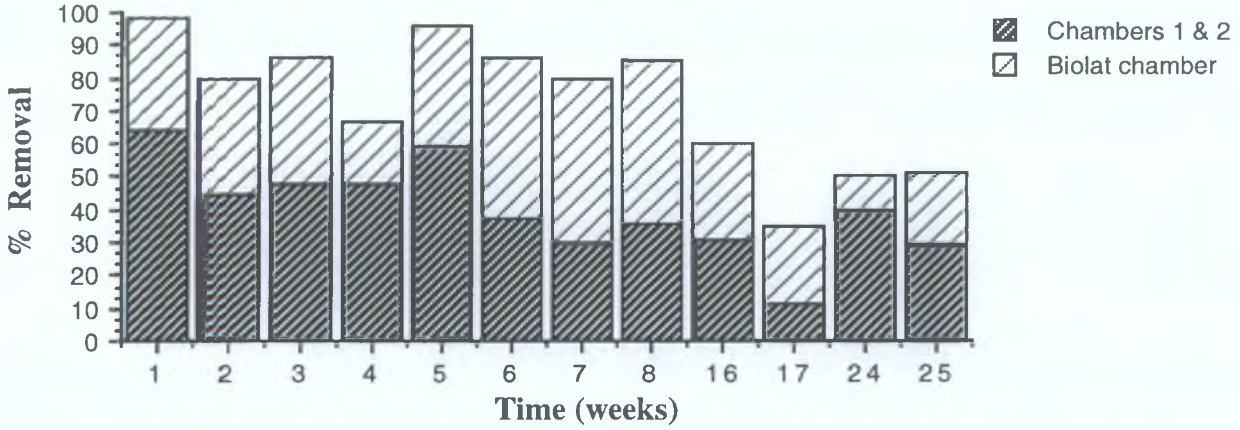

Fig. 4.33 Comparison of the average removal rates achieved for ammonia in chambers one and two and in the Biolat chamber of the pilot scale BMS Biolat septic tanks (i.e. Tanks one and two) over a 25 week period.

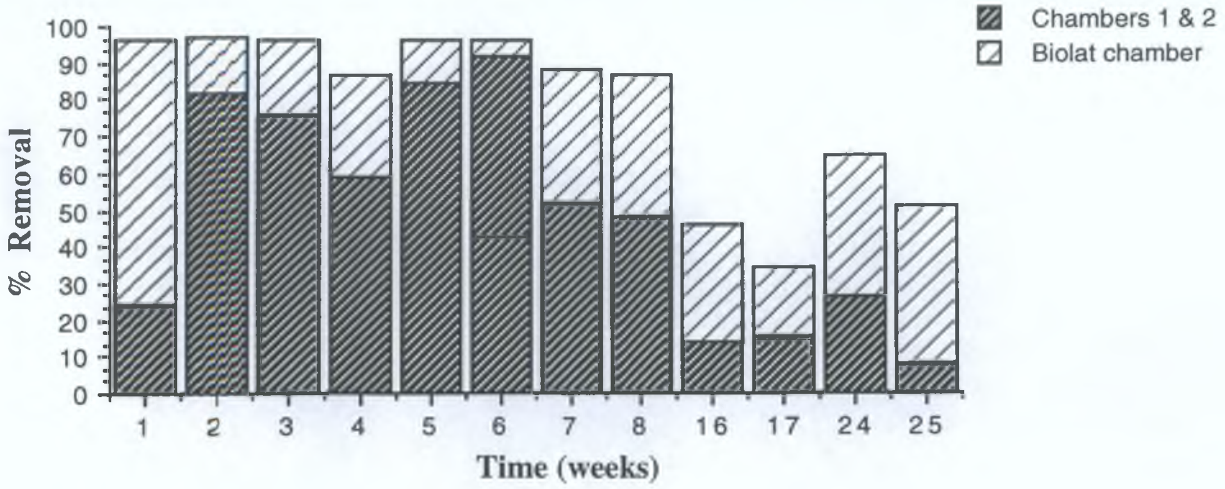

Fig. 4.34 Comparison of the average removal rates achieved for ammonia in chambers one and two and in the Biolat chamber of the pilot scale BMS Biolat septic tanks (i.e. Tanks three and four) over a 25 week period.

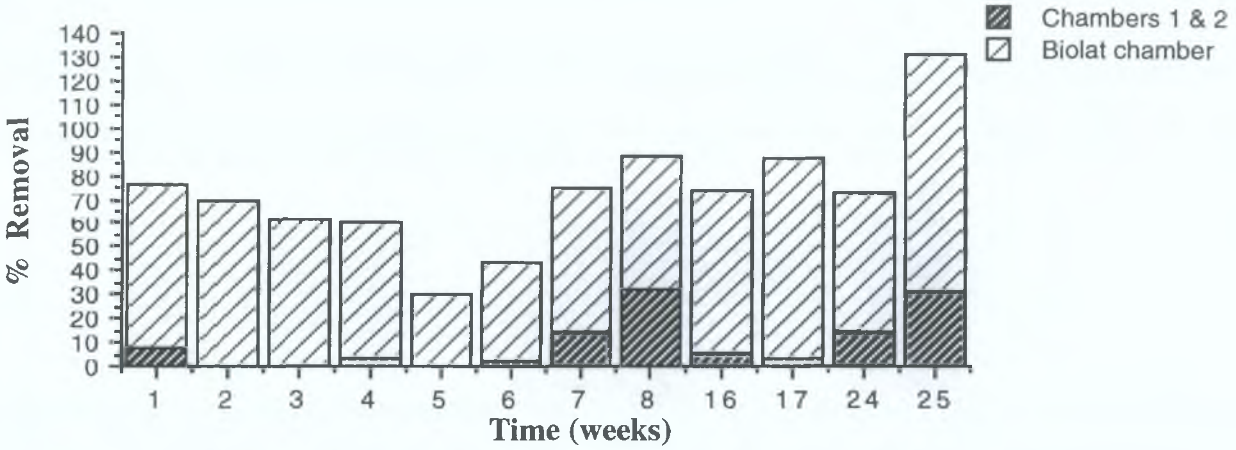

Fig. 4.35 Comparison of the average removal rates achieved for nitrate in chambers one and two and in the Biolat chamber of the pilot scale BMS Biolat septic tanks (i.e. Tanks one and two) over a 25 week period.

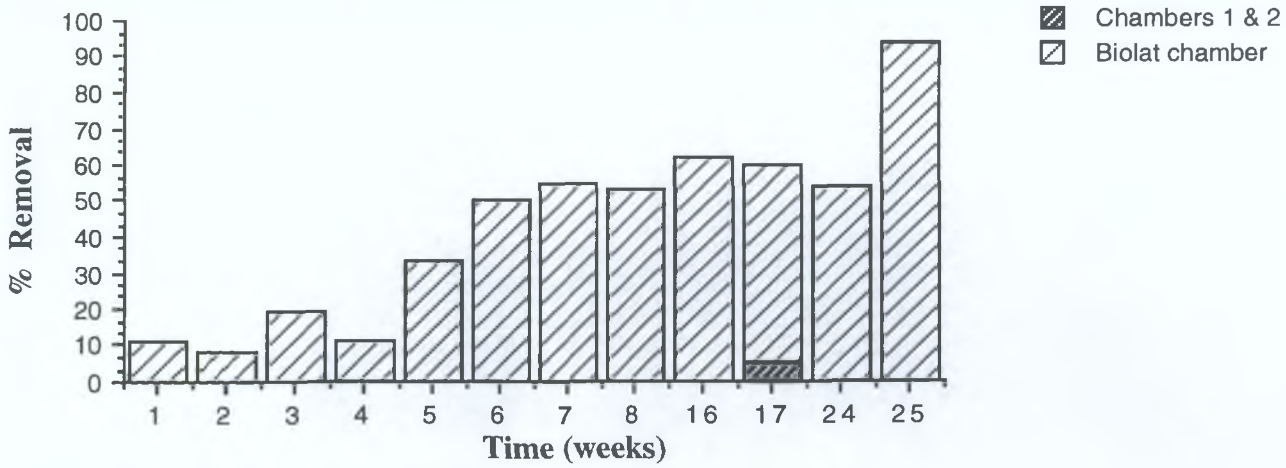

Fig. 4.36 Comparison of the average removal rates achieved for nitrate in chambers one and two and in the Biolat chamber of the pilot scale BMS Biolat septic tanks (i.e. Tanks three and four) over a 25 week period.

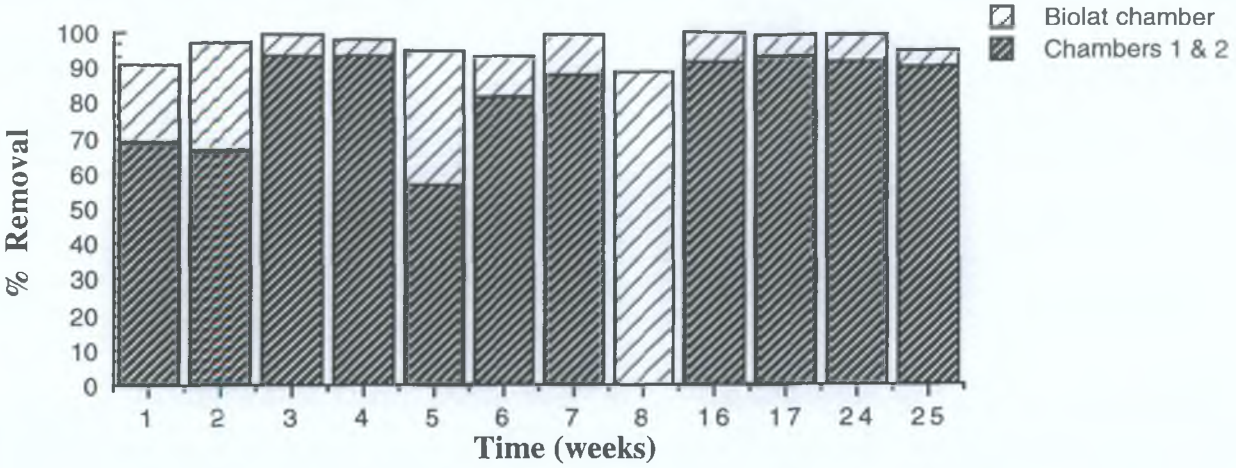

Fig. 4.37 Comparison of the average removal rates achieved for *E. coli* in chambers one and two and in the Biolat chamber of the pilot scale BMS Biolat septic tanks (i.e. Tanks one and two) over a 25 week period.

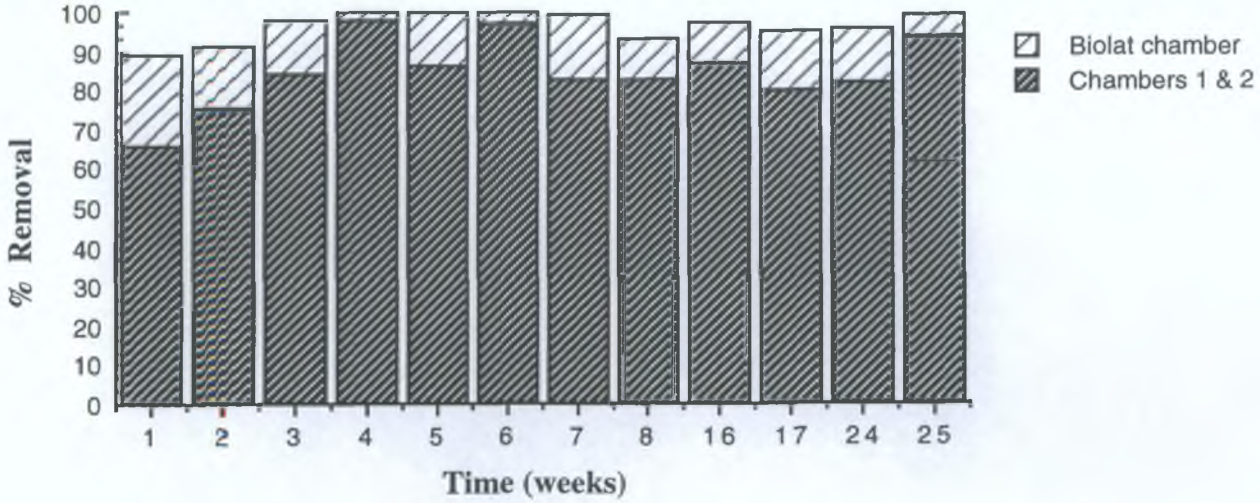

Fig. 4.38 Comparison of the average removal rates achieved for *E. coli* in chambers one and two and in the Biolat chamber of the pilot scale BMS Biolat septic tanks (i.e. Tanks three and four) over a 25 week period.

4.3 Biolat columns

Results from Table 4.3 (page 135) indicated that Biolat was capable of removing phosphate and ammonium when present in either distilled water or domestic sewage. The observed removal rates for both ammonium and phosphate were in excess of 98.5% over the concentrations tested i.e. 50, 100 and 200 mg/l. The results obtained also indicated that over the phosphate / ammonium concentrations tested, concentration did not affect the removal rate i.e. a removal rate of greater than 98.5% was achieved regardless of influent concentration over the five day test period. Biolat was not capable of removing nitrate to any great degree. A maximum removal rate of only 7% was observed in this set of experiments.

The faecal bacteria, *E. coli* appeared to be readily removed from domestic sewage by Biolat. Removal rates in excess of 75% were achieved for an average influent concentration of 1.6×10^6 cfus/100 mls over the five day test period. The removal of *E. coli* from Ringer's solution by Biolat was less successful than its removal from domestic sewage (i.e. less than 40% removal was observed). When various concentrations of the organism, namely 1.6×10^6, 1.9×10^8 and 2.0×10^{10} cfus/100 mls, were prepared in Ringer's solution and passed through Biolat the influence of concentration of *E. coli* on the percentage removal rates was not evident i.e. at a 95% confidence interval there was no difference in the mean values of percentage removal rates obtained.

	Water			Domestic Sewage		
	50 ppm	100 ppm	200 ppm	50 ppm	100 ppm	200 ppm
Phosphate	98.5%	99.6%	99.7%	98.5%	99.6%	99.4%
Ammonium	96.7%	98.0%	98.6%	97.0%	98.2%	98.3%
Nitrate	3.0%	1.0%	1.5%	7.0%	4.8%	4.0%

Table 4.3 The average percentage removal by Biolat of phosphate, ammonium and nitrate prepared in both distilled water and domestic sewage. Note; Averages were obtained from triplicate samples over a five day test period.

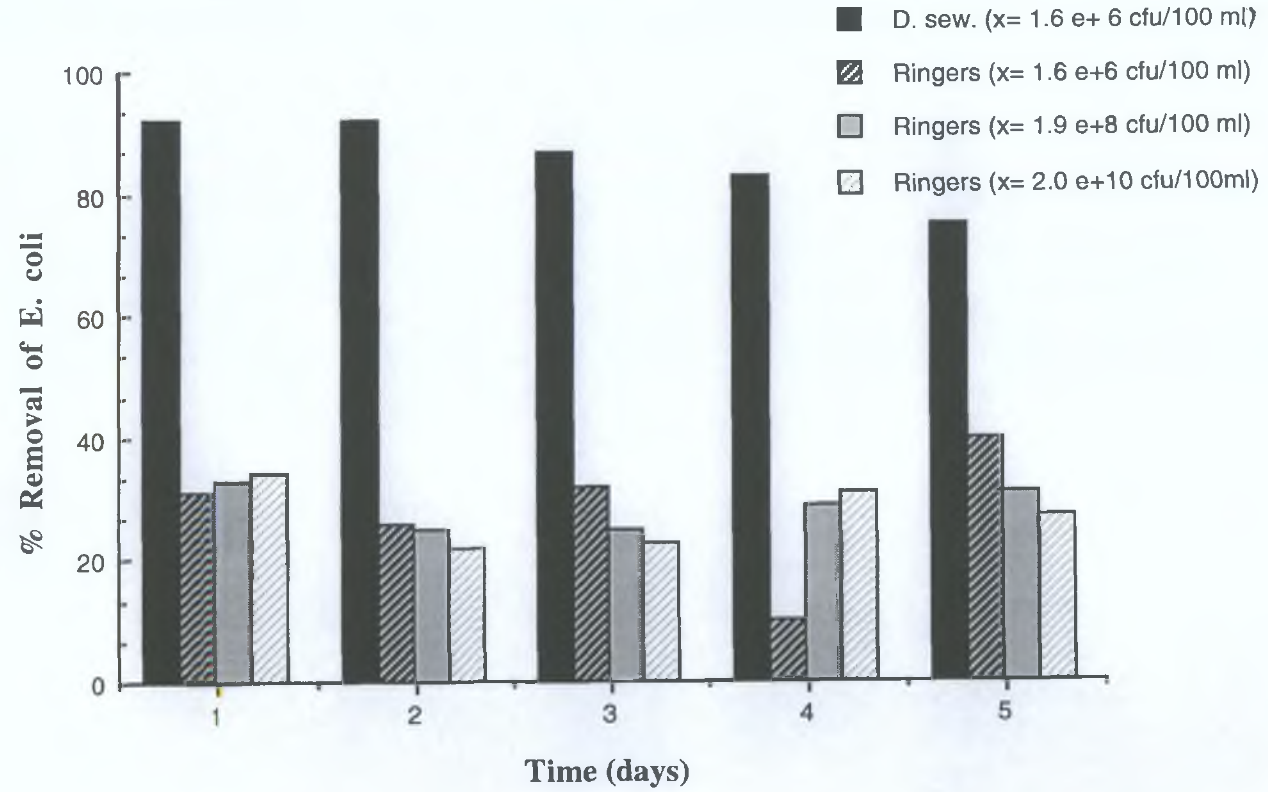

Fig. 4.39 The average removal rates obtained for *E. coli* in Biolat. The removal of *E. coli* was investigated both in domestic sewage (indigenous population) and in Ringer's solution (innoculated with various concentrations of the organism).

4.4 Determination of the removal capacity of Biolat for ammonium and phosphate

- Removal of phosphate by Biolat

Figure 4.40 (page 137) and Table 4.4 (page 138) show the adsorption of various concentrations of phosphate over time by Biolat. Concentrations of 50, 100 and 200 mg/l PO_4-P were used for this experiment and a HRT of one day was allowed. Figure 4.40 (page 137) shows the progressive adsorption of the influent phosphate with time. Initially the curve rose quite steeply indicating a high removal rate of influent phosphate followed by a more gradual rise as the removal rate decreased (Table 4.4, page 138). The curve then levelled off as the Biolat became saturated and was capable of removing no more phosphate. The total mass of phosphate adsorbed by Biolat was dependent on the concentration of phosphate in the influent solution. A total weight of 548.5 mg of phosphate was adsorbed per 600g of Biolat at the 200 mg/l PO_4-P concentration. A total weight of 293.2 mg of phosphate was adsorbed at the 100 mg /l PO_4-P concentration while 164.2 mg of phosphate was adsorbed at the lowest concentration of 50 mg/l PO_4-P.

- Removal of ammonium by Biolat

Figure 4.41(page 137) and Table 4.5 (pages 139) show the adsorption of ammonium by Biolat. The concentrations of ammonium used in the experiments were 50, 100 and 200 mg/l NH_4-N. A one day HRT was allowed.

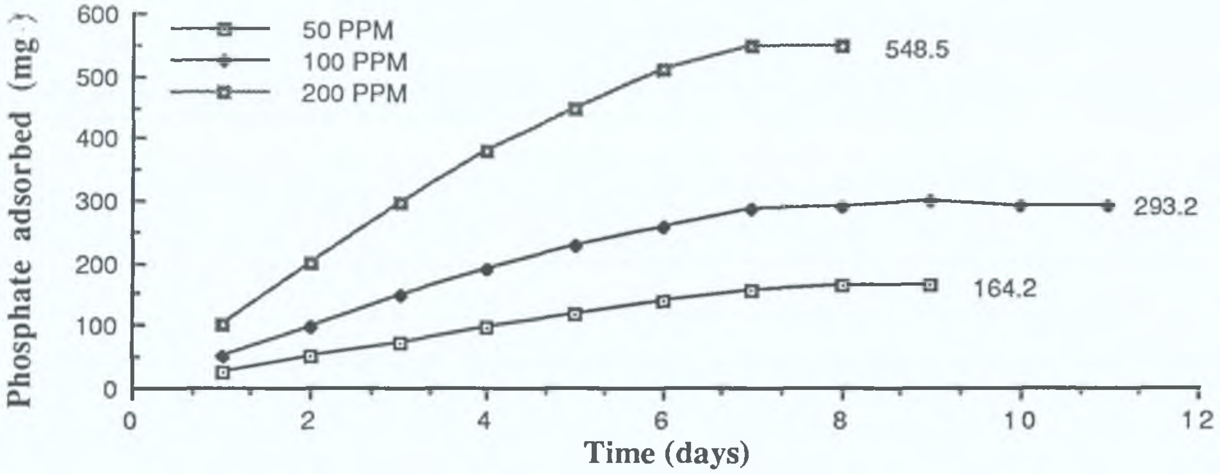

Fig 4.40. The cumulative weight of phosphate adsorbed over time by Biolat at various influent concentrations until saturation level was reached. (HRT of 1day).

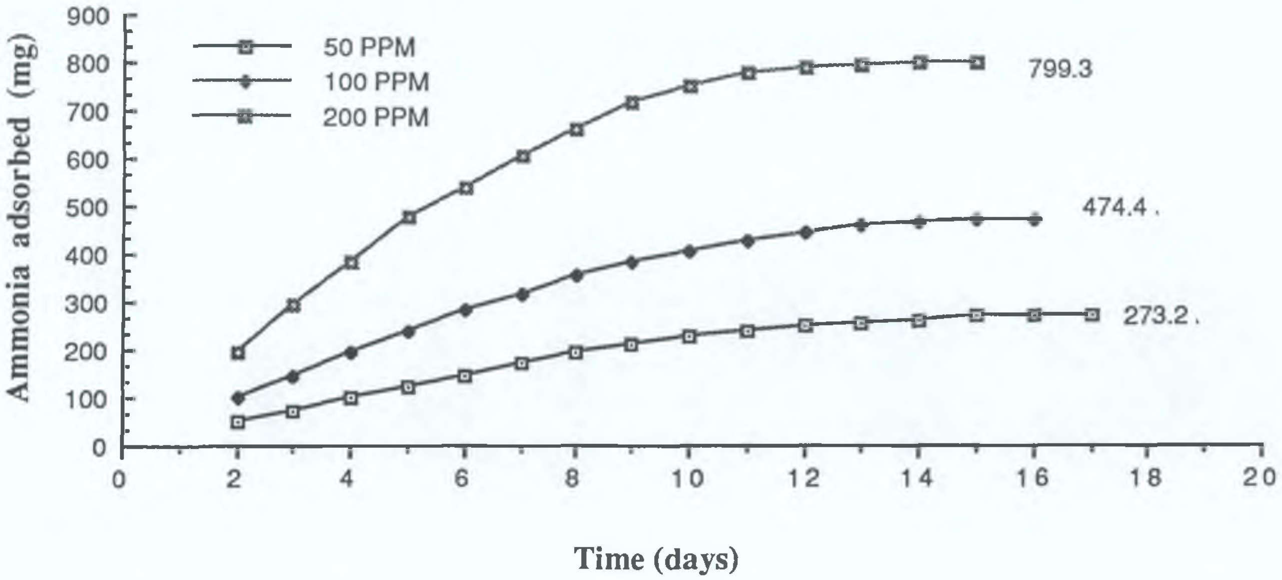

Fig 4.41. The cumulative weight of ammonium adsorbed over time by Biolat at various influent concentrations until saturation level was reached. (HRT of 1day).

Day	Parameter	50 ppm	100 ppm	200 ppm
1	Total mg PO_4 P added	25.00	50.00	100.00
	mg removed daily	25.00	50.00	100.00
	Total mg removed	25.00	50.00	100.00
	% removal daily	(100.00)	(100.00)	(100.00)
2	Total mg PO_4 P added	50.00	100.00	200.00
	mg removed daily	23.95	48.90	99.00
	Total mg removed	48.95	98.90	199.00
	% removal daily	(95.80)	(97.80)	(99.00)
3	Total mg PO_4 P added	75.00	150.00	300.00
	mg removed daily	24.35	49.20	95.00
	Total mg removed	73.30	148.10	294.00
	% removal daily	(97.40)	(98.40)	(95.00)
4	Total mg PO_4 P added	100.00	200.00	400.00
	mg removed daily	23.37	43.70	85.30
	Total mg removed	96.67	191.80	379.30
	% removal daily	(93.50)	(87.40)	(85.30)
5	Total mg PO_4 P added	125.00	250.00	500.00
	mg removed daily	22.60	36.85	70.10
	Total mg removed	119.27	228.65	449.40
	% removal daily	(90.40)	(73.70)	(70.10)
6	Total mg PO_4 P added	150.00	300.00	600.00
	mg removed daily	20.15	30.25	60.40
	Total mg removed	139.42	258.90	509.80
	% removal daily	(80.60)	(60.50)	(60.40)
7	Total mg PO_4 P added	175.00	350.00	700.00
	mg removed daily	17.50	16.75	38.70
	Total mg removed	156.92	275.65	548.50
	% removal daily	(70.00)	(33.50)	(38.70)
8	Total mg PO_4 P added	200.00	400.00	800.00
	mg removed daily	7.25	6.00	0.00
	Total mg removed	164.17	281.65	548.50
	% removal daily	(29.00)	(12.00)	(0.00)
9	Total mg PO_4 P added	225.00	450.00	
	mg removed daily	0.00	7.25	
	Total mg removed	164.17	288.9	
	% removal daily	(0.00)	(14.50)	
10	Total mg PO_4 P added		500.00	
	mg removed daily		4.3	
	Total mg removed		293.2	
	% removal daily		(8.60)	
11	Total mg PO_4 P added		550.00	
	mg removed daily		0.00	
	Total mg removed		293.2	
	% removal daily		(0.00)	

Table 4.4 The cumulative weight of PO_4-P adsorbed over time by Biolat at various influent concentrations, together with the percentage removal rate and quantity of phosphate removed daily until the saturation level was reached. (1 day HRT)

Day		50 ppm	100 ppm	200 ppm
1	Total mg NH_4-N added	25.00	50.00	100.00
	mg removed daily	24.93	49.50	99.00
	Total mg removed	24.93	49.50	99.00
	% removal daily	99.70	99.00	99.00
2	Total mg NH_4-N added	50.00	100.00	200.00
	mg removed daily	24.85	48.00	98.00
	Total mg removed	49.78	97.50	197.00
	% removal daily	99.40	96.00	98.00
3	Total mg NH_4-N added	75.00	150.00	300.00
	mg removed daily	24.85	48.15	97.60
	Total mg removed	74.60	145.65	294.60
	% removal daily	99.40	96.30	97.60
4	Total mg NH_4-N added	100.00	200.00	400.00
	mg removed daily	24.50	47.10	90.20
	Total mg removed	99.10	192.75	384.80
	% removal daily	98.00	94.20	90.20
5	Total mg NH_4-N added	125.00	250.00	500.00
	mg removed daily	24.00	44.90	90.40
	Total mg removed	123.10	237.65	475.20
	% removal daily	96.00	89.80	90.40
6	Total mg NH_4-N added	150.00	300.00	600.00
	mg removed daily	24.05	43.40	76.10
	Total mg removed	147.15	281.05	551.30
	% removal daily	96.20	86.80	76.10
7	Total mg NH_4-N added	175.00	350.00	700.00
	mg removed daily	23.90	37.50	62.20
	Total mg removed	171.05	318.55	613.50
	% removal daily	95.60	75.00	62.20
8	Total mg NH_4-N added	200.00	400.00	800.00
	mg removed daily	22.70	36.50	58.80
	Total mg removed	193.75	355.05	672.30
	% removal daily	90.80	73.00	58.80
9	Total mg NH_4-N added	225.00	450.00	900.00
	mg removed daily	17.50	27.00	44.20
	Total mg removed	211.25	382.05	716.50
	% removal daily	70.00	54.00	44.20
10	Total mg NH_4-N added	250.00	500.00	1000.00
	mg removed daily	15.67	25.00	32.80
	Total mg removed	226.95	407.05	749.30
	% removal daily	62.70	50.00	32.80
11	Total mg NH_4-N added	275.00	550.00	1100.00
	mg removed daily	12.50	19.60	26.40
	Total mg removed	239.45	426.65	775.70
	% removal daily	50.00	39.20	26.40

ctd overleaf

Day (ctd)		50 ppm	100 ppm	200 ppm
12	Total mg NH_4-N added	300.00	600.00	1200.00
	mg removed daily	9.00	20.00	12.60
	Total mg removed	248.45	446.65	788.30
	% removal daily	36.00	40.00	12.60
13	Total mg NH_4-N added	325.00	650.00	1300.00
	mg removed daily	7.60	12.30	6.80
	Total mg removed	256.05	458.95	795.10
	% removal daily	30.40	24.60	6.80
14	Total mg NH_4-N added	350.00	700.00	1400.00
	mg removed daily	7.55	10.10	4.20
	Total mg removed	263.60	469.05	799.30
	% removal daily	30.20	20.20	4.20
15	Total mg NH_4-N added	375.00	750.00	1500.00
	mg removed daily	6.15	5.30	0.00
	Total mg removed	269.75	474.35	799.30
	% removal daily	24.60	10.60	0.00
16	Total mg NH_4-N added	400.00	800.00	
	mg removed daily	3.50	0.00	
	Total mg removed	273.25	474.35	
	% removal daily	14.00	0.00	
17	Total mg NH_4-N added	425.00		
	mg removed daily	0.00		
	Total mg removed	273.25		
	% removal daily	0.0		

Table 4.5 The cumulative weight of ammonium adsorbed over time by Biolat at various influent concentrations, together with the percentage removal rate and quantity of phosphate removed daily until the saturation level is reached. (1 day HRT)

The shape of the adsorption curve for ammonium followed the same general pattern as for phosphate. It began initially with a steep slope which became more gradual with time as the removal rates decreased and finally reached a plateau as the Biolat became saturated. A total mass of 799.3 mg of ammonium was adsorbed by Biolat (600g) at the 200 mg/l NH_4-N concentration. The total quantities of ammonium adsorbed at the 50 and 100 mg/l NH_4-N concentrations were 273.2 and 474.4 mgs of ammonium, respectively.

