QUALITY CONTROL OF
REUSED POTATO SLICE RINSE WATER

A Thesis

Submitted to the Faculty

of

Graduate Studies

The University of Manitoba

by

Sik-Teng, Lim

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

Department of Food Science

May 1978

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SIK-TENG LIM

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TO MY BROTHERS AND SISTERS

ACKNOWLEDGEMENT

The author wishes to express his sincere gratitude to Dr. R. A. Gallop, Head of the Department of Food Science, for his valuable advice and support in this research project. He also wishes to acknowledge with deep appreciation the time and unfailing assistance offered by Mr. A. W. Hydamaka throughout the course of this project and the write-up of this thesis. Thanks also go to Dr. G. Blank for his numerous suggestions and discussions.

Technical assistance from Messrs. T. S. Sohal and P. Stephen is appreciated.

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Lim, Sik-Teng, M.Sc., The University of Manitoba, May, 1978.

Quality Control of Reused Potato Slice Rinse Water. Major Professor: Dr. R. A. Gallop.

Powdered activated carbon (PAC) was shown to remove several selected microorganisms from both buffered phosphate water and raw potato slice rinse water. Variations in the removal of the individual test organisms in buffered phosphate water was observed. A few species of the cocci were noted to be more readily adsorbed/filtered than some rod shaped organisms. Studies also appeared to indicate preferential removal of some bacteria. Yeasts and molds were found to be effectively removed through the process of filtration. Variations in the removal of the test organisms were believed to be due to an intricate interplay of a number of cellular factors. However, individual effects of each factor could not be isolated.

PAC was observed to be highly efficient in the elimination of turbidity, color and odor of the potato slice rinse water. Removal of microorganisms from the water appeared to be affected by the presence of the organic components in the rinse water. However, the effect of effluent strength was not significant.

Among the various possible factors, the initial microbial load in the rinse water was found to be the determinant in the optimal carbon dosage required. A dosage of 5 g/l was deemed optimal in purifying an effluent with an usual bacterial load of

10^3 organisms per ml. Split or multiple applications of PAC proved to be more efficient than single application in the treatment of effluent with high bacterial level in excess of 10^5 organisms per ml.

A treatment frequency of ten reuse cycles per PAC application was recommended to avoid excessive build up of microbial load which would otherwise impair the microbiological quality of the reused water.

Treated effluents were found to be capable of sustaining microbial growth for more than a week. Deterioration in the keeping quality of the effluents upon storage was noted 8 - 12 hours after carbon treatments at levels of 0.01 to 0.5 g/100 ml, as indicated by the appearance of turbidity and odor. The development of turbidity in the stored effluents was found to be caused by bacterial activities. It was further suggested to be due to the discharge of cellular content of the dead cells. Turbidity development was observed to be time-dependent, and to follow a parallel trend with bacterial growth. Storage at refrigeration temperature (4 °C) of the effluents was demonstrated to be effective in controlling the occurrance of turbidity from 8 to 32 hours, depending on the initial PAC dosages. Sterilization by millipore filtration and acidification of the effluents to pH 4.5 proved effective in retaining the effluent keeping quality for a 3 day period.

Intermittent batch treatments with PAC at a minimal dosage of 0.01 g/100 ml was shown to be effective in eliminating

the odor, turbidity and microbial cell density in the effluents. High dosages of PAC were not feasible in terms of total carbon usage. With dosages from 0.01 to 0.5 g/100 ml, six to nine carbon treatments were found to be necessary to maintain clarity of the effluent for a 3 day period.

However, it was noted that turbidity was not an appropriate index for microbiological quality of the effluent. A net increase in viable bacterial count in the effluents was observed despite complete elimination of turbidity and odor by intermittent carbon re-treatments at points of visually noticeable turbidity.

INTRODUCTION

INTRODUCTION

The rational concepts of water reuse when applied to proper engineering terms, will alleviate and eventually eliminate the severity of the problems faced by the municipalities, the supplier of quality raw potable water and its consumers, in particular, the food processing industry. The two major problems with urgency for solutions are water supply and effluent discharge, which occur at each end of a linear processing line.

Surface waters are subject to ever increasing withdrawals to supply a growing population, industry and agriculture. It is generally recognized that our relatively fixed natural supply will be inadequate to meet the growing demands. Moreover, excessive water withdrawals may have an adverse effect on the chemical quality of the supply. The waters are returned to the natural supply with increasing quantities of refractory organic wastes, bacteria, virus, algal nutrients, oxygen demand, suspended and dissolved solids. The task of furnishing safe water is expected to becomre more difficult and costly in the future because of the necessity of treating raw water of poorer quality.

The fast expanding food processing industry faces the dilemma of an increasing demand for water and its escalating cost. Food processing industries, as one of the major consumers of fresh

water in the United States, uses about 99 million gallons annually (101). It subsequently discharges tremendous wastes with probably the richest sources of organic wastes per ton of product. It has been estimated that a ton of raw potatoes when processed, can produce sewage loads equivalent to those of about 300 people (59). It is obviously an intolerable level to discharge without utilization or purification. The food industry has been known to generate water containing organic materials up to 40,000 mg/l COD. Industrial pollution accounts for 45 percent of water pollution, with 85 percent of that total attributed to the food industry (5).

The discharge of food processing effluents has thus been facing mounting regulations of increasing stringency. In the United States, the Federal Water Pollution Control Act 1972 Ammendation was passed on October 18, 1972. Under Title III the law establishes deadlines for actions to control pollution from industrial sources and more importantly, it calls for the elimination of discharge of pollutants into all waters by 1985 (43). This is known as "Zero Discharge". In Canada, the regulations are similar to those of the EPA, but are not quite as stringent for a variety of reasons. The Environmental Protection Service has currently been promulgating effluent guidelines for the various food sectors such as the meat, dairy, fruit and vegetable, and potato processing industries. While most of these guidelines are awaiting to be enacted in 1978, some are now available, for example, guidelines for the meat

and poultry products (40).

These two problems of water supply and effluent discharge have created considerable complications in the setting up of new plants and threatened the viability of many existing plants. According to a quarterly report on economic dislocation resulting from environmental control, 75 plants in the United States have been closed during the last five years (January 1971 through September 1975) as a result of such control, with a loss of 15,700 jobs (92).

