MICROBIAL FILTRATION BY 0.2 MICRON MEMBRANE FILTERS IN COMBINATION WITH CATION-EXCHANGE RESINS

By

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PREFACE

Filtration was carried out by 0.2 micron membrane filters for various bacterial concentrations. To reduce the pH of water, different types and amounts of cation-exchange resins were used. Filtration rates and microbial removal efficiencies were obtained for different pH. The results of this study can be used to develop a filter that could remove bacterial contamination from water more effectively.

I wish to express my sincere gratitude to my major adviser, Dr. Gary L. Foutch, for his guidance, inspiration, and invaluable counsel. I am also thankful to Dr. Ruth C. Erbar and Dr. Edward J. Zecchini, for serving on my committee.

I am grateful to Oklahoma Center for the Advancement of Science and Technology (OCAST) for the financial support I received for the project.

My deepest appreciation is extended to my parents and my sisters for their love, support, moral encouragement, and understanding.

This work is solely dedicated to my parents.

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CHAPTER I

INTRODUCTION

Water is indispensable for human life. The health of a community depends on the water supply. Several illnesses, from minor ailments to serious epidemics, can be transmitted by water. The agents conveyed by water may be chemical substances (including poisons), pathogenic micro-organisms (e.g. bacteria, viruses, and protozoa), or higher forms of parasitic life (e.g. worms) (1).

The danger of microbial polluted water comes from living organisms and not from dead organic matter. What is most feared is the presence of pathogenic bacteria which may cause diseases like cholera, dysentery and enteric fever. Therefore, a safe water supply free of bacterial contamination is necessary for good health (1).

There are several ways of removing bacterial contaminants from water. Treatment of water with ozone, silver, hydrogen peroxide and ultra violet rays destroy the bacteria in water. Ozone oxidizes the cell protoplasm of the bacteria and denatures it (30). Chlorination, heat treatment and filtration are other methods for bacterial decontamination. To effectively eliminate bacterial contamination from water, membrane filters are used (6).

Filters are used to remove scattered particles from a fluid. For bacterial filtration the solid particles of

concern are micro-organisms. Membranes can remove turbidity, bacteria and other micro-organisms. Membrane filters are classified as surface or screen filters, where the particles are retained on the surface of the filter or within a depth of 10 to 15 microns. This characteristic distinguishes membrane filters from depth filters or filter aids, which trap particles within the filter matrix (9).

Membrane filters retain micro-organisms and particles by sieving action, adsorption, reaction with the membrane itself or coagulation. Some membrane filters selectively adsorb certain organisms when the pore diameter greatly exceeds the size of the organisms, whereas other filters allow the organisms to pass through. Retention by sieving action is a very important mechanism, this type of particle capture is absolute in its reliability. This mechanism depends on the pore sizes and pore size distribution of the filters. Membrane filters have a narrower pore size distribution than other types of filters (i.e., depth filter) (15,18). The fundamental mechanism of filtration may be considered as sieving modified by adsorption or blocking arising from a large ratio of pore length to pore diameter. The ratio of pore length to width in a 0.2 micron pore size filter is approximately 750 (14). This ratio, in combination with the geometric configuration of the tortuous pore structure, heavily influences the retention of particles by the membrane.

Clogging of the filter depends on the particle concentration and size and shape of the microorganisms. Clogging occurs very rapidly with small pore size filters.

By reducing bacterial clogging, the effective life of the filter can be extended and large quantities of water can be processed with an improved filtration rate.

Bacteria are greatly influenced by the environment around them. Shirato & Esumi (3) have documented the effect of pH on the physical characteristics of the bacteria, this work showed that filtration rate of Streptomyces griseus improved drastically when pH was reduced to approximately four. At this pH the bacteria becomes more spherical and pack on the filter with more void volume. Also, the changes in pH changes the surface charges of the bacteria and the degree of adsorption on the filter (24). At neutral pH there is a negative charge on the surface of the bacteria. With reduction of pH, the surface charges of bacteria neutralize and natural repulsion is reduced and organisms precipitate (23). Cation exchange resins are used to reduce the pH by replacing minerals such as calcium, magnesium and iron with hydrogen ions. Water has sufficient dissolved mineral concentration to drive the ion-exchange process.

Taking filtration rate and microbial retention on the filter into consideration, a 0.2 micron filter is selected. Membranes offer the distinct advantage of limiting the amount of chemicals needed for water purification and provide water which is free from microorganisms.

The purpose of this work is to study water filtration rate and microbial removal efficiency of membrane filters using cation exchange resins. The information from this study may be applied to improve the existing filtration

schemes for removing bacterial contamination from water. This study uses the change of physical characteristics of bacteria at low pH to improve the filtration rate and extend the life of the filter by reducing clogging.

CHAPTER II

LITERATURE REVIEW

A review of the relevant literature was performed. This background material can be divided into three areas; membrane filters, physiology of bacteria, and ion-exchange resins. Each topic will be addressed separately.

Membrane Filters

Using membranes for water treatment is a relatively new and effective technology with many advantages and a few problems (6). Membranes can remove suspended particles, bacteria, microorganisms, organic compounds and dissolved salts. Membrane processes such as reverse osmosis, nanofiltration, and electro-dialysis are applicable for water treatment. For bacterial removal ultra- or micro-filtration is applicable (6).

Filters can remove particles by several mechanisms including sieve retention and adsorption (15,11,19). Filtrative behavior is governed by; the porous nature of the filter, its total porosity, and the size and distribution of the pores. Particle capture by sieve retention is absolute in reliability and its performance is complete if the smallest particle being filtered is larger than the largest pore of the filter.

The scattered particles removed from a fluid are

almost never all one size. They have a certain particle-size spread or distribution. Also, the filter pore sizes are not uniform, they too show a size distribution (18). Membrane filters have narrower pore size distribution than other types of filters (15). A filter's pore size distribution influences the particle retention capabilities and the flow characteristics (17). Narrow pore size distribution reduces the chance of accidental overlap of particle and pore size distribution, this kind of overlap would not have absolute sieve retention (15). Depth filters have broader pore-size distributions compared to membrane filters of the same rating. Depth filters give greater rates of flow than membrane filters of the same rating. Since there is a broader pore size distribution, large amounts of particulate matter can be retained on the vast inner surfaces of a depth-type filter. Depth filters have high particulate loading capability, or large dirt holding capacity. However depth type filters are not totally reliable for particulate retention.

A restricted pore-size distribution has its limitations. They may have sudden catastrophic clogging. A broader pore-distribution however offers some resistance to early clogging (18). A broader pore size distribution in membranes can be used to advantage in filtration, in that it imparts a degree of high loading capacity, a depth filter quality applied to membrane filters.

When a particle is small enough to enter the pore, the narrower the pore diameter, the more likely the particle is to encounter the pore wall and be captured before it finds

its way with the convective stream. Therefore, particle trapping increases with an increase in filter thickness (20). Thick filters have a longer pore-path and provide larger residence times for particles negotiating these pore passages. This leads to greater probabilities of pore wall encounters and enhanced particle captures.

Filters are often described as either absolute or nominal (18). This characterization does not describe the inherent quality of filters. Whether a given filter is nominal or absolute depends on the particle size distribution that confronts its pore size distribution. The same filter may not be absolute to flow particles if there are particles smaller than a few larger pores. In this case, the filter, relative to this given particle size-distribution is said to be nominal since the retention of all small particles may not be accomplished. The broader the pore size distribution of a filter, the more likely it is to be nominal in its retentivity.

The pore size distribution of filters depends on the method of their manufacture (15). A solution is made of polymer, solvent and pore forming agent. A thin coating of this solution is spread very evenly on a smooth surface and the evaporation of solvent forms a mesh. The solute or polymer molecules in the solution are evenly distributed, this distribution is not accidental, it depends on the thermodynamic laws that govern the solution. This causes pores of nearly equal size and distribution. Depth filters are manufactured by positioning individual fibers or bits and pieces of ceramic, metal or plastic on a surface, then

matting, gluing or sintering the fibers or particles into a mat or solid composition. The fibers are positioned at random, and as a consequence, there is uneven spacing and broader pore size distribution.

The emphasis on particle retention requires consideration of pore size measurement. There is no completely reliable way of measuring the pore sizes of microporous filters directly. Measurements involve assumptions regarding the pore structure that are usually over simplified. As a result reported pore sizes are approximations. Indirect measurements of pore size distribution use the flow of air and water, under high pressure. They may employ particles for sizing (including bacteria) (5,17). Since each method has certain drawbacks, two or more of them are often used to fully characterize a membrane. Various filter manufacturers do not necessarily use the same method for classifying the porosity rating of their products (17). Therefore the use of identical pore size designation by two different manufacturers does not mean that the two filters are identical (15).

Filters work best at low applied differential pressure. At higher pressure the flow rates are greater, but the total throughput may not be as great because the life of the filter is compromised, especially if particulate matter being removed is deformable. Also, the efficiency of the filter in terms of particle trapping is often enhanced at lower pressures since the adsorption of the particles by the filter is not reduced at low pressures. With membrane filters, when the system is

properly sized, particle retention based on sieve capture will take place regardless of pressure unless the shape of the particle or the pore is distorted. Depth filters may capture particles at low pressures and may unload them at higher pressures (15).

There are other methods whereby particles are removed by filters apart from sieve retention. Filters acquire electrostatic charges when fluids pass through them and retain particles by this mechanism. Where electrostatic retention is involved, a particle may be small enough to enter a pore and yet be captured by electrostatic attraction. There are two general types of electrostatic filters. Electronegative filters have net negative charges at pH between 4 and 6, while electropositive filters have net positive charges or slight negative charges over the same pH range (Sobsey and Glass,1980; Sobsey and Jones 1979). Both type of filters have been used to recover bacteria from water. Viruses adsorb on electronegative filters when the pH of water is lowered and/or cations are added (Wallis & Melmick, 1967).

Bacteriophages can be retained on electropositive filters at an ordinary pH range without being denatured. The compositions of membranes vary, which influences the mechanism whereby bacteria are removed from water. Various polymeric materials are used to produce synthetic membrane filters; of these materials, cellulose nitrate, polytetrafluoroethylene and polyvinylidene fluoride are among the more widely known (14).

In an adsorptive mechanism, a particle may come close

enough to the pore wall to become subject to attractive forces such as hydrogen bonding, electrokinetic attraction or other electrical charge-induced phenomena. Because of adsorption mechanisms, membrane filters far exceed performance predictions based solely on their pore size measurements (15).

Wallhausser (5) had reported the passage of pseudomonas through 0.2 micron filter. Below certain pore sizes, sterile filtrate was always produced regardless of the organism concentration (21). Work at the Gelman sciences laboratories and at Pall & Millipore laboratories showed complete retention of Pseudomonas diminuta up to 90 psi pressure differences(15). Membranes that are 0.2 micron show complete reliability for Pseudomonas dimunata regardless of the challenge levels and the applied differential pressures. But Wallhausser showed that 0.2 micron filters do not show absolute retention for smaller organisms. For such organisms, membranes with smaller pore size ratings would be required, but smaller diameter pores will exhibit sharply reduced flow rates. This will result in appreciably higher filtration costs.