4.5 Factors controlling adsorption by Biolat.

- *Concentration / Retention time.*

Figure 4.42 (page 148) and Table 4.6 (page 146) show the removal rates of phosphate from various concentrations of phosphate solutions over a 24 hour period. Removal rates of approximately 40-50% were achieved during the first hour of contact for concentrations between 10 and 1000 mg/l PO_4-P. The removal rates observed within one hour of contact decreased at the higher concentrations of 5,000 and 10,000 mg/l PO_4-P, to less than 30% removal (i.e. 27.8% removal was achieved for the former and 13.9% in the latter). Upon examination of the total quantity of phosphate adsorbed by Biolat in the first hour, values ranging from 0.49 mgs to 139.70 mg of PO_4-P / 100g of Biolat were observed for the extremities of 10 and 10,000 mg/l PO_4-P i.e. the total mass of phosphate removed increased progressively as the concentration of phosphate in each flask was increased. For the 10, 50, 100, 500 and 1,000 mg/l

PO_4-P concentrations, greater than 85% removal was observed within 24 hours, while only 54 and 46% removal was achieved for the 5,000 and 10,000 mg/l PO_4-P concentrations, respectively. At the end of the test period the total mass of phosphate adsorbed at the various concentrations were 1.00, 4.36, 9.09, 42.55, 87.50, 270.00 and 475.50 mg/100g of Biolat for the 10, 50, 100, 500, 1,000, 5,000 and 10,000 mg/l PO_4-P concentrations, respectively.

The removal of ammonium by Biolat was also influenced by the concentration of ions in solution and the HRT allowed. From Table 4.7 (page 147) and Figure 4.43 (page 148) it is evident that a removal rate of greater than 90% was achieved within the first four hours of contact when the concentrations were between 10 and 100 mg/l NH_4-N. For higher concentrations of ammonium, i.e. above 500 mg/l NH_4-N, longer contact times were required. The bulk of ammonium removal, i.e. greater than 75%, was observed within the first 8 hours of contact for the 500 and 1000 mg/l NH_4-N concentrations. However, in the flasks containing concentrations of 5,000 mg/l NH_4-N, a contact time of 24 hours yielded a removal rate of only 52.6%. On investigation of the total mass of ammonium removed it was evident that even though the percentage removal decreased with increased concentration, the quantity of ammonium adsorbed actually increased. At the end of the test period the total mass of ammonium adsorbed at the various concentrations were 0.97, 4.74, 9.50, 43.80, 86.00 and 263.00 mg NH_4-N / 100g for the 10, 50, 100, 500, 1,000 and 5,000 mg/l NH_4-N concentrations, respectively.

In addition to the above experiments, which investigated the effect of concentration and HRT on the removal of ammonium and phosphate by Biolat, experiments were also conducted on the effect of the above on the total adsorption capacity of Biolat. HRTs of one, two and three days were used. The results obtained from these experiments are shown in Table 4.8 (page 149) and Figures 4.44 to 4.47 (pages 150-151). The total adsorption capacity of Biolat for phosphate of a given concentration did not differ significantly at a 95% confidence level, when HRTs of one, two or three days were investigated. At the 50 mg/l PO_4-P concentration, total adsorption capacities of 27.4, 24.0 and 23.1 mg PO_4-P /100g of Biolat were obtained for the one, two and three day HRT, respectively. When the Biolat was subjected to concentrations of 100 mg/l PO_4-P, total adsorption capacities of 48.9, 48.1 and 47.3 mg PO_4-P/ 100g of Biolat were observed for the one, two and three day HRT, respectively. The corresponding values obtained at an influent concentration of 200 mg/l PO_4-P were 91.4, 93.0 and 90.3 mg PO_4-P/100g of Biolat. The total adsorption capacity experiments for Biolat at 400 mg/l PO_4-P were performed only at two and three day HRTs. These experiments yielded total adsorption capacity values of 187.7 and 191.9 mg PO_4-P /100g of Biolat for the two and three day HRT, respectively. The standard deviation values obtained over the ranges of concentrations tested at the one, two and three day HRTs ranged from 1.35 to 2.40 mg PO_4-P/ 100g of Biolat, indicating the similarities in the values obtained.

The variation in results obtained for the total adsorption capacity of Biolat for ammonium was more pronounced than for phosphate. The standard deviation values ranged from 3.09 to 19.7 mg NH_4-N / 100g of Biolat over the four concentrations tested. However, at a 95% confidence interval no significant variation occurred. For an influent concentration of 50 mg/l NH_4-N values ranging from 30.8 to 45.5 mg NH_4-N /100g of Biolat were observed. The mean value was 37.7 mg NH_4-N/ 100g, with a standard deviation of 7.3 mg NH_4-N/ 100g. The highest value of 45.5 mg was obtained at the one day HRT while the lowest value of 30.8 mg was obtained at the three day HRT. At the 100 mg/l NH_4-N concentration less variation occurred among the adsorption capacities observed at various HRTs. The mean value obtained was 75.8 mg NH_4-N /100g with a standard deviation of 3.09 mg NH_4-N /100g Again the highest adsorption capacity of 79.1 mg NH_4-N /100g of Biolat occurred at the one day HRT, but the lowest value of 73.1 mg NH_4-N was observed at the two day HRT. Influent ammonium concentrations of 200 mg/l yielded adsorption capacity values of 133.2, 129.0 and 137.9 mg NH_4-N /100g of Biolat for the one, two and three day HRTs, respectively. The mean value obtained was 133.4 mg NH_4-N /100g and the standard deviation was 4.47 mg NH_4-N /100g In this instance the highest total adsorption capacity value was obtained at the three day HRT, while the lowest value was observed at the two day HRT. The greatest standard deviation (i.e. 19.7 mg NH_4-N /100g) in results obtained for total adsorption capacity occurred when the influent concentration of ammonium was 400 mg/l NH_4-N. Although the experiments were not conducted for a one day HRT, the results obtained for the two and three day HRT differed by 37.4 mg NH_4-N /100g of Biolat. A total adsorption capacity value of 259.4 mg NH_4-N /100g of Biolat was obtained at the two day HRT, while the corresponding value achieved for the three day HRT was 222.0 mg NH_4-N /100g of Biolat.

Time	**mg/l PO_4-P added**	10	50	100	500	1,000	5,000	10.000
(hrs)	**mg PO_4-P added**	1.0	5.0	10.0	50.0	100.0	500.0	1,000.0
1	mg PO_4-P removed	0.491	2.655	4.160	21.60	44.500	139.00	139.700
	Total mg PO_4-P removed	0.491	2.655	4.160	21.60	44.500	139.00	139.700
	Total % removed	(49.1)	(53.1)	(41.6)	(43.2)	(44.5)	(27.8)	(13.97)
2	mg PO_4-P removed	0.097	0.565	1.480	5.500	7.100	5.500	79.000
	Total mg PO_4-P removed	0.588	3.220	5.640	27.10	51.600	144.50	218.000
	Total % removed	(58.8)	(64.4)	(56.4)	(54.2)	(51.6)	(28.9)	(21.8)
4	mg PO_4-P removed	0.202	0.360	2.700	6.600	9.700	41.500	188.000
	Total mg PO_4-P removed	0.790	3.580	8.340	33.70	61.300	186.00	406.000
	Total % removed	(79.0)	(71.6)	(83.4)	(67.4)	(61.3)	(37.2)	(40.6)
6	mg PO_4-P removed	0.100	0.160	0.090	1.200	1.900	11.500	26.000
	Total mg PO_4-P removed	0.890	3.740	8.430	34.90	63.200	197.50	432.000
	Total % removed	(89.0)	(74.8)	(84.3)	(69.8)	(63.2)	(39.5)	(43.2)
8	mg PO_4-P removed	0.030	0.510	0.200	4.550	12.700	63.000	8.000
	Total mg PO_4-P removed	0.920	4.250	8.630	39.45	75.900	260.50	440.000
	Total % removed	(92.0)	(85.0)	(86.3)	(78.9)	(75.9)	(52.1)	(44.0)
24	mg PO_4-P removed	0.080	0.110	0.460	3.100	11.600	9.500	17.500
	Total mg PO_4-P removed	1.000	4.360	9.090	42.55	87.500	270.00	457.500
	Total % removed	(100.0)	(87.2)	(90.9)	(85.1)	(87.5)	(54.0)	(45.75)

Table 4.6 Removal rates achieved over time, together with the mass of phosphate adsorbed over time when varying concentrations of phosphate solution are added to 100g of Biolat.

Time	**mg/l NH_4-N added**	10	50	100	500	1,000	5,000
(hrs)	**mg NH_4-N added**	1.0	5.0	10.0	50.0	100.0	500.0
1	mg NH_4 -N removed	0.560	3.720	7.390	15.200	29.800	0.00
	Total mg NH_4-N removed	0.560	3.720	7.390	15.200	29.800	0.00
	Total % removed	(56.60)	(74.40)	(73.9)	(30.40)	(29.8)	(0.00)
2	mg NH_4 -N removed	0.260	0.630	1.600	18.550	31.100	82.000
	Total mg NH_4-N removed	0.820	4.350	9.050	33.750	60.900	82.000
	Total % removed	(82.50)	(87.00)	(90.50)	(67.50	(60.9)	(16.4)
4	mg NH_4 -N removed	0.110	0.180	0.200	1.970	7.700	126.900
	Total mg NH_4-N removed	0.930	4.530	9.250	35.720	68.600	209.800
	Total % removed	(93.4)	(90.6)	(92.5)	(71.44)	(68.6)	(41.96)
6	mg NH_4 -N removed	0.006	0.000	0.250	5.080	5.300	6.200
	Total mg NH_4-N removed	0.936	4.530	9.500	40.800	73.900	216.000
	Total % removed	(93.60)	(90.60)	(95.0)	(81.60)	(73.90)	(43.20)
8	mg NH_4 -N removed	0.034	0.180	0.000	0.000	1.100	7.000
	Total. mg NH_4-N removed	0.970	4.710	9.500	40.800	75.000	223.000
	Total % removed	(97.00)	(94.20)	(95.0)	(81.60)	(75.00)	(44.60)
24	mg NH_4 -N removed	0.000	0.030	0.000	3.000	11.000	40.000
	Total mg NH_4-N removed	0.970	4.740	9.500	43.800	86.000	263.000
	Total % removed	(97.00)	(94.8)	(95.0)	(87.6)	(86.00)	(52.60)

Table 4.7: Removal rates achieved over time, together with the mass of ammonium adsorbed over time when varying concentrations of ammonium solution are added to 100g of Biolat.

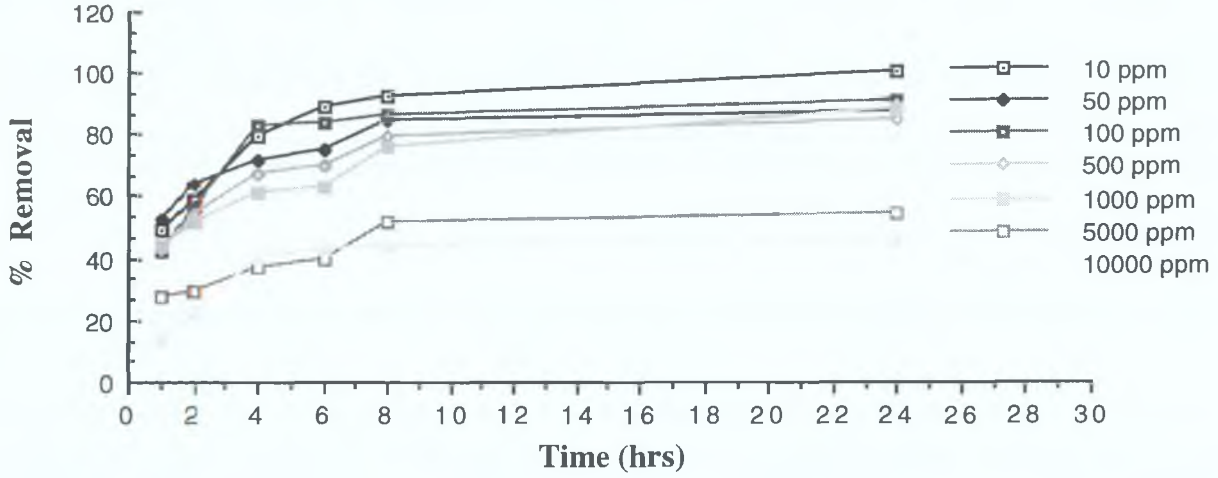

Fig. 4.42 The removal of various concentration of phosphate by Biolat at specific time intervals.

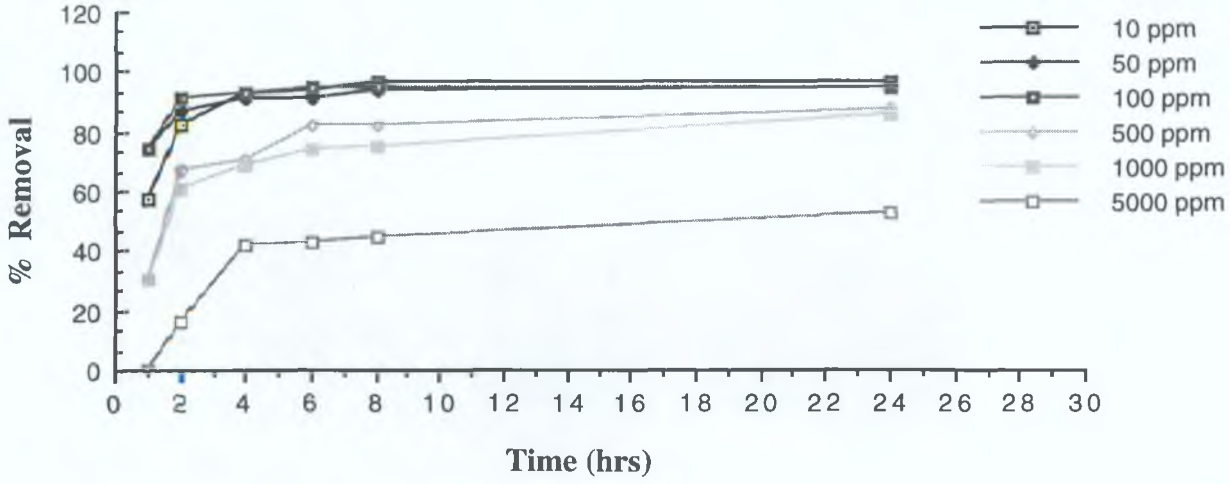

Fig. 4.43 The removal of various concentration of ammonium by Biolat at specific time intervals.

	Phosphate				Ammonium			
	50 ppm	**100 ppm**	**200 ppm**	**400 ppm**	**50 ppm**	**100 ppm**	**200 ppm**	**400 ppm**
1 day HRT	27.4	48.9	91.4	N.A.	45.5	79.1	133.2	N.A.
2 day HRT	24.0	48.1	93.0	187.7	36.8	73.1	129.0	259.4
3 day HRT	23.1	47.3	90.3	191.9	30.8	75.1	137.9	222.0
Mean	24.8	48.1	91.6	189.8	37.7	75.8	133.4	240.7
Standard deviation.	2.4	1.50	1.35	2.1	7.3	3.09	4.47	19.7

Table 4.8 The total adsorption capacity of Biolat for ammonium and phosphate when various influent concentrations were applied at one, two and three day HRTs. The adsorption values given for each concentration are mean values obtained from triplicate sets of samples.

The adsorption capacity is expressed as mgs of phosphate/ ammonium adsorbed per 100g of Biolat.

Key: N.A. = Not available

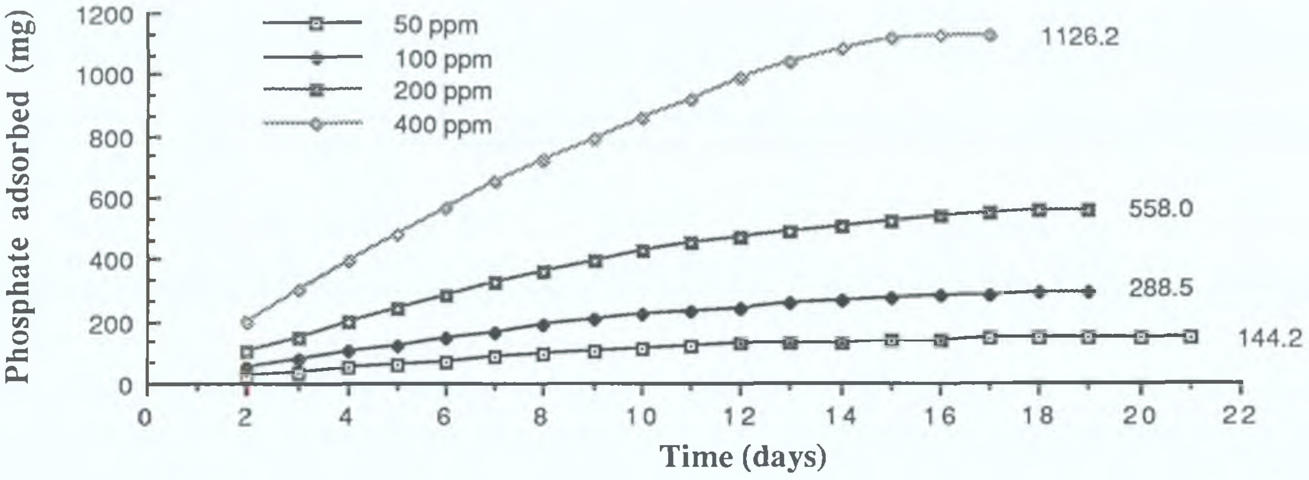

Fig. 4.44. The cumulative weight of phosphate adsorbed over time by Biolat at various influent concentrations until saturation level was reached.
A two day HRT was used.

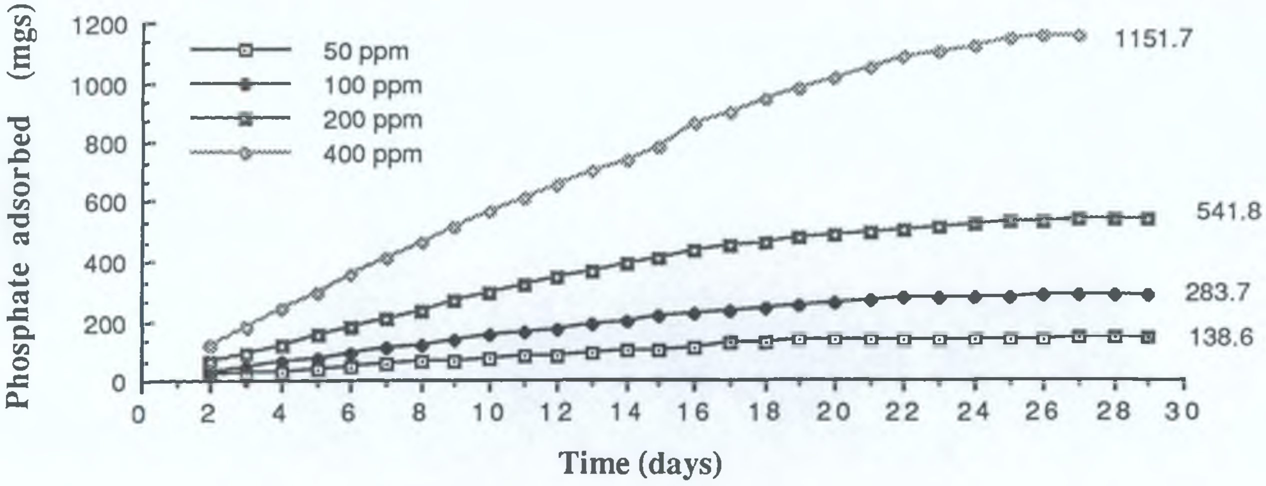

Fig. 4.45. The cumulative weight of phosphate adsorbed over time by Biolat at various influent concentrations until saturation level was reached.
A three day HRT was used.

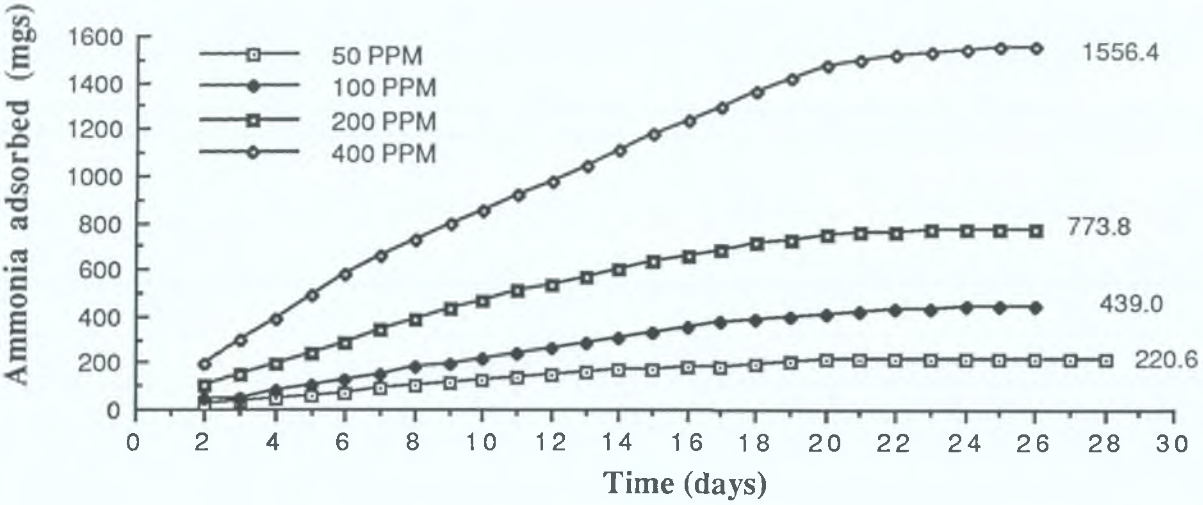

Fig. 4.46. The cumulative weight of ammonium adsorbed over time by Biolat at various influent concentrations until saturation level was reached.
A two day HRT was used

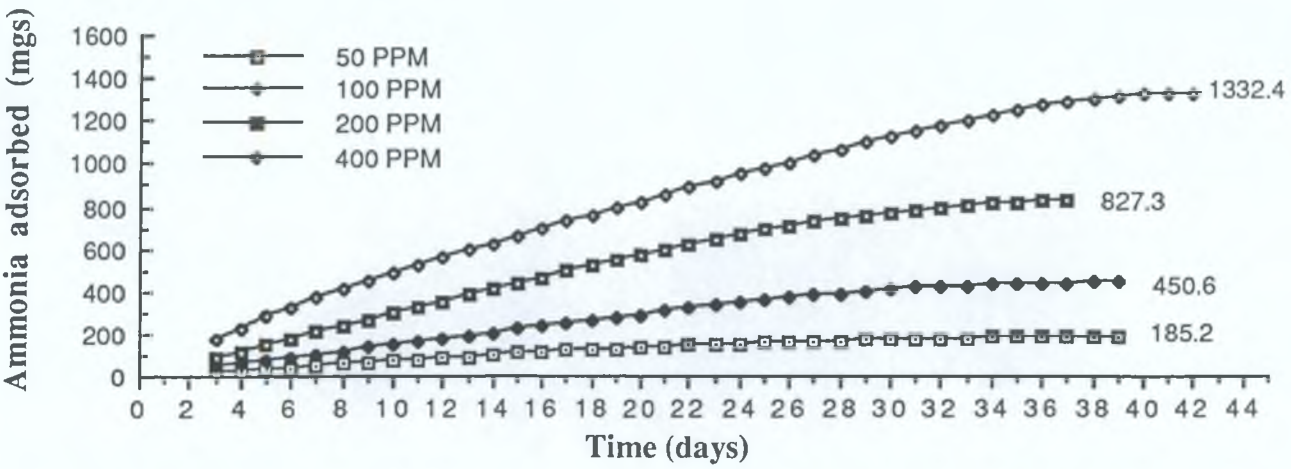

Fig. 4.47. The cumulative weight of ammonium adsorbed over time by Biolat at various influent concentrations until saturation level was reached.
A three day HRT was used.

- *pH.*

Results from Table 4.9 (page 153) indicate that Biolat was capable of removing ammonium and phosphate in the pH range of 2 to 12. Removal rates of greater than 80% were achieved over this pH range for influent ammonium concentrations of 100 mg/l NH_4-N and a HRT of eight hours. The greatest removal rates were observed in the pH range 4 to 10 i.e. greater than 93%, while the removal rates decreased to 80% at pH 2 and 12. The pH of the supernatant was checked after the eight hour test period. Results indicate that Biolat exerts a pH adjustment capacity when influent pHs are acidic or alkaline i.e. for an influent pH of 2, the solution was pH adjusted to pH 4.2 after eight hours. Similarly the solution at pH 12 was pH adjusted to pH 9.4 in the same time period. When the initial pH was in the range 4 to 10, a final pH of between 7 and 8 was observed.

Phosphate removal also occurred in the pH range 2 to 12. Removal rates of greater than 74.1% were achieved for influent concentrations of 100 mg/l PO_4-P in this pH range. In general the highest removal rates occurred between pH 6 and 12, ranging from 77.9 to 80.0% removal. Lesser removal rates were observed at pH 2 and 4 i.e. 74.1% and 74.6%, respectively. Observed final pHs were similar to those achieved in the ammonium experiments.

	Ammonium		Phosphate	
Initial pH	**% Removal**	**Final pH**	**% Removal**	**Final pH**
2	80.0	4.2	74.1	4.2
4	94.0	7.4	74.6	7.1
6	93.0	7.2	80.0	7.2
8	93.0	7.6	78.0	7.8
10	93.5	8.0	78.0	8.0
12	80.0	9.4	77.9	9.0

Table 4.9 The percentage removal of ammonium and phosphate when the influent solutions were prepared at various pHs. Also shown is the final pH observed in the various solutions following the eight hour test period.

The initial concentration of phosphate and ammonium in solution was 100 mg/l.

- *Grain size of Biolat.*

The results of experiments set up to determine the effect, if any, of the grain size of Biolat on the removal of phosphate and ammonium are shown in Figures 4.48 to 4.51 (page 158-159). One hundred and fifty ml quantities of a 50 mg/l solution of phosphate/ ammonium were added to 50g quantities of Biolat at the required grain sizes. The experiments were performed on both shaken and unshaken flasks containing the Biolat. Results show that the removal of ammonium and phosphate occurs at all grain sizes from 4.0 mm down to less than 0.25 mm. In the initial stages of contact between Biolat and phosphate grain size influences the removal rates achieved regardless of whether the flasks were shaken or unshaken. This is especially apparent after the initial 15 and 30 minute intervals i.e. after 15 minutes, an 84.7% removal was observed at the 0.25- 0.50 mm grain size while removal rates of 78.8, 64.7 and 49.6% were observed in the 0.50- 1.0, 1.0- 2.0 and 2.0- 4.0 mm grain sizes, respectively (Figure 4.48, page 158). Following a 24 hour contact time the difference in phosphate removal rates among the various grain sizes of Biolat was less apparent, with 99.2% removal evident at the 0.25 to 0.50 mm grain size and 96, 98.3 and 97.9% removal achieved in the 0.5- 1.0, 1.0- 2.0 and 2.0- 4.0 mm grain sizes, respectively. In the unshaken flasks the same pattern was evident (Figure 4.49, page 158). After a 15 minute contact time 36.4% phosphate removal occurred in the 0.25- 0.50 mm grain size flasks, while 18.3, 12.4 and 6.8% removal was observed in the 0.5- 1.0, 1.0- 2.0 and 2.0- 4.0 mm grain sizes, respectively. Following the one and two hour contact time, the difference in phosphate removal rates in the various grain sizes became less apparent. After a 24 hour contact time the differences in phosphate removal rates between the various grain sizes was slight and the trend which occurred at the initial sampling times was reversed i.e. 89.6% removal was observed in the flasks with the 0.25- 0.5 mm grain size, while 91.1, 96.4 and 96.0 % removal was observed in the 0.5- 1.0, 1.0- 2.0 and 2.0- 4.0 mm grain sizes, respectively.

The difference in ammonium removal rates between the various grain sizes was less pronounced than that for phosphate. The greatest difference observed in removal rates in the shaken flasks was after an initial sampling time of 15 minutes (Figure 4.50, page 159) A 59.6% removal rate was observed in the flasks containing the 0.25- 0.50 mm grain size. This was reduced to 52.8% in the 0.5- 1.0 mm flask, 48.3% in the 1.0- 2.0 mm grain size flask and 47.3% in the 2.0- 4.0 mm flasks. Although there was a trend of decreased removal rates as the grain size increased in the initial 15 minutes, the difference between the larger grain sizes of 1.0- 2.0 and 2.0- 4.0 mm was slight, with removal rates of 48.3 and 47.3%, respectively. Following a period of 30 minutes contact time and thereafter there was no significant difference in removal rates at the various grain sizes. Furthermore, the removal rates did not follow any particular trend. After a 24 hour contact time 64.7% ammonium removal was observed in the flasks containing the 0.25- 0.50 mm grain size, while 58.7, 59.9 and 70 % removal was observed in the flasks containing the 0.5- 1.0, 1.0- 2.0 and 2.0- 4.0 mm grain sizes, respectively.