On pollution control and energy conservation, the president of the United States calls for vigorous enforcement of the pollution control laws and appeals to the industries "to make better use of recycled materials, to better manage our solid wastes, and to realize the fuel savings which recycling offers" (21). The rationals of recycling have been demonstrated by R. A. Gallop in the "total system" approach which he elaborated at the Fourth National Symposium on Food Processing Wastes and was subsequently accepted as the most ideal approach to waste management. The approach involves a closed-loop system where water could be recycled with in-plant treatment and the "wastes" become important byproducts to the processing operations. Indeed, in establishing its guidelines for effluent discharge, Environment Canada is hoping that "plants will not opt for biological treatment per se, but take a close look at in-plant controls and physical/chemical treatments in order to eventually come to an almost total recycle and re-use systems" (52). In Canada, a paper and pulp mill has successfully demonstrated the industrial reality

of the closed-loop system (19). It is encouraging to note that under the DPAT (Development and Demonstration of Pollution Abatement Technology) Programs there is a movement towards involvement with technology that will lead to byproduct recovery, water reuse, etc. While acknowledging that biological treatment will be around for a long time, Environment Canada also concedes that "in the final analysis of the overall aim of the programs is towards recycling and reuse system" (52).

Because of its versatility and enormous adsorption capacity, activated carbon has been advocated for in-plant treatments of food processing effluents in a reuse system. The use of activated carbon has been demonstrated to be the most promising of the advanced treatment methods (151). The activated carbon could be produced from solid wastes generated at the plant, and it could also be recycled after regeneration. An advanced physico-chemical system employing activated carbon offers many other advantages over conventional biological methods, as summarized by Gallop(59). The degree of purification of recycling effluents varies according to the specific use.

Understandably, standards will have to be established for the processing effluents. Bacteriological quality of recycling food processing effluents rightly deserves particular attention to prevent build up of pathogenic organisms that would cause potential health hazards. This study thus looks into the bacteriological quality of the recycling potato French fry slice rinse effluents purified by

means of powdered activated carbon. It will serve to provide background information to other bacteriological studies of various food processing effluents subject to similar advanced physico-chemical in-plant treatments.

LITERATURE REVIEW

LITERATURE REVIEW

2.1 Activated Carbon and Its Applications

2.1.1 Introduction

Activated carbon is a carbonaceous material prepared from organic substances such as wood char, bone char, coal char and coconut char (34). The process of carbonization and activation of these substances produces a highly developed porous structure with a very large adsoptive capacity. This porous structure and enormous surface area have given rise to hundreds of applications.

The earliest report on adsorption from aqueous solution dated back to 1785. The basis for the production of activated carbon, however, was established much more recently by the patents of Raphael von Ostrejko (107) in 1901. He developed the preparation of activated carbon by the action of carbon dioxide or steam on charred materials. This method was adopted for the first industrial production of activated carbon in 1911. It was used, in powdered from, primarily as a decolorizer in the manufacture of sugar. During the First World War, granular activated carbon for gas mask was started by activating wood chips with zinc chloride. To date, activated carbon has wide applications in liquid purification systems (74). Activated carbons of specific grades and qualities are being manufactured for specific separations and purifications in the food, pharmaceutical and chemical processing industries. The consumption of activated carbon is about 160 million pounds per year in the U.S. alone (97).

In Canada, the current demand of 8 million pounds per year has been estimated to increase to 15 million pounds per year by 1980 (18). Activated carbon was factored into the development of the 1983 "Best Available Technology" (BAT) guidelines by the EPA for many industrial categories in pollution control.

Powdered activated carbon has been extensively used since 1929 for purifying municipal water supplies to remove undesirable tastes and odors (135). This has led to the recent research on its applications to advanced water treatment of sewage and other wastewaters. Two methods of utilizing activated carbon are now in practice: tertiary treatment and physical-chemical treatment (135). It can be successfully used for high strength effluents. With powdered activated carbon, contact time can be reduced. However, by its physical nature, powdered activated carbon is normally limited to use in a batch-type operation.

Davis and Kaplan (33) attempted to use powdered activated carbon in a column operation without success. This failure was due to a rapid pressure drop in the column. Powdered activated carbon has been incorporated into the conventional wastewater treatment plants to enhance BOD removal. Beebe and Stevens (10) tested the operating parameters of powdered activated carbon to chemically coagulated and settled activated sludge effluent. Coehn (26) applied a two-stage countercurrent process in reducing an influent Total Organic Carbon (TOC) concentrations of 15 - 25 mg/l to 1.5 - 3.0 mg/l. Powdered activated carbon is used today as an aid to biological

treatment of wastes (2).

The advent of Advanced Wastewater Treatment (AWT) has led to new methods of regenerating powdered activated carbon. Bloom et al. (14) reported on a transport-type system which was estimated to be capable of regenerating powdered carbon at a cost as low as 1.5 cents per lb. Another method, known as the "Atomized Suspension Technique" (AST) greatly enahnces the potential use for powdered carbon in wastewater treatment (24). This process can regenerate and recover powdered carbon in about 30 seconds. A 90 percent recovery and 95 percent reactivation are attainable in this method. Economics of the AST process show a cost reduction difference of 50 to 70 percent from the cost of continuously replenishing powdered activated carbon.

2.1.2 Adsorption by Activated Carbon

Activated carbon, by virtue of its highly porous structure and enormous adsorptive surface area, can accumulate and retain a broad variety of substances. The process of adsorption is a phenomenon whereby molecules from a solution are attracted to, and held to the surface of a solid. Various theories have been offered to interpret the varied aspects of adsorption on carbon. Roles of surface tension and capillary condensation in adsorption have been investigated by various authors. "Adsorption potential", first suggested by de Saussure in 1814, was developed quantitatively by

Polanyi et al (130).

Langmuir (89, 90), proposed a model which is valid for single layer adsorption, but the mathematics is impossible when allowing for interactions of molecules. This concept, in simple terms, is that when a wandering molecule of vapor collides with a suitable unoccupied surface space, the molecule will adhere.

For multilayer adsorption, the "BET Equation" by Brunauer et al. is more appropriate (16). However, it is not generally applicable to wastewater systems because it requires the identity and concentration of the adsorbates to be known.

The American Society for Testing and Materials recommends the widely used Freundlich Equation (58) for evaluating adsorption data. The Freundlich Equation states a mathematical correlation between the quantity of substance adsorbed and the unadsorbed quantity at a uniform temperature. This is known as the "adsorption isotherm" which is necessary to characterize the adsorptive capacity of the adsorbent towards particular substances to be removed.