Bacterial Physiology

To understand retention and adsorption of bacteria on membrane filters better, the knowledge of structure and physiology of microorganisms may be useful. Bacteria are prokaryotic cells, the bacteria cytoplasmic membranes are surrounded by the cell wall, a rigid network composed of peptidoglycan. The cell wall prevents cells from lysing in

a hypotonic environment. Gram-negative bacteria have an extra membrane system outside the peptidoglycan layer. In both cases, the peptidoglycan layers can be removed by lysozymes resulting in the formation of spherical cells in an isotonic medium. Except in environments of high osmotic pressure, bacteria with damaged cell walls swell and burst (22,23).

Small molecules, like water, pass through cytoplasmic membranes by passive diffusion, while larger molecules cross the membrane by active transport. Active transport requires energy and enzymes. Transport enzymes are proteins within the membrane structure. The flow of molecules and ions between a cell and its environment is precisely regulated by transport systems. Transport processes regulate cell volume and maintain the intercellular pH and ionic composition within a narrow range (22,29).

Each organism has a pH range where growth is possible. Optimum pH for most organisms is between 5 and 9. Acidophilic bacteria grow even when the pH is one. Although micro-organisms are found in habitats over a wide pH range, the pH within the cell is probably close to neutrality.

In acidic environments, organisms can maintain a pH close to neutrality either by keeping hydrogen ions from entering or by actively expelling hydrogen ions as rapidly as they enter. In addition to the direct effects of pH on cells, there are indirect effects due to ionization of organic compounds. The non-ionized form of most compounds

can penetrate more readily than the ionized form. Organisms themselves alter the pH values of their environment through their activities. For instance, bacteria that ferment glucose to produce lactic acid will lower the pH of their environment.

When suspended in a medium of pH 7, bacteria are negatively charged, an increase of pH will result in an increase of negative charge. The charge on the bacterial surface plays a prominent role in adsorption, agglutination phenomena and electrophoresis. Adsorption and agglutination caused by the surface charges are helpful for filtration of bacteria from water (23). Adsorption of cations, particularly hydrogen, by bacteria, is increased as the suspending solution is made progressively more acidic. With increasing adsorption of hydrogen ions, the surface charges are gradually neutralized until it approaches zero and mutual repulsion is reduced, as a result, the organisms which collide tend to stick together and precipitate (agglutinate). This is called acid agglutination and acidity of this solution expressed as pH, is called the isoelectric point. For various species of bacteria, the isoelectric point lies between pH 3.0 and 4.8. An important factor determining whether or not bacteria will pass through a filter is their surface charge relative to that of the filter substance. This can be altered with the pH of the medium. Other changes in the electrolyte of the medium, or addition of surface active materials may alter the surface charge of the bacteria and also the degree of adsorption on the filter (24).

Permeability of the bacteria membrane varies with species and age of the cell (25,26). The organism is thus a small osmotic unit responsive to changes in the composition and osmotic pressure of the environment. This sensitivity results in changes in cell density and water content when the environment is altered. Some bacteria may remain viable despite considerable changes in osmotic pressure (23). Transferring bacteria from a two percent sodium chloride solution to water results in, swelling of cells, extrusion of globules of protoplasm and occasional bursting (27,28). This effect is called plasmoptysis. Transfer of cells from a dilute to higher concentration of salts brings about shrinkage and granulation of the protoplasm within the cell membrane producing plasmolysis. Spores appear to be less susceptible to osmotic changes than are the vegetative forms.

Ion-Exchange Resins

Ion-exchange resins exchange ions with no substantial change in the structure of the resin, they are considered insoluble high molecular weight polymeric electrolytes. The most important ion-exchange resins produced and employed today are synthetic organic resins. These ion-exchange resins are actually a special type of polyelectrolytes (cross-linked polyelectrolytes) that can be visualized as an elastic three dimensional hydrocarbon network, to which is attached a large number of ion active groups. The most useful hydrocarbon network developed to date is that formed by copolymerization of styrene and divinylbenzene. This

structure gives a maximum resistance to oxidation, reduction, mechanical wear and breakage and is insoluble in common solvents (33).

In the preparation of resins, two variables are controlled. They are the crosslinking, or percent divinylbenzene, and particle or mesh sizes. Completing the structure of an ion-exchange resin is the ion active group. The ion active group is fixed to the high molecular weight polymer and is immobile. The electrical charge of the ion active group is balanced by an equivalent number of oppositely charged ions which are mobile and can exchange with other ions of similar charge. The ion active groups determine the chemical behavior of the ion-exchange resin (32).

The total capacity of an ion-exchange resin is the number of ionic sites per unit weight or volume of resin. All ion-exchange resins have preferences for a particular type of ions they will hold if given a chance. This preference is defined as the selectivity of the resin.

The rate of ion exchange reaction depends on many factors, notably the size and charge of ions involved, the degree of crosslinking of the resin, the temperature of the system and size of the resin particles. With decrease in size of resin particles there is a decrease in time required to reach equilibrium with contacting solution and increase in efficiency (31).

Ion-exchange resins have many applications. They can be used for the removal of objectionable cations and anions from drinking and boiler feed water, production of de-

ionized water, purification, concentration and recovery of organic and inorganic chemicals, separation of ions and in analytical chemistry applications (32). Ion-exchange resins can be used with filters for water purification.

CHAPTER III

EXPERIMENTAL PROCEDURE

To find the filtration rate and bacterial removal efficiency, 0.2 micron-rated cellulose nitrate membrane filters were used. The effective area of each filter is 13.85 sq cm (4.2 cm diameter).

The membrane filter is supported by a cellulosic support pad. The unit consists of an upper and lower chamber made of polystyrene, each with 115 ml capacity (Nalgene Company, Nalge NO. 130-4020). To filter more water, the bottom of the lower chamber was removed and processed water was collected in a measuring jar (shown in Figure 1). The water level in the upper chambers was maintained at a constant height to give a constant pressure head. Filtration was carried out for gravity flow and no external pressure was applied.

The test organisms for this study was Escherichia coli (Obtained from United States Department of Agriculture, Agriculture Research Service, Peoria Illinois). The influent water was contaminated with known concentrations of bacterial cells and passed through the filter. The volume of water collected in the measuring jar against time was noted. The filtered water is then tested for cell concentrations, this was done by standard plating techniques. This procedure was repeated using cation-

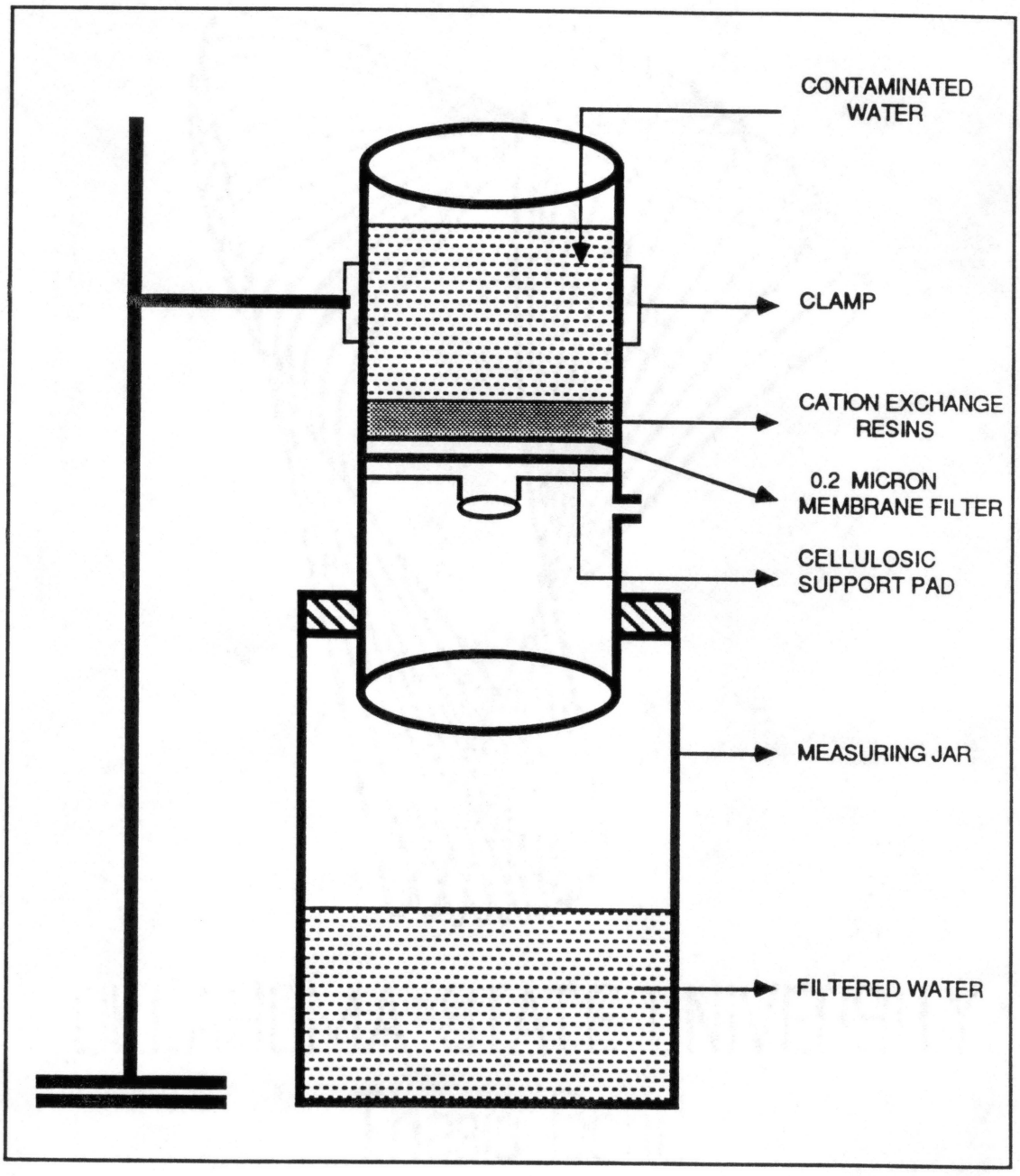

Figure 1. Experimental Set-up for Filtration by a 0.2 Micron Membrane Filter (Nalgene Company) in Combination With Cation Exchange Resins.

exchange resins in varying amounts and different bacterial concentrations. The cation-exchange resins are spread over the membrane filter so that the water pH is changed before bacterial filtration (Figure 1). After processing 250 ml water,the pH of water was found for each experiment. The pH of the treated water was found using a pH meter (Accumet portable pH meter model 956, Fisher Scientific). For this study, Dowex 50 resin and Filtrol were used. Dowex 50 resin is in the form of beads and Filtrol is a powder. Filtration was studied for uncontaminated water, for water with 67,000, 670,000, and 6,700,000 cells/ml of Eschericha coli using 0.18 g/sq cm and 0.36 g/sq cm of Filtrol and Dowex 50 resins. Filtration was also studied for lake water (Lake McMurty, near Stillwater, Oklahoma).