Ammonium removal was also affected by grain size in the initial stages of contact between the ammonium and Biolat in the unshaken flasks. A trend of increased removal was observed as the grain size of Biolat decreased. A removal rate of 22.1% was observed in the flasks containing the 0.25- 0.5 mm grain size while removal rates of 13, 12 and 4.8% were observed in the flasks containing the 0.5- 1.0, 1.0- 2.0 and 2.0- 4.0 mm grain sizes, respectively. This trend was also apparent after the 30 minute sampling period. Thereafter there was no recognisable trend in ammonium removal rates between the various grain sizes. The removal rates achieved after the 24 hour contact time were 36.3, 38.0, 34.1 and 43.5 for the 0.25 - 0.5, 0.5- 1.0, 1.0- 2.0 and 2.0- 4.0 mm grain sizes, respectively.

Another point that became apparent in the grain size experiments was that phosphate removal was greatest (at least over the initial twelve hours) in the flasks which were shaken (Figures 4.48 and 4.49, page 158). For example, comparing the removal rates achieved in the first 15 minutes, 84.7% phosphate removal occurred in the shaken flasks containing the 0.25- 0.5 mm grain size while only 36.4% removal occurred at this grain size in the unshaken flasks. The corresponding values for the 0.5- 1.0 mm grain sizes were 78.8% compared to 18.8% for the shaken and unshaken flasks, respectively. At a grain size of 1.0- 2.0 mm, 64.7% removal occurred in the shaken flasks while only 12.4% removal occurred in the unshaken flasks. There was also a significant difference in removal rates between the shaken and unshaken flasks at the 2.0- 4.0 mm grain sizes, with 49.6 % phosphate removal occurring in the former and 6.8 % occurring in the latter. The variation in removal rates between the shaken and unshaken flasks was less distinct after 24 hours contact time. Removal rates varied between 96 to 99.2% over the range of grain sizes in the shaken flasks and from 89.6 to 96% in the unshaken flasks.

The same trend is apparent for ammonium removal over the various grain sizes during the entire 24 hour sampling period. Ammonium removal rates ranging from 41.3 to 59.6% were observed in the shaken flasks containing the various grain sizes after a 15 minute contact time. The corresponding removal rates in the unshaken flasks ranged from 4.8 to 22.1%. Following a 24 hour contact period, the difference in removal rates between the shaken and unshaken flasks was still apparent with values ranging from 58.7% to 70% observed in the shaken flasks and removal rates of between only 34.1 to 43.5 % evident in the corresponding unshaken flasks.

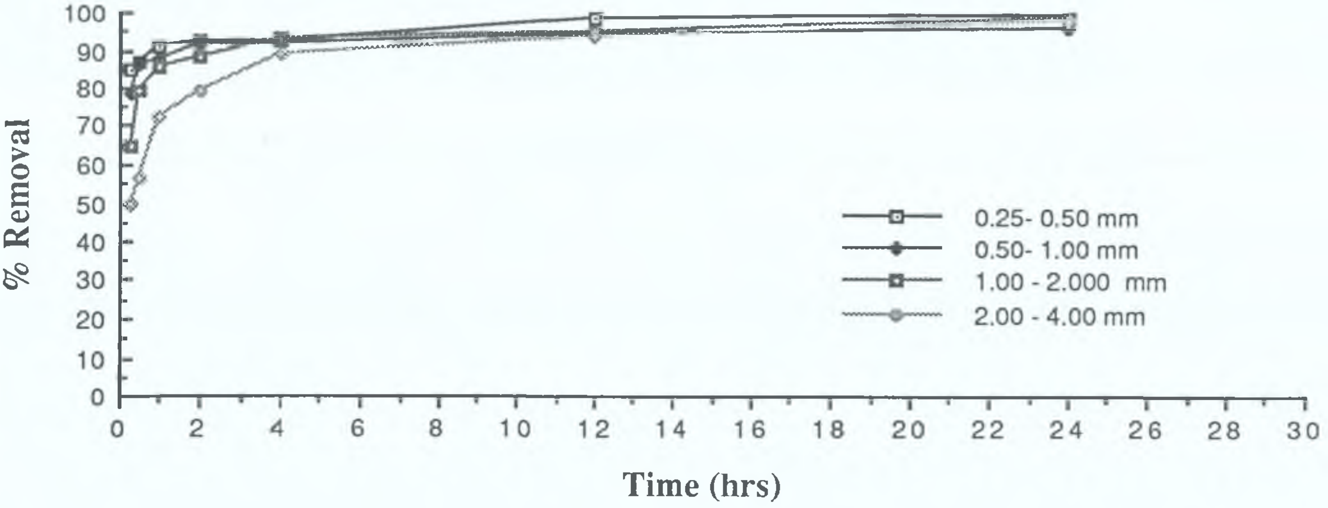

Figure 4.48- The effect of grain size of Biolat on the percentage removal of phosphate . All grain sizes were contacted with a 50 mg/l phosphate solution. Note: All flasks were shaken

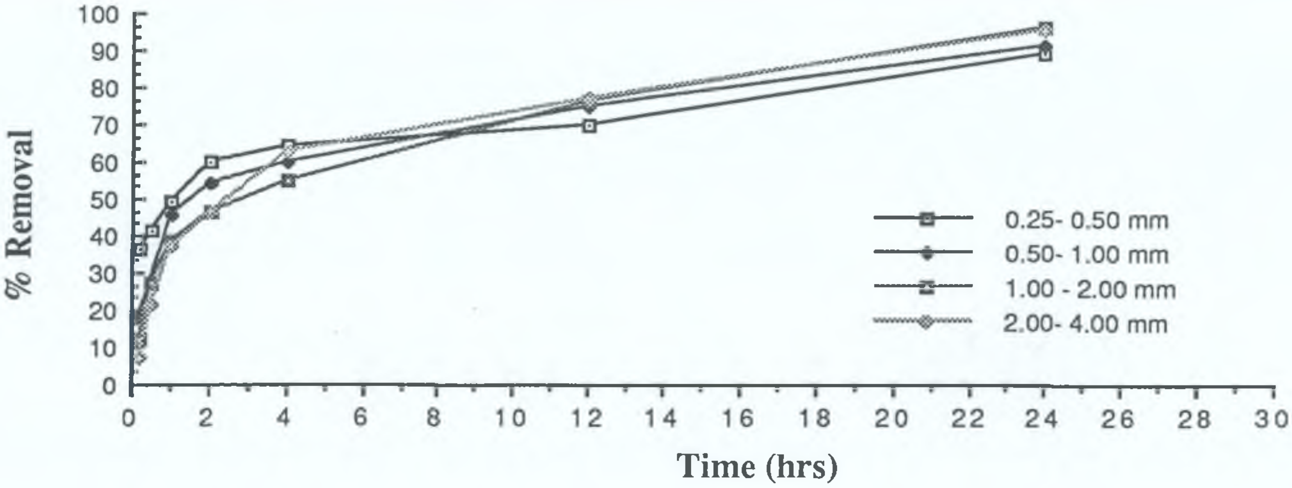

Fig 4.49 The effect of grain size of Biolat on the percentage removal of phosphate. All grain sizes were contacted with a 50 mg/l phosphate solution. Note: All flasks were unshaken

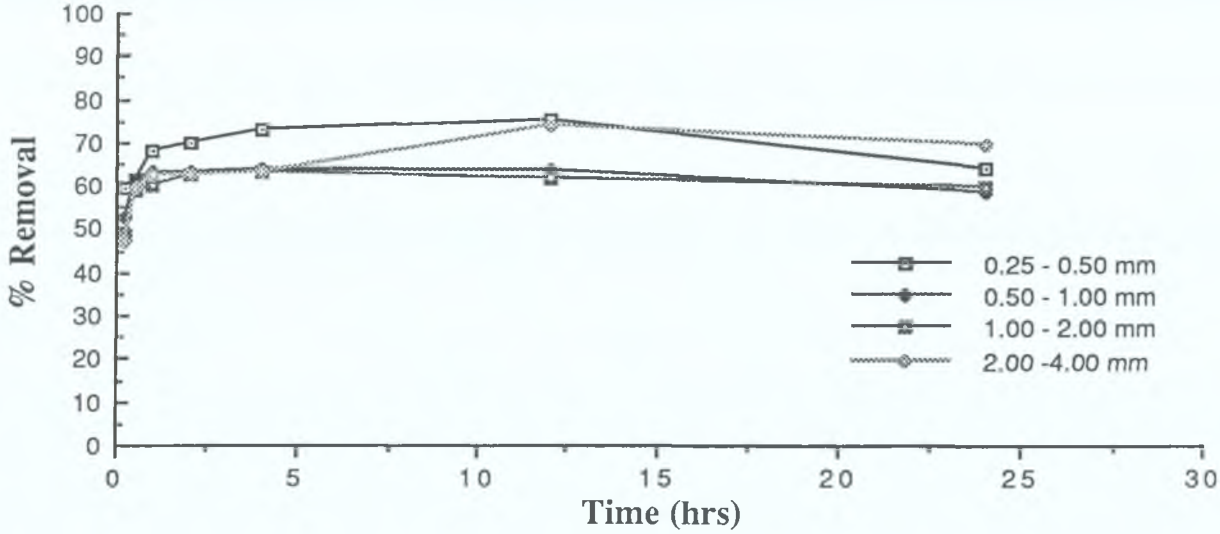

Fig 4.50 The effect of grain size of Biolat on the percentage removal of ammonium. All grain sizes were contacted with a 50 mg/l ammonium solution. Note: All flasks were shaken

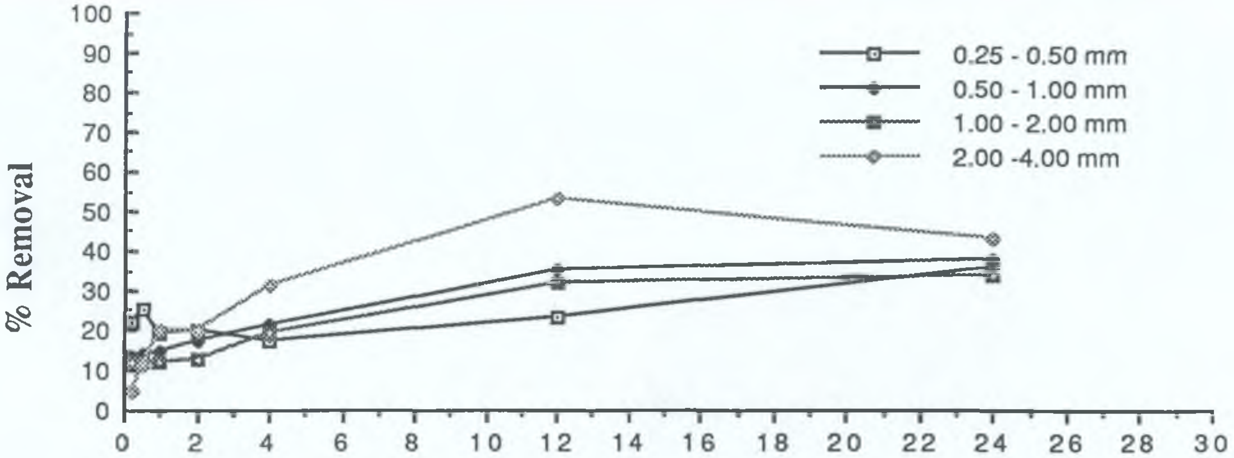

Fig 4.51 The effect of grain size of Biolat on the percentage removal of ammonium. All grain sizes were contacted with a 50 mg/l ammonium solution. Note: All flasks were unshaken

Grain Size (mm)

Time	0.25 - 0.50	0.50 -1.00	1.00 - 2.00	2.00 -4.00
15 min	84.7	78.8	64.7	49.6
30 min	87.1	86.5	79.1	56.3
1 hr	90.8	87.7	85.6	72.5
2 hr	92.3	91.5	88.4	79.6
4 hr	92.7	91.6	93.2	89.2
12 hr	98.4	94.8	95.1	93.9
24 hr	99.2	96.0	98.3	97.9

*** Values are expressed in percentages.**

Table 4.10 The effect of grain size of Biolat on the percentage removal of phosphate . All grain sizes were contacted with a 50 mg/l phosphate solution. Note: All flasks were shaken

Grain Size (mm)

Time	0.25 - 0.50	0.50 -1.00	1.00 - 2.00	2.00 -4.00
15 min	36.4	18.8	12.4	6.8
30 min	41.3	27.9	27.5	21.3
1 hr	49.2	45.9	38.5	36.9
2 hr	60.0	54.1	46.7	46.7
4 hr	64.5	60.3	55.1	62.7
12 hr	69.9	75.3	76.2	77.3
24 hr	89.6	91.1	96.4	96.0

*** Values are expressed in percentages.**

Table 4.11 The effect of grain size of Biolat on the percentage removal of phosphate . All grain sizes were contacted with a 50 mg/l phosphate solution Note: All flasks were unshaken.

	Grain Size (mm)			
Time	**0.25 - 0.50**	**0.50 -1.00**	**1.00 - 2.00**	**2.00 -4.00**
15 min	59.6	52.8	48.3	41.3
30 min	61.6	61.2	59.2	59.6
1 hr	68.1	63.2	60.0	62.4
2 hr	69.7	63.2	62.4	62.7
4 hr	73.2	63.9	63.2	63.3
12 hr	75.2	64.0	61.7	74.4
24 hr	64.7	58.7	59.9	70.0

*** Values are expressed in percentages.**

Table 4.12 The effect of grain size of Biolat on the percentage removal of ammonium. All grain sizes were contacted with a 50 mg/l ammonium solution. Note: All flasks were shaken

	Grain Size (mm)			
Time	**0.25 - 0.50**	**0.50 -1.00**	**1.00 - 2.00**	**2.00 -4.00**
15 min	22.1	13.0	12.0	4.8
30 min	25.2	14.3	12.0	11.6
1 hr	19.2	14.7	12.1	20.0
2 hr	20.0	17.6	12.4	20.0
4 hr	17.1	21.5	19.5	31.1
12 hr	23.1	35.2	32.0	53.6
24 hr	36.3	38.0	34.1	43.5

*** Values are expressed in percentages.**

Table 4.13 The effect of grain size of Biolat on the percentage removal of ammonium. All grain sizes were contacted with a 50 ppm ammonium solution.

Note: All flasks were unshaken

4.6 Desorption Trials.

Figure 4.52 (page 167) demonstrate the removal of phosphate from previously saturated Biolat. Biolat which had been saturated with phosphate using 100, 200 and 400 mg/l PO_4-P concentrations was used (Figure 4.45, page 150). The Biolat was kept in the original columns used in the adsorption trials and distilled water was pumped through the columns in order to remove the phosphate from the Biolat. The graph illustrates the percentage desorption of phosphate as a function of the quantity of water passed through the Biolat column. The initial slope of the curve was rather steep indicating a rapid desorption process. This was followed by a period of less rapid desorption as judged by the slower rise of the curve until a plateau was reached indicating that no more phosphate could be desorbed. Results from Table 4.14 (page 165) show the amount of phosphate desorbed as a percentage of that amount previously adsorbed by Biolat. The desorption of previously sorbed phosphate from Biolat was very efficient, yielding desorption rates of 87.0% for the 100 mg/l PO_4-P, 90.2% for the 200 mg/l PO_4-P and 94.6% for the 400 mg/l PO_4-P concentrations. These percentage desorption rates corresponded to the desorption of 246.8, 488.5 and 1089.5 mgs phosphate/ 600g of Biolat for the 100, 200 and 400 mg/l PO_4-P concentrations, respectively.

Figure 4.53 (page 167) illustrates the desorption of ammonium from previously saturated Biolat columns. The Biolat had been previously saturated with ammonium as shown in Figure 4.47 (page 151). Desorption rates were much less efficient for ammonium than for phosphate. Desorption rates for ammonium were less than 40% over all of the concentration ranges tested. Again there was a trend of increased desorption as the ammonium concentration used to saturated the Biolat was increased. Only 22.1% of previously adsorbed ammonium was desorbed in the 100 mg/l NH_4-N Biolat column, while 27.4% and 39.0% was desorbed in the 200 and 400 mg/l NH_4-N Biolat columns, respectively. These percentage desorption values corresponded to 99.6, 224.6 and 520.7 mgs of ammonium/ 600g of Biolat for the 100, 200 and 400 mg/l NH_4-N concentrations, respectively. The desorption of ammonium from Biolat was more gradual than was observed with phosphate desorption. This was evident from the slope of the curve. From Figure 4.53 (page 167) it was observed that there was a consistent rise of the curve until a plateau was reached where no more ammonium could be removed from the Biolat.

Large volumes of water were required to desorb both ammonium and phosphate from Biolat. Four and a half litres of distilled water were required to desorb the phosphate from the 400 mg/l PO_4-P columns while nine litres were required for the 100 and 200 mg/l PO_4-P Biolat columns. Similarly, approximately nine litres of distilled water were required to desorb ammonium from the 100, 200 and 400 mg/l NH_4-N Biolat columns. Due to the large quantities of water required for desorption an attempt was made to accelerate the desorption process by pH adjusting the distilled water passed through the Biolat. pHs in the range 2 to 12 were investigated. The desorption of ammonium and phosphate at the various pHs were performed in erlenmeyer flasks containing previously saturated Biolat. The reason for this was that the delivery tubes to the Biolat columns could not withstand the extreme pHs used. Complete desorption of ammonium and phosphate from Biolat over the range of pHs was not determined. Instead, that amount of desorption which occurred over a 24 hour contact time at each pH was investigated and compared. The desorption of ammonium and phosphate occurred over the entire pH range investigated, with little difference occurring in the desorption rates regardless of pH i.e. at a 95% confidence interval no significant variation occurred. Phosphate desorption values were between 2.3 and 2.7% of that amount of phosphate previously adsorbed by the Biolat (i.e. 23.4 mg PO_4-P). The higher value of 2.7% was obtained at pH 6, while the lowest value of 2.3% occurred at a pH of 12. The percentage desorption rates of ammonium from Biolat were lower than those achieved for phosphate. The values obtained over the pH range were between 0.8 and 1.0% of that amount previously adsorbed (i.e. 28.9 mg NH_4-N). The highest value of 1% was achieved at pH s 6 and 8, while 0.8% removal occurred over the other pHs investigated.

Parameter	**Concentration Used (mg/l)**	**Total mgs Adsorbed**	**Total mgs Desorbed**	**% Desorbed**
Phosphate	100	283.7	246.8	87.0
	200	541.6	488.5	90.2
	400	1151.8	1089.5	94.6
Ammonium	100	450.6	99.6	22.1
	200	827.3	224.6	27.4
	400	1332.4	520.7	39.0

Table 4.14 Comparison of the amount of phosphate and ammonium adsorbed by a 600g quantity of Biolat at various influent concentrations, to that amount subsequently desorbed by the addition of water.

pH of solution	% Desorption of Phosphate	% Desorption of Ammonium
2	2.6	0.8
4	2.5	0.8
6	2.6	1.0
8	2.6	1.0
10	2.5	0.8
12	2.3	0.8

Table 4.15 Comparison of the percentage ammonium and phosphate desorbed from previously saturated Biolat using distilled water which was pH adjusted in the pH range of 2 to 12.

Note; The quantity of phosphate and ammonium in the previously saturated Biolat was 23.4 mg PO_4-P and 38.9 mg NH_4-N, respectively per 100g of Biolat

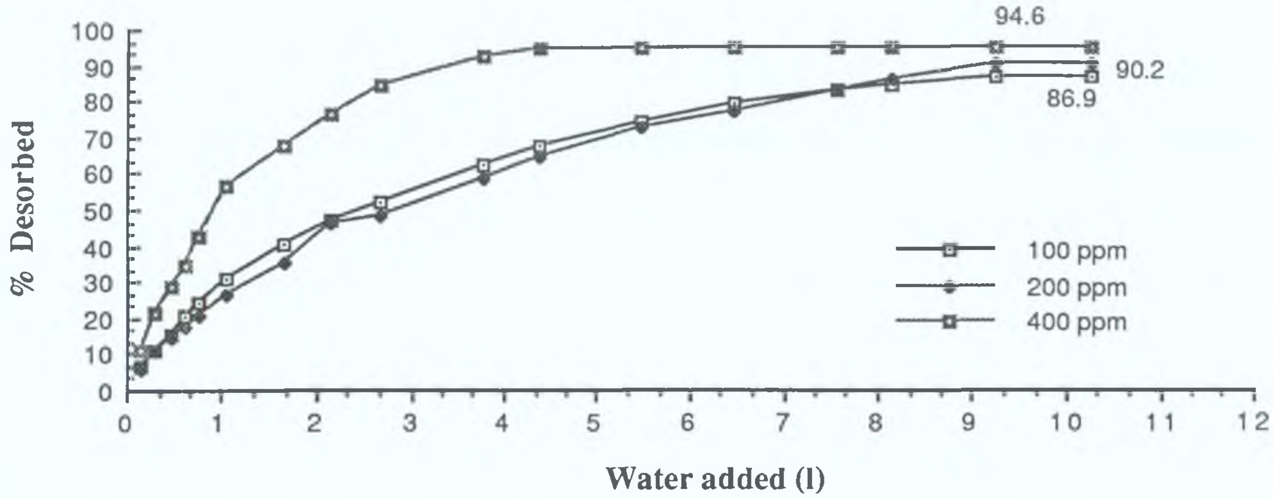

Fig 4.52 The effect of pumping water through Biolat which had been previously saturated with varying concentrations of phosphate (100, 200 and 400 mg/l PO_4-P).

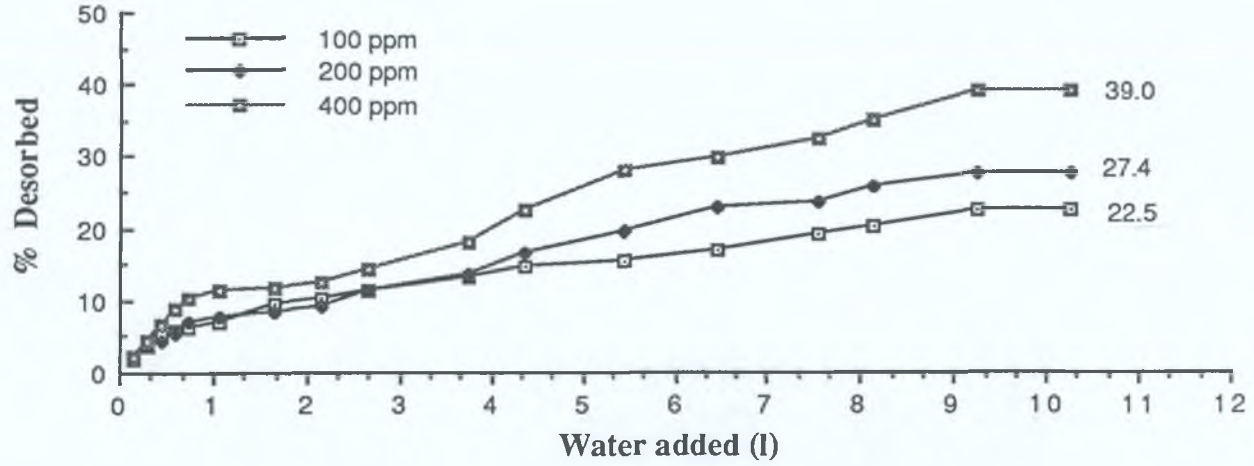

Fig 4.53 The effect of pumping water through Biolat which had been previously saturated with varying concentrations of ammonium (100, 200 and 400 mg/l NH_4-N).

4.7 Investigation into the mechanism of phosphate and ammonium removal by Biolat.

4.7.1 Investigation into the presence of anions in solution when phosphate of various concentrations were contacted with Biolat.

Table 4.17 (page 176) shows the amount of chloride in solution when Biolat was contacted with ultra-pure water and also with a range of phosphate concentrations. The amount of chloride in solution was monitored periodically over a 48 hour period. Average values were then taken for that period and compared. It was evident from the results obtained that there was no significant difference in the quantity of chloride in solution when phosphate concentrations of between 10 and 100 mg/l PO_4-P or ultra pure water were used. When ultra-pure water was contacted with Biolat the average amount of chloride observed in the supernatant was 4.98 mg Cl/ 50g of Biolat over the test period. When the Biolat was contacted with a 10 mg/l PO_4-P solution, the average amount of chloride present in solution was 4.53 mg Cl/ 50g of Biolat. At the 50 mg/l PO_4-P concentration an average amount of 4.55 mgs Cl/ 50g of Biolat was present in solution over the test period. The corresponding value at the 100 mg/l PO_4-P concentration was 5.4 mg Cl/ 50g of Biolat. Larger amounts of chloride were observed in solution when a 500 mg/l PO_4-P concentration was contacted with Biolat i.e. 6.53 mg Cl/ 50g of Biolat.

Both nitrate and nitrite were also observed to be leached from Biolat when it was contacted with ultra-pure water, although to a much lesser extent than was observed for chloride, (Table 4.17, page 176). Again there was no significant increase in either the nitrate or nitrite concentrations when varying concentrations of phosphate were present in the solutions contacted with Biolat. An average quantity of 0.068 mg NO_3-N/ 50g of Biolat was observed in solution when water was contacted with Biolat over a 48 hour period. The quantities of nitrate observed in the 10, 50, 100 and 500 mg/l PO_4-P solutions were 0.062, 0.063, 0.060 and 0.066 mg NO_3-N/ 50g of Biolat, respectively. Similarly, 0.035 mg NO_3-N/ 50g of Biolat was observed in solution when water was contacted with Biolat. This was compared to values of 0.041, 0.038, 0.041 and 0.042 mg NO_3-N/ 50g of Biolat present in the 10, 50, 100 and 500 mg/l PO_4-P solutions, respectively.

Sulphate was also leached off the Biolat when it was contacted with ultra-pure water. The average amount of sulphate observed in the supernatant over the 48 hour test period was 1.62 mg SO_4/ 50g of Biolat. Although over twice as much sulphate was present in solution when the 10 mg/l PO_4-P was contacted with Biolat i.e. 4.14 mg SO_4/ 50g of Biolat, there was no significant increase in sulphate concentration when the influent phosphate concentration was increased to 50 and then 100 mg/l PO4-P. At both these concentrations the amount of sulphate in solution was the same i.e. 4.34 mg SO_4/ 50g of Biolat. At the highest concentration of 500 mg/l PO_4-P, an average of 6.81 mg SO_4/

50g of Biolat was observed in the supernatant over the 48 hour test period (Table 4.17, page 176).

4.7.2 Investigation into the presence of cations in solution when ammonium of various concentrations are contacted with Biolat

Various cations were also released from Biolat when it was contacted with ultra-pure water and then with varying concentrations of ammonium (Table 4.18, page 177). Although there was some wash-off of these cations when the Biolat was contacted with ultra-pure water, higher concentrations were observed when ammonium of increasing concentrations were present in the solution.

An average of 4.05 mg Na/ 50g of Biolat was observed in solution over the 48 hour test period when Biolat was contacted with ultra-pure water. This was increased to 5.93 mg Na/ 50g of Biolat when a concentration of 10 mg/l NH_4-N was added to Biolat. Similarly, concentrations of 6.47, 9.83 and 10.02 mgs Na/ 50g of Biolat were observed when the concentrations of ammonium in solution was increased to 50, 100 and 500 mg/l NH_4-N, respectively.

Although the amount of potassium released from Biolat was less than that of sodium, there was nevertheless a trend of increased potassium loss as the ammonium concentration in the solution was increased. In the flask containing the ultra-pure water and Biolat, the amount of potassium observed in the supernatant was 0.26 mg K/ 50g of Biolat. This was increased to 0.78, 0.93, 2.27 and 2.91 mg K/ 50g of Biolat as the ammonium concentrations were increased to 10, 50, 100 and 500 mg/l NH_4-N, respectively (Table 4.18, page 177)

Magnesium was also washed off from Biolat when it was contacted with ultra-pure water. As the concentration of ammonium in solution increased, a corresponding increase in magnesium concentration was observed. In the flasks containing ultra-pure water and Biolat, an average of 0.44 mg Mg/ 50g of Biolat was observed over the 48 hour test period. This was increased to 1.44 mg Mg/ 50g of Biolat, when the ammonium concentration in solution was 10 mg/l NH_4-N and further increased to 1.79 mg Mg/ 50g of Biolat at an ammonium concentration of 50 mg/l NH_4-N. At 100 and 500 mg/l NH_4-N concentrations, 1.94 mg and 6.09 mg Mg / 50g of Biolat, respectively was observed in solution (Table 4.18, page 177).