2.1.3 Significance of Pore Size Distribution

The pore structure of activated carbon has a great influence on both the equilibrium and rate of adsorption. Many instances in which a carbon seems unable to adsorb the full amount of adsorbates that could be theoretically accomodated are traced to a screening

action due to the pore structure.

Activated carbon usually has pores belonging to several groups, each having a certain range of the effective radii, based wholly on arbitrary choice. Dubinin (38) originated the classification of the pores into three basic groups: micropores, transitional pores and macropores according to various physically substantiated criteria. According to Dubinin, the effective radii of micropores is less than 18 to 20 Å. The size of transitional pores is in the range of effective radii from about 20 to 500 - 1000 Å. The effective radii of macropores are frequently in the range of 500 to 20,000 Å. Table 1 summarizes the characteristics of the three groups of pores discussed by Dubinin.

Activated carbon usually contains all the three groups of pores. Each group has its specific purpose in the process of adsorption on activated carbon. Micropores, because of their extremely large specific surface area and large volume, significantly determines the adsorptive capacity of a particular activated carbon. According to Dubinin (38), the porous structure of activated carbon predominantly arranged in such a way that only the macropores open out directly to the external surface of the particles, with transitional pores branch off from the macropores; and micropores, in turn, branch off from the transitional pores.

In liquid systems the activated carbon tends to have a preference not only for substances which are of higher molecular weight but also for those substances which are non-polar in nature. The

TABLE 1. PORE SIZE DISTRIBUTION

TYPE OF PORES	EFFECTIVE RADIUS A	VOLUME mg/l	SP. SURFACE m^2/g	SP. SURFACE %Total
Micropore	18 - 20	.15 - .50	100-1000	95
Transitional pores	20 - 1000	.02 - .10	200	5
Macropores	5000 - 20000	.20 - .50	0.5 - 2.0	-

forces of attraction between the carbon and adosrbing molecules are known to be greater the more similar the adsorbing molecules are in size to the pores. The most tenacious adsorption takes place when the pores are barely large enough to admit the adsorbing molecules. The smaller the pores with respect to the molecules the greater the forces of attraction. The pores cannot be so small, however, that the adsorbing molecules find it difficult to enter, or the adsorptive capacity for those molecules will be greatly reduced. It can be seen, therefore, that the pore structure of activated carbon is extremely important in determining its adsorptive properties.

There are two general types of activated carbon: gas-adsorbent carbon, which adsorbs impurities from gases or recovers valuable vapors and liquid-phase or decolorizing carbon, which removes impurities from aqueous or organic liquids and solutions, and from liquefiable substances. Figure 1 illustrates the pore size distribution of two such types of activated carbon (55). The gas-adsorbent carbon possesses predominantly the micropores while there is a more even distribution of the three types of pores in the decolorizing carbon.

There are experiences with adsorption, however, that cannot be adequately explained on the basis of pore size distribution. This leads to the hypothesis of separate surface areas with specific and selective adsorptive powers. Such evidence is based primarily on circumstantial evidence of which direct proof is not yet available. The concept is supported by studies of adsorption on plane

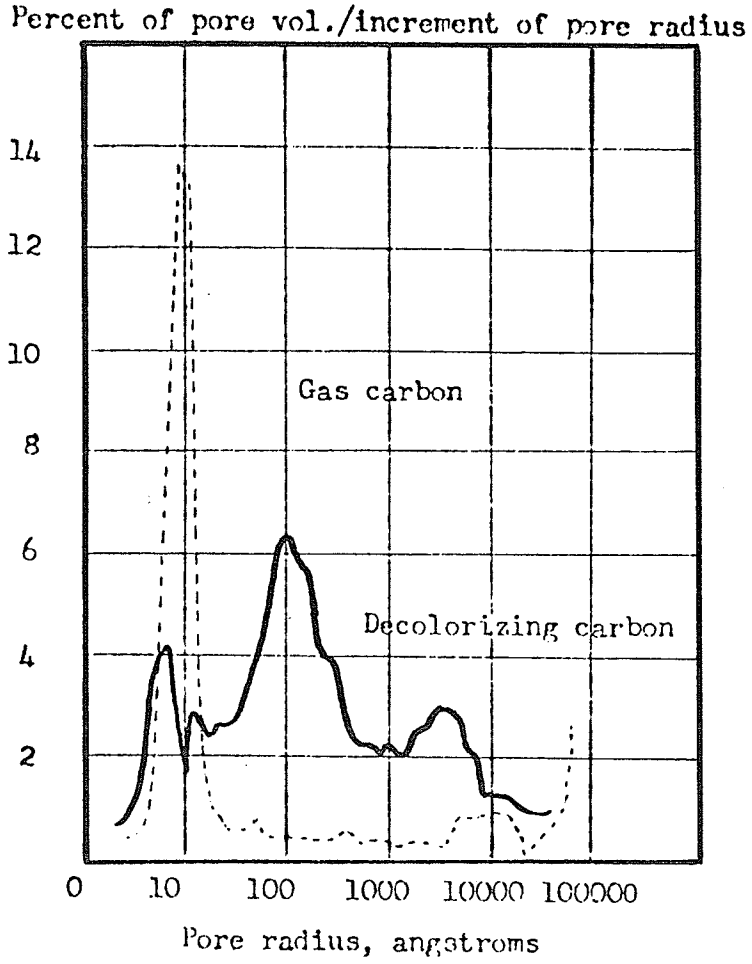


FIGURE 1 Pore Size Distribution in Gas and Decolorizing Carbons

surface (3). Workers in the field of contact catalysis developed the concept of active centers which are patches with specific adsorptive powers, resulted from the etching process of activation. This hypothesis provides convenience of describing heterogeneous adsorptive behavior in terms of space relations. Various studies (23, 156) provide evidence of the coexistence of different types of active centers.

2.1.4 Applications of Activated Carbon in Food Industries

Activated carbon was first used in the sugar industry for the removal of color and organic contaminants (73). It is also used to remove off-flavors in the soft drink industry, to remove color and odor in alcoholic beverages, and in the purification of oils, fats, gelatin, pectin, alginates, maple syrup, honey, candy, and to remove turbidity in fruit juices (74). In Canada, its utilization by the food industries has been small, accounting for only 12 percent of the total powdered form and 9 percent of the granular form of the total consumption (18).

At present the sugar industry uses the following decolorizers: bone char (on a decreasing scale), powdered activated carbon, granular charcoal and decolorizing ion-exchangers (130). Treatment with activated carbon gives the sugar solution a better optical appearance and also markedly improves its processing properties. Sawyer (125) suggested the use of adsorption of sugars on activated

carbon as an alternate method to obtain the value of the optical rotation of sugars.