The parameters that were studied are: concentration of bacterial cells, type of resin, amount of resin and flow rate. All the experiments were carried out using 0.2 micron-rated cellulose nitrate membrane filter.

Special care was taken for growth and enumeration of bacteria. The glassware that was used was always cleaned with detergent, rinsed with distilled water and sterilized in an autoclave for 15 minutes at 15 psig and 115^{O}C.

The bacteria was cultivated in a Baltimore Biological Laboratories (BBL) nutrient broth medium. To deionized sterile water at neutral pH the nutrient broth is added and warmed slightly before autoclaving at 121^{O}C for 15 minutes. After cooling the medium, the bacterial culture is added and incubated (Fisher Isotemp Incubator Model 225D) for 48

hours at 35^{o}C. After growth, the culture media is stored in a refrigerator.

Enumeration of bacteria can be done by many biological methods. For comparative and legal purposes, a standard plate count is useful. Bacteria are rarely separated entirely from each other and are often dumped together in large numbers particularly if actively reproducing. A single colony may therefore develop from one organism or from hundreds. Each colony forms from each visible unit. The Standard plate count method (like other biological methods) assumes that a visible colony will develop from each organism, therefore we get only an approximate number of cells from the number of colony forming units.

Samples to be tested were diluted to get a total number of colonies on the plate between 30 and 300. The dilution was done in sterile water. For plating, the medium on which cells are grown was made from MFC broth. Sterile water with pH 7.4 is boiled and MFC broth and agar were added. After cooling this medium, and before solidifying, it is poured into petri dishes and allowed to set. The petri dishes were disposable polystyrene dishes manufactured by Fisher. Disposable syringes were used to measure 0.1 ml of the sample and transfer it to the medium in the petri dishes. The sample drops in the petri dish are spread uniformly on the medium for even growth using a glass rod. The glass rod can be sterilized easily by heating it over a flame each time, and spreading is easy. After spreading the sample drops of water, the dishes are

inverted and kept in an incubator for 48 hours at $35^{O}C$ for the colonies to form.

The counting of the colonies was done using a colony counter and the number of colonies are recorded. The colony counter was a Fisher Acculite colony counter (Model 133-8002). The number of colonies represent an approximate number of cells in 0.1 ml of sample.

CHAPTER IV

EXPERIMENTAL RESULTS AND DISCUSSION

In this section the filtration results will be presented. Table I lists the conditions and the effluent properties for each experiment using tap water. Table II lists the volume of water collected with time for each experiment. The raw data is presented in Appendix.

Plots were made for each cell concentration using different types and amounts of resin. Comparisons were made for different cell concentrations.

Figure 2 shows that, for uncontaminated water, the filtration rate is faster without the resin. When resin is placed on the membrane filter, the resistance to flow increases. The pH decrease did not improve the filtration rate of uncontaminated tap water.

Figure 3 shows the results for water with 67,000 cells/ml. For water with 67,000 cells/ml, the difference in filtration rate without resin and with different types and amounts of resins is reduced compared to uncontaminated water, but no improvement in filtration using resin is observed at this cell concentration. By using 0.18 and 0.36 g/sq cm of Dowex resin, the effluent pH of 250 ml water was 2.4 in both cases. Since, 0.36 g/cm offered more resistance than 0.18 g/cm , the filtration rate in the latter case is faster. By using 0.18 and 0.36 g/sq cm of

TABLE I

SUMMARY OF CONDITIONS AND EFFLUENT PROPERTIES ON FILTRATION STUDY USING TAP WATER

Exp	Type of Resin	Amount g/sq cm	Feed Conc. cells/ml	Effluent pH	Effluent cells/ml
1	None	0.00	0	7.2	0
2	None	0.00	67,000	7.2	0
3	None	0.00	670,000	7.2	0
4	None	0.00	6,700,000	7.2	400
5	Dowex	0.18	0	2.4	0
6	Dowex	0.18	67,000	2.4	0
7	Dowex	0.18	670,000	2.7	0
8	Dowex	0.18	6,700,000	2.5	0
9	Filtrol	0.18	0	4.0	0
10	Filtrol	0.18	67,000	4.1	0
11	Filtrol	0.18	670,000	4.0	0
12	Filtrol	0.18	6,700,000	4.1	90
13	Dowex	0.36	0	2.4	0
14	Dowex	0.36	67,000	2.4	0
15	Dowex	0.36	670,000	2.4	0
16	Dowex	0.36	6,700,000	2.4	0
17	Filtrol	0.36	0	4.2	0
18	Filtrol	0.36	67,000	3.7	0
19	Filtrol	0.36	670,000	3.8	0
20	Filtrol	0.36	6,700,000	3.8	0

TABLE II

VOLUME COLLECTED WITH TIME FOR CONDITIONS IN TABLE I

Exp	Time (min) 0	100	200	300	400
	Volume Collected (ml)				
1	0	110.0	209.2	-	-
2	0	93.3	173.3	-	-
3	0	85.0	164.2	240.0	-
4	0	56.7	93.3	123.3	152.0
5	0	80.0	160.0	231.7	-
6	0	88.3	160.0	220.0	-
7	0	93.3	166.7	221.7	-
8	0	73.3	129.2	180.0	225.0
9	0	75.0	165.0	-	-
10	0	67.5	138.3	214.2	-
11	0	66.7	124.2	175.0	223.2
12	0	65.8	119.2	161.7	196.7
13	0	75.0	153.3	220.8	-
14	0	68.3	126.0	176.2	222.5
15	0	66.7	118.3	165.7	207.5
16	0	61.7	113.3	156.3	193.7
17	0	82.7	169.2	-	-
18	0	84.2	161.7	232.3	-
19	0	95.0	199.5	-	-
20	0	60.0	120.0	180.0	243.3

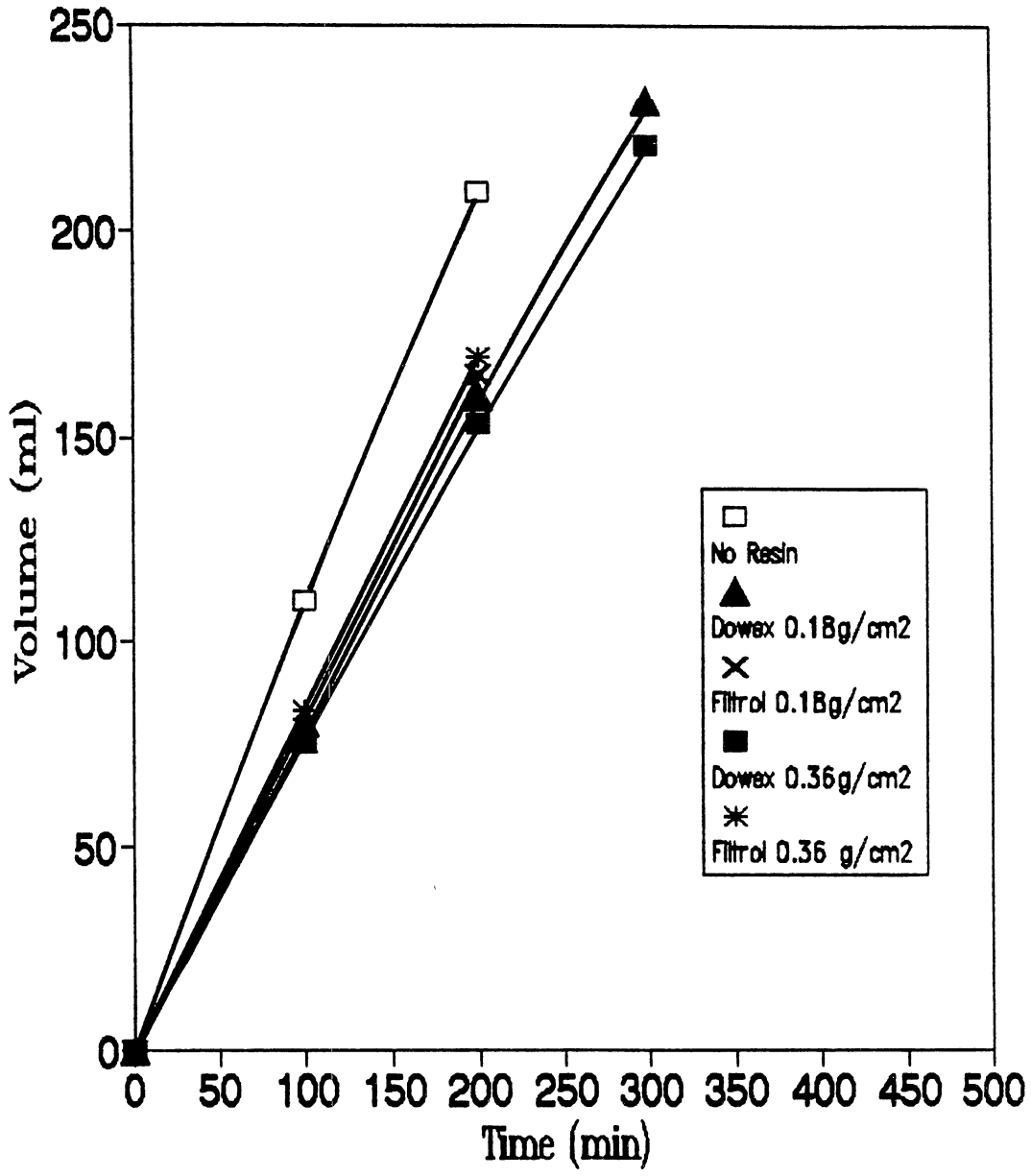

Figure 2. Comparison of Filtration for Uncontaminated Tap Water Using Different Types and Amounts of Resin.