The most dramatic increase in cation release with increasing ammonium concentration was observed for calcium. While that amount of calcium washed off from Biolat in ultra pure water was only 1.31 mg Ca/ 50g of Biolat, the amount released in the 500 mg/l NH_4-N solution was 23.61 mg Ca/ 50g of Biolat. Intermediate concentrations of 4.52, 5.79 and 6.36 mg Ca/ 50g of Biolat were observed in the 10, 50 and 100 mg/l NH_4-N solutions, respectively (Table 4.18, page 177)

4.7.3 Cation exchange capacity of Biolat.

Cation exchange capacity experiments using Biolat yielded a value of 15 meq/100g of Biolat using the ammonium saturation method (Black *et al*, 1965)

4.7.4 Application of adsorption data to the Freundlich Adsorption Isotherm

Tables 4.19 and 4.20 (page 178) show the results generated in experimental trials for phosphate and ammonium adsorption by Biolat. The concentrations used in these experiments ranged from 10 to 500 mg/l. Together with the adsorption of phosphate/ ammonium by Biolat over time, the tables also show the average amount of phosphate/ ammonium adsorbed by Biolat at the equilibrium stage. When the logarithm of concentration was plotted graphically against the logarithm of that amount of phosphate/ ammonium adsorbed by one gram of Biolat in these experiments, a correlation coefficient of 1.000 was obtained. This indicated that the adsorption phenomenon obeyed the Freundlich adsorption isotherm. From the graphs plotted for both ammonium and phosphate adsorption (Figures 4.54 and 4.55, page 179) equations of the lines were obtained in each case. Using this model predictions were made with respect to the equilibrium value which would be obtained with arbitrary concentrations of both ions. The arbitrary concentrations chosen were 75, 300 and 700 mg/l of ammonium or phosphate. The 75 and 300 mg/l concentrations were chosen because they were within the 10 to 500 mg/l phosphate/ ammonium range represented in the graphs (Figures 4.54 and 4.55, page 179) and therefore theoretically should coincide with the predicted values. The 700 mg/l concentration lay outside this range. Experiments were carried out to investigate whether this higher concentration would still obey the adsorption isotherm. The concentrations chosen were equivalent to 11.5, 45 and 105 mgs of phosphate or ammonium, respectively. In the case of phosphate it was predicted that 10.9, 41.9 and 95.4 mgs of phosphate, respectively would be adsorbed by a 50g quantity of Biolat for each of the above concentrations. Experiments were carried out over a number of days by placing the appropriate concentrations in contact with 50g quantities of Biolat and sampling and analysing the supernatant. This was continued until an equilibrium situation was achieved in solution. The equilibrium state was reached when the Biolat was incapable of removing any more phosphate (Table 4.21, page 180). When these values were compared to the values predicted from the equation, it was noted that there was good correlation between the observed and predicted values at the 75 and 300 mg/l PO_4-P concentrations but not at the higher concentration of 700 mg/l PO_4-P. For the 75 mg/l PO_4-P concentration, the observed adsorption value was 11.25 mgs This was comparable to the predicted value of 10.9 mgs. Similarly, the observed value of 41.1 mgs of phosphate adsorbed at the 300 mg/l PO_4-P concentration was comparable to the predicted value of 41.9 mgs. At the 700 mg/l PO_4-P concentration the predicted value for phosphate adsorption by Biolat was 95.4 mgs, while the actual amount adsorbed was only 77.6 mgs (Figure 4.21, page 180). The same trend was evident in ammonium adsorption, however, in this case the adsorption isotherm also encompassed the 700 mg/l NH_4-N concentration. The predicted adsorption values for the 75, 300 and 700 mg/l NH_4-N concentrations were 8.2 and 31.7 and 72.6 mgs while the actual values observed were 10.2, 34.0 and 66.9 mgs of ammonium (Table 4.22, page 181).

Cation/ Anion	Retention Time	Linearity	Average RSD over linear range	Range of RSD values in the linear range
Phosphate	5.2	0 - 30.0 ppm	0.74%	0.40 - 1.4%
Nitrate	3.2	0 -12.5 ppm	0.78%	0.20 -1.8%
Nitrite	1.8	0 - 25.0 ppm	1.28%	0.80 - 2.0%
Chloride	1.5	0 - 15.0 ppm	1.15%	0.30 - 2.5%
Sulphate	6.7	0 - 45.0 ppm	0.88%	0.19 - 2.4%
Sodium	3.7	0 - 10.0 ppm	0.81%	0.30 - 1.97 %
Ammonium	4.3	0 - 10.0 ppm	0.74%	0.40 - 2.00%
Potassium	5.7	0 - 15.0 ppm	2.00%	0.98 - 3.40%
Magnesium	8.0	0 - 10.0 ppm	1.00%	0.56 - 1.60 %
Calcium	9.8	0 - 15.0 ppm	1.10%	0.17 - 2.00%

Table 4.16 Results from validation experiments for the ion chromatograph (Dionex DX100) showing the retention time, linearity, average values and the range of RSD values for each of the ions of interest.

Note; The eluent used for elution of anions was a sodium carbonate buffer which flowed through the column at a rate of 2.0 mls/min.

The eluent used for the elution of cations was a 22 mN sulphuric acid solution which flowed through the column at a rate of 1.0 ml/ min.

Anion	Water	10 ppm PO_4-P (1.5 mg)	50 ppm PO_4-P (7.5 mg)	100 ppm PO_4-P (15.0 mg)	500 ppm PO_4-P 75.0 mg)
Chloride	4.980	4.530	4.550	5.400	6.530
Nitrate	0.068	0.062	0.063	0.060	0.066
Nitrite	0.035	0.041	0.038	0.041	0.042
Sulphate	1.620	4.140	4.340	4.340	6.81

Table 4.17 The average amount of chloride, nitrate, nitrite and sulphate observed in solution when ultra-pure water and phosphate of various solutions were contacted with Biolat over a 48 hour period.

Cation	**Water**	**10 ppm NH_4-N (1.5 mg)**	**50 ppm NH_4-N (7.5 mg)**	**100 ppm NH_4-N (15.0 mg)**	**500 ppm NH_4-N 75.0 mg)**
Sodium	4.05	5.93	6.47	9.83	10.02
Potassium	0.26	0.78	0.93	2.27	2.91
Magnesium	0.44	1.44	1.79	1.94	6.09
Calcium	1.31	4.52	5.79	6.36	23.61

Table 4.18 The average amount of sodium, potassium, magnesium and calcium observed in solution when ultra-pure water and ammonium of various solutions were contacted with Biolat over a 48 hour period.

Time	1.5 mg NH_4-N (10 ppm)	7.5 mg NH_4-N (50 ppm)	15.0 mg NH_4-N (100 ppm)	75.0 mg NH_4-N (500 ppm)
15 min	0.56	3.41	8.61	37.6
30 min	0.62	3.60	9.08	40.0
1 hr	0.66	4.34	9.46	41.5
2 hr	0.79	4.52	6.65	42.1
4 hr	0.90	4.73	10.02	45.1
6 hr	0.96	4.95	11.4	47.2
8 hr	0.99	5.08	10.43	49.5
16 hr	1.02	5.30	10.88	50.4
24 hr	1.09	5.31	10.42	51.3
48 hr	1.18	5.48	9.98	53.6
72 hr	1.19	5.46	10.56	54.3
96 hr	1.20	5.44	10.32	53.1
120 hr	1.18	5.48	9.96	53.6
144 hr	1.16	5.63	10.60	53.6
168 hr	1.16	5.46	10.98	53.8

Table 4.19 The amount (mg) of ammonium adsorbed by Biolat when it was contacted with a range of ammonium concentrations. (Flasks shaken)

Time	1.5 mg PO_4-P (10 ppm)	7.5 mg PO_4-P (50 ppm)	15.0 mg PO_4-P (100 ppm)	75.0 mg PO_4-P (500 ppm)
15 min	0.86	2.03	5.66	8.15
30 min	1.09	4.64	6.60	16.05
1 hr	1.30	4.64	6.85	22.98
2 hr	1.37	5.96	6.99	26.55
4 hr	1.34	6.79	11.99	35.41
6 hr	1.34	6.77	12.46	37.9
8 hr	1.41	7.16	12.94	38.50
16 hr	1.47	7.19	13.61	50.85
24 hr	1.48	7.18	13.97	54.38
48 hr	1.50	7.35	14.09	56.10
72 hr		7.46	14.65	60.08
96 hr		7.50	14.50	66.6
120 hr			14.72	66.9
144 hr			14.75	68.2
168 hr			14.95	66.0

Table 4.20 The amount (mg) of phosphate adsorbed by Biolat when it was contacted with a range of phosphate concentrations. (Flasks shaken)

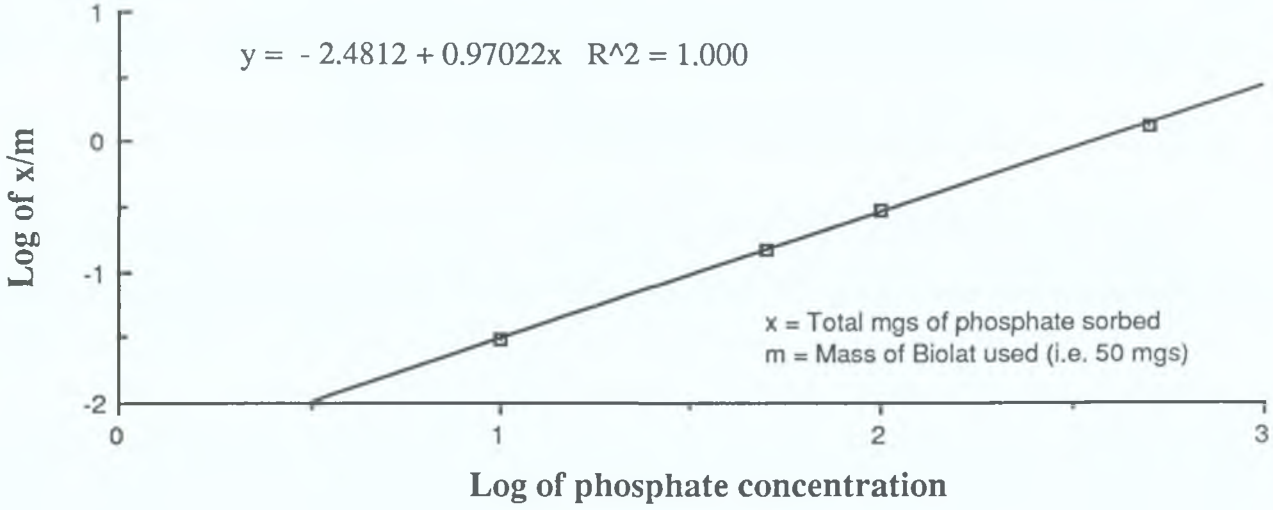

Figure 4.54 Plot of the relationship between the log of phosphate concentration versus the log of that amount of phosphate adsorbed by Biolat (1g) over a range of phosphate concentrations (i.e. 10 to 500 mg/l PO4-P).

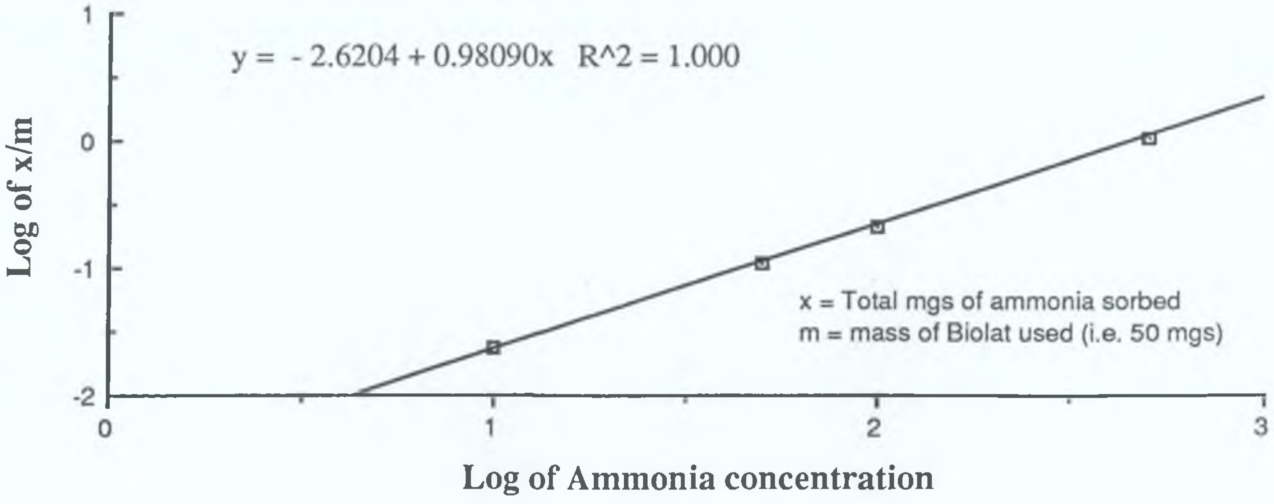

Figure 4.55 Plot of the relationship between the log of ammonium concentration versus the log of that amount of ammonia adsorbed by Biolat (1g) over a range of ammonium concentrations (i.e.10 to 500 mg/l NH_4-N)

Time (days)	11.5 mgsPO$_4$-P (75 ppm)	45 mg PO$_4$-P (300 ppm)	105 mg PO$_4$-P (700 ppm)
1	11.16	39.80	73.90
2	11.20	40.30	74.90
3	11.20	41.00	76.20
4	11.25	41.30	74.60
5	11.22	41.20	77.70
6	11.37	41.60	84.30
7	11.35	42.60	81.70
Average	11.25	41.11	77.60
Predicted value	10.90	41.90	95.40

Table 4.21 The average amount (mg) of phosphate removed when 50g of Biolat was contacted with a range of phosphate concentrations over a 7 day period as compared to that amount predicted to be removed using the Freundlich adsorption isotherm.

Time (days)	**11.5 mg NH_4-N (75 ppm)**	**45 mg NH_4-N (300 ppm)**	**105 mg NH_4-N (700 ppm)**
1	10.00	33.10	67.90
2	10.20	34.30	65.30
3	10.35	33.70	67.50
4	10.25	33.80	62.70
5	10.25	34.80	68.70
6	10.27	34.00	68.00
7	10.32	34.60	68.20
Average	10.23	34.04	66.90
Predicted Value	8.20	31.7	72.6

Table 4.22 The amount (mg) of ammonium removed when 50 g of Biolat was contacted with a range of ammonium concentrations over a 7 day period as compared to that amount predicted to be removed using the Freundlich adsorption isotherm.

CHAPTER FIVE

DISCUSSION

5.0 Discussion of Results.

5.1 Prototype BMS Biolat Septic Tank.

Results obtained for the influent domestic sewage to the prototype BMS septic tank are in general fairly typical of influent values to a conventional septic tank as reported by the Council on Environmental Quality, (1974) and Bauer, Conrad and Sherman (1979).

The average removal of BOD observed in the prototype BMS septic tank over the four year investigation period was 59.3%, with values ranging between 21.6 and 83.0% (Fig. 4.1, page 106). During the first two years of operation, an average removal rate of 66% was observed. This value was in the removal range observed by Goldstein and Wenk (1972), but was above the removal rates observed by many workers (Laurence, 1973; Ziebell *et al*, 1974 and Christoulas and Andreadakis, 1989). These workers cite BOD removal rates to be in the range of 7 to 50%. When sampling of the effluent from the BMS prototype septic tank was resumed following four years in usage, the BOD removal rate had fallen to an average of 36%. The BOD concentration in the septic tank effluent from the BMS septic tank was between < 5 and 268 mg/l BOD ($x = 93$ mg/l BOD) over the four year investigation period (Fig. 4.4, page 107). Viraghavan and Warnock (1976) report typical BOD concentrations in septic tank effluent to be between 140 and 624 mg/l BOD while Preul (1965), Polkowski and Boyle (1970) and Canter and Knox (1985), observed average concentrations of 130, 102 and 140 mg/l BOD, respectively. Henry

(1990) observed BOD concentrations of between 140 and 822 mg/l in septic tank effluent. The average BOD concentrations obtained in the septic tank effluent from the BMS septic tank were at least as low as these values in the first two years of operation. In the fourth year of operation, an average concentration of 218 mg/l BOD was observed in the septic tank effluent. Although this value was above the concentrations of BOD observed by some workers (Preul, 1965; Polkowski and Boyle, 1970 and Canter and Knox, 1985) it was nevertheless within the concentration ranges observed by other workers (Viraghavan and Warnock 1976 and Henry, 1990).

An average removal rate of 54% was obtained for COD in the BMS prototype septic tank over the four year investigation period. While there are no comparable figures available for the percentage removal of COD in a conventional septic tank, Viraghavan and Warnock (1976) cite typical COD concentrations in septic tank effluent to be between 240 and 2026 mg/l COD. Canter and Knox (1985) observed an average concentration of 300 mg/l COD, while Henry (1990) observed COD concentrations between 316 and 1800 mg/l. The COD concentrations of the septic tank effluent from the BMS tank ranged from <50 to 385 mg/l COD (x = 168 mg/l COD) over the four year investigation period. These values were below those concentrations normally observed in septic tank effluent from a conventional septic tank (Fig. 4.5, page 108).

The removal of suspended solids within the prototype septic tank ranged from 15.8 to 87.0% (x = 63.6%) over the four year investigation period (Fig.

4.3, page 107). During the first two years of usage the average removal rate for SS was 71.0%. This value fell to 35.0% during the fourth year in operation. The removal rates achieved for SS in a conventional septic tank have been shown to vary from 0 to 85%, being normally above 35- 40%. (Baumann and Babbitt, 1953; Bailey and Wallmann, 1971; Goldstein and Wenk, 1972; Laurence, 1973; Laak, 1980 and Christoulas and Andreadakis, 1989). The SS concentration in the BMS septic tank effluent ranged from 3 to 88 mg/l, with an average value of 39 mg/l SS over the four year investigation period. During the initial two years of usage, the average value for SS concentration in the BMS septic tank effluent was 36 mg/l. The average value observed following a four year operational period was 53 mg/l (Fig. 4.6, page 108). Many workers have investigated SS concentration in septic tank effluent and found average values of between 40 and 176 mg/l SS (Preul, 1965; Polkowski and Boyle, 1970; Viraghavan and Warnock, 1976 and Canter and Knox, 1985) however, values as high as 708 mg/l have been observed (Henry, 1990). Therefore, SS removal was greater in the BMS prototype septic tank than in a conventional septic tank over the initial two year investigation period. After this time the removal was at least as efficient as in conventional septic tank.

The removal of phosphate within a conventional septic tank is generally agreed by many workers to be quite low. Viraghavan (1976) found that the removal of phosphate in a septic tank varied between 34 and 56%. However, a number of workers have found that phosphate concentrations within a septic tank actually increase upon passage through the tank (Doyle and Thorn, 1987 and Henry, 1990). An average removal rate of 73.1% was observed for phosphate in the BMS septic tank over the four year investigation period with removal rates ranging from 22.3 to 99.0% (Fig. 4.2, page 106). Following four years in operation, approximately 26.7% of the influent phosphate continued to be removed from the BMS prototype septic tank (Fig 4.2, page 106). This was somewhat less than the removal rates experienced in the first two years of operation. During the first nine months of usage the removal of phosphate in the BMS prototype septic tank was in excess of 90%. Over the next few months the removal rate fell to 75% and by the seventeenth month, a percentage removal rate of 56% was observed. This seemed to indicate that there was a steady decline in the usefulness of the BMS prototype septic tank for the removal of phosphate. However, sampling during subsequent months showed that the percentage removal of phosphate fluctuated over time, with observed removal rates ranging between 68 and 82% (Fig. 4.2, page 106). These fluctuations could not be correlated positively or negatively with high influent phosphate concentrations, but appeared to be due to an inherent variability in the performance of the tank itself. When sampling of the BMS prototype septic tank was resumed on a number of occasions following an operational lifespan of four years, an average removal rate of 26.7% was observed for phosphate. Phosphate removal in the BMS prototype septic tank far exceeded its removal in a conventional septic tank during the initial two years of operation yielding an average value of 85% over this time. Following a four year operational period, the removal rate had decreased substantially to 26.7%.

Although the observed removal rates for phosphate had decreased significantly in the BMS prototype septic tank after a four year operational period, phosphate concentrations in the BMS septic tank effluent were still quite low in comparison to its concentration in normal septic tank effluent as observed by other workers (Preul, 1965; Bradley, 1981; Doyle and Thorn, 1987 and Henry, 1990). The concentration of phosphate in the septic tank effluent from the BMS septic tank varied between 0.03 and 8.0 mg/l PO_4-P ($x = 2.8$ mg/l PO_4-P) over the four year investigation period. Doyle and Thorn (1987) and Henry (1990) observed concentrations as high as 52 and 63 mg/l PO_4-P, respectively, in septic tank effluent, while Preul (1965) and Bradley (1981) found concentrations of 20 and 21 mg/l PO_4-P, respectively in septic tank effluent. Concentrations quoted by Viraghavan and Warnock (1976) as typical of phosphate concentrations in septic tank effluent were in the range of 6.2 to 30.0 mg/l PO_4-P. Phosphate concentrations in the septic tank effluent from the BMS septic tank were much lower than these values and were in effect more comparable to concentrations typical of effluent from a soil absorption system (i.e. Viraghavan and Warnock, 1976) reported concentrations of 6 to 9 mg/l PO_4-P as being typical of phosphate concentrations in septic tank soil absorption system effluent).

The average removal rate achieved for ammonia in the BMS septic tank over the four year investigation period was 41.6%, with values ranging from 13.0 to 83.0%. There are no comparable data available for the percentage removal of ammonia in a normal septic tank. However, a number of workers state that its removal within a septic tank is low (Patterson *et al*, 1971; Canter and Knox, 1985 and Henry, 1990). Anaerobic conditions within a septic tank result in much of the organic nitrogen in domestic sewage being converted to ammonia (Canter and Knox, 1985). Comparison of the ammonia concentrations observed in the BMS septic tank effluent to those obtained in conventional septic tank effluent demonstrated that the BMS septic tank was more efficient for ammonia removal only during the first two years of operation. Viraghavan and Warnock (1976) cite average ammonia concentrations in septic tank effluent to be 97.0 mg/l NH_3-N. Henry (1990) observed ammonia concentrations between 13.5 and 71.8 mg/l NH_3-N. The corresponding value obtained for the BMS septic tank was 28.3 mg/l NH_3-N, ranging from 0.5 to 96.1 mg/l NH_3-N over the four year investigation period. It must be stated that the very high value of 96.1 mg/l NH_3-N was observed only once in the four year period and this occurred following four years in usage. In general, during the initial two year sampling period ammonia levels in the septic tank effluent did not exceed 36.2 mg/l NH_3-N and averaged at 19.2 mg/l. The average removal rate for ammonia observed over this time was 47.6%. The efficiency of the BMS septic tank for ammonia removal decreased when sampling was resumed in the fourth year of operation. An average removal rate of only 22.3% was observed after this period (Fig 4.2, page 106). The removal of ammonia within the BMS septic tank was therefore substantial in the initial two years of operation exceeding that removal observed in a conventional septic tank. After this time ammonia removal was at least as efficient as in a conventional septic tank as reported by other workers (Patterson *et al*, 1971; Viraghavan and Warnock, 1976; Canter and Knox, 1985 and Henry, 1990).

Influent nitrate concentrations to a septic tank are normally low with average concentrations typically being around 0.6 mg/l NO_3-N. The average concentration of nitrate in the influent domestic sewage to the BMS prototype septic tank was 1.7 mg/l NO_3-N. Due to the anaerobic conditions present in septic tanks (which prevent the conversion of ammonia to nitrate) nitrate concentrations usually remain unchanged upon passage through a septic tank. The percentage removal of nitrate within the BMS prototype septic tank fluctuated between -190 and +100%. This indicated that on some sampling occasions nitrate was generated within the tank probably by the process of nitrification. This was observed mainly after a four year operational period. During the first two years of usage an average removal rate of 67% was observed for nitrate in the BMS prototype septic tank. Following four years in usage, nitrate levels consistently increased on passage through the septic tank. Viraghavan and Warnock (1976) cite a value of 0.026 mg/l NO_3-N as characteristic of nitrate concentrations in septic tank effluent. Henry (1990) observed concentrations of between 0 and 1.4 mg/l NO_3-N (x = 0.4 mg/l NO_3-N,) while Preul (1965) and Polkowski and Boyle (1970) observed concentrations of 0.15 and 0.13 mg/l NO_3-N, respectively. On most sampling occasions the nitrate concentration in septic tank effluent from the BMS prototype septic tank was in accordance with these values (i.e. < 0.4 mg/l NO_3-N). However, in some instances, as previously stated, nitrate was generated within the septic tank leaving the overall mean value observed over the four year investigation period at 1.3 mg/l NO_3-N.

Influent concentrations of the faecal coliform, *E. coli* to the BMS prototype septic tank are typical of those values obtained in domestic sewage. Gray (1989) quoted an average concentration of 1.3 x 10^6 cfus/100 mls as typical of *E. coli* concentrations in domestic sewage. The corresponding value for the influent to the BMS septic tank was 3.2 x 10^6 cfus /100mls, with values ranging from 3.4 x 10^4 to 2.0 x 10^7 cfus / 100 mls. A number of studies suggest that the removal of coliforms in septic tanks is low (Robeck *et al*, 1964; Patterson *et al*, 1971; Ziebell *et al*, 1974; and Thorn *et al*, 1985). The die-off rate of *E. coli* in domestic sewage is given by Dor *et al* (1976) to be 99% in 44 hours. Feacham *et al* (1983) suggests that they may have a greater than 70 hour survival time at 20 ^{O}C. In a correctly functioning septic tank a three day HRT is usual. This should allow adequate time for a large proportion of the coliforms in domestic sewage to die off naturally. If the HRT within a septic tank is less than three days (due to sludge build up or poor tank construction) then insufficient time is available for the micro-organisms to die and inadequate removal of coliforms and other pathogenic organisms will ensue. The HRT within the prototype BMS septic tank was calculated to be approximately one week. This may have accounted for the high removal rate of *E. coli* observed (i.e. 89.6%). Most workers agree that the number of faecal bacteria in septic tank effluent is very high (Cain and Beaty, 1965; Patterson *et al*, 1971; Viraghavan, 1973 and Mc Coy and Hagedorn, 1979). The concentration of *E. coli* in the effluent from the BMS septic tank was between 1.1 x 10^1 and 1.8 x 10^6 cfus / 100 mls. The average number of *E. coli* in the BMS septic tank effluent was 2.7 x 10^5 cfus/100 mls. Ziebell *et al* (1974) found the average concentration of *E. coli* in septic tank effluent to be in the order of 4.2 x 10^5 cfus/100mls, while other workers observed concentrations in the range 1.3 to 5.0 x 10^6 cfus /100 mls (Robeck *et al,* 1964; Bradley, 1981; Thorn *et al*, 1985 and Henry, 1990). Based on the comparisons between the number of *E. coli* in septic tank effluent from a conventional septic tank as compared to the number in the septic tank effluent from the BMS prototype septic tank, the removal of *E. coli* in the BMS septic tank was at least as efficient as in a conventional septic tank throughout a four year investigation period.

In summary, during the first two years of operation, the BMS prototype septic tank yielded removal rates above those observed in a conventional septic tank for phosphate, ammonia, SS, nitrate and COD. In addition, the BMS prototype septic tank was at least as efficient for BOD and *E.coli* removal.

After a four year operational period the BMS prototype septic tank had lost its superior performance over a conventional septic tank for the removal of phosphate, ammonia, SS and COD. After this time removal rates for these pollutants and also for BOD and *E. Coli* were at least as efficient as in a conventional septic tank. Nitrate removal was lower than usually observed in a conventional septic tank following a four year operational period..

5.2 Pilot scale BMS septic tanks.

The pilot scale BMS septic tanks offered a more controllable environment to observe processes occurring within the BMS septic tank. The greatest advantage of the pilot scale systems over the prototype septic tank was that sampling of the influent domestic sewage was performed prior to entering the septic tank instead of in the first chamber. The hydraulic retention time (HRT) was also more closely controlled. Sampling of the intermediate chambers of the pilot scale septic tanks was undertaken so as to determine the extent of removal of the various pollutants at each stage in the BMS septic tank and more importantly the benefits of adding the Biolat media to the septic tank.

Another aspect involving the pilot scale septic tanks was to determine if aeration of the second chamber of the BMS septic tank would enhance the removal rate of pollutants within the septic tank. Two of the four pilot scale septic tanks were aerated.

5.2.1 The influence of aeration on the pilot scale septic tanks.

Discussion of the influence of aeration on the performance of the BMS pilot scale septic tanks comprises comparison of the concentration of each of the pollutants in the influent domestic sewage to the tanks with those pollutant concentrations in chamber two. Also the effect of aeration, if any, on the performance of the Biolat chamber for pollutant removal is discussed.

The removal of BOD was greatest within the aerated pilot scale septic tanks. This was due to the extra oxygen supplied for the aerobic respiration of carbonaceous material. Many workers have found that aerobic treatment of domestic sewage is more efficient than anaerobic treatment for the decomposition of carbonaceous material (Magdoff *et al*, 1974 Pell and Nyberg, 1990 and Wakatsuki *et al*, 1991). This was evident in the pilot scale septic tanks. An average BOD removal rate of 63% was obtained from influent domestic sewage to chamber two in the aerated pilot scale septic tank while a corresponding value of 50% was obtained in the unaerated pilot scale septic tanks. The overall removal rates obtained for BOD was 56% in the unaerated pilot scale septic tanks and 65% in the aerated pilot scale septic tanks. Although the difference in total removal rates between the aerated and unaerated tanks was less than that observed between chambers two, it was nevertheless significant at a 95% confidence interval.

Similar values (i.e. 50%) were observed for COD removal from influent to chamber two in both the aerated and unaerated pilot scale septic tanks. It was expected that COD removal would be greater in the aerated pilot scale septic tanks than in the unaerated tanks due to a more efficient aerobic respiration of carbonaceous material. It was unknown why this was significant in the removal of BOD but not for COD in the aerated pilot scale septic tanks.

The effect of aeration on SS removal in the pilot scale septic tank was to prevent the normal settlement of solids in the second chamber of the tanks. An average SS removal rate of 94% was observed from influent to chamber two in the unaerated pilot scale septic tanks while a corresponding removal rate of 87% was observed in the aerated pilot scale septic tanks. While most of the solids were actually removed in chamber one, there was some carry over of solids to the second chamber. These could be seen to be agitated and held in suspension by the bubbles of air produced by the aerator in the aerated tanks. Visual observation of the effluent in the second chamber of the unaerated tanks showed the solids to settle and not to remain in suspension at the top of the liquid level. There was no difference in the average overall SS removal rates (i.e. from influent to effluent) between the aerated and unaerated pilot scale septic tanks. An average value of 98% removal was obtained for both the aerated and unaerated septic tanks. The Biolat therefore clearly exerted a filtering effect, filtering out the SS in the effluent from the second chamber. However, since extra solids were carried over into the Biolat chamber from chamber two of the aerated tanks, it would follow that the Biolat would become clogged with solids more quickly if aeration of the second chamber was continued.