In distilleries activated carbon has replaced the wood (mostly lime wood) charcoal (130). Activated carbon is used to remove off-flavors, or modify the color of wines. It also reduces the amounts of aldehydes, oils and other undesirable compounds in the raw distillate, and it will accelerate maturing.

Activated carbon is used for the same purpose in the treatment of beer. Furthermore, it is used for the purification of air, carbon dioxide and water. Carbon-treating the sparges has been demonstrated to improve the bitter taste of beer (115).

Activated carbon filters have been used for the purification and reuse of brines (56). Ralls et al. (117) and Popper et al. (114) discussed the use of carbon for the adsorption of phenolics in the brines. The feasibility of activated carbon renovation of maraschino cherry brine effluent was evaluated by Beavers et al. (9). Schultz and co-workers (126) reported the use of activated carbon as an alternate method for adsorbing volatiles in commercial apple essence.

2.1.5 Applications of Activated Carbon In the Treatment of Industrial and Municipal Wastes

Carbon treatment of wastewaters from municipal and industrial sources has gained widespread use in the recent years due to the development of economical regeneration methods and equipment. Adsorption processes for wastewater purification have a number of advantages

over conventional biological treatment methods (67, 79). Applications of carbon adsorption for treatment of wastewaters have been extensive, both in pilot-plant and full-scale operations. Excellent reviews have been provided by several authors (145, 36, 100). For the 1983 "BAT" Technology, EPA proposed an end-of-pipe treatment system "based on the addition of activated carbon adsorption in fixed bed columns to the treatment system proposed as 1977 BTP Technology" (54).

The two prominent methods of utilizing activated carbon, namely, tertiary treatment and physical-chemical treatment (PCT) are illustrated by Suhr and Culp (135). A review of presently available physical-chemical wastewater treatment methods was prepared by Cooper (30). Rizzo and Schade (119) studied a physical chemical system employing granular activated carbon columns and an anionic polymer. Weber et al. (151) have reported on studies of carbon treatment of raw sewage through an expanded carbon bed. Zuckerman and Molof (99, 156) have developed the "Z-M" process for PCT, involving high pH (> 11) treatment prior to carbon treatment. However, other investigators have been unable to duplicate the reported benefits of high water quality claimed by Zuckerman and Molof (135). Results of pilot-plant investigations undertaken by researchers of the Ontario Ministry of the Environment showed conclusively definite effectiveness of the physical-chemical treatment of municipal primary effluents by means of lime precipitation followed by sand and activated carbon filtration (148).

Promising regeneration methods for powdered activated carbon have been developed in recent years (24). Batch regeneration of activated carbon was achieved in a laboratory-scale fluid bed reactor (75). Basch et al. (15) manufactured activated carbon from waste activated sludge on a laboratory-scale by drying, carbonizing, and steam activating at 800 °C. However, poor yield was obtained and the adsorption capacities of the regenerated carbon was correspondingly less than commercial carbons. Shuckrow et al. (129) reported a pilot-plant study on the recovery of powdered activated carbon and its subsequent recycling as an acidified slurry. A process consisted of powdered activation carbon addition followed by chemical coagulation and diatomite filtration for treatment of laundry, kitchen , hospital, shower and human wastes was discussed by Wang et al. (147). The system was projected to remove at least 90 percent TOC.

Ayres et al. (7) discussed the operation and performance of a physical chemical pilot-plant treating domestic wastewater at Owasso, Michigan. Stander et al. (131) reported the development of a physical chemical system at Windhoek, South Africa to reclaim potable water from raw sewage. PCT for refinery wastes was reported by Huang and Hardie (80). Cohen (27) reviewed the recent literature on physical-chemical methods. The EPA recently conducted a comprehensive pilot-plant study treating petroleum refinery effluent by activated carbon. Carbon adsorption following biological treatment was found to be particularly effective in reducing both BOD and COD

to low levels (54).

2.1.6 Activated Carbon Treatment of Food Processing Wastes

Conventional primary and secondary treatment processes are presently largely used to treat food industry waste effluents. However, the methods of primary screening and secondary biological operations often do not provide the degree of purity required by more stringent waste effluent guidelines. Granular activated carbon was subsequently employed as a tertiary step following biological treatment. The food processing industry in 1970 began a national program of research and development of pollution control methods of which activated carbon was a potential candidate, capable of higher degrees of treatment with the aim of in-plant water reuse (150). Activated carbon is now one of the primary processes factored into the development of the EPA's 1983 Best Available Technology (BAT) guidelines for many industrial categories (53). Interests in the recent years have focussed on the development of physical-chemical processes of which carbon adsorption has often been one of the unit operations to polish food processing effluents for possible recycling or before discharge.

Tuwiner (143) conducted laboratory studies on COD reduction of electrolyzed whey from dairy processing plants. He proposed electrolytic oxidation with froth collection and carbon adsorption as an attractive and feasible procedure for

recovery of valuables from the whey. On the recovery of soluble serum protein from meat industry wastes, Greiling (64) reported 90 percent COD reductions by activated carbon treatment from the supernatant of the chemically treated serum waste. Sugimoto (134) obtained a 60 percent COD removal in the treatment of meat processing wastes with granular and ball-type activated carbon. Berry et al. (13) investigated sand filtration and granular activated carbon treatment of chiller water and total plant effluent from poultry processing operations. They reported TOC and Soluble Solids (SS) removals of 75 to 77 and 97 to 99 perecent respectively.

Gallop et al. (60) demonstrated the potential of purifying several food industry wastes by the Manitoba Food Science Department Process utilizing activated carbon, preferably made from selected solid organic wastes. Hager (67) reported carbon treatment of food processing wastes such as natural cheese, fluid milk, canned fruits, vegetables, preserves, jams and jellies, fats and oils. Tebbutt and Bihiah (138) found that in general, fatty acids and lipids are more efficiently adsorbed than amino acids. On their laboratory scale study on control of color problems during recycling of food processing wastes, Hydamaka (83) reported activated carbon to be an essential ingredient in the control of color. Woodard (154), on investigating carbon treatment of pretreated total plant effluent from poultry processing wastewater, reported poor efficiency of adsorption for TOC removal in terms of carbon laoding rate, resulting in a cost of more than $5.00 per thousand gallons of wastewater

treated. On commercial applications of activated carbon treatment of storage brines for recycling, researchers at the National Canners Association Research Foundation estimated a cost of $12.80 per thousand gallons of reconditioned brine produced, on the premise of regenerating the spent carbon at a centrally located reactivation facility for ten participating olive canneries (41).