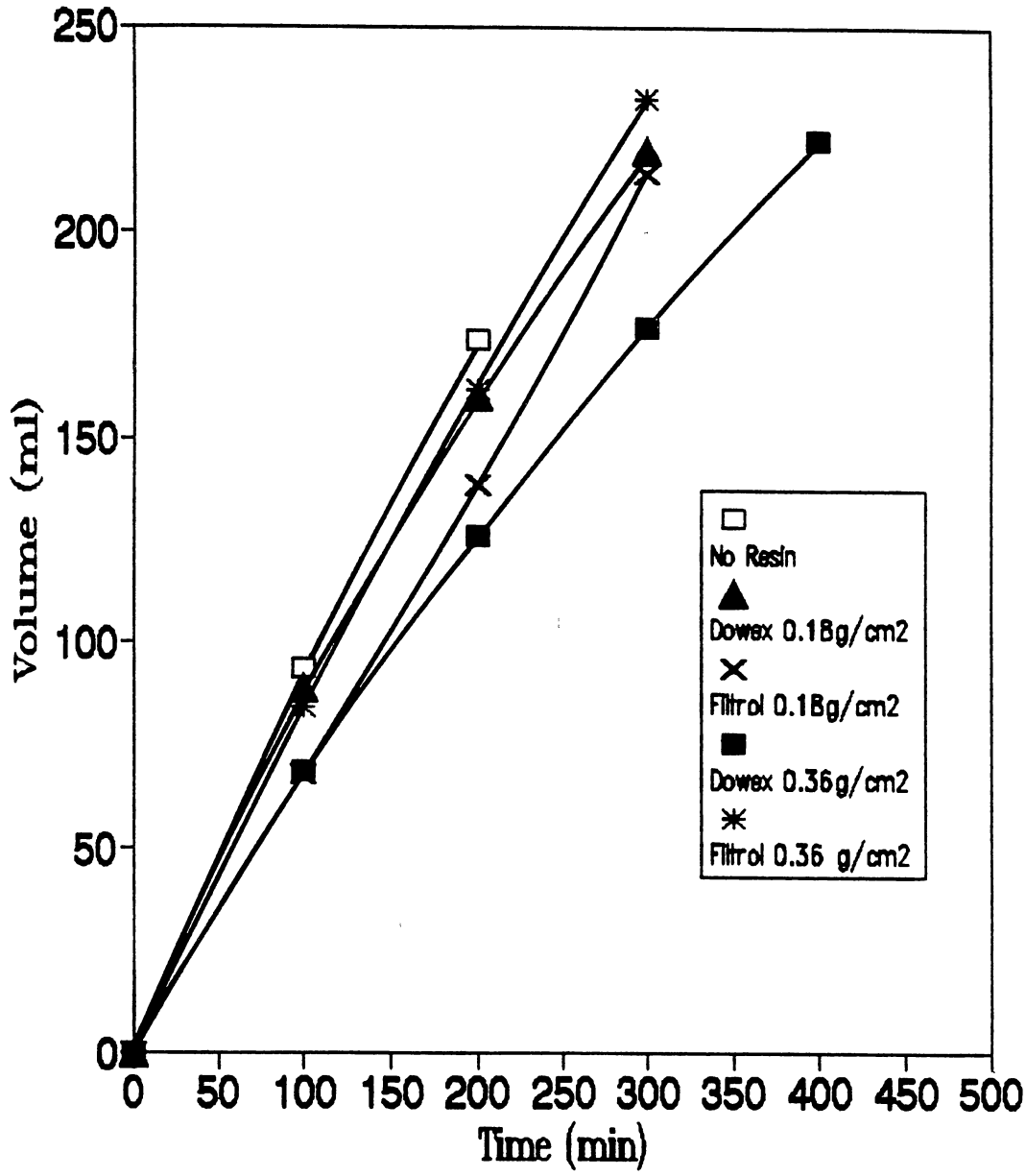

Figure 3. Comparison of Filtration for Tap Water With a Concentration of 67,000 Cells/ml Using Different Types and Amounts of Resin.

Filtrol, the effluent pH of 250 ml water was 4.1 and 3.7 respectively. The filtration rate was faster in the latter case due to lower pH. Comparing filtration using different types and amounts of resins, we find that filtration is slowest using 0.36 g/sq cm Dowex resin and fastest using 0.36 g/sq cm Filtrol or 0.18 g/sq cm Dowex resin.

For water having 670,000 cells/ml, the filtration rate is marginally faster using 0.36 g/sq cm Filtrol (Figure 4). Though the pH using 0.18 and 0.36 g/sq cm of Dowex resin is 2.7 and 2.4 respectively, the filtration rate is faster using 0.18 g/sq cm, which is nearly the same as the filtration without resin. 0.18 and 0.36 g/sq cm of Filtrol gave a pH of 4.0 and 3.8 respectively. Filtration using 0.36 g/sq cm of Filtrol is substantially faster compared to 0.18 g/sq cm.

Figure 5 shows for concentration of 6,700,000 cells/ml water, the filtration rate is drastically improved by reducing the pH of water. The filtration rate is the fastest using 0.36 g/sq cm of Filtrol and 0.18 g/sq cm of Dowex resin, these give pH of 3.8 and 2.5 respectively.

For filtration without using resin, the rate decreases with increasing cell concentration in the influent water (Figure 6). The difference in filtration rate is not high up to concentrations of 670,000 cells/ml, however the rate drops substantially at 6,700,000 cells/ml. Using 0.18 g/sq cm Dowex resin, the effluent pH was around 2.5. From Figure 7 little difference in the filtration rate of uncontaminated water and water of cell concentrations up to 670,000 cells/ml is observed. Figures 8 and 9 show a

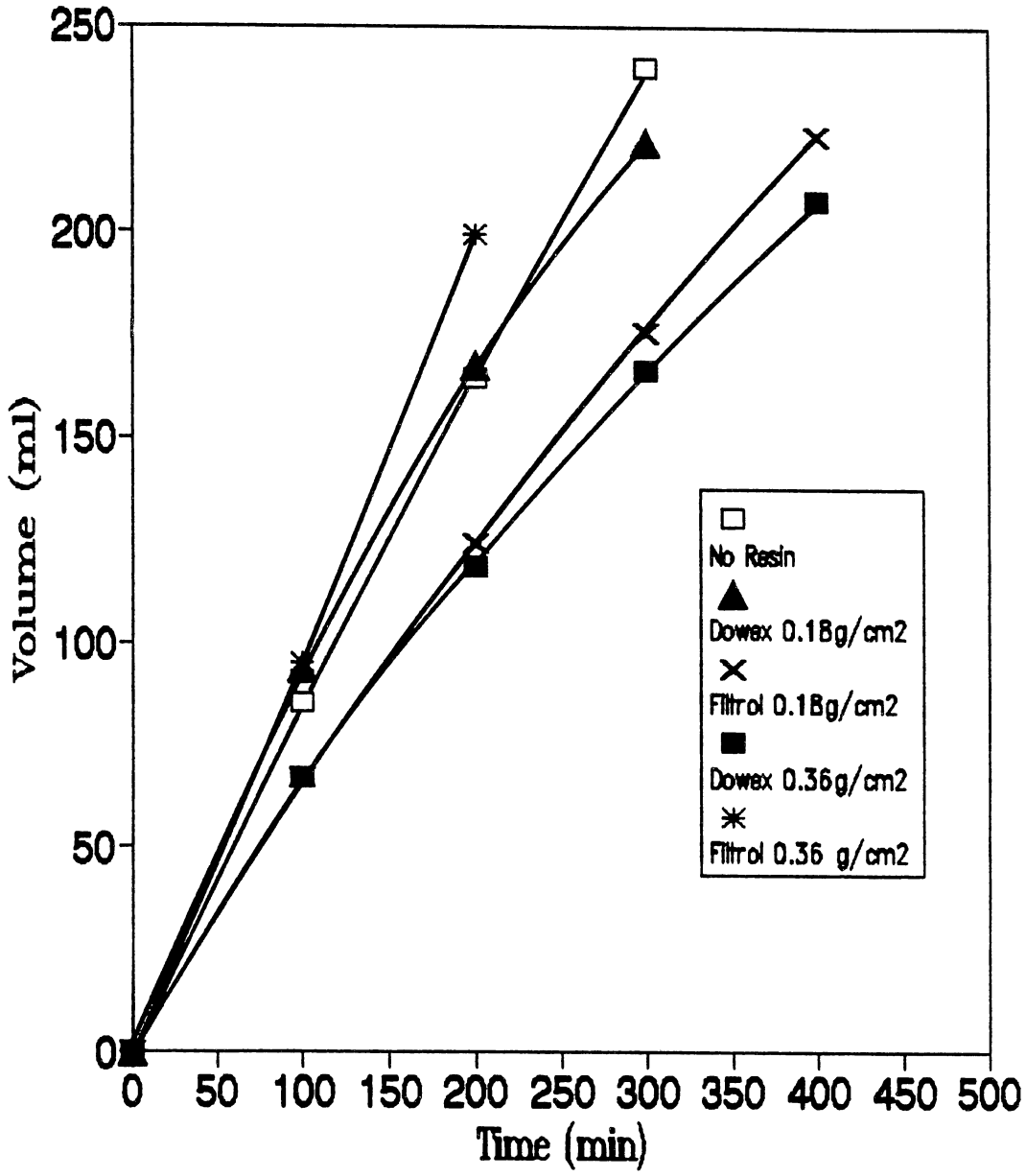

Figure 4. Comparison of Filtration for Tap Water With a Concentration of 670,000 Cells/ml Using Different Types and Amounts of Resin.