Aeration of the pilot scale septic tanks did not significantly enhance phosphate removal. The concentration of phosphate observed in the second chamber of both the aerated and unaerated pilot scale septic tanks was similar i.e. a concentration of 4.1 mg/l PO_4-P was observed in the former while a concentration of 4.4 mg/l PO_4-P was observed in the latter. The overall average removal rates observed for phosphate within both the aerated and unaerated pilot scale septic tanks were also similar i.e. 70% in the former and 69% in the latter. This indicated that Biolat removed phosphate equally in both the aerated and unaerated tanks regardless an the influence of aeration.

The removal of ammonia was greatest in the aerated pilot scale septic tanks. Ammonia concentrations were on average lower in chamber two of the aerated pilot scale septic tanks than in the second chamber of the unaerated septic tanks. The average concentration of ammonia observed in chamber two of the aerated septic tanks was 13.5 mg/l NH_3-N, while the corresponding ammonia concentration in the unaerated septic tanks was 17.6 mg/l NH_3-N (Table 4.2, page 118). This was due to the conversion of ammonia to nitrate in the aerated septic tanks by the process of nitrification. Nitrification is an aerobic process performed mainly by obligate autotrophic micro-organisms, with NO_3^- as the main end product (Painter, 1970 and Bourma, 1979). The conversion of ammonia to nitrate is normally retarded in a conventional septic tanks by the lack of oxygen (Viraghavan, 1973). Results obtained for nitrate concentrations within the aerated pilot scale septic tanks showed that the process of nitrification occurred to a large extent. There was an overall 88% average increase in nitrate concentration from influent domestic sewage to the second chamber of the aerated pilot scale septic tanks. The corresponding value for the unaerated tanks was a 1% decrease in nitrate concentration (Table 4.2, page 118). The total removal rates achieved for nitrate in the pilot scale septic tanks were greatest in the unaerated septic tanks i.e. an average removal rate of 63% was observed in the unaerated septic tanks while the corresponding removal rate achieved in the aerated septic tanks was 42%. Given that the nitrate concentration increased by 88% from the influent domestic sewage to the second chamber of the aerated septic tanks, the difference in removal rates between the aerated and unaerated tanks was not as great as expected. The effect of aerating the pilot scale septic tanks at any rate served to decrease the ammonia concentration of the domestic sewage as it flowed through the tank at the expense of increasing the nitrate concentration. This was an undesirable effect since the Biolat could not remove nitrate to the same extent as ammonia. Nitrate removal by Biolat only occurred when conditions for denitrification were favourable (Section 5.3, page 207). Therefore, in this instance the effect of aerating the BMS septic tank was undesirable.

The percentage reduction of *E. coli* from influent domestic sewage to the second chamber was greatest in the aerated septic tanks, i.e. 84% removal was achieved in the aerated septic tanks while 73% removal was observed in the unaerated septic tanks. The reason for this was not clear since it was expected that less removal would occur in the aerated septic tanks due to re-entrainment of solids (to which the bacteria may have attached). It may have been that under the aerobic conditions in the pilot scale septic tanks predation by protozoans etc. was more important than under anaerobic conditions, resulting in higher removal rates for *E.coli*. Hanes *et al* (1964) reported that a cool anaerobic environment had a protective effect for coliforms in domestic sewage. The average total percentage removal of *E. coli* in the pilot scale septic tanks was similar in both the aerated and unaerated septic tanks. An average value of 96% was obtained in the former while a corresponding value of 97% was observed in the latter. The average total removal rates achieved in both the aerated and unaerated pilot scale septic tanks were the same only because Biolat was efficient in the removal of *E. Coli* present in domestic sewage.

In general therefore aeration of the BMS pilot scale septic tanks was beneficial only in the removal of BOD. Although *E. Coli* removal was greater in chamber two of the aerated tanks than in the unaerated tanks the efficiency of Biolat in the removal of *E. Coli.* when present in domestic sewage meant that the average overall removal rates were similar regardless of aeration. Ammonia removal occurred under aerobic conditions only at the expense of an increase in nitrate concentration. The usual settlement of SS under gravity separation was retarded in an aerated environment. COD and phosphate removal in the BMS pilot scale septic tanks appeared unaffected by aeration.

5.2.2 The removal of pollutants by Biolat.

The removal of BOD, COD, SS and *E. coli* occurred predominantly in chambers one and two of the pilot scale septic tanks while the removal of phosphate and nitrate occurred predominantly in the Biolat chamber. The removal of ammonia occurred both in chambers one and two and in the Biolat chamber.

The removal rates achieved for BOD in the pilot scale septic tanks are comparable to the removal rates achieved in the prototype BMS septic tank (Tables 4.1, page 105 and 4.2, page 118). For the purpose of comparing like with like, only the removal rates observed in the unaerated pilot scale septic tanks shall be compared to removal rates observed by other workers in a conventional septic tank. An average removal rate of 56.0% was observed in the unaerated pilot scale septic tank over the 25 week test period, while an average removal rate of 59.3% was obtained in the prototype septic tank over a four year investigation period. BOD concentrations arising in the effluent from the unaerated pilot scale septic tank were between 37 and 110 mg/l BOD, with an average value of 63 mg/l BOD. BOD concentrations in the pilot scale septic tank effluent over the 25 week investigation period were much lower than its concentration in septic tank effluent as observed by other workers (Preul, 1965; Polkowski and Boyle, 1970; Viraghavan and Warnock, 1976; Canter and Knox, 1985 and Henry, 1990). The bulk of of BOD removal occurred in chambers one and two of the pilot scale septic tanks and so theoretically should be achievable in any normal septic tank which is constructed and maintained properly. The Biolat chamber was not responsible to any great extent for BOD removal (Figure 4.25, page 127).

The removal of COD in the unaerated pilot scale septic tanks and in the prototype BMS septic tank was similar. Average removal rates of approximately 53 and 54%, respectively were observed for each (Tables 4.1, page 105 and Table 4.2, page 118). COD concentrations in the septic tank effluent from the unaerated pilot scale septic tanks was between 69 and 264 mg/l COD with an average concentration of 107 mg/l COD over the 25 week investigation period. These COD concentrations were much lower than those values observed by other workers (Viraghavan and Warnock, 1976; Canter and Knox, 1985 and Henry, 1990). Again the removal of COD in the pilot scale septic tanks occurred predominantly in chambers one and two, with little or no removal occurring in the Biolat chamber (Figure 4.27, page 128).

Biolat was not very efficient in the removal of BOD and COD in septic tank effluent when compared to removal rates achieved in other media. Christoulas and Andreadakis (1989), Ebers and Bischofsberger (1990), Pell and Nyberg (1990) and Fazio *et al* (1993) observed removal rates greater than 75% for BOD and COD removal in a sand absorption system which followed a septic tank. Similarly, much higher removal rates for BOD and COD were observed in peat systems used for treating septic tank effluent (Rock *et al*, 1982; Brookes *et al*, 1984 and Viraghavan *et al*, 1987). These workers observed BOD removal rates ranging from 30 to >90%.

An average removal rate of 98.0% was observed for SS in the unaerated pilot scale septic tanks over the 25 week investigation period. Of this value 94.0% removal was achieved in chambers one and two and so was attributable to sedimentation. The average removal rate obtained in the BMS prototype septic tank was 63.6%. The latter value was more comparable to removal rates observed in septic tanks by other workers (Baumann and Babbitt, 1953; Goldstein and Wenk, 1972; Bailey and Wallmann, 1971 and Christoulas and Andreadakis, 1989) The reason for the increased removal rates in the pilot scale septic tank may be due to the lack of turbulence at the inflow to the pilot scale septic tanks which is typical of normal septic tanks. The pilot scale septic tanks were continuously fed by means of a peristaltic pump and therefore there were no turbulent flows. Although this may have lead to better settling conditions for SS in the pilot scale septic tanks, it did not adequately resemble normal conditions. It is also worth noting that influent SS concentrations to the pilot scale septic tanks were somewhat lower than usual to a normal septic tank. This would undoubtedly lead to lower concentrations in the septic tank effluent.

The removal of phosphate occurred predominantly in the Biolat chamber of the pilot scale septic tanks (Figure 4.31, page 130) The average removal rate achieved for phosphate from influent domestic sewage to effluent was 69.0% in the unaerated pilot scale septic tanks. The bulk of this removal i.e. 53% was achieved in the Biolat chamber while chambers one and two was responsible for only 16% of the removal. This agrees well with the findings of Patterson *et* *al* (1971) and Canter and Knox (1985) who report that anaerobic processes within a septic tank were largely ineffective in reducing the concentration of phosphorous in influent wastewater. The efficiency of Biolat in the removal of phosphate undoubtedly accounted for the fact that phosphate removal in the BMS prototype septic tank was higher than in a conventional septic tank i.e. 73.1%. Phosphate concentrations in the septic tank effluent from both the unaerated pilot scale septic tanks and the BMS prototype septic tanks were low, with an average phosphate concentration of 1.6 mg/l PO_4-P in the former and 2.8 mg/l PO_4-P in the latter. These concentrations were well below observed phosphate concentrations in septic tank effluent as observed by other workers (Preul, 1965 Bradley, 1981; Doyle and Thorn, 1987 and Henry, 1990). Viraghavan and Warnock (1976) cite an average phosphate concentration of 11.6 mg/l as typical of phosphate in septic tank effluent, with values ranging from 6.2 to 30.0 mg/l. In fact, the observed phosphate concentrations in septic tank effluent from the pilot scale septic tanks were more comparable to phosphate concentrations in soil absorption field effluents than in a septic tank effluent. Viraghavan and Warnock (1976) cite typical concentrations of phosphate reaching groundwater from a soil absorption system as being between 6 and 9 mg/l P. Although these values are not directly comparable to orthophosphate concentrations, Bourma (1975) reports that greater than 85% of total phosphorous in septic tank effluent is in the orthophosphate form.

Other workers have investigated the removal of phosphate from domestic sewage using a range of different media. Rock *et al* (1982) used peat for this purpose and observed removal rates between 58.0 and 94.0% while Viraghavan *et al* (1987) found the removal of phosphate in peat to be between 0.0 and 25.0%, while and Brookes *et al* (1984) observed a removal rate of 96.0%. The removal of phosphate in septic tank effluent using sand was investigated by Ebers and Bischofsberger (1990). They observed removal rates ranging from 5.7 to 86.0% for a fine grained sand and 86.0 to 99.3.0% for a slightly silty sand. Pell and Nyberg (1990) observed the removal of phosphate present in septic tank effluent using sand to be in the region of 70.0%. Therefore, for the concentrations of phosphate present in septic tank effluent, removal rates observed in Biolat were comparable to the removal rates observed in other media such as sand and peat.

It must be noted that the efficiency of phosphate removal fluctuated in the BMS pilot scale septic tanks over the 25 week sampling period. This was similar to the pattern observed in the prototype septic tank (Fig 4.2, page 106 and Fig 4.31, page 130). During the first three weeks, a steady decline was observed in the percentage removal of phosphate in the unaerated pilot scale septic tanks. On week one a removal rate in excess of 95% was observed in the pilot scale septic tanks. This value was reduced to 65% on week three. It could be argued that the decrease in phosphate concentration was due to a steady increase in phosphate concentration over the three week period. However, if this theory is examined over the entire 25 week sampling period it is evident that the removal efficiency of the BMS pilot scale septic tanks for phosphate does not correspond negatively or positively to high influent phosphate concentrations. The observed fluctuations in removal rates must therefore be due to other factors occurring within the septic tank or Biolat media itself (Fig 4.17, page 123 and Fig 4.31, page 130). In general there appeared to be a downward trend in the removal efficiency of phosphate by the BMS pilot scale septic tanks. Looking at the average phosphate removal rates obtained over the initial eight week period, a value of 76% was observed. Over the second eight week period this value was decreased to 54%, indicating a steady decline in the usefulness of Biolat for phosphate removal.

The removal rates achieved for ammonia in the unaerated pilot scale septic tanks were much greater than in the BMS prototype septic tank (i.e. an average removal rate of 70.0% was observed in the former while a corresponding value of 41.6% was achieved in the latter). On average 40.0% of the observed ammonia removal in the unaerated pilot scale septic tanks occurred in chambers one and two, while 30.0% removal occurred in the Biolat chamber. Studies by other workers have shown that the removal of ammonia within a septic tank is generally low (Patterson *et al*, 1971 Canter and Knox, 1985 and Henry, 1990), or that ammonia levels increase within a septic tank (Viraghavan, 1973 and Canter and Knox, 1985). The reason for the higher removal rates observed in chambers one and two of the pilot scale septic tanks was unclear. However, it was evident that Biolat contributed to the high final removal rates obtained. The ammonia concentrations in the septic tank effluent from the pilot scale septic tanks were much lower than observed in septic tank effluent from a conventional septic tank. Ammonia concentrations in the effluent from the pilot scale septic tanks were between 0.7 and 16.3 mg/l NH_3-N, with an average concentration of 7.2 mg/l NH_3-N observed over the 25 week investigation period. Viraghavan and Warnock (1976) quote characteristic ammonia concentrations in septic tank effluent to be in the region of 97.0 mg/l NH_3-N. Henry (1990) observed ammonia concentrations between 13.5 and 71.8 mg/l NH_3-N while Preul (1965); Robeck *et al* (1964) and Polkowski and Boyle (1970) observed ammonia concentrations of 25.0, 22.0 and 14.0 mg/l NH_3-N, respectively. Therefore, from data obtained from these experiments over a 25 week investigation period, the BMS pilot scale septic tanks showed a marked improvement over a conventional septic tank for ammonia removal.

The observed removal rate for ammonia fluctuated over the 25 week sampling period. Although the percentage removal rates differed from one sampling period to another (probably due to conditions within the pilot scale septic tanks or in the Biolat medis itself), there appeared to be a general downward trend in the efficiency of ammonia removal over the 25 week investigation period (Fig. 4.33, page 131). The percentage removal in the first half of the investigation period was greater than in the second half i.e. a removal rate of 73% was obtained for the former and 49% in the latter.

Nitrate concentrations are generally low in septic tank effluent i.e. between 0.0 and 1.4 mg/l NO_3-N (Table 2.4, page 30). This is due to anaerobic conditions within a septic tank (Viraghavan, 1973). The nitrate concentration in the effluent from the unaerated pilot scale septic tanks reached an uppermost limit of 2.5 mg/l NO_3-N (with a mean value of 1.3 mg/l NO_3-N). The average removal rate achieved for nitrate in the unaerated pilot scale septic tanks was 62%. The removal of nitrate in the pilot scale septic tanks occurred predominantly in the Biolat chamber. Only 1% of the observed 62% removal of nitrate was achieved in chambers one and two of the unaerated septic tanks. This is in agreement with the findings of Kaplan (1988) and Perkins (1989) who found that nitrate was not removed to any great extent in septic tanks. Further experiments revealed that the Biolat media itself was not responsible for nitrate removal (Section 4.3, page 134), therefore the removal of nitrate in the Biolat chamber of the pilot scale septic tanks may have been due to biological processes i.e. denitrification, occurring within the chamber. If the correct conditions for denitrification are present in the Biolat chamber (denitrifying bacteria, carbon source, anoxic environment, correct temperature and adequate hydraulic retention time) then denitrification may occur.

The removal of nitrogen both as ammonia and nitrate in the BMS pilot scale septic tanks, over the 25 week investigation period, far surpassed its removal in a conventional septic tank and was comparable to removal rates achieved in other media designed to remove pollutants from septic tank effluent. The Biolat chamber was responsible for removing 33.3 to 100.0% of the nitrate arising in chamber two of the unaerated pilot scale septic tanks. Similarly, it was responsible for removing approximately 52.6% of the ammonia arising in chamber two of the unaerated septic tanks. Although most workers have looked at total N removal in septic tank effluent using various media, Rock *et al*, 1982 looked specifically at ammonia and nitrate removal in peat. They observed a 94.0% decrease in ammonia concentration on passage of the septic tank effluent through a peat filter, however a 275.0% increase in nitrate concentration was also observed. Brookes *et al* (1984) observed the removal of total N in peat and found removal rates of between 58.0 and 62.0%, while Viraghavan *et al*, 1987 also using peat, observed removal rates of between 0.0 and 90.0%. Pell and Nyberg (1990) and Fazio *et al* (1993) observed a 60.0% and 90.0% decrease, respectively, in the total N content of septic tank effluent when using a sand filter. Ebers and Bischofsberger (1990) observed a decrease of between 39.0 and 68.4% in nitrogen concentration by using a slightly silty sand and between 90.0 and 91.3% decrease when using a fine grained sand.

The removal rates achieved for *E. coli* in the pilot scale septic tanks were consistently greater than 89.0% over the 25 week test period. The average removal rates observed in the pilot scale septic tanks were slightly higher than in the BMS prototype septic tank (i.e. 97.0% as compared to 89.6%). The removal of *E. coli* occurred predominantly in chambers one and two of the pilot scale septic tanks although some removal also occurred in the Biolat chamber. It is known that *E. coli* present in domestic sewage become attached to the SS also present in the sewage. When the solids settle out in the septic tank so too do the attached bacteria (Patterson *et al*, 1971). Gray (1989) cites Gainey and Lord (1952) who report a removal rate of between 45.0 and 75.0% of bacteria present in domestic sewage and attributed it to the sedimentation of solids. The removal of *E. coli* in Biolat may be accounted for by the filtration of solids in the effluent by Biolat which also served to remove attached *E. coli*. In experiments performed on the removal of *E. coli* in domestic sewage and in a buffered water solution, it was observed that much greater removal rates occurred in domestic sewage due to the presence of SS (Section 4.3, page 134). When there were no SS present (i.e. in Ringer's solution) much lower removal rates were observed. The removal of *E. coli* in Biolat may be in essence the same as their removal in a soil absorption system as described by Mc Coy and Hagedorn (1979), Lewis *et al* (1982) and Canter and Knox (1985). These workers have shown that bacteria behave as other effluent particulate matter in soil treatment and filtration plays a vital role in restricting their movement.

An average value of 2.1 x 10^5 cfus/100 mls was observed in the septic tank effluent from the unaerated pilot scale septic tanks while an average of 2.7 x 10^5 cfus/100 mls was obtained in the prototype septic tank. Ziebell *et al* (1974) observed concentrations of *E. coli* in septic tank effluent to be in the order of 4.2 x 10^5 cfus / 100 mls. However, other workers have observed concentrations ranging from 1.2 to 5.0 x 10^6 cfus / 100 mls (Robeck *et al*, 1964; Patterson *et al*, 1971, Bradley, 1981, Thorn *et al*, 1985 and Henry, 1990). Although many workers report a negligible removal of bacteria in septic tanks, the bulk of *E. coli* removal in the pilot scale septic tanks occurred in chambers one and two (Fig. 4.37, page 133) indicating that sedimentation and the natural die- off of the organisms may have been responsible for their removal. The average percentage removal of *E. coli* from the second chamber of the unaerated septic tanks to effluent was 24.0%.

The removal of indicator organisms in septic tank effluent has been investigated by many workers. Peat, sand, chalk and loam are among the media investigated to this end. Excellent removal rates of indicator organisms i.e. greater than 95% have been observed in both peat and sand (Rock *et al*, 1982; Brookes *et al*, 1984 and Viraghavan *et al*, 1987). Montgomery (1988) observed a 99% removal of indicator organisms in chalk beds which followed a septic tank while Yamaura *et al* (1986) observed a greater than 90% removal in loam columns receiving septic tank effluent. No mechanism of removal has been suggested for the removal of indicator bacteria in these media but it is likely that as with Biolat, filtration plays a major role.

5.3 Biolat columns.

From experiments conducted to assess the capability of Biolat to remove phosphate, ammonium and nitrate, the various ions were prepared in isolation both in distilled water and in domestic sewage of known composition. The concentrations used were the same for all of the nutrients under investigation i.e. 50, 100 and 200 mg/l. Excellent removal rates (i.e. greater than 98.5%) were achieved for ammonium and phosphate when present in both distilled water and in domestic sewage (Table 4.3, page 135) The percentage removal rates did not vary significantly with increased concentration of phosphate and ammonium in the range 50 to 200 mg/l. The quantity of ammonium and phosphate ions removed increased as a function of concentration over the five day trial period.

The separate Biolat column experiments showed that Biolat did not remove nitrate to any great extent whether it was present in domestic sewage or distilled water. Removal rates of less than 7.0% were observed for nitrate using influent concentrations in the range 50 to 200 mg/l and allowing a one day hydraulic retention time (Table 4.3, page 135). The removal of nitrate had occurred in the pilot scale septic tanks and moreover its removal occurred specifically in the Biolat chamber of the tanks (Figures 4.35 and 4.36, page 132). Therefore, as stated previously, the removal of nitrate in the Biolat chamber was not attributable directly to the Biolat media but possibly to biological processes occurring within the Biolat chamber i.e denitrification, which occurs under specific conditions. These criteria were evidently not met in the Biolat columns but were present in the pilot scale septic tanks.

The removal of the faecal coliform, *E. coli* by Biolat was also investigated. Results from Section 4.2 had indicated that Biolat was responsible to some extent for the removal of *E. coli* within the pilot scale septic tanks. The Biolat columns were set up to investigate the removal of *E. coli* both in domestic sewage and in a buffered solution of sterile water (Ringer's solution). The typical concentration of *E. coli* in domestic sewage is in the region of 1.3 x 10^6 cfus/100 mls (Gray, 1989). The domestic sewage used in this set of experiments had an average concentration of 1.2 x 10^6 cfus/100 mls, ranging from 9.7 x 10^5 to 1.9 x 10^6 cfus/ 100 mls. Removal rates of greater than 75% were obtained for *E. coli* present in domestic sewage over the five day test period (Figure 4.39, page 135). These removal rates were comparable to the removal rates of *E. coli* in peat, sand, chalk and loam as previously discussed (Section 5.2.2, page 207)

Various concentrations of *E. coli* were also prepared in Ringer's solution (i.e. 1.6 x 10^6, 1.9 x 10^8 and 2.0 x 10^{10} cfus / 100 mls). These concentrations were prepared by using a pure culture of the organism. The removal rate achieved for *E. coli* when present in Ringer's solution was less than half of that observed when *E. coli* was present in domestic sewage. Removal rates were in the order of 10 to 40% in the Ringer's solution (Figure 4.39, page 135). The effect of concentration of *E. coli* on percentage removal rates was not evident. At a 95% confidence interval there was no variation in the mean value obtained for percentage removal over the five day trial period. However, greater numbers of *E. coli* were removed as their concentration in Ringer's solution increased. The reason for this is not known and requires further investigation. The greater removal rates achieved for *E. coli* in domestic sewage rather than in Ringer's solution may have been due to the presence of SS in domestic sewage. Bacteria in domestic sewage normally adhere to SS (Polkowski and Boyle, 1970). The *E. coli* may have adhered to the SS in the domestic sewage and when the solids were filtered by the Biolat media then the *E. coli* may also have been removed. When *E. coli* were present in Ringer's solution alone, they did not have a surface for attachment and therefore may have been too small to be filtered by the Biolat media.

5.4 Determination of the removal capacity of Biolat for ammonium and phosphate.

A number of points became evident from the experiments performed to determine the adsorption capacity of Biolat for ammonium and phosphate (Table 4.4, page 138 and 4.5, page 139). The most important point noted was that the concentration of ions in the influent solution influenced the total amount of ions which were removed by Biolat. Concentrations of 50, 100 and 200 mg/l of phosphate or ammonium were used in this set of experiments. Five hundred ml quantities of each of the concentrations were applied daily until the Biolat could remove no more phosphate or ammonium. This volume corresponded to a one day HRT within the Biolat columns. The total mass of ions removed by Biolat increased as the concentration of ions in the influent solution increased. In the case of phosphate, the observed quantity of phosphate removed by Biolat almost doubled for each twofold increase in the influent concentration of phosphate. The quantity of phosphate removed per 100g of Biolat was 27.4 mg at the 50 mg/l PO_4-P concentration, 48.9 mg at the 100 mg/l PO_4-P concentration and 91.4 mg at the 200 mg/l PO_4-P concentration. Similarly the total mass of ammonium removed per 100g of

Biolat was 45.5, 79.1 and 133.2 mgs for the 50, 100 and 200 mg/l NH_4-N concentrations, respectively. The same trend was evident when the adsorption capacity of Biolat was investigated at these influent concentrations over a two and three day HRT (Table 4.8, page 149).

5.5 Factors controlling the removal of phosphate and ammonium by Biolat.

- Concentration / Retention time.

As already stated in Section 5.4, the amount of phosphate and ammonium removed by Biolat increased with increased initial influent concentration. The experiments conducted to investigate the removal of various concentrations of both phosphate and ammonium after specific time intervals further demonstrated this fact. The time intervals investigated were 1, 2, 4, 6, 8 and 24 hours. From Figure 4.42 (page 148), very high concentrations of phosphate can be removed by Biolat i.e. up to 1,000 mg/l PO_4-P in 24 hours. Higher concentrations of phosphate can also be removed but these require longer HRTs. The range of phosphate concentrations used in the experiments were 10, 50, 100, 500, 1,000, 5,000 and 10,000 mg/l PO_4-P. A rapid removal of phosphate occurred in the first hour of contact with Biolat. This was followed by a slower removal rate. This trend was evident over the entire range of concentrations used. Greater than 40% removal of phosphate occurred in the first hour of contact with Biolat for concentrations up to 1,000 mg/l PO_4-P. While the percentage removal of phosphate differed only between 41.6 and 53.1% in this concentration range, the mass of ions removed increased progressively as the influent phosphate concentration was increased. During the first hour of contact, 0.49 mgs of phosphate were removed per 100g of Biolat at the 10 mg/l PO_4-P concentration, while 2.66, 4.16, 21.60 and 44.50 mgs of phosphate were removed in the first hour at the 50, 100, 500 and 1,000 mg/l PO_4-P concentrations, respectively. Although the percentage removal of phosphate decreased at the higher concentrations of 5,000 and 10,000 mg/l PO_4-P, the amounts of phosphate removed at these concentrations were similar i.e. 139.0 mg/100g Biolat for the former and 139.7 mg/ 100g of Biolat for the latter. This may have indicated that the Biolat was becoming saturated at these high concentrations. The observed initial fast removal rate for phosphate was followed by a more gradual removal and for concentrations up to 1000 mg/l PO_4-P, a 24 hour contact time was required for equilibrium conditions to be established. Even longer retention times were required as the phosphate concentrations were increased to 5,000 and 10,000 mg/l PO_4-P. Removal rates of only 54.0 and 45.7%, respectively were achieved for these concentrations, after a 24 hour HRT.

Similar trends were evident in the removal of ammonium by Biolat as were evident in phosphate removal i.e. the weight of ammonium removed increased with increased initial influent concentration and also there was an initial period of fast removal of ammonium by Biolat followed by a slower removal rate. For concentrations up to 1000 mg/l NH_4-N, a one day HRT was required to achieve adequate removal rates i.e. >85%. Above these concentrations longer HRTs were required.

The removal of phosphate by Biolat followed a similar pattern to its removal by other media. Shiao *et al* (1977), using activated red mud (spent bauxite) for the removal of phosphate, observed that 50% of influent phosphate was removed in the first 10 minutes of contact with 72% removal occurring within 120 minutes. These workers suggested that the transition point between the initial rapid removal and the later phase of slower removal by an adsorbent may represent a transition point in which pore diffusion rather than surface layer adsorption control phosphate removal. Similarly, Van Riemsdijk *et al* (1979) reported that the adsorption of phosphate onto $Al(OH)_3$ was comprised of a fast reaction followed by a much slower one. ($Al(OH)_3$ is formed on the surface of Al_2O_3 in water). These workers claimed that phosphate adsorption may be slow if the monolayer coverage region is being approached or completed, but that the amount of phosphate taken up in the slow reaction may amount to 30 or 40 % of that taken up in the fast reaction.

In experiments conducted to determine the effect, if any, of HRT on the adsorption capacity of Biolat for ammonium and phosphate, one, two and three day HRTs were examined. The concentrations of phosphate and ammonium used were 50, 100, 200 and 400 mg/l. The total quantities of phosphate removed by Biolat at a given concentration were very similar over the various HRTs investigated (Table 4.8, page 149). Standard deviation values ranged from 1.35 to 2.4 mg phosphate / 100 g of Biolat. At a 95% confidence interval there was no significant variation between the various HRTs investigated at a given concentration. This followed from previous experiments which showed that a one day HRT was sufficient for concentrations below 1,000 mg/l PO_4-P. Since the concentrations used in this experiment were $\leq$ 400 mg/l PO_4-P, then a one day HRT was sufficient to remove the phosphate in the influent solutions and no further removal was achieved upon increasing the HRT to two and three days.

The quantities of ammonium removed by Biolat yielded greater variation over the various HRTs investigated (Table 4.8, page 149). The standard deviation values for a given ammonium concentration ranged from 3.19 to 19.70 mg NH_4-N/ 100g of Biolat over the various HRTs. It must be stated however that for the 50, 100 and 200 mg/l NH_4-N concentrations, the standard deviation values were between 3.09 and 7.30 mg NH_4-N / 100g of Biolat. It was at the 400 mg/l NH_4-N concentration that the highest value of 19.70 mg NH_3-N/ 100g of Biolat was obtained for standard deviation. The reason for the greater deviation values obtained for the removal of ammonium by Biolat over the various HRTs was probably due to the inherent variability of the Biolat itself. However, it was evident that increasing the HRT did not generally improve its adsorption capacity in the concentration range of 50 to 400 mg/l

NH_4-N. In general the highest removal occurred at the lower HRTs (Table 4.8, page 149). Again this can be related to previous experiments which showed that a one day HRT was sufficient to remove ammonium concentrations less than 1,000 mg/l NH_4-N.