On full-scale operation, carbon adsorption is an expensive tertiary treatment step. Because of its relatively high cost and tertiary application, carbon adsorption has not been used for wastewater treatment by the fruit and vegetable processors (43). In fact, tertiary advanced waste treatment is not now practised by the food processing industry with the exception of 2 or 3 rapid sand filtration installations (45). It is not expected that it will be necessary to meet the 1977 EPA requirements, but tertiary processes may be required for 1983. Homel and McVaugh (78), on a bench-scale testing program found that the costs of physical-chemical treatments including carbon adsorption were prohibitive in the treatment of meat processing wastewater.

2.2 Water Reuse in Food Processes

The necessity of water reuse as a means of combating water shortage problem and escalating costs in some locations and overcoming pollution control legislation needs no further emphasis. The reuse of treated wastewater will result in a reduction in the total wastewater flow and it has been estimated that the extent of recycle can range from 50 to 75 percent of the process operation water flow with water recycle in the same operation unit (150). The National Canners Association (101) has produced a water economy "check list" which indicates whether or not the water from specific equipment may be reused, and the source of water for reuse in the specific equipment. (See Appendix Table 1.)

Although it has not been demonstrated in the food processing industry, a total closed-loop system remains the ideal and ultimate of water reuse and conservation. Such a system in a metal-plating and finishing plant using activated carbon and ion exchange resins to achieve Zero Discharge had been described, and the process produced a 75 percent reduction in water costs (111). In Canada, a paper and pulp mill successfully demonstrated the real-life application of the closed-loop technology. It is at the stage of closing the final loops of the salt recovery process (19).

2.2.1 Cannery

In the canning and freezing industry, there has been an estimated 64 percent reuse of the processing and container cooling

waters. This is about 180 billion gallons of its intake water, and resulted in an approximately 100 billion gallons of discharge (98). Esvelt et al. (48) reported an approximately 35 percent reduction in cannery wastewater discharge through reuse of biologically treated effluent that had been further subjected to tertiary treatment. They also projected a 50 percent or greater effluent reduction from full scale reuse of the cooling water. Berbinni and Calzoni (11) reviewed the water consumption and reuse of the canning industry in Italy.

2.2.2 Fruit and Vegetable Processes

In the fruit and vegetable industry, Hoehn et al. (76) developed an experimental system for washing collards and spinach. The system, which utilized washwater recycling reduced water consumption by 77 percent over conventional washers. By the utilization of a new dry-caustic peeling process and extensive in-plant water reuse a potato processing plant in the U.S. reported a reduction in water usage from 3,500 gallons per ton of raw product to approximately 813 gallons per ton (37). With the installation of tertiary treatment system, a fruit cannery anticipated approximately 80 percent reuse of its treated secondary effluent should the reused water be acceptable in all processes in the cannery (87). The National Canners Association Research Foundation in California (123) initiated a test program on a water recycle system incorporating a flocculation unit to determine the feasibility of maintaining a closed loop system of water usage around the tomato bin dump. A

swirl concentrator returned about 86 percent of the water to the dump tank in the cleaning of tomatoes (122). Follow-up studies by Dornbush et al. (37) illustrated economical feasibility of various systems of water reuse with disc cleaning of the tomatoes. An in-plant water recycle system with off-line mud removal was demonstrated by Wilson et al. (154) they estimated a 50 percent savings in the total annual wastewater related costs, accounting to about $47,000. Furthermore, an increase of 26 percent in the tonnage of tomato processed was realized. Biological treatments for potato wastes and techniques for using recovered water for pre-washing and peeling had been described by Plowright (112). Taylor (137) discussed the use of hydrasieves and cyclone equipment in treating potato processing effluents for possible reuse. Kenneth and Schmidt (126) evaluated the various in-plant control technology for the fruit and vegetable processing industry. Countercurrent reuse of wash/flume/cooling waters was among those unit processes identified to be feasible and having an impact on raw waste load and water usage reductions.

2.2.3 Meat and Poultry Processes

In their investigations of potential methods for reducing wastewater from in-plant hog slaughtering operations, Grothman et al. (65) noted in one location the use of wastewater to sluice hair to the sewage treatment plant, and in another plant to sluice condemned viscera to the rendering washer. However, the investigators questioned reuse for these purposes, and felt that dry conveying

would be better. They identified various points for possible water reuse. However, many were eliminated because of the USDA specifies the use of potable water.

Hamza et al. (68) reported in-plant water reuse in poultry processing. Countercurrent multiple water reuse of the chiller water together with modification in the evisceration operation had been shown to save 40 percent of the current process water usage. A further 25 percent saving on water usage was projected by recycling the condensing water to the rendering cookers. Reuse of poultry processing water through tertiary treatment has been reported by many investigators. Aldelman and Clise (4) demonstrated possible reuse of the renovated water subjected to secondary and tertiary treatments. Similar principles were used by McGrail to reclaim same processing wastewater. Woodard (154) employed activated carbon adsorption and DAF filtration in the treatment and recycle of the scalder and chiller water from poultry processing. In terms of loading rate, the carbon adsorption system was found to be poor in TOC removal. Similar study was conducted by Berry et al. (13) their system gave a TOC and SS removals of 75 - 77 and 97 - 99 percent respectively.

2.2.4 Pickling

Researchers at the National Canners Association in California investigated the recycling of olive processing brines after activated

carbon treatment (41). They showed the volume of brine which can be reconditioned and reused to be 20,000 gallons. Furthermore, the reconditioned brine can be stored for six weeks before reuse. Teranishi and Stern (139) described a lime, charcoal, and calcium carbonate process for treating olive-processing liquor that can be used to produce a recyclable water to process fresh olives. The Water Pollution Control Directorate of Canada has also noted the applicability of brine recycling in pickles and sauerkraut processings (149). McFeeters et al. (95) reported substantial savings and about 95 percent recovery of brine by means of recycling and pasteurization of the brine after each cycle of fermentation of the cucumbers.

2.2.5 Others

In Switzerland, a new system was being tested for reusing the same water repeatedly for cooling and washing the butter each churning. Substantial decrease in effluent discharge as well as considerable savings were reported. No compositional, bacteriological or organoleptic changes were noted in the butter produced using the same recycling water (118, 144).