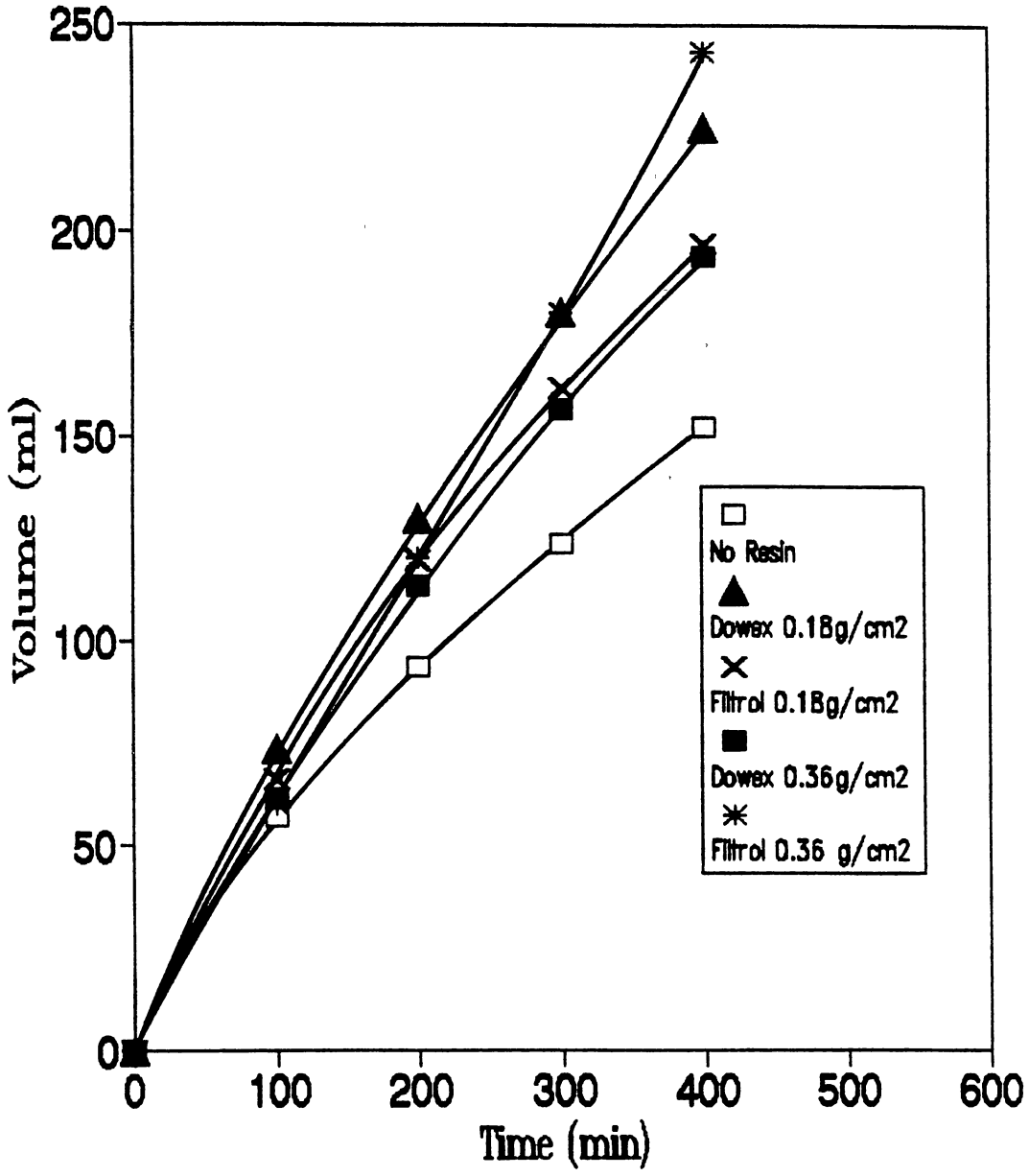

Figure 5. Comparison of Filtration for Tap Water With a Concentration of 6,700,000 Cells/ml Using Different Types and Amounts of Resin.

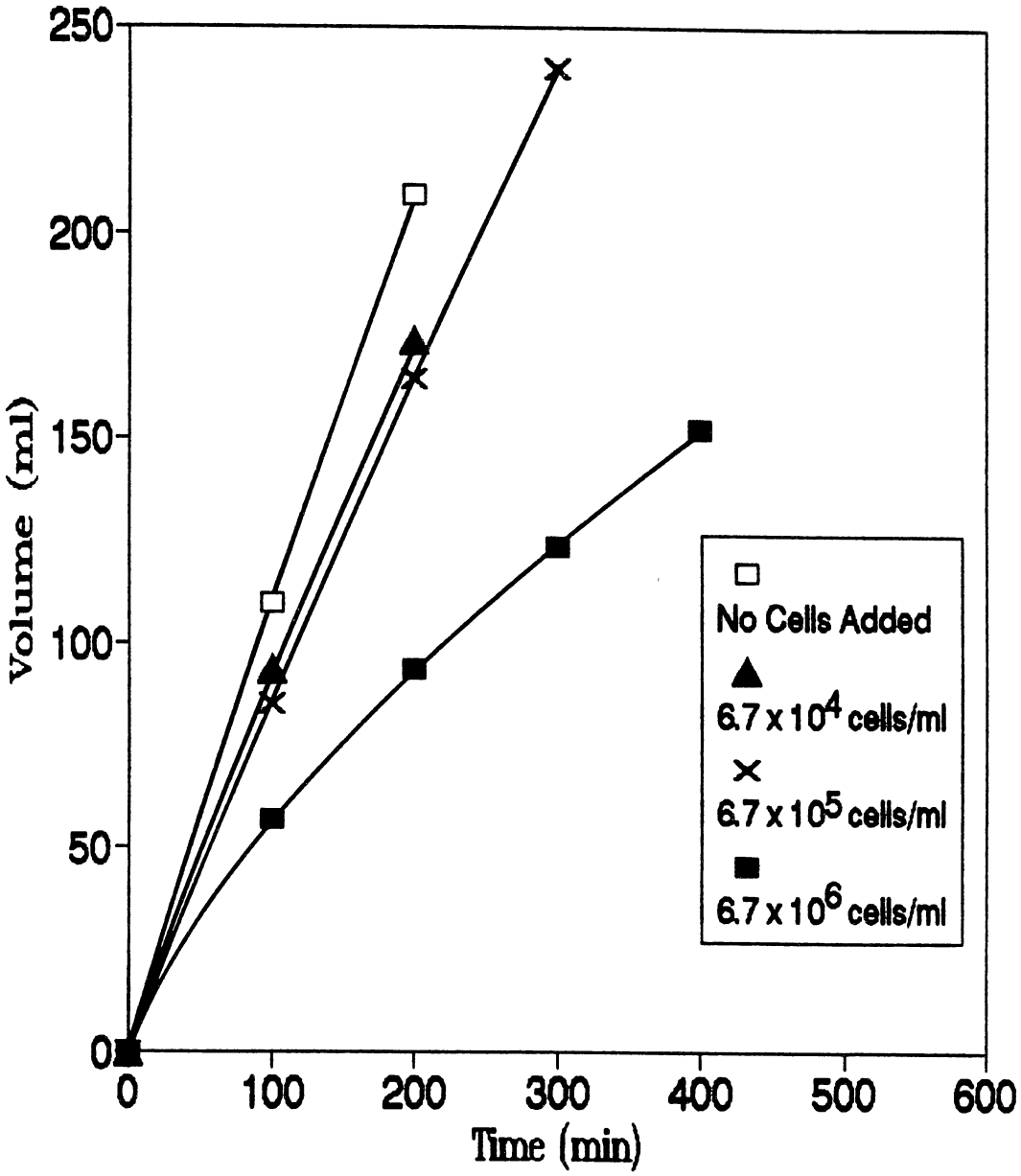

Figure 6. Comparison of Filtration Without Using Resin for Tap Water With Different CellConcentrations.

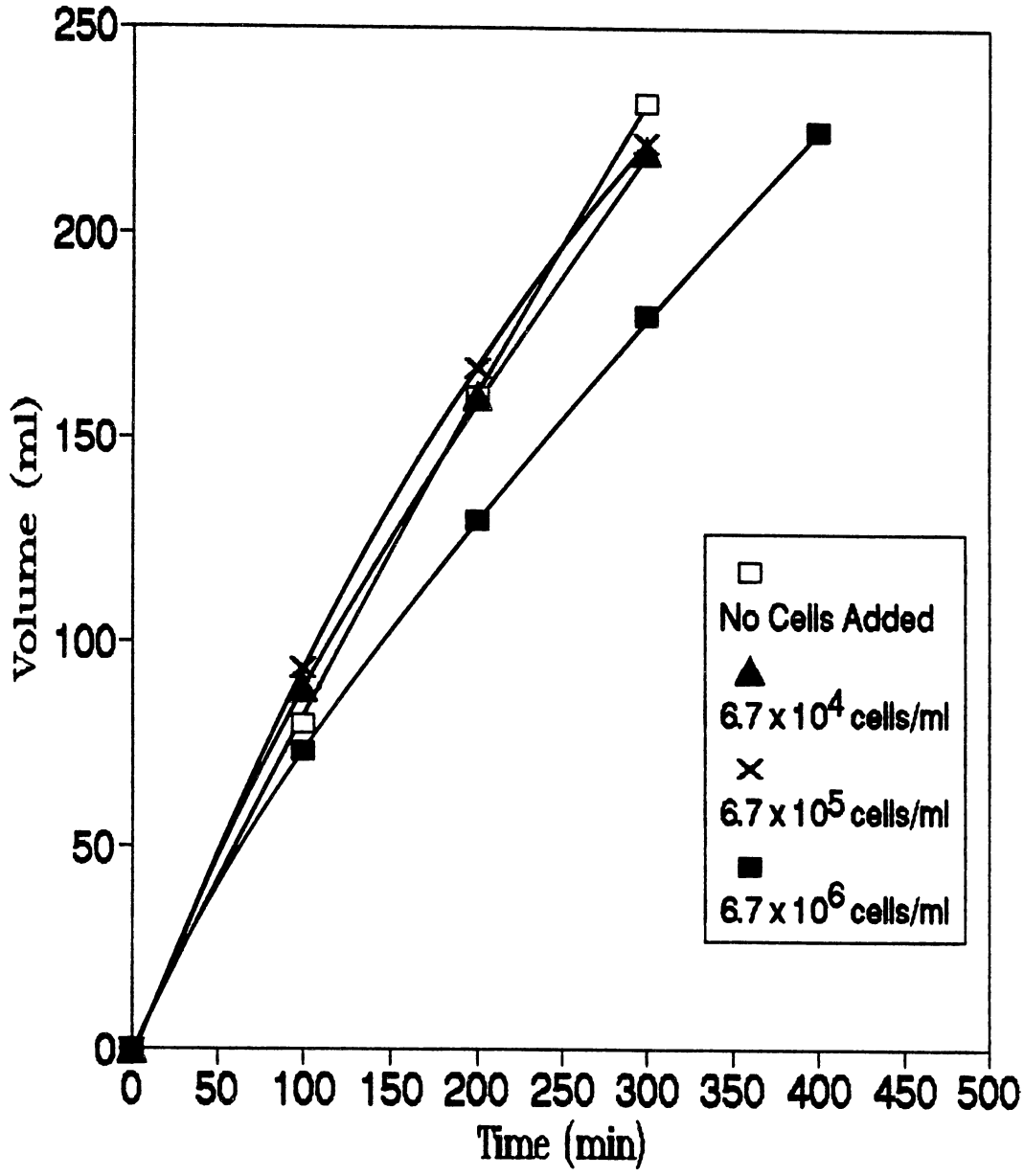

Figure 7. Comparison of Filtration Using 0.18 g/sq cm Dowex Resin for Tap Water With Different Cell Concentrations.

gradual decrease in filtration rate with increasing cell concentrations in the influent water. In Figure 10, although the filtration rate gradually decreased with increasing cell concentration, the rate was unusually high for a concentration of 670,000 cells/ml using 0.36 g/sq cm of Filtrol.

No cells were detected in the filtered water with influent concentrations of 67,000 and 670,000 cells/ml. For influent concentration of 6,700,000 cells/ml, filtration using 0.18 g/sq cm Dowex resin, 0.36 g/sq cm Dowex resin, and 0.36 g/sq cm Filtrol showed no cells in the filtered water. Without using resin for this cell concentration, the filtered water had 400 cells/ml concentration. The filtered water had 90 cells/ml concentration when 0.18 g/sq cm Filtrol was used.

Table III lists the experimental conditions and effluent properties using lake water. The lake water had 3.76 g of particulate matter per liter and a pH 7.2. Lake water had 100 cells of Escherichia coli and other microorganisms per ml of water. Table IV lists the volume collected with time for these experiments. Plots were made for lake water using different types and amounts of resins.

Figure 11 shows that there is no improvement in the filtration rate for lake water using resins except in the case of 0.18 g/sq cm Dowex resin. The filtered water showed no cells on examination.