Results obtained from the adsorption capacity trials of Biolat for phosphate yielded mean values of between 23.1 and 191.9 mg phosphate / 100 g of Biolat (or 0.23 to 1.92 g/kg) for influent concentrations between 50 and 400 mg/l PO_4-P. The quantity of ammonium removed by Biolat ranged from 30.8 to 259.4 mg ammonium / 100g of Biolat (or 0.31 to 2.59 g/kg) for influent concentrations between 50 and 400 mg/l NH_4-N. Biolat therefore has the potential to remove large quantities of phosphate and ammonium. To achieve maximum benefits, very high concentrations of phosphate or ammonium must be used i.e. greater than 400 mg/l. The Biolat therefore is being underutilised for septic tank effluent where phosphate concentrations are well below these concentrations i.e.Viraghavan and Warnock (1976) cited a concentration of 11.6 mg/l PO_4-P as typical of phosphate in septic tank effluent. Ammonium concentrations in septic tank effluent are generally higher than those of phosphate. Viraghavan and Warnock (1976) cited a value of 97.0 mg/l NH_4-N as typical of ammonium concentrations in septic tank effluent. Therefore Biolat would be better suited to ammonium removal in septic tank effluent rather than for phosphate removal. However, the full potential of Biolat would still not be utilised fully.

The values obtained for the removal of phosphate and ammonium by Biolat was compared to other soils which have been investigated for this purpose. Wakatsuki *et al* (1991) found that the phosphate adsorption capacities of soils varied depending on the soil type. He found that some andisols could fix up to 1 g/ kg while quartz rich sandy soil could only fix 0.1 g/ kg. Sanchez and Uehara (1980) found that the adsorption capacities of clays rich in iron and aluminium oxides ranged from 0.2 g/kg to 5.6 g/ kg depending on the clay mineral content and on whether the colloids were amorphous or crystalline. Greater removal rates were achieved when the clay content was high and the colloids were amorphous. Kodama (1983) used $Al(OH)_3$ containing sulphate together with clinoptilite zeolite in order to remove phosphate and ammonium from solution. The composite material adsorbed 16g of phosphate/ kg and 5g of ammonia/ kg. Fukumi *et al* (1977) used amorphous aluminium silicate to treat a wastewater containing ammonium. Using 20g of $Al_2O_3.9SiO_2$, 4.0 mg of ammonium was adsorbed on the silicate from a 20 mg/l NH_4-N concentration (i.e. 0.2 g/kg). Urano and Tachikawa (1991a) used a commercial activated alumina combined with sulphates (aluminium or iron) to remove phosphates from wastewater. These workers found that the phosphate adsorption capacity of this combination averaged at 17 g /kg with an uppermost value of 23g/ kg. Therefore in general the adsorption capacity of Biolat for ammonium and phosphate was quite low when compared with other materials that have been investigated to this end.

- **pH of influent solution.**

Phosphate and ammonium removal by Biolat occurred in the pH range 2 to 12. In the case of ammonium the greatest percentage removal was observed between pHs 4 and 10 (i.e. > 93% removal was observed in this range). An 80% removal of ammonium was observed at pH 2 and 12 (Table 4.9, page 153). In general phosphate removal was greatest between pH 6 and 12, ranging from 77.9 to 80.0%. Somewhat lesser removal rates were observed at pH 2 and 4 i.e. 74.1 and 74.6%, respectively. Many workers have investigated the pH dependency of adsorption reactions (Weber, 1972; Faust and Aly, 1987 and Van Reimsdjik *et al*, 1979). More specifically Van Reimsdjik *et al* (1979) demonstrated the effect of pH on the adsorption of phosphate onto $Al(OH)_3$. These workers found that the adsorption of phosphate increased as the pH decreased. Urano and Tachikawa (1991a) found that phosphate adsorption by activated alumina occurred only in the pH range 4 to 7. Brady (1974) states that as the pH is raised, the negative charges on some silicate clays and iron and aluminium hydroxides increase thus affecting effect adsorption reactions. Sanchez and Uehara (1980) found that the fixation of phosphate on geothite which is present in laterite) occurred over a relatively wide pH.

Cation exchange reactions are affected by pH. This is indirectly related to adsorption reactions which serve as a precursor to ion exchange. As pH is increased the negative charge on silicate clays, allophane and iron and aluminium hydroxides (all of which are present in laterites) increase thereby increasing the cation exchange capacity. This was observed to some degree in the removal of ammonium by Biolat where greatest removal was observed between pH 4 and 10. However, ammonium removal was nevertheless high above and below this range (i.e. > 80%). The reason why ammonium and phosphate removal was relatively unaffected by pH may have been due to the fact that Biolat exerted a buffering effect. When the initial pH of the influent solutions was in the pH range 4 to 10 a final pH of between 7 and 8 was observed. For the more acidic pH of 2, a final pH of 4.2 was observed. Also pHs of 12 were buffered to between 9.2 and 9.4. Brady (1974) states that aluminium and iron compounds have an effect on the buffering capacity of soils. In particular, the presence of aluminium compounds tend to enhance the buffering capacity of soils. Since there are large quantities of aluminium in Biolat (approx 30%) perhaps this is exerting the buffering effect making the influence of pH of the influent phosphate and ammonium solution less significant with regard to their removal.

- **Grain size of Biolat.**

The grain size experiments were performed both in flasks which were shaken and also in unshaken flasks. Grain sizes of 0.25- 0.50, 0.50- 1.00, 1.00- 2.00 and 2.00- 4.00 mm were used. The effect of grain size on phosphate removal was most apparent during the initial 15 minute contact time (Table 4.10, page 160 and Fig. 4.48, page 158) when 84.7% phosphate removal was observed at the 0.25- 0.50 mm grain size and 78.8, 64.7 and 49.6% removal was observed in the 0.5- 1.0, 1.0- 2.0 and 2.0- 4.0 mm grain sizes, respectively. Following a one hour contact time and in subsequent sampling intervals the effect of grain size on phosphate removal became less apparent. At this stage it was possible that pore diffusion rather than surface layer adsorption was controlling phosphate removal. Following a 24 hour contact time there was no significant difference at a 95% confidence interval in phosphate removal at the various grain sizes. The trend of increased phosphate removal with decreased grain size of Biolat was also observed in the unshaken flasks (Table 4.11, page 160) in the initial stages of contact i.e. up to two hours. After this time the effect of grain size became less apparent.

The removal of ammonium was also greatest for the lower grain sizes of Biolat in both the shaken and unshaken flasks. This trend however was only evident during the first stages of contact between ammonium and Biolat. A removal rate of 59.6% was observed for ammonium in the first 15 minutes of contact for a grain size of 0.25- 0.50 mm in the shaken flasks. This removal rate decreased to 52.8, 48.3 and 41.3% for grain sizes of 0.50- 1.0, 1.0- 2.0 and 2.0 and 4.0 mm, respectively (Table 4.12, page 161). After this time the effect of grain size on ammonium removal became irrelevant and there was no observable trend in ammonium removal over the various grain sizes. The effect of increased ammonium removal with decreased grain size was more apparent in the unshaken flasks (Table 4.13, page 161). Following a 15 minute contact time, removal rates of 22.1, 13.0, 12.0 and 4.8% were observed at the 0.25-

0.50, 0.50- 1.0, 1.0- 2.0 and 2.0 and 4.0 mm grain sizes, respectively. The trend was still apparent following a 30 minute contact time. However, after this time and in subsequent sampling periods there was no particular trend of increased/ decreased ammonium removal at the various grain sizes.

The effect of decreased removal rates at higher grain sizes was probably due to a lowering of the surface area of Biolat to a threshold where adsorption reactions were affected. Bhargava and Sheldakar (1992) found that the adsorption of phosphate onto rinsed tamarind activated carbon increased with decreasing adsorbent sizes. They attributed this phenomenon to the fact that adsorption was a surface phenomenon and that smaller adsorbent sizes offered comparatively larger surface areas. Smith *et al* (1993) found that the particle size of bauxite had an effect on the removal of phosphate. These workers found that the bauxite appeared to function through an adsorptive process and therefore the greater the surface area of particles, the greater the effect. Since the ratio of surface area to mass of particles is inversely related to the size of a particle, it would appear that the use of extremely fine particles might be desirable. However, these workers also observed that the fine particles functioned as a mechanical filter that removed suspended particles from water. Thus the rate of clogging of the bauxite bed was inversely related to the particle size.

When small grain sizes of Biolat (i.e. < 0.25 mm) were used in experiments small particles became suspended in solution (even in unshaken flasks) causing a highly coloured effluent which required filtration prior to analysis. This would not be a desirable effect in effluent treatment. In addition, clogging of the Biolat matrix would be likely to occur more quickly if such small grain sizes were used. Since after 24 hours there was no significant variation in phosphate or ammonium removal rates between the various grain sizes, it followed that the grain size of Biolat most practical for the treatment of effluent containing phosphate and ammonium should be between 2.0 and 4.0 mm. This would achieve good removal rates yet minimise clogging of the Biolat media.

5.6 Desorption of phosphate and ammonium from Biolat.

The desorption of previously phosphate saturated Biolat using distilled water proved to be very efficient. In order to initially saturate the Biolat with phosphate, it was continuously fed with phosphate solutions of various concentrations i.e. 100, 200 and 400 mg/l PO_4-P, until equilibrium conditions were established. Quantities of 47.30, 90.27 and 191.97 mgs phosphate/ 100g of Biolat achieved these conditions in the 100, 200 and 400 mg/l PO_4-P concentrations, respectively. From these values 87.0% desorption was observed in the Biolat columns receiving an influent solution of 100 mg/l PO_4-P, 90.2% desorption was observed in the 200 mg/l PO_4-P Biolat columns and 94.6% desorption was observed in the 400 mg/l PO_4-P Biolat columns. These desorption rates corresponded to the removal of 41.1, 81.4 and 181.6 mgs phosphate from a 100g quantity of Biolat. The high rate of phosphate desorption indicated that the phosphate was not bound strongly to the surface of the Biolat. The shape of the desorption curve shows an initial rapid desorption reaction occurred followed by a more gradual desorption process (Figure 4.52, page 167). Large quantities of water were required for the desorption process. Four and a half litres of water were required to desorb phosphate from Biolat (600g) which had been saturated using a 400 mg/l PO_4-P concentration, while over nine litres were required to desorb Biolat which had been saturated using 100 and 200 mg/l PO_4-P concentrations. These volumes were higher than the corresponding volumes of phosphate solution used to initially saturate the Biolat columns i.e. 4.20 l for the 100 and 200 mg/l PO_4-P concentrations and 4.05 l for the 400 mg/l PO_4-P concentrations. In the Biolat columns which had been saturated using 100 and 200 mg/l PO_4-P solutions almost twice the quantity of water was used to desorb the phosphate from Biolat as was used initially to saturate it. However, for the Biolat which had been saturated using the 400 mg/l PO_4-P concentration, the difference in volume was only 0.5 litres. Distilled water was used in all of the desorption experiments. The volume of water required for desorption may have differed if ordinary tap water had been used in the experiments. In reality if desorption of phosphate was to be attempted it would be more feasible to use tap water, however for the purpose of reproducibility, distilled water was used in these experiments.

Desorption occurred more readily in the Biolat columns receiving higher concentrations of phosphate than in those receiving lower influent concentrations. As cited previously 181.6 mgs phosphate/ 100g of Biolat was desorbed in the Biolat which had been saturated with the 400 mg/l PO_4-P concentrations while 81.4 and 41.1 mgs phosphate/ 100g of Biolat were desorbed in the Biolat saturated with the 200 and 100 mg/l PO_4-P concentrations, respectively.

The same trends were evident for ammonium desorption as for phosphate desorption i.e. greater desorption rates were observed as the concentration initially used to saturate the Biolat increased and also large volumes of water were required for the desorption process. The quantities of ammonium required to saturate the Biolat at a 3 day HRT were 75.1, 137.9 and 222.0 mgs ammonium/ 100g of Biolat for influent concentrations of 100, 200 and 400 mg/l NH_4-N. The highest desorption rate observed for ammonium was in the Biolat column receiving an influent concentration of 400 mg/l NH_4-N. Here, a desorption rate of 39% was achieved. Percentage desorption values of 27.1 and 22.1% were observed in the Biolat receiving influent concentrations of 200 and 100 mg/l NH_4-N, respectively. These percentage desorption rates corresponded to masses of 16.6, 37.4 and 86.8 mgs ammonium/ 100g of Biolat for the 100, 200 and 400 mg/l NH_4-N concentrations, respectively. The lower desorption values obtained for ammonium as compared to phosphate indicated a greater level of interaction between the ammonium ion and the substrate as might be explained on the basis of the ammonium ions being strongly bound to specific sites of negative charge within the structure. With respect to the phosphate anion, the nature of the interaction was much more dynamic and hence there was a much greater level of desorption when water was forced through the material.

The requirement for large volumes of water for the desorption of phosphate and ammonium from Biolat prompted the investigation on the influence of pH on desorption. Distilled water which was pH adjusted in the pH range 2 to 12 was used for the investigation. Results showed that the pH of the desorbing medium did not significantly affect the desorption rates of either phosphate or ammonium at a 95% confidence interval over the pHs investigated over an eight hour test period. In the case of phosphate desorption, a desorption rate of between 2.5 and 2.6% was observed between pH 2 and 10 while a desorption rate of 2.3% was observed at pH 12. Ammonium desorption was greatest between pH 6 and 8, yielding a desorption rate of 1%. This was reduced to 0.8% at the other pHs investigated. It was expected that the desorption of phosphate or ammonium by Biolat would be accelerated by pH adjustment. However, this proved to be ineffective probably because of the pH adjustment capabilities of Biolat itself (Section 5.5, page 211).

5.7 Investigation into the mechanism of phosphate and ammonium removal by Biolat.

5.7.1 Investigation into the presence of anions in solution when phosphate of various concentrations was contacted with Biolat.

The anions which were present in solution when phosphate was contacted with Biolat were chloride, nitrate, nitrite and sulphate (Table 4.17, page 176). These ions were also present when Biolat was contacted with ultra-pure water. The experiments were performed using ultra-pure water and a range of phosphate solutions in order to distinguish between those ions which were being washed off from the Biolat due to its contact with water and those ions which were released to solution as a result of possible anion exchange with phosphate. A variety of concentrations of phosphates were used in these studies.

Fluctuations in the concentrations of each of the anions in solution were observed over the 48 hour test period. For this reason, and for ease of comparison between the various anions, average concentrations were calculated for each of the anions over the 48 hour test period. At a 95% confidence interval there was no difference in the amount of either nitrate or nitrite ions released from the Biolat whether it was contacted with ultra-pure water or with various phosphate solutions. The average amount of nitrite washed off the Biolat over all of the phosphate concentrations investigated was 0.039 mg/ 50g of Biolat. The corresponding value for nitrate was 0.064 mg/ 50g of Biolat (Table 4.17, page 176).

A larger quantity of chloride was observed in solution when Biolat was contacted with both ultra-pure water and various phosphate solutions. The amount of chloride released from Biolat ranged from 4.53 to 6.53 mg/ 50g of Biolat over the range of phosphate concentrations used. Again there was no significant difference observed in the amount of chloride in solution using ultra-pure water or phosphate concentrations up to 100 mg/l PO_4-P. When the phosphate concentration was increased to 500 mg/l PO_4-P there was an increase in the amount of chloride in solution. This increase was significant at a 95% confidence interval when compared to the amount of chloride in solution when the Biolat was contacted with lower phosphate concentrations. At the higher phosphate concentration of 500 mg/l PO_4-P it was apparent that some exchange between chloride and phosphate occurred.

When Biolat was contacted with ultra-pure water over a 48 hour period, the average quantity of sulphate observed in solution was 1.62 mg/ 50g of Biolat. The amount of sulphate observed in solution almost trebled when phosphate solutions between 10 and 100 mg/l PO_4-P were contacted with Biolat. The increased amount of sulphate in solution indicated that a quite effective exchange was occurring between phosphate and sulphate. The amount of sulphate in solution did not differ significantly at a 95% confidence interval using concentrations between 10 and 100 mg/l PO_4-P. The average amount of sulphate in solution over this range was 4.28 mg/ 50g of Biolat.

When a 500 mg/l PO_4-P concentration was contacted with Biolat over a 48 hour period the average amount of sulphate observed in solution increased to 6.81 mg/50g of Biolat. The reason why the amount of sulphate in solution remained the same for influent phosphate concentrations between 10 and 100 mg/l PO_4-P but increased with a mg/l PO_4-P concentration was unclear however, it was apparent that sulphate was taking part at least to some degree in ion exchange.

5.7.2 Investigation into the presence of cations in solution when ammonium of various concentrations was contacted with Biolat.

The cations observed to be present in solution when Biolat was contacted with ultra-pure water or ammonium of various concentrations were sodium, potassium, magnesium and calcium. Although each of these cations were present in solution to varying degrees when Biolat was contacted with ultra-pure water, an increase in quantity was observed when ammonium was added to the solution (Table 4.18 page 177)

The amount of sodium released from Biolat increased progressively with increased ammonium concentrations. When Biolat was contacted with ultra-pure water the average amount of sodium detected in solution was 4.05 mg/ 50g of Biolat. This amount increased to 5.93, 6.47, 9.83 and 10.02 mg Na / 50g of

Biolat when the concentration of ammonium was increased to 10, 50,100 and 500 mg/l NH_4-N, respectively.

The same trend was evident in the amount of potassium released to solution when Biolat was contacted with ultra-pure water and then with various concentrations of ammonium. The amount of potassium observed in solution was much lower than that of sodium i.e. 0.26 mg K/ 50g of Biolat was present in solution when Biolat was contacted with ultra-pure water. This amount was increased to 0.78, 0.93, 2.27 and 2.91 mg/ 50g of Biolat when the ammonium concentrations were increased to 10, 50, 100 and 500 mg/l NH_4-N, respectively.

There was little wash-off of magnesium from Biolat using ultra-pure water as compared to that amount observed in solution when various ammonium solutions were used. The average amount of magnesium in solution when Biolat was contacted with ultra-pure water was 0.44 mg Mg/ 50g of Biolat. This value was increased to 1.44 mg Mg/ 50 g of Biolat 10 mg/l NH_4-N was used. The quantity of magnesium observed in the 50 and 100 mg/l NH_4-N solutions were 1.79 and 1.94 mg Mg/ 50g of Biolat, respectively. At the highest concentration of 500 mg/l NH_4-N, the amount of magnesium in solution was significantly higher than for the other concentrations and averaged at 6.09 mg/ 50g of Biolat, over the 48 hour period.

Calcium was also released from Biolat when it was contacted with ultra-pure water. An average of 1.31 mg Ca/ 50g of Biolat was observed over the 48 hour investigation period. Elevated amounts of calcium were observed when ammonium of varying concentrations was added to the solutions contacted with Biolat. Quantities of 4.52, 5.79, 6.36 and 23.61 mg Ca/ 50g of Biolat were observed for influent ammonium concentrations were 10, 50, 100 and 500 mg/l NH_4-N, respectively.

For each of the above cations it is evident that although certain quantities of the ions were removed from Biolat merely by contacting with ultra-pure, the vast quantity of the cations observed in solution were present due to the fact that they had undergone a cation exchange reaction with the ammonium initially in solution. The amount of each of the cations exchanged with ammonium increased progressively with an increase in ammonium concentration. In terms of ultimate concentration realised in exchange with ammonium, the cations may be ranked in the following order.

$$Na^{+} > Ca^{2+} > Mg^{2+} > K^{+} \qquad (1)$$

Only at the 500 mg/l NH_4-N concentration was the order

$$Ca^{2+} > Na^{+} > Mg^{2+} > K^{+} \qquad (2)$$

(1) above mirrors the order which was obtained on contacting laterite with ultra-pure water. Brady (1974) states that under conditions of identical cationic concentration, adsorption of cations on aluminosilicate minerals is in the order

$Ca^{2+} > Mg^{2+} > K^{+} = NH_4^{+} > Na^{+}$ .... for well drained soils

$H^{+} = Al^{3+} = Ca^{2+} > Mg^{2+} > K^{+} = Na^{+}$ .... for humid region soils

When drainage is impeded and alkaline salts accumulate, adsorbed Na^{+} ions are likely to become more prominent and may equal or even exceed those of adsorbed calcium. This appears to be the situation in the case of Biolat.

5.7.3 Cation exchange capacity of Biolat.

The cation exchange capacity of Biolat was observed to be 15meq/ 100g of Biolat. This means that theoretically it should be capable of exchanging approximately 270 mgs of ammonium/ 100g of Biolat.

The CEC value obtained for Biolat was typical of that of a 1:1 type silicate clay such as kaolin and was greater than typical CECs for the hydrous oxides of iron and aluminium (i.e. 4 meq/ 100g). As expected, the CEC obtained for Biolat was much lower than that of a 2:1 type silicate clays such as montmorillonite or illite. These have typical CEC values of approximately 100 and 150 meq/100g, respectively (Brady, 1974). The higher CEC of these minerals is due to the structure of the colloids which allow expansion of the layers and therefore access to interlayer cations. These interlayer cations are available for exchange with other cations. As discussed previously, kaolin type minerals, which are abundant in Biolat, do not exhibit this flexibility to any great extent in their structure and hence the CEC is much lower.

As stated previously, based on the calculated CEC of Biolat it should be able to exchange 270 mgs of ammonium/100g of Biolat before it reached saturation with respect to that ion, however, this value was seldom realised in an experimental situation (Table 4.19, page 178, Fig. 4.41, page 137 and Figs. 4.46 and 4.47, page 151). This was due to the fact that the concentration of ammonium used to saturate the Biolat was higher in the CEC determination than was used in any of the adsorption experiments i.e. in experiments used to determine the CEC of Biolat, a 1N solution of ammonium acetate was used (as per Black *et al,* 1965). This corresponded to a concentration of 18,000 mg/l NH_4-N. As determined from experimentation, the saturation value for Biolat with respect to ammonium increased with increased influent ammonium concentration. Therefore, the results obtained for CEC could not truly be compared with the saturation values obtained using between 50 and 500 mg/l NH_4-N concentrations.

5.7.4 Application of the adsorption of phosphate/ammonium by Biolat to the Freundlich adsorption isotherm.

The data in Tables 4.19 and 4.20 (page178) were obtained when varying concentrations of ammonium and phosphate were contacted with Biolat until such a time as an equilibrium stage was reached. The equilibrium stage was reached when the Biolat was capable of removing no more phosphate/ ammonium at a particular concentration. Using these data it was decided to attempt to describe the results in terms of a model which might give structure to the data obtained and allow prediction of further saturation values.

Due to the nature of the observed phenomenon, it was decided to employ the Freundlich model, which has been applied to many instances of adsorption from solution to a solid support (Bhargava and Sheldakar, 1982 and Yamanda *et al*, 1986)). As explained earlier, if the data fits this model then a plot of the log of the amount adsorbed per unit mass of adsorbent versus the log of the concentration of the adsorbing species should yield a straight line. When the data obtained from experimentation (for both ammonium and phosphate) were fitted to this equation both curves displayed a correlation co-efficient of 1.000. From the equation of the lines obtained predictive evaluations were made as to the amount which would be adsorbed at arbitrary concentrations of 75, 300 and 700 mg/l concentrations of ammonium/ phosphate. These concentrations corresponded to 11.5, 45.0 and 105.0 mgs of phosphate/ ammonium. The equilibrium values predicted for the removal of ammonium at these concentrations were 8.2, 31.7 and 72.6 mgs ammonium/ 50g of Biolat, respectively. The actual values obtained from experimentation were 10.23, 34.04 and 66.9 mgs ammonium/50g of Biolat indicating that predicted and actual values agreed well. The equilibrium values predicted for the removal of phosphate at the 75, 300 and 700 mg/l PO4-P concentrations were 10.9, 41.9 and 95.4 mgs phosphate/ 50g of Biolat, respectively. The actual values obtained from experimentation were 11.25, 41.11 and 77.60 mgs/ 50g of Biolat. Therefore, the predicted and actual values were in general agreement for 75 and 300 mg/l phosphate concentrations but the actual values obtained for the 700 mg/l concentrations were much lower than the predicted values indicating that the Freundlich expression did not extend to this range i.e. the Biolat was becoming saturated.

Yamanda *et al* (1986) observed that the adsorption of phosphate onto slag obeyed the Freundlich expression up to an equilibrium concentration of 400 mg/l PO$_4$-P. Similarly Bhargarva and Sheldarkar (1982) found that the adsorption of phosphate onto rinsed tamarind activated carbon had the form of the Freundlich isotherm. Such a linearization of the adsorption isotherm plots had also been reported by Weber (1972) and Faust and Aly (1987). These workers found that the intercept of the linearized isotherms on the vertical axis of the graph was a rough indicator of the adsorption capacity of an adsorbent and the slope of the line was an indication of the adsorption intensity. The slope of the line obtained from the Freundlich model for phosphate in this study was 0.97. In the case of ammonium the slope of the line was 0.98.

CHAPTER SIX

CONCLUSION

6.1 Conclusion.

The main conclusions of the study are as follows.

1. The BMS prototype septic tank displayed higher removal rates for phosphate (85%), ammonia (48%), SS (71%) nitrate (67%) and COD (60%) during its initial two years of operation than are normally observed in a conventional septic tank. During the same period, observed removal rates for BOD (66%) and *E. coli* (87%) were at least as efficient as those observed in a conventional septic tank.

Following a four year operational period, the BMS prototype septic tank had lost its superior performance over a conventional septic tank for the removal of SS, COD and ammonia (i.e. the removal rates observed after this time were COD (32%), SS (35%) and ammonia (22%). Observed concentrations of COD, SS and ammonia in the effluent from the BMS prototype septic tank after this time were similar to those observed in conventional septic tank effluent. After a four year operational period the observed removal rate for phosphate had fallen to 27%. This removal rate was substantially less than that value observed during the initial two years of operation however, the concentration of phosphate in the effluent from the BMS prototype septic tank was still below that observed by other workers in conventional septic tank effluent. Following four year in usage, *E. coli* removal in the BMS prototype septic tank was at least as efficient as in a conventional septic tank as observed by other workers. Nitrate removal was below that observed in a conventional septic tank.

Based on the above results the operational lifespan of the Biolat in the BMS septic tank lies somewhere between two and four years. After this time it is suggested that the Biolat should be removed from the tank and replenished.

2. Pilot scale BMS septic tanks were used over a 25 week investigation period in order to determine if the pollutants present in domestic sewage were predominantly removed in chambers one and two or in the Biolat chamber of the tanks. Results showed that of the various pollutants investigated, some were predominantly removed in the first two chambers of the septic tank while others were predominantly removed in the Biolat chamber.

(a) The removal of BOD, COD, SS and *E. coli* occurred predominantly in chambers one and two and so theoretically should be comparable to removal rates observed in a conventional two chamber septic tank. The removal of the above pollutants may be attributed mainly to the sedimentation of the solids in domestic sewage i.e. solids are a source of BOD and COD and also serve as a surface for *E. coli* attachment. The removal of BOD, COD, SS and *E. coli* in the pilot scale septic tanks over a 25 week investigation period was at least as efficient, and in some cases surpassed, those removal rates observed in conventional septic tanks. Any additional removal of these pollutants by the Biolat septic tank was believed to be due to the superior construction of the tank rather than any unique properties afforded by Biolat itself. Many septic tanks are not properly constructed or maintained and hence optimum solids removal is unobtainable. The Biolat septic tank on the other hand is constructed strictly to SR6 recommendations.

(b) The removal of phosphate and nitrate occurred mainly in the Biolat chamber of the pilot scale septic tanks, with little removal observed in chambers one and two. The low removal rates observed in chambers one and two concur with the finding of other workers who found that the removal of these entities in septic tanks is limited (Patterson *et al*, 1971; Perkins, 1989; and Henry, 1990). The removal of phosphate was attributable to the Biolat media itself. However, the removal of nitrate could not be attributed to the media, but rather to conditions occurring within the Biolat chamber which induced the removal of nitrate, probably by biological denitrification. The removal of phosphate and nitrate in the BMS pilot scale septic tank over the 25 week period far surpassed observed removal rates in a conventional septic tank.

(c) Ammonia was equally removed in the Biolat chamber and in chambers one and two of the pilot scale septic tanks. Ammonia is not usually removed to any great extent in septic tanks (Patterson *et al*, 1971 and Canter and Knox, 1985). The removal of ammonia in the BMS pilot scale septic tanks was much higher than in a conventional septic tank over the 25 week investigation period. The reason for the increased removal rates in chambers one and two of the pilot scale septic tanks was unclear however, it was evident that Biolat contributed to the high final removal rates observed. The observed concentrations of both phosphate and ammonia in the effluent from the pilot scale septic tanks over the

25 week investigation period were more comparable to those concentrations observed following passage of septic tank effluent through a soil absorption field.

3. Separate experiments were conducted using the BMS pilot scale septic tanks in order to determine whether aeration of the second chamber would enhance pollutant removal from domestic sewage. The following points were observed

(a) Aeration of the BMS pilot scale septic tanks was beneficial in the removal of BOD. Approximately 10% more of influent BOD was removed under aerobic conditions due to the more efficient respiration of organic matter under aerobic conditions.

(b) Although *E. coli* removal was greater in chamber two of the aerated pilot scale septic tanks, the ability of Biolat to remove *E. coli* (when present in domestic sewage) meant that the average overall removal rates were equal in both the aerated and unaerated pilot scale septic tanks.