Research by Lewis (97) showed the feasibility of recycling process waters in the beer brewing industry, and research data indicated recycling did not affect the quality and flavor of the beer. Van der Beken (146) discussed the reduction of water consumption in two brewery steeping processes and indicated that reclaimed

water was lower in impurities with immersion of the barley than with sprinkling.

Novitzki (104) described recycling operation at a fish hatchery that involved treating the water by returning it to the groundwater through an infiltration pond and withdrawing it for reuse. The treatment and use of recycled water from boiling mackeral and pike in Japan was reported by Osada and Maebuchi (106).

Champemont et al. (22) reported recycling of effluents in the confectionary industry by employing treatment with activated carbon and ion exchange.

2.3 Microbiology of Activated Carbon

2.3.1 Adsorption of Bacteria by Activated Carbon

Data on adsorption of bacteria by activated carbon has been limited. Early investigators (105, 116, 133) showed that activated carbon can accumulate bacteria in its pores. This however, is not regarded as an true adsorption phenomenon, but a process of mechanical and biological nature the details of which are not well understood. The relatively large size of bacteria make it questionable that their removal can be regarded as true adsorption. Gunnison and Marshall (66) studied a number of bacteria. They were unable to microscopically an affinity between adsorbents and the bacteria. It has been suggested that carbon, by adsorbing protective

colloids, may leave the bacteria in a condition that permits them to clump and be mechanically trapped by the carbon particles.

Selective removal had been observed in a number of studies on the adsorption of bacteria by activated carbon. Gunnison and Marshall (66) found that activated carbon adsorbed Lactobacillus acidophilus, but not Escherichia coli or Clostridium welchii. Salus (124) observed that typhoid bacteria were more readily adsorbed than E. coli and less readily adsorbed than the cocci. This selective removal indicates that more than a mechanical action is involved. Bacteria have been studied in recent years in medical research on their sorption to glass (109).

2.3.2 Effects of Activated Carbon on Bacterial Physiology

Activated carbon has been demonstrated to affect the physiological activities of some bacteria. Oksentyan (105) found that adsorption did not affect the production of lactic acid, but lowered the physiological functions of the lactic acid bacteria. Haynes et al. (70) found that activated carbon caused ready sporulation of B. popilliae which would otherwise be impossible in a liquid culture. The use of activated carbon was traced to cause definite changes in the pattern of its growth. Previous workers have suggested that the growth promoting power of carbon for certain microorganisms might lie in its ability to combine with toxic fatty acids present in the medium. In their further investigations, Haynes et al. (71)

reported that with the addition of activated carbon, liquid shaken cultures of B. popilliae produce refractile spores and remain viable for several weeks. In liquid medium without activated carbon, the spores expire in a week.

Carbon may accelerate biological activity by adsorbing toxic metabolites, or may retard it by adsorbing nutrients necessary for growth and enzymes necessary for biochemical activities. Therefore, during fermentation, apart from direct catalytic action, indirect effects may be present. Activated carbon may alter the course of reaction and different products are formed. Acceleration of biological activity during the fermentation of sugars was reported by many investigators. Lampe (88) noted a 0.1 percent of activated carbon greatly accelerated the fermentation of molasses. On the production of aldehydes, contradictory results were reported between Lampe and Abderhalden (1). Tomoda (141) found that activated carbon added to sugar mash increased the yield of fusel oil.

2.3.3 Bacterial Growth on Activated Carbon

The possible growth of bacteria on activated carbon has been of growing concern because of the increasing use of carbon filters in domestic water system (63). It has been speculated that microbial build up in activated carbon filter units could present a health hazard. However, study by Fiore and Babineau (51) in-

dicated that the activated carbon home water filter units used in their investigation appeared to be microbiologically neutral devices in that they neither improved nor detracted from the microbial quality of water. They concluded that water supplies that were microbiologically safe without filtration were microbiologically safe with filtration. Furthermore, in their investigation with well water contaminated with coliforms, they observed that the coliforms did not colonize the filter system and grow to levels above those found for the unfiltered water. Their findings were confirmed by similar studies reported by Johnston et al. (84)

Fiore and Babineau (51) also isolated the presence of Gram-positive spore-forming bacilli, Gram-positive cocci and some molds from the filters before use. This could be expected as bacillus species, mold spores, and Gram-positive cocci have been known to survive long periods in a dormant condition. They did not find any Gram-negative bacteria in the unused filters and accounted for such an observation by the lack of usable organic matter and low available water in the unused filters.

Johnston and Burt (84) revealed that tap water seeded with coliforms contained less of the organisms after it was flushed through an activated carbon filter. They concluded that, whereas bacteria indigenous to tap water may survive and multiply in the carbon bed, coliforms may have been at a competitive disadvantage.

Biological activity in granular activated carbon beds used for water treatment has been reported conclusively (97). Under certain conditions, granular carbon beds provide favorable conditions for the production of hydrogen sulfide gas which has an unpleasant odor. This has been attributed to a number of factors including low concentrations or absence of dissolved oxygen and nitrate in the carbon contactor inffluent, high concentrations of BOD and sulfates, long detention times and low flow-through velocities (135). Bacteria readily attach themselves to the irregular external surface of the carbon particles and are very difficult to remove via backwashing procedures. Also, because chlorine reacts very rapidly with , residual chlorine is not likely to penetrate the bed very far. Love et al. (94) reported high bacterial plate counts in granular activated carbon bed effluent and slime growth within the bed. There are, however, beneficial aspects of microorganism growth in granular activated carbon beds. Working at the Bremen pilot-plant in West Germany, Eberhardt et al. (39) observed bacterial activity to aid in the removal of organic substances. The amount of substance removed by biological oxidation was found to be dependent on the concentration in the influent and the residence time in the filter.

In the treatment of food processing effluents with granular carbon column, the build up of soluble organic material on the activated carbon rapidly promoted biological activity within the adsorp-

tion system. Hopkin et al. (79) suggested that activated carbon provides an excellent surface for concentration of organic biological substrate material. The high organic load of the column influent provided ample substrate materials for rapid microbiological growth. The occurrence of the microbial growth in the activated carbon column suggested several operational complications or other sterilization methods to ensure desirable effluent quality. Weber et al. (151) reported that the biological growth did not appear to hinder the adsorption process. Hydamaka (83) observed the gradual downward spread of microbial growth and the eventual conversion of the columns into submerged anaerobic trickling filters.