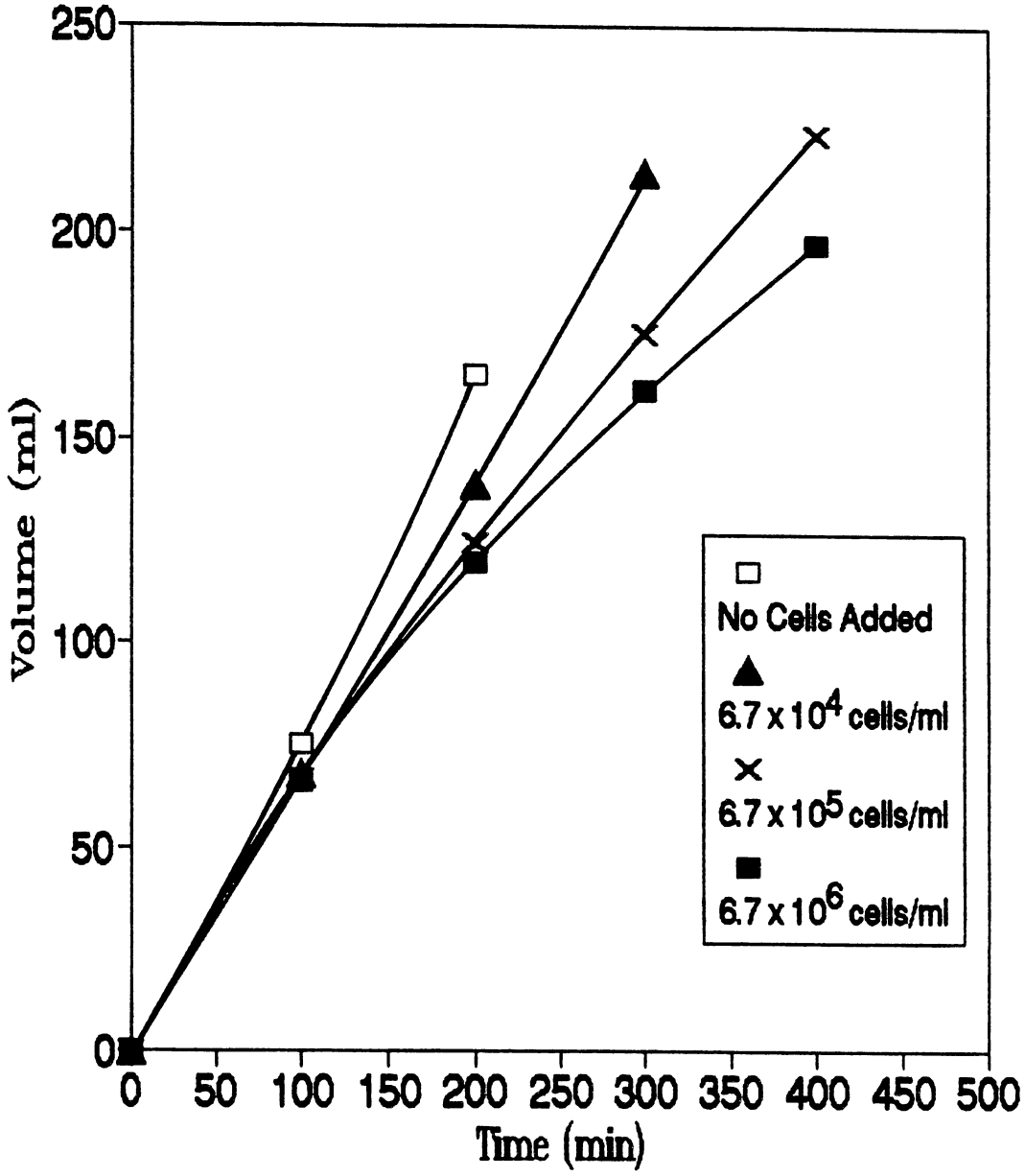

Figure 8. Comparison of Filtration Using 0.18 g/sq cm Filtrol for Tap Water With Different Cell Concentrations.

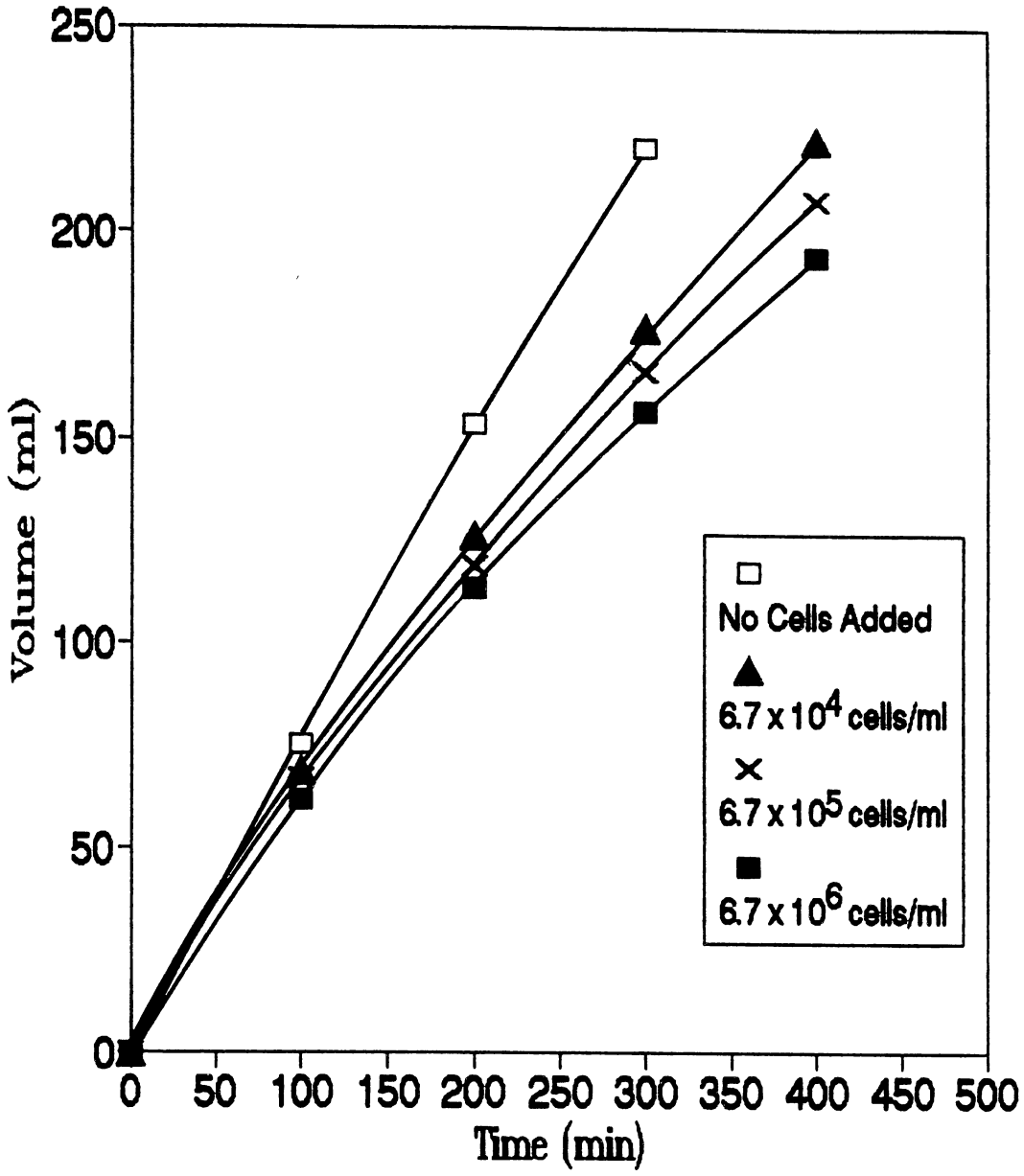

Figure 9. Comparison of Filtration Using 0.36 g/sq cm Dowex Resin for Tap Water With Different Cell Concentrations.

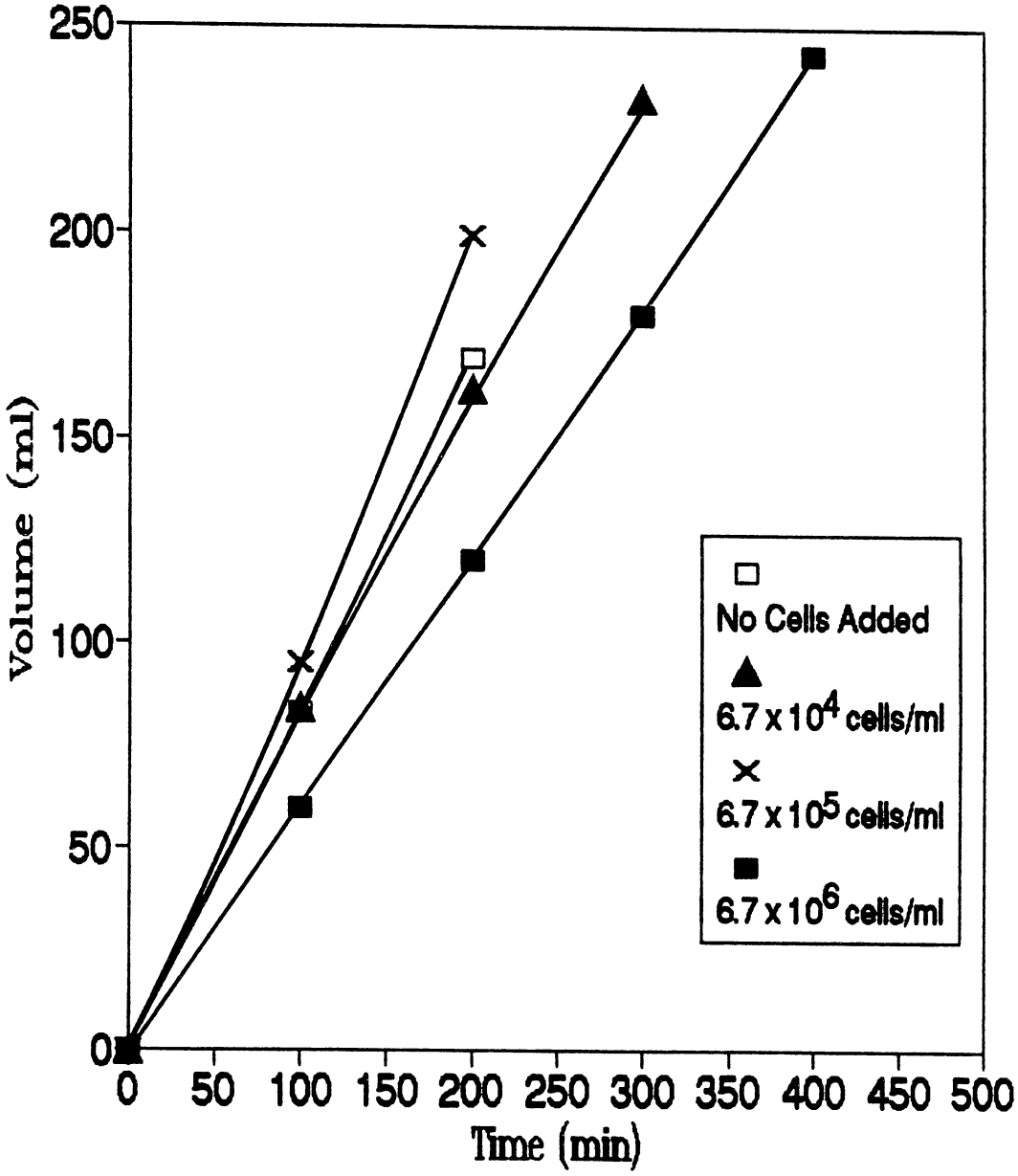

Figure 10. Comparsion of Filtration Using 0.36 g/sq cm Filtrol for Tap Water With Different Cell Concentrations.