(c) Ammonia removal occurred under aerobic conditions only at the expense of an increase in nitrate concentration. This was an undesirable effect since Biolat did not remove nitrate to the same extent as ammonia unless conditions for denitrification were present in the Biolat.

(d) The natural settlement of SS was retarded in an aerated environment. Higher concentrations of SS were observed in chamber two of the aerated pilot scale septic tanks than in chamber two of the unaerated tanks. Since the Biolat media filtered SS from the effluent from chamber two, it follows that the disruption of solids settlement in chamber two would cause a greater solids loading to the Biolat media and thus the Biolat would become clogged more quickly.

(e) COD and phosphate removal in the BMS pilot scale septic tanks appeared unaffected by aeration.

Since the only advantage of aerating the BMS septic tank was an increase of 10% in BOD removal the practice would not be worthwhile.

4. In experiments conducted with Biolat media alone, housed in separate columns, it was observed that Biolat was very efficient in the removal of ammonia and phosphate whereas nitrate was not removed to any great extent.

The efficiency of removal of *E. coli* by Biolat was dependent on whether the *E. coli* were present in domestic sewage or in a buffered sterile water i.e. Ringer's solution. Removal rates were much greater when *E. coli* were present in domestic sewage. This was thought to be due to the presence of SS in the domestic sewage (which were not present in Ringer's). It was believed that the *E. coli* attached themselves to the SS and were subsequently filtered out by the Biolat. When there were no SS present, filtration of *E. coli* by Biolat became less significant owing to the small size of the bacteria. Any removal of *E. coli* from Ringers solution by Biolat was thought to have been due to the natural die-off of the bacteria in the generally unfavourable environment. The removal of *E. coli* in domestic sewage by Biolat is comparable to removal rates observed by other workers in media such as peat, sand, loam and chalk (Magdoff *et al*, 1974; Rock *et al*, 1982; Brookes *et al*, 1984; Viraghavan *et al*, 1987, and Pell and Nyberg, 1990)

5. The factors that influenced the adsorption of phosphate and ammonium by Biolat were as follows

(i) The concentration of the influent solution.

As the concentration of phosphate and ammonium in the influent increased so too did the mass of ions removed. The total adsorption capacity of Biolat almost doubled for each twofold increase in the concentration of ammonium or phosphate in the influent solution in the range 50 to 400 mg/l. The adsorption of ammonium by Biolat obeyed the Freundlich adsorption isotherm over the range of ammonium concentrations investigated i.e. 10 to 700 mg/l NH_4-N. The adsorption of phosphate fitted the Freundlich adsorption isotherm in the range 10 to 500 mg/l PO_4-P. Above this concentration the adsorption of phosphate by Biolat did not obey the Freundlich adsorption isotherm.

(ii) Contact time or hydraulic retention time (HRT) between the Biolat and the influent solution.

An adequate contact time was required to effectively remove phosphate and ammonium from solution. The contact time required was dependent on the concentration of the influent solution. A one day HRT was required for concentrations between 10 and 1000 mg/l of ammonium or phosphate whereas concentrations above this required longer HRTs. An initial fast adsorption reaction was evident on first contacting Biolat with phosphate and ammonium followed by a more gradual adsorption process.

(iii) Grain size of Biolat.

The grain size of Biolat affected both ammonium and phosphate adsorption by Biolat especially in the initial stages of contact. The grain sizes used were 0.25-0.50, 0.50- 1.0, 1.0-2.0 and 2.0-4.0 mm. There was a trend of increased adsorption of phosphate and ammonium as the grain size of Biolat was decreased. This could be explained by the fact that adsorption is a surface phenomenon and that smaller grain sizes offered comparatively larger surface areas. The effect of increased adsorption with decreasing grain size was effectively eliminated after the initial stages of contact i.e. > 2 hours. After this time there was no observable trend in phosphate or ammonium removal at the various grain sizes.

(iv) pH of the influent solution.

The removal of phosphate by Biolat was unaffected by the pH of the influent solution in the pH range 2 to 12. In addition Biolat served to buffer the pH of the influent solution. When the pH of the influent solution was between 4 and 10, the solution was buffered to between pH 7 and 8. For more acidic or basic pHs, a 2- 3 unit shift towards a neutral pH, was observed upon contacting the solution with Biolat.

The removal of ammonium by Biolat was unaffected by pH in the pH range 4 to 10, however somewhat lower removal rates were observed at pHs 2 and 12. Between pHs 4 and 10 an average of 93.4% removal was observed, while at pHs 2 and 12 only 80% removal was observed.

(v) The type of ion in solution.

Biolat appeared to be selective in the ions that it adsorbed. Biolat adsorbed phosphate and ammonium ions but did not adsorb nitrate ions.

6. The adsorption capacity of ammonium and phosphate by Biolat was quite low when compared to other materials which have been used for the removal of ammonium and phosphate in wastewater. The total adsorption capacity of Biolat was dependent on the influent concentration of phosphate or ammonia. Adsorption levels of between 0.23 to 1.92g of phosphate per kg of Biolat were observed when influent concentrations of phosphate were between 50 and 400 mg/l PO_4-P. Adsorption levels between 0.31 and 2.59 g of ammonium per kg of Biolat were observed when influent concentrations were between 50 and 400 mg/l NH_4-N. Other materials which have been investigated for the adsorption of phosphate and ammonium have yielded higher adsorption capacities e.g. activated alumina combined with iron and aluminium sulphates. This suggests that the Biolat in the third chamber of the BMS septic tank could be replaced with a more adsorbent material. However,

materials reported by other workers as having high adsorption capacities were not investigated under the same conditions as Biolat in the BMS septic tank. The replacement of Biolat by one of these materials should be preceded by investigations into the lifespan of the material and its ability to remove phosphate and ammonia when present in domestic sewage.

7. When Biolat was contacted with ultra-pure water it was observed that a number of cations and anions were released into solution from the Biolat matrix. The anions observed to be in solution were nitrate, nitrite, sulphate and chloride. The quantity of anions released were in the order $Cl^- > SO_4^{2-} > NO_3^-$. NO_2^- Average values of 4.98, 1.62, 0.068 and 0.035 mgs/ 50 g of Biolat were observed in solution for each of the anions respectively over a 48 hour period. The quantity of cations released to solution when ultra-pure water was contacted with Biolat was in the order $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ Average values of 4.05, 1.31, 0.44 and 0.26 mgs/ 50g of Biolat were released into solution for each of these cations respectively over a 48 hour period.

8. Although certain quantities of each of the cations listed above were released into solution when Biolat was contacted with ultra-pure water, much larger quantities were observed to be released to solution when Biolat was contacted with ammonium solutions of varying concentrations (i.e. between 10 and 500 mg/l NH_4-N). When ammonium solutions were contacted with Biolat there was a resulting decrease in ammonium concentration and a parallel

increase in the quantity of each of the cations in solution indicating that ammonium was involved in a definite cation exchange process.

Although cation exchange reactions were evident in Biolat, the exchange of anions was less obvious. This was evident from the fact that nitrate, nitrite and chloride concentrations in solution were not enhanced by the addition of phosphate solutions in the range 10 to 100 mg/l PO_4-P to ultra-pure water. Larger quantities of chloride were released from Biolat when it was subjected to 500 mg/l PO_4-P concentrations. This trend was not evident for nitrate or nitrite. There was a substantial increase in the sulphate concentration in solution when Biolat was contacted with phosphate concentrations of 10, 50, 100 and 500 mg/l PO_4-P, as compared to its concentration when Biolat was contacted with ultra-pure water. The larger quantities of sulphate and chloride observed in solution when the influent phosphate concentration was high indicated that these anions were taking part to some degree in an anion exchange reaction.

9 Phosphate removal by Biolat appeared to be predominantly by physisorption. Physisorption is a weak adsorption reaction occurring when ions are held in a colloidal crystal by weak van der Waals bonds. These bonds are easily broken as was observed when the passage of distilled water through phosphate saturated Biolat served to desorb greater than 87% of the adsorbed phosphate. The adsorption of phosphate onto Biolat obeyed the Freundlich expression in the range 0-500 mg/l PO_4-P. Above this range adsorption of

phosphate did not follow the Freundlich isotherm indicating that Biolat was becoming saturated with respect to phosphate at this concentration. However, other experiments on the total adsorption capacity of Biolat for phosphate indicated that the adsorption capacity of Biolat could extend well beyond this range. Barrow (1988) states that physisorption may result in multi-layers of adsorbate being adsorbed onto an adsorbent. The Freundlich adsorption isotherm however applies only to surface layer adsorption. Therefore additional phosphate may be adsorbed onto Biolat but the adsorption may not fit into the Freundlich expression.

Results from experimentation showed that anion exchange had occurred in the Biolat between phosphate and sulphate/chloride. Since not all of the phosphate could be desorbed from Biolat using water, some phosphate ions appeared to be strongly bound to specific sites within the Biolat i.e. in anion exchange.

Ammonium ions were adsorbed onto the surface of the colloidal micelles in Biolat. Here, they underwent a cation exchange reaction with cations which already occupied the adsorption sites in Biolat. This was evident when ammonium in solution contacted with Biolat caused an increase in the amount of calcium, sodium, magnesium and potassium in solution and a parallel decrease in the concentration of ammonium. The reaction was also concentration driven i.e. an increase in ammonium concentration caused an increase in the process reaction rate. The nature of the interaction which occurred between Biolat and ammonium was stronger than those between

Biolat and phosphate i.e. ammonium was not as readily desorbed from Biolat indicating that these ions were strongly bound to specific sites within the Biolat. Less than 40% of the amount of previously adsorbed ammonium was desorbed from Biolat using distilled water.

10. As discussed previously phosphate was readily removed from Biolat by the addition of water due to the nature of the adsorption process. This would account for the fluctuations in removal rates observed in the BMS prototype and pilot scale septic tanks. Clearly there was a continual wash on/ wash off of phosphate ions in the Biolat media. In the case of both phosphate and ammonium, the ions were more easily desorbed from Biolat when large quantities of same were used to saturate the Biolat. An initial rapid reaction rate was evident in the desorption of phosphate from Biolat followed by a longer desorption phase. This trend was also evident in the desorption of ammonium by Biolat, although to a lesser degree. Large volumes of distilled water were required for the desorption of both ammonium and phosphate from Biolat. The desorption efficiency was not enhanced by pH adjusting the distilled water used for desorption in the pH range 2 to 12. This was due to the pH adjustment capacity of Biolat.

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Appendix

Table 1. The Results Obtained From the Monitoring of the BMS Prototype Septic Tank over a Four Year Period. Included are the Results Obtained From the Influent to the BMS Prototype Septic Tank as Well as the Effluent. The Percentage Reduction in the BMS Prototype Septic Tank has been Calculated From the Influent and Effluent Values.

Date	**24/03/93**			**26/04/93**			**28/04/93**		
	Infl.	**Eff.**	**% redn.**	**Infl.**	**Eff.**	**% redn.**	**Infl.**	**Eff.**	**% redn.**
pH	-	-	-	8.9	7.8	-	8.9	7.9	-
BOD	30.0	<5.0	83.0%	82.0	22.0	73.0%	108.0	30.0	72.0%
COD	<50.0	<50.0	-	192.0	61.0	68.0%	200.0	69.0	66.0%
S.S	11.0	3.0	73.0%	103.0	47.0	54.0%	93.0	36.0	61.0%
NO3 -N	4.5	1.6	64.0%	1.0	0.3	70.0%	1.5	0.4	73.0%
NH3 -N	2.9	0.5	83.0%	22.6	19.6	13.0%	39.0	26.0	33.0%
PO4 -P	3.2	0.03	99.0%	6.9	0.07	99.0%	8.7	0.16	98.2%
E. Coli	62,000	11.0	99.99%	70,000	450	99.4%	142,000	660.0	99.54%

ctd. →

Date	04/05/93			06/05/93			25/11/93		
	Infl.	**Eff.**	**% redn.**	**Infl.**	**Eff.**	**% redn.**	**Infl.**	**Eff.**	**% redn.**
pH	8.8	8.0	-	9.0	7.5	-	7.96	7.92	-
BOD	115.0	76.0	33.9%	95.0	38.0	60.0%	570.0	108.0	81.0%
COD	261.0	165.0	37.0%	215.0	77.0	64.0%	603.0	163.0	73.0%
S.S	80.0	13.0	84.0%	156.0	66.0	58.0%	198.0	88.0	56.0%
NO3 -N	1.6	N.D	100.0%	0.9	N.D	100.0%	2.1	0.1	95.2%
NH3 -N	42.6	21.0	51.0%	48.2	36.2	25.0%	54.3	33.3	39.0%
PO4 -P	10.2	0.17	98.3%	13.2	0.22	98.3%	37.8	2.38	93.7%
E. Coli	1,000,000	560	99.94%	30,000	5,000	83.33%	78,000	54,000	30.8%

Date	25/04/94			14/07/94			22/09/94		
	Infl.	**Eff.**	**% redn.**	**Infl.**	**Eff.**	**% redn.**	**Infl.**	**Eff.**	**% redn.**
pH	8.1	8.18	-	8.6	7.2		8.4	7.0	
BOD	130.0	41.0	68.5%	262.0	58.0	78.0%	248.0	100.0	60.0%
COD	304.0	146.0	52.0%	400.0	120.0	70.0%	350.0	154.0	56.0%
S.S	69.0	22.0	68.1%	98.0	13.0	87.0%	114.0	22.0	81.0%
NO3 -N	0.3	N.D	100.0%	1.2	N.D	100.0%	1.9	N.D.	100.0%
NH3 -N	15.6	4.8	69.2%	36.0	12.6	65.0%	41.0	32.8	20.0%
PO4 -P	12.9	3.2	75.2%	10.6	4.7	56.0%	8.2	2.6	68.0%
E. Coli	50,000	2,800	94.4%	1,100,000	88,000	92.0%	7,000,000	810,000	88.0%

ctd.→

Date	10/11/94			22/02/95			15/04/95		
	Infl.	**Eff.**	**% redn.**	**Infl.**	**Eff.**	**% redn.**	**Infl.**	**Eff.**	**% redn.**
pH	8.9	8.0	-	8.1	7.0		7.9	7.0	
BOD	300.0	84.0	72.0%	112.0	52.0	54.0	298.0	120.0	60.0%
COD	470.0	200.0	57.0%	240.0	96.0	60.0%	500.0	220.0	56.0%
S.S	168.0	40.0	76.0%	135.0	44.0	67.0%	210.0	38.0	82.0%
NO3 -N	4.2	0.8	81.0%	0.9	N.D	100.0%	3.3	9.1.	-175.0%
NH3 -N	34.6	21.6	38.0%	30.0	11.4	62.0%	36.5	10.0	73.0%
PO4 -P	13.6	2.4	82.0%	9.8	2.5	74.0%	10.2	2.6	74.0%
E. Coli	N.A	N.A	-	2,200,000	100,000	95.5%	20,000,000	1,800,000	91.0%

Date	15/01/97			03/02/97			14/02/97		
	Infl.	**Eff.**	**% redn.**	**Infl.**	**Eff.**	**% redn.**	**Infl.**	**Eff.**	**% redn.**
pH	8.8	8.0		7.8	7.6	-	7.8	7.6	-
BOD	320	166	48.4	300	220	27.0	342	268	21.6
COD	515	275	46.6	526	385	26.8	440	338	23.2
S.S	88.0	27.2	69.0	102.7	86.5	15.8	56.5	44.6	21.1
NO3 -N	2.1	6.1	+65.6	N.D	0.4	-100.0	0.5	1.3	+160.0
NH3 -N	129.6	96.1	25.8	66.7	49.2	26.2	71.0	49.9	15.6
PO4 -P	10.2	7.2	29.4	10.3	8.0	22.3	10.5	7.5	28.6
E. Coli	6,700,000	550,000	91.8	N.A	N.A	N.A	2,700,000	95,000	99.6

Tanks 1 & 2

Week No.	Influent	C2	% reduction (Influent - C2)	Effluent	Total reduction (%)
1	96.0	61.0	37	55.0	43
2	66.0	39.0	41	37.0	44
3	170.0	100.0	41	70.0	59
4	156.0	66.0	58	64.0	59
5	108.0	61.0	44	54.0	50
6	120.0	73.0	39	60.0	50
7	200.0	46.0	77	40.0	80
8	180.0	64.0	65	66.0	65
16	160.0	80.0	47	64.0	61
17	212.0	116.0	45	110.0	48
24	128.0	85.0	34	72.0	34
25	200.0	70.0	66	66.0	67
Mean	**150.0**	**71.0**	**50**	**63.0**	**56**

Tanks 3 & 4

Week No.	Influent	C2	% reduction (Influent - C2)	Effluent	Total reduction (%)
1	96.0	53.0	45	52.0	46
2	66.0	25.0	62	19.0	71
3	170.0	47.0	72	54.0	68
4	156.0	62.0	60	60.0	62
5	108.0	53.0	51	54.0	50
6	120.0	39.0	67	38.0	68
7	200.0	37.0	82	36.0	82
8	180.0	40.0	79	37.0	80
16	160.0	70.0	56	64.0	60
17	212.0	83.0	61	93.0	65
24	128.0	53.0	59	55.0	62
25	200.0	63.0	69.	58.0	71
Mean	**150.0**	**52.0**	**64**	**50.0**	**65**

Key: Influent is the influent to septic tank.
C2 is chamber 2 (i.e. pre Biolat chamber).
Effluent is the effluent from septic tank (i.e. post Biolat chamber).

Table 2. The average concentration of BOD at each stage in the pilot scale BMS septic tanks, together with the percentage reduction achieved following each stage. Tanks 1 and 2 were not aerated while Tanks 3 and 4 were aerated.

Tanks 1& 2

Week No.	Influent	C2	% reduction (Influent - C2)	Effluent	Total reduction (%)
1	162.0	106.0	35.0	101.0	38.0
2	120.0	69.0	43.0	64.0	47.0
3	250.0	116.0	54.0	105.0	58.0
4	220.0	114.0	48.0	96.0	56.0
5	160.0	96.0	40.0	94.0	42.0
6	144.0	72.0	50.0	64.0	56.0
7	360.0	78.0	78.0	77.0	79.0
8	180.0	95.0	47.0	98.0	46.0
16	245.0	98.0	60.0	83.0	66.0
17	456.0	264.0	42.0	228.0	50.0
24	216.0	114.0	47.0	114.0	47.0
25	365.0	168.0	54.0	158.0	57.0
Mean	**240**	**116.0**	**50.0**	**107.0**	**53.0**

Tank 3 & 4

Week No.	Influent	C2	% reduction (Influent - C2)	Effluent	Total reduction (%)
1	162.0	106.0	35.0	91.0	44.0
2	120.0	69.0	42.0	68.0	43.0
3	250.0	168.0	33.0	134.0	46.0
4	220.0	109.0	51.0	108.0	51.0
5	160.0	86.0	46.0	74.0	54.0
6	144.0	67.0	54.0	57.0	60.0
7	360.0	96.0	73.0	92.0	74.0
8	180.0	87.0	52.0	79.0	56.0
16	245.0	119.0	51.0	94.0	62.0
17	456.0	218.0	51.0	128.0	72.0
24	216.0	95.0	56.0	110.0	49.0
25	365.0	170.0	53.0	126.0	65.0
Mean	**240.0**	**116.0**	**50.0**	**96.0**	**56.0**

Key: Influent is the influent to septic tank.
C2 is chamber 2 (i.e. pre Biolat chamber).
Effluent is the effluent from septic tank (i.e. post Biolat chamber).

Table 3. The average concentration of COD at each stage in the pilot scale BMS septic tanks, together with the percentage reduction achieved following each stage.
Tanks 1 and 2 were not aerated while Tanks 3 and 4 were aerated.

Tank 1 & 2

Week No.	Influent	C2	% reduction (Influent - C2)	Effluent	Total reduction (%)
1	66.0	3.2	95.0	1.1	98.0
2	72.0	4.0	94.0	0.9	99.0
3	56.0	6.6	88.0	2.0	96.0
4	77.0	3.5	95.0	0.9	99.0
5	54.0	3.5	94.0	1.0	98.0
6	62.0	4.3	93.0	1.1	99.0
7	117.0	3.2	97.0	1.3	99.0
8	96.0	3.6	96.0	1.0	99.0
16	46.0	5.5	88.0	3.1	95.0
17	58.0	4.1	93.0	1.7	97.0
24	56.0	3.1	95.0	1.4	98.0
25	92.0	2.0	98.0	0.7	99.0
Mean	**71.0**	**3.9**	**94.0**	**1.4**	**98.0**

Tank 3 & 4

Week No.	Influent	C2	% reduction (Influent - C2)	Effluent	Total reduction (%)
1	66	9.6	85.0	1.5	98.0
2	72	8.2	89.0	1.5	98.0
3	56	12.1	78.0	2.7	95.0
4	77	9.3	88.0	1.8	98.0
5	54	9.3	83.0	1.2	98.0
6	62	12.0	81.0	1.5	98.0
7	117	10.7	90.0	1.6	99.0
8	96	9.8	90.0	1.3	99.0
16	46	4.7	90.0	1.6	97.0
17	58	5.1	91.0	1.1	98.0
24	56	6.1	89.0	0.6	99.0
25	92	6.7	93.0	0.9	99.0
Mean	**71.0**	**8.6**	**87.0**	**1.4**	**98.0**

Key: Influent is the influent to septic tank.
C2 is chamber 2 (i.e. pre Biolat chamber).
Effluent is the effluent from septic tank (i.e. post Biolat chamber).

Table 4. The average concentration of suspended solids at each stage in the pilot scale BMS septic tanks, together with the percentage reduction achieved following each stage. Tanks 1 and 2 were not aerated while Tanks 3 and 4 were aerated.

Tank 1& 2

Week No.	Influent	C2	% reduction (Influent - C2)	Effluent	Total reduction (%)
1	3.4	1.7	50.0	0.2	94.0
2	3.6	1.7	53.0	0.9	75.0
3	4.0	3.5	13.0	1.4	65.0
4	3.1	2.7	12.0	0.9	70.0
5	4.0	3.0	25.0	1.2	70.0
6	4.9	4.1	16.0	1.5	68.0
7	3.5	4.0	-14.0	0.5	86.0
8	3.6	3.4	6.0	0.6	83.0
16	2.0	1.8	10.0	1.3	35.0
17	14.6	13.6	6.8	4.4	70.0
24	7.8	7.2	7.7	4.2	46.0
25	5.0	4.6	8.0	1.9	62.0
Mean	**4.9**	**4.4**	**16.0**	**1.6**	**69.0**

Tank 3 & 4

Week No.	Influent	C2	% reduction (Influent - C2)	Effluent	Total reduction (%)
1	3.4	1.6	53.0	0.0	100.0
2	3.6	2.1	43.0	1.0	86.0
3	4.0	3.2	20.0	0.8	80.0
4	3.1	2.7	10.0	1.0	67.0
5	4.0	3.2	20.0	1.1	73.0
6	4.9	3.1	34.0	1.2	74.0
7	3.5	4.2	20.0	0.6	83.0
8	3.6	3.7	-10.0	0.8	78.0
16	2.0	1.6	20.0	1.3	35.0
17	14.6	11.5	21.0	4.6	68.0
24	7.8	7.0	10.0	4.7	40.0
25	5.0	4.7	6.0	2.5	50.0
Mean	**4.9**	**4.1**	**21.0**	**1.6**	**70.0**

Key: Influent implies influent to septic tank.
C2 is chamber 2 (i.e. pre Biolat chamber).
Effluent implies effluent from septic tank (i.e. post Biolat chamber).

Table 5. The average concentration of phosphate at each stage in the pilot scale BMS septic tanks, together with the percentage reduction achieved following each stage. Tanks 1 and 2 were not aerated while Tanks 3 and 4 were aerated.

Tanks 1& 2

Week No.	Influent	C2	% reduction (Influent - C2)	Effluent	Total reduction (%)
1	34.5	12.5	64.0	0.7	98.0
2	33.7	18.4	45.0	6.9	80.0
3	27.4	14.1	48.0	3.8	86.0
4	16.9	8.8	48.0	5.5	67.0
5	34.2	14.1	59.0	1.2	96.0
6	22.5	14.1	37.0	4.4	80.0
7	30.1	21.1	30.0	5.9	80.0
8	28.6	18.2	36.0	4.4	85.0
16	28.5	19.8	31.0	11.4	60.0
17	15.6	13.9	11.0	10.2	35.0
24	32.5	19.5	40.0	16.3	50.0
25	19.8	14.1	29.0	9.7	51.0
Mean	**27.1**	**17.6**	**40.0**	**6.7**	**72.0**

Tank 3 & 4

Week No.	Influent	C2	% reduction (Influent - C2)	Effluent	Total reduction (%)
1	34.5	26.3	24.0	1.2	97.0
2	33.7	6.1	82.0	1.0	97.0
3	27.4	6.7	76.0	1.0	96.0
4	16.9	7.0	59.0	2.2	87.0
5	34.2	5.3	85.0	1.5	96.0
6	22.5	1.7	92.0	0.9	96.0
7	30.1	14.4	52.0	3.7	88.0
8	28.6	14.9	48.0	3.8	87.0
16	28.5	24.4	14.0	15.4	46.0
17	15.6	13.3	15.0	10.3	34.0
24	32.5	24.0	26.0	11.4	65.0
25	19.8	18.2	8.0	9.8	51.0
Mean	**27.1**	**13.5**	**48.0**	**5.2**	**78.0**

Key: Influent is the influent to septic tank.
C2 is chamber 2 (i.e. pre Biolat chamber).
Effluent is the effluent from septic tank (i.e. post Biolat chamber).

Table 6. The average concentration of ammonia nitrogen at each stage in the pilot scale BMS septic tanks, together with the percentage reduction achieved following each stage. Tanks 1 and 2 were not aerated while Tanks 3 and 4 were aerated.

Tanks 1 & 2

Week No.	Influent	C2	% reduction (Influent - C2)	Effluent	Total reduction (%)
1	6.6	6.1	8.0	2.1	68.0
2	1.3	2.1	-61.0	0.4	69.0
3	2.6	3.6	-38.5	1.0	62.0
4	3.5	3.4	3.0	1.5	57.0
5	3.0	3.0	0.0	2.1	30.0
6	4.2	4.1	2.4	2.5	41.0
7	4.0	3.4	15	1.6	60.0
8	4.5	3.0	33.4	2.0	56.0
16	3.4	3.2	5.9	1.1	68.0
17	2.0	1.9	5.0	0.3	84.0
24	2.6	2.2	15	1.1	58.0
25	0.8	0.6	31.3	0.0	100.0
Mean	**3.2**	**3.1**	**1.4**	**1.3**	**63.0**

Tanks 3 & 4

Week No.	Influent	C2	% reduction (Influent - C2)	Effluent	Total reduction (%)
1	6.6	9.0	-36.0	5.9	11.0
2	1.3	4.7	-262.0	1.2	8.0
3	2.6	5.0	-92.0	2.1	19.0
4	3.5	6.8	-94.0	3.1	11.0
5	3.0	8.3	-177.0	2.0	33.0
6	4.2	8.6	-105.0	2.1	50.0
7	4.0	9.3	-133.0	1.8	55.0
8	4.5	9.0	-100.0	2.1	53.0
16	3.4	4.3	-26.0	1.3	62.0
17	2.0	1.9	5.0	0.9	55.0
24	2.6	2.9	-11.5	1.2	54.0
25	0.8	1.0	-25.0	0.1	94.0
Mean	**3.2**	**5.9**	**-88.0**	**2.0**	**42.1**

Key: Influent implies influent to septic tank.
C2 is chamber 2 (i.e. pre Biolat chamber).
Effluent implies effluent from septic tank (i.e. post Biolat chamber).

Table 7. The average concentration of nitrate nitrogen at each stage in the pilot scale BMS septic tanks, together with the percentage reduction achieved following each stage. Tanks 1 and 2 were not aerated while Tanks 3 and 4 were aerated.

Tanks 1 & 2

Week No.	Influent	C2	% reduction (Influent - C2)	Effluent	Total reduction (%)
1	8.0 E+6	2.5 E+6	69.0	7.2 E+5	91.0
2	7.2 E+6	2.4 E+6	67.0	1.7 E+5	97.0
3	7.0 E+6	5.2 E+5	93.0	8.8 E+4	99.0
4	7.0 E+6	5.0 E+5	93.0	6.8 E+3	98.0
5	7.0 E+6	3.0 E+6	57.0	3.2 E+5	95.0
6	1.2 E+6	2.2 E+5	82.0	9.0 E+4	93.0
7	3.1 E+7	3.7 E+6	88.0	3.2 E+5	99.0
8	2.6 E+6	3.6 E+6	-38.0	2.9 E+5	89.0
16	7.0 E+6	6.1 E+5	92.0	2.0 E+4	99.0
17	1.1 E+6	7.3 E+4	93.0	1.5 E+4	99.0
24	8.9 E+6	7.0 E+5	92.0	1.6 E+4	99.0
25	8.6 E+6	8.5 E+5	90.0	4.0 E+5	95.0
Mean	**8.05 E +6**	**1.6 E +6**	**73.0**	**2.1 E + 5**	**97.0**

Tanks 3 & 4

Week No.	Influent	C2	% reduction (Influent - C2)	Effluent	Total reduction (%)
1	8.0 E+6	2.7 E+6	66.0	9.4 E+5	89.0
2	7.2 E+6	1.8 E+6	75.0	6.3 E+5	91.0
3	7.0 E+6	1.1 E+6	84.0	1.3 E+5	98.0
4	7.0 E+6	1.1 E+5	98.0	1.8 E+4	100.0
5	7.0 E+6	1.0 E+5	86.0	1.1 E+4	99.9
6	1.2 E+6	3.5 E+4	97.0	3.6 E+3	99.7
7	3.1 E+7	5.2 E+6	83.0	1.7 E+5	99.0
8	2.6 E+6	4.4 E+5	83.0	1.9 E+5	93.0
16	7.0 E+6	8.7 E+5	87.0	1.9 E+5	97.0
17	1.1 E+6	2.2 E+5	80.0	5.9 E+4	95.0
24	8.9 E+6	1.6 E+6	82.0	2.5 E+5	97.0
25	8.6 E+6	5.5 E+5	94.0	1.7 E+5	98.0
Mean	**8.08 E +6**	**1.3 E + 6**	**84.0**	**2.4 E + 5**	**96.0**

Key: Influent implies influent to septic tank.
C2 is chamber 2 (i.e. pre Biolat chamber).
Effluent implies effluent from septic tank (i.e. post Biolat chamber).