2.3.4 Adsorption of Viruses and Toxins

Experiments conducted in vitro provided more positive evidence on the adsorption of toxins and viruses. Hassler (73) compiled a bibliography of studies on adsorption of a number of viruses, venoms, toxins, antitoxins and agglutinins. Earlier studies were done with the foot-and-mouth virus. The adsorption of each virus was found to depend on the experimental conditions and the types of carbon used. Poppe and Busch (113) observed strong adsorption of the foot-and-mouth virus at pH 6.5 to 8.4. The adsorbent and supernatant fluid was rendered not infectious to the guinea pigs. Cordier (31) reported that the virus was not destroyed but the viral activity

was reduced. He also noted that a small amount of adsorbed virus immunized the test animal whereas large doses caused ulcers. Use of activated carbon to adsorb polio virus and infectious hepatitis virus was reported in 1959. Cookson and North (29) showed the adsorption of E. coli bacteriophage T_4 to be mainly on the surface. They noted that the phage was not inactivated, and that the adsorption process was reversible, and obeyed the Langmuir Isotherm.

The presence of virus in supposedly pure drinking water promises potential usefulness of activated carbon for water treatment. Samples collected from the carbon column effluent at the South Tahoe public utility district water reclamation plant revealed excellent viral removal (142). In the treatment of municipal water, Robeck et al. (121) demonstrated the mixed-media filters to be more efficient in virus removal than coal-sand media. The die-off rate of viruses in the aquatic environment is a complex phenomenon which is dependent upon many factors such as temperature, nature and chemical characteristics of the water. Oza and Chaudhuri (108) investigated the sorption of bacterial virus MS2 on bituminous coal. They found that sorption increased with ionic strength and temperature and decreased with increasing pH.

Activated carbon has been known as a detoxification agent of relatively universal effectiveness. Medically, it has been used to remove bacterial toxins in catarrhal infections of the digestive system. It is prescribed in large doses in all cases of acute gas-

tritis and enteritis (86). It is a very effective antidote of all cases of poisoning (130). In water purification processes, activated carbon has been found to be highly effective in the removal of toxic substances produced by algal species such as Microcystis aeruginosa. Hoffmann (77) investigated the removal of toxin produced by the M. aeruginosa by conventional water treatment methods and by activated filtration. He found that unit processes such as chlorination, flocculation, sedimentation did not remove the toxins to below the "active levels" by toxicity tests. The use of activated carbon, however, effectively reduced the toxins to below the active levels.

2.4 Characteristics of Test Organisms

The following test organisms were selected for various studies as illustrated in Figure 2.

2.4.1 Escherichia coli

The genus Escherichia belongs to the family Enterobactericeae (12). E. coli are straight rods, measured 1.5 - 2.5 by 2.0 - 6.0 u in the living state, and 0.4 - 0.7 by 1.0 - 3.0 u while dried and stained. They are Gram-negative organisms, occuring singly or in pairs.

E. coli readily grows on simple nutrient media. The colonies on nutrient agar may be smooth (S), low convex, moist, gray, with shiny surface and entire margin, easily emulsified in saline; or

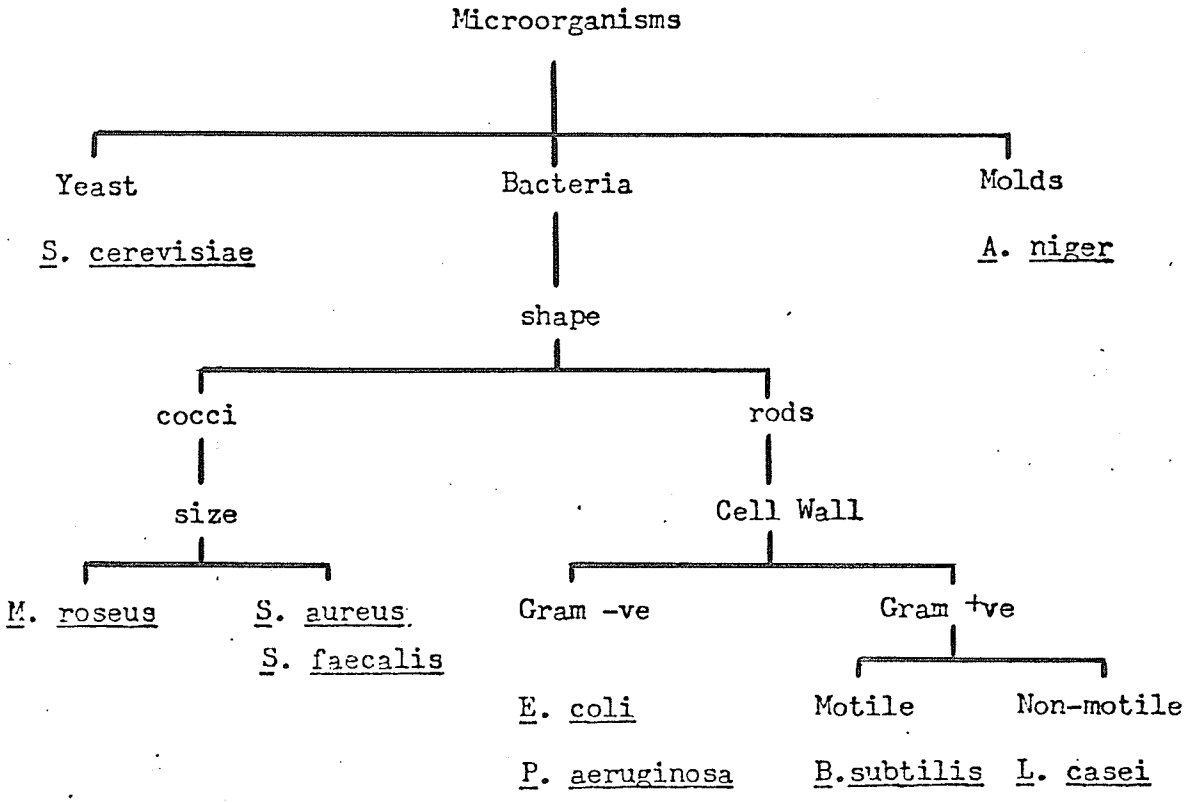


FIGURE 2 Selection of Test Organisms

rough (R), dry and do not emulsify well in saline.

They are found at the lower part of the intestine of warm-blooded animals. Many, if not all, members may show opportunistic pathogenicity, causing urinary infections in man and mastitis in cows, etc.