TABLE III

SUMMARY OF CONDITIONS AND EFFULENT PROPERTIES ON FILTRATION STUDY OF LAKE WATER

Exp	Type of Resin	Amount g/sq cm	Effluent pH	Effluent cells/ml
21	None	0.00	7.5	0
22	Dowex	0.18	3.7	0
23	Filtrol	0.18	6.5	0
24	Dowex	0.36	3.2	0
25	Filtrol	0.36	4.0	0

TABLE IV

VOLUME COLLECTED WITH TIME FOR CONDITIONS IN TABLE III

Exp	Time (min) 0	100	200	300	400
	Volume Collected (ml)				
21	0	48.0	80.0	103.0	124.0
22	0	49.0	80.0	104.0	127.0
23	0	47.0	75.0	100.0	120.0
24	0	42.0	66.0	85.0	104.0
25	0	46.0	74.0	98.0	118.0

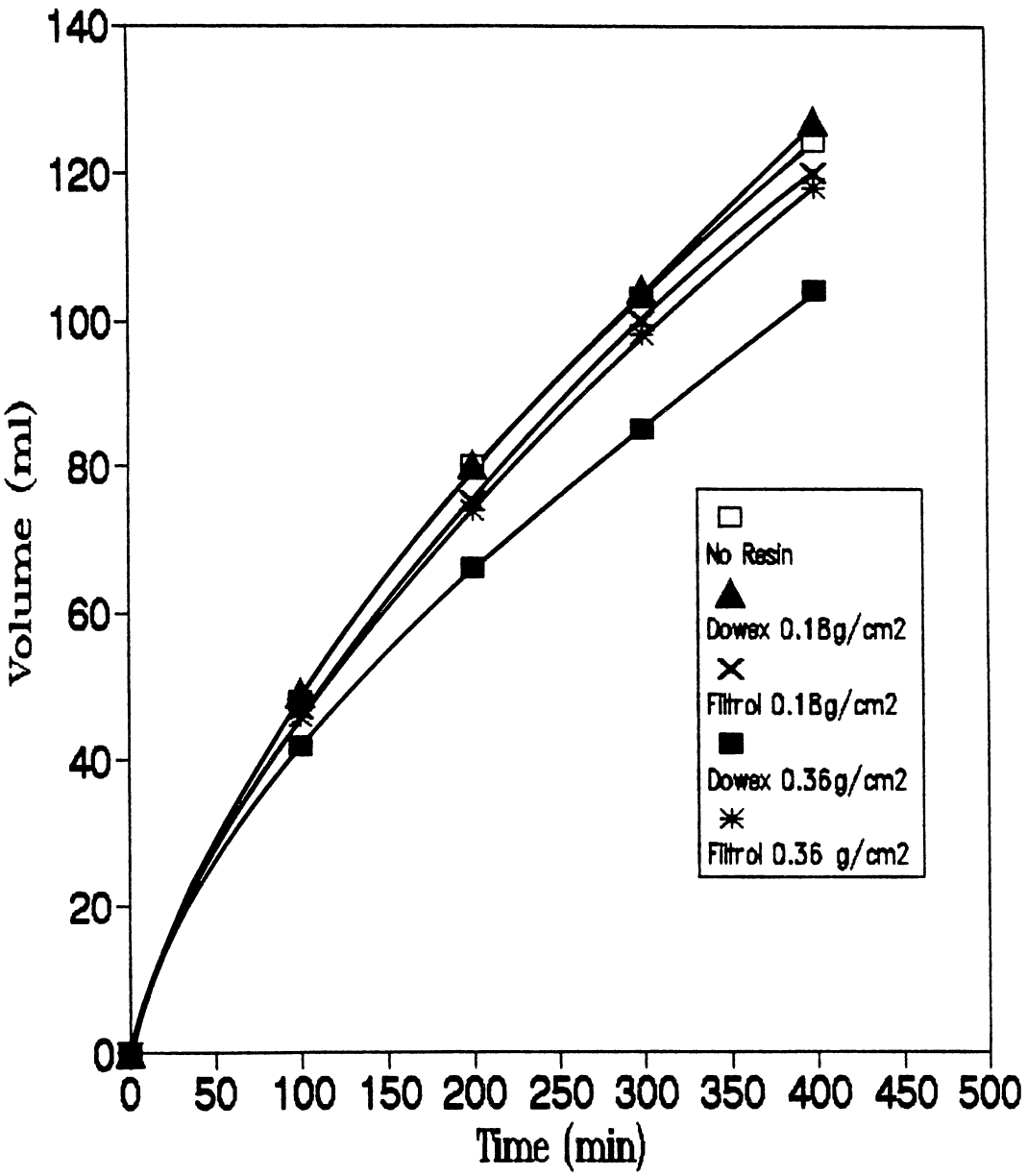

Figure 11. Comparsion of Filtration for Lake Water Using Different Types and Amounts of Resin.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This work involved the measurement of water filtration rate and microbial removal efficiency of 0.2 micron membrane filters using cation-exchange resins. In light of the experimental results, the following conclusions can be drawn:

1. For elimination of bacterial contamination of water, 0.2 micron membrane filters are effective. At very high cell concentrations, even though the filtered water had few microorganisms, the efficiency is high.
2. The presence of cation-exchange resins did not improve the filtration rate at lower cell concentrations, and instead offered resistance to flow.
3. At high concentrations, for example 6,700,000 cells/ml, the reduction in pH using cation-exchange resins improved the filtration rate.
4. Experiments with Filtrol showed that there is a substantial improvement in the filtration rate when the pH is reduced from 4.1 to 3.8.
5. At high cell concentrations there is no further improvement in filtration rate when the pH is reduced from around 3.7 to 2.5.
6. The presence of cation-exchange resin on the filter did not improve the filtration rate of lake water.

7. For lake water 0.2 micron membrane filters did not yield good filtration rates and the pores clogged faster.

From the above experimental results the following recommendations are made for filter use.

1. For water with very high cell concentrations, cation-exchange resins which give a pH of 3.7 can be used with 0.2 micron to effectively remove bacterial contamination.
2. When strong cation-exchange resins are used with filters for bacterial elimination, coating of the resin is recommended. Coating the resin using a suitable method controls the pH drop and maintains it at a desired level and also, the additional capacity of the resin can be used to process large volumes.
3. When the cell concentration is not very high, filtration by 0.2 micron membrane filter without resin is recommended.
4. For highly turbid water, if 0.2 micron filters are used it is recommended that the water should be initially treated for removing turbidity. By pretreating water for turbidity, the life of the filter can be extended.

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APPENDIX

EXPERIMENTAL DATA

EXPERIMENT 1

FEED CONCENTRATION : NO CONTAMINATION

RESIN : NONE

EFFLUENT : pH 7.2

Volume (ml)	Time Total (min)
0	0.00
10	10.08
20	18.42
30	28.18
40	38.00
50	48.43
60	59.52
70	68.38
80	77.37
90	86.87
100	91.32
110	106.00
120	114.30
130	123.98
140	133.75
150	143.58
160	152.75
170	161.97
180	170.58
190	180.35
200	191.25
210	201.03
220	211.03
230	221.37
240	232.00
250	241.00

EXPERIMENT 2

FEED CONCENTRATION : 67,000 CELLS/ML

RESIN : NONE

EFFLUENT : pH 7.2 ; NO CELLS DETECTED

Volume (ml)	Time Total (min)
0	0.00
10	12.75
20	22.17
30	33.83
40	46.17
50	56.17
60	66.33
70	77.00
80	88.00
90	98.00
100	108.00
110	119.00
120	140.00
130	157.00
140	166.00
150	174.00
160	186.83
170	197.00
180	208.00
190	218.00
200	231.00
210	242.00
220	253.00
230	264.00
240	277.00
250	289.00

EXPERIMENT 3

FEED CONCENTRATION : 670,000 CELLS/ML

RESIN : NONE

EFFLUENT : pH 7.2 ; NO CELLS DETECTED

Volume (ml)	Time Total (min)
0	0.00
10	12.00
20	25.00
30	36.50
40	48.00
50	59.00
60	71.00
70	85.00
80	97.75
90	109.00
100	119.50
110	131.00
120	144.75
130	157.58
140	168.33
150	181.00
160	194.67
170	205.83
180	217.58
190	231.75
200	245.00
210	258.00
220	270.00
230	283.25
240	297.00
250	310.00

EXPERIMENT 4

FEED CONCENTRATION : 6,700,000 CELLS/ML

RESIN : NONE

EFFLUENT : pH 7.2 ; 400 CELLS/ML

Volume (ml)	Time Total (min)
0	0.00
10	13.30
20	29.50
30	47.00
40	65.00
50	87.00
60	108.00
70	133.33
80	162.42
90	189.67
100	218.00
110	254.00
120	290.00
130	330.00
140	362.00
150	397.00
160	442.00
170	482.00
180	527.00
190	575.00
200	622.00
210	668.00
220	720.00
230	779.00
240	840.00
250	900.00

EXPERIMENT 5

FEED CONCENTRATION : NO CONTAMINATION

RESIN : 0.18 G/SQ CM DOWEX RESIN

EFFLUENT : pH 2.4

Volume (ml)	Time Total (min)
0	0.00
10	12.25
20	25.25
30	38.00
40	51.00
50	62.00
60	76.00
70	87.00
80	101.00
90	112.00
100	126.00
110	140.00
120	152.00
130	164.00
140	177.00
150	188.00
160	201.00
170	215.00
180	227.00
190	240.00
200	253.00
210	267.00
220	278.25
230	293.00
240	307.00
250	321.00

EXPERIMENT 6

FEED CONCENTRATION : 67,000 CELLS/ML

RESIN : 0.18 G/SQ CM DOWEX RESIN

EFFLUENT : pH 2.4 ; NO CELLS DETECTED

Volume (ml)	Time Total (min)
0	0.00
10	14.10
20	24.20
30	33.55
40	43.22
50	54.98
60	65.00
70	76.75
80	89.00
90	99.00
100	113.67
110	126.00
120	140.67
130	152.75
140	167.75
150	182.00
160	197.00
170	215.00
180	234.00
190	249.00
200	263.75
210	280.00
220	296.00
230	312.83
240	329.00
250	347.00