Table 8. The average concentration of *E. coli* at each stage in the pilot scale BMS septic tanks, together with the percentage reduction achieved following each stage.
Tanks 1 and 2 were unaerated while Tanks 3 and 4 were aerated.

Table 9. The Adsorption of Phosphate by Biolat at a Two Day HRT.

Day		**50 ppm** 12.5 mg	**100 ppm** 25.0	**200 ppm** 50.0	**400 ppm** 100.0 mg
2	Total mg added	25.0	50.0	100.0	200.0
	mg removed daily	24.8	49.5	99.6	198.4
	Total mg removed	24.8	49.5	99.6	198.4
	Removal rate %	99.2	99.0	99.6	99.2
3	Total mg added	37.5	75.0	150.0	300.0
	mg removed daily	12.29	24.8	49.75	98.6
	Total mg removed	37.09	74.3	149.35	297.0
	Removal rate %	98.3	99.2	99.5	98.6
4	Total mg added	50.0	100.0	200.0	400.0
	mg removed daily	12.03	24.4	48.8	96.0
	Total mg removed	49.12	98.7	198.15	393.0
	Removal rate %	96.2	97.6	97.6	96.0
5	Total mg added	62.5	125.0	250.0	500.0
	mg removed daily	11.9	24.25	45.1	90.6
	Total mg removed	61.02	122.95	243.25	483.6
	Removal rate %	95.2	97.0	90.2	90.6
6	Total mg added	75.0	150.0	300.0	600.0
	mg removed daily	11.53	22.65	42.6	86.4
	Total mg removed	72.6	145.6	285.85	570.0
	Removal rate %	92.3	90.6	85.2	86.4
7	Total mg added	87.5	175.0	350.0	700.0
	mg removed daily	11.2	20.5	40.3	80.6
	Total mg removed	83.8	166.1	326.15	650.6
	Removal rate %	89.6	82.0	80.6	80.6
8	Total mg added	100.0	200.0	400.0	800.0
	mg removed daily	10.78	19.0	37.15	70.2
	Total mg removed	94.58	185.1	363.3	720.0
	Removal rate %	86.2	76.0	74.3	70.2
9	Total mg added	112.5	225.0	450.0	900.0
	mg removed daily	8.5	17.5	34.3	68.2
	Total mg removed	103.08	202.65	397.6	789.0
	Removal rate %	68.2	70.2	68.6	68.2
10	Total mg added	125.0	250.0	500.0	1000.0
	mg removed daily	6.75	16.55	32.5	64.0
	Total mg removed	111.83	219.2	430.1	853.0
	Removal rate %	54.0	66.2	65.0	64.0
11	Total mg added	137.5	275.0	550.0	1100.0
	mg removed daily	6.75	13.15	24.0	68.0
	Total mg removed	118.58	232.15	454.1	921.0
	Removal rate %	54.0	52.6	48.0	68.0
12	Total mg added	150.0	300.0	600.0	1200.0
	mg removed daily	5.25	11.9	19.0	60.9
	Total mg removed	123.83	244.25	473.1	981.9
	Removal rate %	42.0	47.6	38.0	60.9
13	Total mg added	162.5	325.0	650.0	1300.0
	mg removed daily	5.08	11.3	18.35	58.6
	Total mg removed	128.91	255.55	491.45	1040.5
	Removal rate %	40.6	45.2	36.7	58.6
14	Total mg added	175.0	350.0	700.0	1400.0
	mg removed daily	3.5	11.25	17.5	40.6
	Total mg removed	132.41	266.8	508.95	1081.1
	Removal rate %	28.0	45.0	35.0	40.6
15	Total mg added	187.5	375.0	750.0	1500.0

Day		**50 ppm** 12.5 mg	**100 ppm** 25.0	**200 ppm** 50.0	**400 ppm** 100.0 mg
	mg removed daily	3.5	9.5	17.5	30.6
	Total mg removed	135.91	276.3	526.4	1111.7
	Removal rate %	28	38.0	35.0	30.6
16	Total mg added	200.0	400.0	800.0	1600.0
	mg removed daily	3.2	5.5	12.0	14.5
	Total mg removed	139.11	281.8	538.7.	1126.2
	Removal rate %	25.6	34.0	24.0	14.6
17	Total mg added	212.5	425.0	850.0	1700.0
	mg removed daily	2.33	4.1	10.0	0.0
	Total mg removed	141.44	285.9	548.7	1126.2
	Removal rate %	18.6	16.4	20.0	0.0
18	Total mg added	225.0	450.0	900.0	
	mg removed daily	1.4	2.55	9.3	
	Total mg removed	142.84	288.45	558.0	
	Removal rate %	11.2	10.2	18.6	
19	Total mg added	237.5	475.0	950.0	
	mg removed daily	1.03	0.0	0.0	
	Total mg removed	143.87	288.45	558.0	
	Removal rate %	8.2	0.0	0.0	
20	Total mg added	250.0			
	mg removed daily	0.375			
	Total mg removed	144.24			
	Removal rate %	3.0			
21	Total mg added	262.5			
	mg removed daily	0.0			
	Total mg removed	144.24			
	Removal rate %	0.0			

Table 10. The Adsorption of Phosphate by Biolat at a Three Day HRT.

Day		**50 ppm** 7.5 mg	**100 ppm** 15mg	**200 ppm** 30 mg	**400 ppm** 60 mg
2	Total mg added	15.00	30.00	60.00	120.00
	mg removed daily	14.85	29.90	59.70	117.60
	Total mg removed	14.85	29.90	59.70	117.60
	Removal rate %	(99.00)	(99.70)	(99.50)	(99.00)
3	Total mg added	24.50	45.00	90.00	180.00
	mg removed daily	7.40	14.80	29.85	39.40
	Total mg removed	22.25	44.70	89.55	177.0
	Removal rate %	(99.00	(98.70)	(99.50)	(99.00)
4	Total mg added	30.00	60.00	120.00	240.00
	mg removed daily	7.35	14.80	29.77	59.40
	Total mg removed	29.60	59.50	119.30	236.40
	Removal rate %	(98.00)	(98.70)	(99.20)	(98.50)
5	Total mg added	37.50	75.00	130.00	300.00
	mg removed daily	7.32	14.30	29.72	59.26
	Total mg removed	36.92	73.80	149.0	295.66
	Removal rate %	(97.60	(95.30)	(99.00)	(98.00)
6	Total mg added	45.00	90.00	180.00	360.00
	mg removed daily	7.20	14.30	28.95	58.17
	Total mg removed	44.12	88.10	177.19	353.83
	Removal rate %	(96.00)	(95.30)	(97.00)	(97.00)
7	Total mg added	52.50	105.00	210.00	420.00
	mg removed daily	7.12	14.30	28.87	55.01
	Total mg removed	51.24	102.40	206.77	408.84
	Removal rate %	(95.00)	(95.30)	(96.00)	(92.00)
8	Total mg added	60.00	120.00	240.00	480.00
	mg removed daily	7.08	14.10	28.66	55.01
	Total mg removed	59.32	116.50	235.44	463.80
	Removal rate %	(94.40)	(94.00)	(95.50)	(92.00)
9	Total mg added	67.50	135.00	270.00	540.00
	mg removed daily	6.81	13.92	28.09	53.26
	Total mg removed	65.13	130.42	263.53	517.06
	Removal rate %	(91.00	(92.80)	(94.00)	(89.00)
10	Total mg added	75.00	150.00	300.00	600.00
	mg removed daily	6.30	13.16	27.21	49.77
	Total mg removed	71.43	143.48	290.74	566.83
	Removal rate %	(83.00)	(87.70)	(90.70)	(83.00)
11	Total mg added	82.50	165.0	330.00	660.00
	mg removed daily	5.91	13.30	27.00	47.56
	Total mg removed	77.34	156.78	317.74	614.40
	Removal rate %	(79.00)	(88.10)	(90.00)	(79.20)
12	Total mg added	90.00	180.00	360.00	720.00
	mg removed daily	5.61	12.88	25.56	42.9
	Total mg removed	82.95	169.66	343.30	657.30
	Removal rate %	(74.80)	(85.90)	(85.00)	(71.50)
13	Total mg added	97.50	195.00	390.00	780.00
	mg removed daily	5.40	12.26	24.21	42.00
	Total mg removed	88.35	186.92	367.51	657.3
	Removal rate %	(72.00)	(81.70)	(80.70	(70.00)
14	Total mg added	105.00	210.00	420.00	840.00
	mg removed daily	5.43	11.30	21.375	41.865
	Total mg removed	93.78	193.20	388.88	741.165
	Removal rate %	(72.40)	(75.30)	(71.30)	(70.00)
15	Total mg added	112.50	225.00	450.00	900.00
	mg removed daily	4.71	10.25	21.38	41.87
	Total mg removed	98.49	203.45	410.26	783.03

Day		**50 ppm** 7.5 mg	**100 ppm** 15mg	**200 ppm** 30 mg	**400 ppm** 60 mg
ctd.	Removal rate %	(62.80)	(68.30)	(71.00)	(65.20)
16	Total mg added	120.00	240.00	480.00	960.00
	mg removed daily	4.47	9.96	21.38	39.12
	Total mg removed	102.96	213.41	431.64	861.3
	Removal rate %	(59.60)	(66.40)	(71.00)	(64.70)
17	Total mg added	127.50	255.00	510.00	1020.00
	mg removed daily	4.00	9.02	18.14	38.79
	Total mg removed	124.96	222.43	449.74	890.09
	Removal rate %	(48.00)	(60.10)	(60.50)	(64.70)
18	Total mg added	135.00	270.0	540.00	1080.00
	mg removed daily	2.97	9.10	15.13	38.87
	Total mg removed	127.93	231.53	464.87	938.96
	Removal rate %	(39.60)	(60.70)	(50.50)	(64.10)
19	Total mg added	142.50	285.00	570.00	1140.00
	mg removed daily	2.61	8.76	12.72	34.92
	Total mg removed	130.54	240.29	477.59	975.885
	Removal rate %	(34.80)	(58.40)	(42.40)	(59.50)
20	Total mg added	150.00	300.0	600.00	1200.00
	mg removed daily	1.80	8.70	12.45	37.20
	Total mg removed	132.34	248.99	490.4	1013.085
	Removal rate %	(24.00)	(58.00)	(41.50)	(62.00)
21	Total mg added	157.50	315.00	630.00	1260.00
	mg removed daily	1.47	6.70	11.91	36.00
	Total mg removed	133.81	255.60	501.95	1049.05
	Removal rate %	(19.60)	(44.70)	(39.70	(60.00)
22	Total mg added	165.00	330.00	660.00	1320.00
	mg removed daily	1.38	6.70	8.86	36.00
	Total mg removed	133.72	262.30	510.81	1085.055
	Removal rate %	(18.40)	(44.70)	(30.00)	(60.00)
23	Total mg added	172.50	345.00	690.00	1380.00
	mg removed daily	1.24	6.40	7.50	26.70
	Total mg removed	134.97	268.70	518.31	1101.755
	Removal rate %	(16.60)	(42.70)	(250)	(44.50)
24	Total mg added	180.00	360.00	720.00	1440.00
	mg removed daily	1.20	5.20	6.60	22.10
	Total mg removed	136.17	273.95	524.91	1123.85
	Removal rate %	(16.00)	(34.70)	(22.00)	(36.70)
25	Total mg added	187.50	375.00	750.00	1500.00
	mg removed daily	0.81	4.10	6.60	21.30
	Total mg removed	136.98	278.05	531.51	1145.155
	Removal rate %	(10.80)	(27.30)	(22.00)	(35.50)
26	Total mg added	195.00	390.00	780.00	1560.00
	mg removed daily	0.72	3.60	4.80	6.50
	Total mg removed	137.7	281.65	536.31	1151.75
	Removal rate %	(9.60)	(24.00)	(16.00)	(11.00)
27	Total mg added	202.50	405.00	810.00	1620.00
	mg removed daily	0.31	1.80	3.30	0.00
	Total mg removed	138.00	283.45	539.61	1151.75
	Removal rate %	(2.80)	(12.00)	(11.00)	(0.00)
28	Total mg added	210.00	420.00	840.00	-
	mg removed daily	0.60	0.35	2.20	-
	Total mg removed	138.61	283.70	541.80	-
	Removal rate %	(8.00)	(2.30)	(7.30)	-
29	Total mg added	217.50	435.00	870.00	-
	mg removed daily	0.00	0.00	0.00	-
	Total mg removed	138.61	283.70	541.81	-
	Removal rate %	(0.00)	(0.00)	(0.00)	-

Table 11. The Adsorption of Ammonium by Biolat at a Two Day HRT.

Day		**50 ppm** 12.5 mg	**100 ppm** 25.0 mg	**200 ppm** 50.0 mg	**400 ppm** 100.0 mg
2	Total mg added	25.0	50.0	100.0	200.0
	mg removed daily	24.98	49.5	99.0	198.2
	Total mg removed	24.98	49.5	99.0	198.2
	Removal rate %	99.9	99.0	99.0	99.1
3	Total mg added	37.5	75.0	150.0	300.0
	mg removed daily	12.49	24.63	43.1	94.3
	Total mg removed	37.44	74.13	142.1	292.5
	Removal rate %	99.9	98.5	96.2	94.3
4	Total mg added	50.0	100.0	200.0	400.0
	mg removed daily	12.03	24.56	49.3	97.8
	Total mg removed	49.47	98.71	191.4	390.3
	Removal rate %	96.2	98.3	98.6	97.8
5	Total mg added	62.5	125.0	250.0	500.0
	mg removed daily	12.18	24.7	49.1	94.0
	Total mg removed	61.65	123.41	240.5	484.3
	Removal rate %	97.4	98.8	98.2	94.0
6	Total mg added	75.0	150.0	300.0	600.0
	mg removed daily	12.05	24.48	48.0	90.2
	Total mg removed	73.7	147.89	288.5	574.5
	Removal rate %	96.4	97.9	96.0	90.2
7	Total mg added	87.5	175.0	350.0	700.0
	mg removed daily	12.08	23.2	46.6	78.6
	Total mg removed	85.78	171.09	335.1	653.1
	Removal rate %	96.6	92.8	93.2	78.6
8	Total mg added	100.0	200.0	400.0	800.0
	mg removed daily	11.75	24.35	45.95	68.5
	Total mg removed	97.53	195.44	381.05	721.6
	Removal rate %	94.0	97.4	91.9	68.5
9	Total mg added	112.5	225.0	450.0	900.0
	mg removed daily	11.75	24.05	46.3	68.5
	Total mg removed	109.28	219.45	427.35	790.1
	Removal rate %	94.0	96.2	92.6	68.5
10	Total mg added	125.0	250.0	500.0	1000.0
	mg removed daily	11.58	23.88	39.3	65.0
	Total mg removed	120.86	243.37	466.65	855.1
	Removal rate %	92.6	95.5	78.6	65.0
11	Total mg added	137.5	275.0	550.0	1100.0
	mg removed daily	11.33	23.28	39.0	62.6
	Total mg removed	132.19	266.65	505.35	917.7
	Removal rate %	90.6	93.1	78.0	62.6
12	Total mg added	150.0	300.0	600.0	1200.0
	mg removed daily	11.08	21.2	32.8	62.8
	Total mg removed	143.27	287.85	538.15	980.5
	Removal rate %	88.6	84.8	65.6	62.8
13	Total mg added	162.5	325.0	650.0	1300.0
	mg removed daily	11.28	20.7	32.7	68.0
	Total mg removed	154.55	308.55	570.85	1048.5
	Removal rate %	90.2	82.8	65.4	68.0
14	Total mg added	175.0	350.0	700.0	1400.0
	mg removed daily	10.62	21.65	32.75	68.2
	Total mg removed	165.17	330.2	603.6	1116.7

Day		50 ppm	100 ppm	200 ppm	400 ppm
	Removal rate %	85.0	86.6	65.5	68.2
15	Total mg added	187.5	375.0	750.0	1500.0
	mg removed daily	9.01	21.5	28.6	62.4
	Total mg removed	174.18	351.7	632.2	1179.1
	Removal rate %	72.1	86.0	57.2	62.4
16	Total mg added	200.0	400.0	800.0	1600.0
	mg removed daily	5.08	19.05	28.0	60.0
	Total mg removed	179.26	370.75	660.0	1239.1
	Removal rate %	70.6	76.2	56.0	60.0
17	Total mg added	212.5	425.0	850.0	1700.0
	mg removed daily	8.05	14.1	25.0	60.0
	Total mg removed	187.31	384.88	685.2	1299.1
	Removal rate %	64.4	56.4	50.0	60.0
18	Total mg added	225.0	450.0	900.0	1800.0
	mg removed daily	8.03	14.85	26.0	58.8
	Total mg removed	195.34	399.73	711.2	1357.9
	Removal rate %	64.2	59.4	52.0	58.8
19	Total mg added	327.5	475.0	950.0	1900.0
	mg removed daily	7.58	13.15	19.3	58.6
	Total mg removed	202.92	412.88	730.5	1416.5
	Removal rate %	60.6	52.6	38.6	58.6
20	Total mg added	250.0	500.0	1000	2000.0
	mg removed daily	7.08	9.35	15.3	36.6
	Total mg removed	210.0	422.23	745.8	1453.1
	Removal rate %	56.6	37.4	30.6	36.6
21	Total mg added	262.5	525.0	1050.0	2100.0
	mg removed daily	3.78	7.6	11.65	30.4
	Total mg removed	213.78	429.83	757.45	1483.5
	Removal rate %	30.2	30.4	23.3	30.4
22	Total mg added	275.0	550.0	1100	2200.0
	mg removed daily	3.08	4.4	6.5	34.3
	Total mg removed	216.86	434.23	763.95	1517.8
	Removal rate %	24.6	17.6	11.0	34.3
23	Total mg added	287.5	575.0	1150.0	2300.0
	mg removed daily	1.78	3.5	4.4	13.3
	Total mg removed	218.64	437.73	768.35	1531.1
	Removal rate %	14.2	14.0	8.8	13.3
24	Total mg added	300.0	600.0	1200.0	2400.0
	mg removed daily	1.28	1.3	3.0	15.4
	Total mg removed	219.92	439.03	771.35	1546.5
	Removal rate %	10.2	5.2	6.0	15.4
25	Total mg added	312.5	650.0	1250.0	2500.0
	mg removed daily	0.45	0.0	2.4	5.3
	Total mg removed	220.37	439.03	773.75	1551.8
	Removal rate %	3.6	0.0	4.8	5.3
26	Total mg added	325.0		1300.0	2600.0
	mg removed daily	0.25		0.0	3.0
	Total mg removed	220.62		773.75	1554.8
	Removal rate %	2.0		0.0	3.0
27	Total mg added	337.5			2700.0
	mg removed daily	0.0			1.6
	Total mg removed	220.62			1556.4
	Removal rate %	0.0			1.6
29	Total mg added				2800.0
	mg removed daily				0.0
	Total mg removed				1556.4
	Removal rate %				0.0

Table 12. The Adsorption of Ammonium by Biolat at a Three Day HRT

Day		**50 ppm** 7.5 mg	**100 ppm** 15.0 mg	**200 ppm** 30.0 mg	**400 ppm** 60.0 mg
3	Total mg added	22.50	45.00	90.00	180.00
	mg removed daily	21.80	43.65	88.20	172.80
	Total mg removed	21.80	43.65	88.40	172.80
	Removal rate %	98.00	97.00	98.00	96.00
4	Total mg added	30.00	60.00	120.00	240.00
	mg removed daily	7.16	14.55	29.32	55.68
	Total mg removed	28.96	58.20	117.50	228.48
	Removal rate %	95.40	97.00	97.75	92.80
5	Total mg added	37.50	75.00	150.00	300.00
	mg removed daily	7.20	14.37	29.32	55.68
	Total mg removed	36.16	72.57	146.82	284.16
	Removal rate %	96.00	95.80	97.72	90.00
6	Total mg added	45.00	90.00	180.00	360.00
	mg removed daily	7.23	14.34	28.98	41.22
	Total mg removed	43.39	86.91	175.78	325.38
	Removal rate %	96.40	95.60	96.60	68.70
7	Total mg added	52.50	105.00	210.00	420.00
	mg removed daily	7.17	14.34	28.98	40.80
	Total mg removed	50.56	101.6	204.85	366.18
	Removal rate %	95.60	98.0.	96.90	68.00
8	Total mg added	60.00	120.00	240.00	480.00
	mg removed daily	7.14	14.70	29.07	40.80
	Total mg removed	57.70	116.30	233.92	406.98
	Removal rate %	95.20	98.40	96.90	65.90
9	Total mg added	67.50	135.00	270.00	540.00
	mg removed daily	7.05	14.50	29.37	39.54
	Total mg removed	64.75	130.81	263.92	446.52
	Removal rate %	95.20	98.40	96.90	65.90
10	Total mg added	75.00	150.00	300.00	600.00
	mg removed daily	7.06	14.50	29.37	39.54
	Total mg removed	71.82	145.31	292.69	486.06
	Removal rate %	94.00	96.70	97.90	65.00
11	Total mg added	82.50	165.00	330.00	660.00
	mg removed daily	7.02	14.55	29.10	38.10
	Total mg removed	78.84	159.94	321.16	524.16
	Removal rate %	93.60	97.00	98.20	63.50
12	Total mg added	90.00	180.00	360.00	720.00
	mg removed daily	6.99	14.53	29.55	35.52
	Total mg removed	85.83	174.47	350.71	559.68
	Removal rate %	93.20	96.90	98.50	59.20
13	Total mg added	97.50	195.00	390.00	780.00
	mg removed daily	6.82	14.55	29.51	35.10
	Total mg removed	92.65	189.03	380.22	594.78
	Removal rate %	91.00	97.00	98.35	58.50
14	Total mg added	105.00	210.00	420.00	840.00
	mg removed daily	6.57	14.52	28.83	30.00
	Total mg removed	99.20	203.55	409.05	624.78
	Removal rate %	87.60	96.80	96.10	50.00
15	Total mg added	112.50	225.00	450.00	900.00
	mg removed daily	6.49	14.52	27.96	34.90
	Total mg removed	105.72	218.07	437.01	659.68
	Removal rate %	86.60	96.80	93.20	58.10
16	Total mg added	120.00	240.00	480.00	960.00
	mg removed daily	6.30	14.61	28.00	34.80

Day		50 ppm	100 ppm	200 ppm	400 ppm
	Total mg removed	112.02	232.68	465.00	694.48
	Removal rate %	84.00	97.40	93.35	58.00
17	Total mg added	127.50	255.00	510.00	1020.00
	mg removed daily	5.97	14.64	27.90	34.47
	Total mg removed	117.99	247.32	492.90	728.95
	Removal rate %	79.60	97.60	93.00	57.45
18	Total mg added	135.00	270.00	540.00	1080.00
	mg removed daily	5.46	14.68	27.66	30.04
	Total mg removed	123.45	262.00	520.56	758.62
	Removal rate %	72.80	97.90	92.20	55.08
19	Total mg added	142.50	285.00	570.00	1140.00
	mg removed daily	5.10	14.70	29.31	33.00
	Total mg removed	128.55	276.70	549.87	791.62
	Removal rate %	68.00	98.00	87.70	55.00
20	Total mg added	150.00	300.00	600.00	1200.00
	mg removed daily	5.04	14.70	23.10	31.56
	Total mg removed	133.59	291.40	572.94	823.20
	Removal rate %	67.20	98.00	77.00	52.60
21	Total mg added	157.50	315.00	630.00	1260.00
	mg removed daily	4.83	14.65	23.40	32.40
	Total mg removed	138.42	306.05	596.37	855.56
	Removal rate %	64.40	97.70	78.00	54.00
22	Total mg added	165.00	330.00	660.00	1320.00
	mg removed daily	4.47	14.65	23.66	32.14
	Total mg removed	142.89	320.71	620.00	887.96
	Removal rate %	59.60	97.70	78.85	54.00
23	Total mg added	172.50	345.00	690.00	1380
	mg removed daily	4.26	14.60	23.40	31.56
	Total mg removed	147.15	334.80	643.40	919.52
	Removal rate %	56.80	97.50	78.00	52.60
24	Total mg added	180.00	360.00	720.00	1440.00
	mg removed daily	4.02	13.48	23.28	30.54
	Total mg removed	151.17	348.30	666.68	950.10
	Removal rate %	53.60	89.90	77.60	50.90
25	Total mg added	187.50	375.00	750.00	1500.00
	mg removed daily	4.08	10.53	21.81	30.00
	Total mg removed	155.25	358.80	688.49	980.10
	Removal rate %	53.60	89.90	77.60	50.90
26	Total mg added	195.00	390.00	780.00	1560.00
	mg removed daily	3.75	10.20	19.75	30.00
	Total mg removed	159.00	369.00	708.20	1010.00
	Removal rate %	50.00	68.00	65.85	50.00
27	Total mg added	202.50	405.00	810.00	1620.00
	mg removed daily	3.57	9.32	19.16	29.50
	Total mg removed	162.57	378.30	726.40	1039.50
	Removal rate %	47.60	62.10	60.55	49.20
28	Total mg added	210.00	420.00	840.00	1680.00
	mg removed daily	3.30	9.32	15.54	31.2.00
	Total mg removed	165.87	387.60	741.90	1070.00
	Removal rate %	44.00	62.10	51.80	52.00
29	Total mg added	217.50	435.00	870.00	1740.00
	mg removed daily	2.86	9.07	14.355	30.00
	Total mg removed	168.73	399.67	756.26	1100.00
	Removal rate %	38.20	60.50	47.85	50.00
30	Total mg added	225.00	450.00	900.00	1800
	mg removed daily	2.61	8.85	13.95	29.28
	Removal rate %	34.80	59.00	46.50	48.80
31	Total mg added	232.50	465.00	930.00	1860.00
	mg removed daily	2.61	8.31	9.60	28.50
	Total mg removed	173.95	416.83	779.83	1157.80

Day		50 ppm	100 ppm	200 ppm	400 ppm
	Removal rate %	34.80	55.40	32.00	47.50
32	Total mg added	240.00	480.00	960.00	1920
	mg removed daily	2.32	7.97	10.76	16.85
	Total mg removed	176.27	424.8	790.56	1174.6
	Removal rate %	31.00	53.1	35.85	46.8
33	Total mg added	247.50	495.00	990.00	1980.00
	mg removed daily	1.77	6.53	10.50	27.60
	Total mg removed	178.04	431.33	811.60	1201.60
	Removal rate %	23.60	43.50	35.00	46.00
34	Total mg added	255.00	510.00	1020.00	2040.00
	mg removed daily	1.41	4.17	6.19	26.52
	Total mg removed	180.86	435.50	817.79	1228.12
	Removal rate %	14.80	27.8	20.65	40.00
35	Total mg added	262.50	525.00	1050.00	2100.00
	mg removed daily	1.11	3.03	6.19	24.00
	Total mg removed	181.97	438.53	823.99	1252.12
	Removal rate %	14.80	27.80	20.65	40.00
36	Total mg added	270.00	540.00	1080.00	2160.00
	mg removed daily	1.33	3.30	3.30	19.80
	Total mg removed	183.3	441.83	827.29	1271.90
	Removal rate %	17.80	22.00	11.00	33.00
37	Total mg added	277.50	555.00	1110.00	2220.00
	mg removed daily	0.96	3.06	0.00	17.70
	Total mg removed	184.26	444.86	827.29	1289.60
	Removal rate %	12.80	20.40	0.00	29.50
38	Total mg added	285.00	570.00		2280.00
	mg removed daily	0.75	2.65		14.38
	Total mg removed	185.01	447.52		1303.60
	Removal rate %	10.00	17.70		24.30
39	Total mg added	292.5	585.00		2340.00
	mg removed daily	0.21	3.15		11.70
	Total mg removed	185.22	450.69		1314.00
	Removal rate %	2.80	21.00		19.50
40	Total mg added	300.00	600.00		2400.00
	mg removed daily	0.00	0.00		8.01
	Total mg removed	185.22	450.69		1322
	Removal rate %	0.00	0.00		13.35
41	Total mg added				2460
	mg removed daily				7.08
	Total mg removed				1329.08
	Removal rate %				13.35
42	Total mg added				2520
	mg removed daily				3.36
	Total mg removed				1332.4
	Removal rate %				5.60
43	Total mg added				2580
	mg removed daily				0.00
	Total mg removed				1332.40
	Removal rate %				0

Statistical Analysis.

For the analysis of variance between the removal of phosphate or ammonia by Biolat under various conditions (i.e. grain size, influent pH etc.) the following formula was used

$$F = \frac{n(Sdx)}{Sd^2} \qquad F_{k-1,\, k(n-1)}$$

where n = Number of Treatments.
k = Number of Replications.
x = The mean ratio calculated.
Sd = Standard deviation.
Sdx = Standard Deviation of mean ratios

The resultant value obtained was compared with F critical at a 5% level in order to determine if any variation was significant at a 95% level.