EXPERIMENT 7

FEED CONCENTRATION : 670,000 CELLS/ML

RESIN : 0.18 G/SQ CM DOWEX RESIN

EFFLUENT : pH 2.7 ; NO CELLS DETECTED

Volume (ml)	Time Total (min)
0	0.00
10	10.75
20	18.48
30	29.17
40	39.50
50	50.00
60	60.48
70	71.62
80	83.35
90	95.80
100	107.43
110	120.00
120	133.88
130	147.67
140	161.00
150	177.00
160	191.50
170	208.00
180	224.00
190	240.00
200	258.00
210	275.75
220	296.00
230	313.00
240	334.08
250	355.00

EXPERIMENT 8

FEED CONCENTRATION : 6,700,000 CELLS/ML

RESIN : 0.18 G/SQ CM DOWEX RESIN

EFFLUENT : pH 2.5 ; NO CELLS DETECTED

Volume (ml)	Time Total (min)
0	0.00
10	13.08
20	26.17
30	32.33
40	52.17
50	65.75
60	80.42
70	95.33
80	109.75
90	125.67
100	142.00
110	160.00
120	178.88
130	195.50
140	217.00
150	238.00
160	259.50
170	277.50
180	298.50
190	316.50
200	339.00
210	360.75
220	384.00
230	409.00
240	433.08
250	460.00

EXPERIMENT 9

FEED CONCENTRATION : NO CONTAMINATION

RESIN : 0.18 G/SQ CM FILTROL

EFFLUENT : pH 4.0

Volume (ml)	Time Total (min)
0	0.00
10	15.00
20	29.67
30	41.92
40	56.58
50	71.50
60	83.00
70	95.42
80	106.83
90	118.08
100	129.67
110	140.67
120	152.17
130	162.75
140	172.87
150	187.17
160	195.75
170	206.33
180	216.33
190	225.50
200	236.67
210	246.67
220	256.42
230	266.08
240	275.00
250	286.00

EXPERIMENT 10

FEED CONCENTRATION : 67,000 CELLS/ML

RESIN : 0.18 G/SQ CM FILTROL

EFFLUENT : pH 4.1 ; NO CELLS DETECTED

Volume (ml)	Time Total (min)
0	0.00
10	18.33
20	33.00
30	46.00
40	62.00
50	78.00
60	91.00
70	106.00
80	118.00
90	129.00
100	144.00
110	157.00
120	172.50
130	185.75
140	199.50
150	215.50
160	230.50
170	242.75
180	257.00
190	270.00
200	283.33
210	297.33
220	312.50
230	325.00
240	338.50
250	353.28

EXPERIMENT 11

FEED CONCENTRATION : 670,000 CELLS/ML

RESIN : 0.18 G/SQ CM FILTROL

EFFLUENT : pH 4.0 ; NO CELLS DETECTED

Volume (ml)	Time Total (min)
0	0.00
10	16.27
20	31.90
30	44.05
40	59.78
50	74.65
60	90.05
70	102.50
80	119.25
90	137.00
100	154.33
110	170.00
120	190.00
130	209.00
140	229.50
150	247.50
160	266.42
170	286.50
180	310.00
190	327.67
200	350.58
210	370.33
220	390.83
230	416.30
240	435.00
250	456.42

EXPERIMENT 12

FEED CONCENTRATION : 6,700,000 CELLS/ML

RESIN : 0.18 G/SQ CM FILTROL

EFFLUENT : pH 4.1 ; 90 CELLS/ML

Volume (ml)	Time Total (min)
0	0.00
10	11.25
20	22.83
30	39.33
40	55.50
50	72.67
60	93.83
70	105.75
80	120.00
90	139.00
100	159.00
110	180.00
120	201.00
130	224.00
140	247.00
150	271.00
160	296.00
170	318.50
180	345.50
190	380.00
200	410.00
210	445.50
220	478.00
230	514.00
240	540.00
250	575.00

EXPERIMENT 13

FEED CONCENTRATION : NO CONTAMINATION

RESIN : 0.36 G/SQ CM DOWEX RESIN

EFFLUENT : pH 2.4

Volume (ml)	Time Total (min)
0	0.00
10	14.00
20	29.83
30	42.80
40	49.83
50	66.80
60	80.67
70	92.50
80	105.42
90	115.83
100	131.00
110	143.50
120	156.50
130	170.00
140	183.00
150	196.00
160	211.00
170	225.00
180	238.00
190	252.00
200	269.00
210	283.00
220	300.00
230	314.00
240	331.50
250	347.75

EXPERIMENT 14

FEED CONCENTRATION : 67,000 CELLS/ML

RESIN : 0.36 G/SQ CM DOWEX RESIN

EFFLUENT : pH 2.4 ; NO CELLS DETECTED

Volume (ml)	Time Total (min)
0	0.00
10	13.00
20	26.00
30	40.50
40	54.00
50	71.33
60	86.00
70	100.00
80	117.00
90	135.00
100	153.50
110	169.00
120	187.50
130	204.00
140	223.50
150	242.00
160	263.00
170	284.50
180	304.50
190	326.50
200	350.00
210	373.00
220	393.00
230	417.00
240	441.00
250	468.00

EXPERIMENT 15

FEED CONCENTRATION : 670,000 CELLS/ML

RESIN : 0.36 G/SQ CM DOWEX RESIN

EFFLUENT : pH 2.4 ; NO CELLS DETECTED

Volume (ml)	Time Total (min)
0	0.00
10	13.00
20	26.00
30	41.50
40	58.00
50	72.75
60	93.47
70	108.00
80	128.00
90	145.00
100	162.50
110	182.00
120	203.50
130	222.50
140	244.00
150	265.50
160	285.50
170	306.00
180	333.00
190	356.00
200	384.50
210	407.50
220	430.17
230	457.50
240	480.00
250	502.00

EXPERIMENT 16

FEED CONCENTRATION : 6,700,000 CELLS/ML

RESIN : 0.36 G/SQ CM DOWEX RESIN

EFFLUENT : pH 2.4 ; NO CELLS DETECTED

Volume (ml)	Time Total (min)
0	0.00
10	13.67
20	26.00
30	40.00
40	59.50
50	77.00
60	94.42
70	112.33
80	132.18
90	151.00
100	172.00
110	193.67
120	213.42
130	234.50
140	260.75
150	285.50
160	311.00
170	336.50
180	362.50
190	390.00
200	414.50
210	442.50
220	472.50
230	502.00
240	529.00
250	557.00

EXPERIMENT 17

FEED CONCENTRATION : NO CONTAMINATION

RESIN : 0.36 G/SQ CM FILTROL

EFFLUENT : pH 4.2

Volume (ml)	Time Total (min)
0	0.00
10	13.00
20	25.50
30	37.00
40	49.00
50	62.00
60	72.75
70	84.75
80	96.67
90	109.33
100	120.00
110	133.00
120	144.50
130	154.50
140	167.50
150	177.75
160	188.67
170	200.00
180	211.83
190	222.75
200	232.33
210	245.75
220	257.00
230	268.33
240	280.25
250	293.00

EXPERIMENT 18

FEED CONCENTRATION : 67,000 CELLS/ML

RESIN : 0.36 G/SQ CM FILTROL

EFFLUENT : pH 3.7 ; NO CELLS DETECTED

Volume (ml)	Time Total (min)
0	0.00
10	13.75
20	24.00
30	34.75
40	46.50
50	58.00
60	70.00
70	82.75
80	95.33
90	107.00
100	120.00
110	133.00
120	146.00
130	157.75
140	174.00
150	187.33
160	201.00
170	214.00
180	226.75
190	240.00
200	253.50
210	268.00
220	282.00
230	295.33
240	308.25
250	323.00

EXPERIMENT 19

FEED CONCENTRATION : 670,000 CELLS/ML

RESIN : 0.36 G/SQ CM FILTROL

EFFLUENT : pH 3.8 ; NO CELLS DETECTED

Volume (ml)	Time Total (min)
0	0.00
10	12.50
20	25.17
30	37.00
40	47.50
50	57.00
60	66.58
70	75.42
80	85.00
90	95.00
100	104.50
110	114.33
120	124.67
130	132.75
140	143.50
150	152.00
160	161.50
170	172.30
180	181.00
190	190.75
200	201.00
210	212.00
220	221.00
230	231.83
240	242.25
250	254.00

EXPERIMENT 20

FEED CONCENTRATION : 6,700,000 CELLS/ML

RESIN : 0.36 G/SQ CM FILTROL

EFFLUENT : pH 3.8 ; NO CELLS DETECTED

Volume (ml)	Time Total (min)
0	0.00
10	16.42
20	32.00
30	48.00
40	68.50
50	85.42
60	99.50
70	117.75
80	134.33
90	151.00
100	167.50
110	183.05
120	203.00
130	217.50
140	232.67
150	250.00
160	266.75
170	282.33
180	298.00
190	315.00
200	333.00
210	351.33
220	365.00
230	380.00
240	394.00
250	410.00

EXPERIMENT 21

FEED : LAKE WATER

RESIN : NONE

EFFLUENT : pH 7.5 ; NO CELLS DETECTED

Time (min)	Volume (ml)
0	0.0
100	48.0
200	80.0
300	103.0
400	124.0

EXPERIMENT 22

FEED : LAKE WATER

RESIN : 0.18 G/SQ CM DOWEX RESIN

EFFLUENT : pH 3.7 ; NO CELLS DETECTED

Time (min)	Volume (ml)
0	0.0
100	49.0
200	80.0
300	104.0
400	127.0

EXPERIMENT 23

FEED : LAKE WATER

RESIN : 0.18 G/SQ CM FILTROL

EFFLUENT : pH 6.5 ; NO CELLS DETECTED

Time (min)	Volume (ml)
0	0.0
100	47.0
200	75.0
300	100.0
400	120.0

EXPERIMENT 24

FEED : LAKE WATER

RESIN : 0.36 G/SQ CM DOWEX RESIN

EFFLUENT : pH 3.2 ; NO CELLS DETECTED

Time (min)	Volume (ml)
0	0.0
100	42.0
200	66.0
300	85.0
400	104.0

EXPERIMENT 25

FEED : LAKE WATER

RESIN : 0.36 G/SQ CM FILTROL

EFFLUENT : pH 4.0 ; NO CELLS DETECTED

Time (min)	Volume (ml)
0	0.0
100	46.0
200	74.0
300	98.0
400	118.0

VITA

SREEKANTH RANGI

Candidate for the Degree of

Master of Science

Thesis: MICROBIAL FILTRATION BY 0.2 MICRON MEMBRANE FILTERS IN COMBINATION WITH CATION-EXCHANGE RESINS

Major Field: Chemical Engineering

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