2.4.2 Bacillus subtilis (12)

Bacillus belongs to the family Bacillaceae. B. subtilis are Gram-positive rods that seldom occur in chains. The possess lateral flagella. B. subtilis cells measured 0.7 - 0.8 by 2 - 3 u and they produce endospores of sizes 0.8 - 1.5 u in diameter.

Their colonies on agar media are round or irregular with dull surface which becomes cream-colored or brown. Active spreading occurs on agar with a moist surface. Maximum temperature for growth is 45 - 55 °C, and minimum temperature is 5 - 20 °C.

2.4.3 Staphylococcus aureus (12)

S. aureus are Gram-positive spheres, about 0.8 - 1.0 u in diameter. The cells occur singly, in pairs or in irregular clusters due to the division of the cells in more than one plane. Some strains possess a capsule or slime layer.

They show abundant growth on agar slants with opaque, smooth, flat, moist and white, yellow or orange colonies. Growth is more

rapid and abundant under aerobic conditions. Optimal temperature for growth is 35 - 40 °C. Optimum pH is 7.0 - 7.5.

2.4.4 Streptococcus faecalis (12)

S. faecalis are ovoid Gram-positive cells elongated in the direction of the chain. The cells are 0.5 - 1.0 u in diameter, occuring mostly in pairs or short chains. Generally they are non - motile. Their colonies are smooth and entire. Growth occurs at 47 °C but not at 50 °C.

They are found in the faeces of humans and warm-blooded animals. They are also common in many food products, often un-related to direct fecal contamination. Their relationship with food poisoning is questionable. They occur frequently in plants where an epiphytic relationship exists.

2.4.5 Micrococcus roseus (12)

They are Gram-positive spheres of 1.0 - 2.5 u in diameter. They occur singly, in pairs and divide in more than one plane to form irregular clusters, tetrads or cubical packets. Some strains are motile by one or two flagella.

They form pink or red, smooth, slightly convex colonies with regular margins. Their optimum temperature for growth is 25 °C, but grow well at 10 °C.

M. roseus has been isolated from dust, water and salt - containing foods. They are not common, and non-pathogenic to man,

plants and animals.

2.4.6 Lactobacillus casei (12)

They are Gram-positive short rods, generally less than 1.5 u wide, and often with square ends. They tend to form chains. Flagella are absent and hence they are non-motile. They become Gram-negative with increasing age and acidity. On pour plate they form deep colonies that are smooth, lens or diamond-shaped, and appear white to light yellow in color.

They are isolated from milk and cheese, dairy products and dairy environments, human intestinal contents and stools.

2.4.7 Pseudomonas aeruginosa (12)

Pseudomonas is the principal genus in the family Pseudomonadaceae. The species P. aeruginosa are Gram-negative rods, measured 0.5 - 0.8 by 1.5 - 3.0 u. They can occur singly, in pairs or short chains. They are motile with polar monotrichous flagellation.

They are obligately aerobic, except in media with nitrate. Optimal temperature for growth is 37 °C. Growth also occurs at 41 °C but not at 4 °C.

They can be isolated from soil and water, particularly from enrichment cultures for dentrifying bacteria.

2.4.8 Aspergillus niger

A. niger belongs to the class fungi imperfecti of the septate molds (57). It is widespread and may be important in foods, particularly in the spoilage of bread, and cause the black mold rot of vegetables and fruits. The multicellular, filamentous fungi bear large, globular conidia that may be black, brownish black, or purple-brown in color. Many strains are used for the commercial production of citric acid and gluconic acid, and a variety of enzyme production.

2.4.9 Saccharomyces cerevisiae

S. cerevisiae is a yeast in the class ascomycetes (true yeasts). The cells may be round, ovate, or elongated and may form pseudomycelium. S. cerevisiae is employed in many food industries, with special strains being used for the leavening of bread, as top yeasts for ale, for wines, and for the production of alcohol, glycerol and invertase.

2.5 Microbiological Quality of Water

The following characteristics are commonly employed in establishing quality criteria for drinking water:

1. physical characteristics which include color, odor and taste, temperature, turbidity and pH;

2. microbiological characteristics which include nuisance organisms, coliforms, pathogenic organisms, and viruses;
3. chemical characteristics including toxic chemicals, biocides and other chemicals; and
4. radioactivity.

Microbiologically, there are 41 types of bacteria, 10 types of fungi, 5 rickettsia and approximately 100 viruses that are of concern to the sanitary design engineers (110).

Biological organisms in concentrations which may produce objectionable color, tastes, odor and turbidity, or which may release toxic metabolites, are undesirable in drinking water. These organisms must be kept below such concentrations as to prevent the aforementioned undesirable effects. Pathogens, in particular, their existence presents potential health hazards. Standards for the microbiological quality of drinking water are obviously essential for the protection of the public from waterborne infections and diseases.

The U.S. Public Health Service Drinking Water Standards of 1962 currently remain the minimum standards for water quality. More stringent standards have been promulgated and revised since then. The Safe Drinking Water Act was passed into law on December 24, 1974. It devised and refined earlier regulations relative to the U.S. Public Health Service and Public Water Supplies, and

gave new powers and responsibilities to EPA to ensure safe drinking water for all citizens (149). In June, 1977, the new Environmental Protection Agency Regulations for drinking water quality in the U.S. came into effect. In Canada, objectives and guidelines of water supply standards had been established by both the CPHU Drinking Water Standards Committee and the Advisory Committee in Public Health Engineering of the Department of National Health and Welfare. These two bodies subsequently collaborated in 1967 and developed the 1968 Canadian Drinking Standards and Objectives (35).

The quality requirements for industrial water are generally consistent with general public demands for clear, attractive water of moderate mineral content, free from Iron and Manganese, with certain requirements that may exceed those of public water supplies for certain industries. The National Technical Advisory Committee of the Federation Water Pollution Control Administration, in its report on water quality criteria included standards for raw water quality for a number of industries from textiles to food and kindred products (50). Culp and Culp (32) also listed the additional water quality required for various industrial processes.

At present no standards are available for recycled food effluents since the technology is still in its infancy and demonstration stages. Dr. Robert Schaffner, Associate Director of FDA's Bureau of Foods, conceded that it is the FDA's responsibility in the issuing of future regulations for the safe use of recycled

waters on foods (98). A workshop group sponsored by the EDA, AWWA and WPCF anticipated that a research program designed to provide priorities and direction for potable reuse will require a minimum of 10 - 15 years to develop sufficient information to clearly define meaningful standards that can be applied with confidence to potable reuse water (46). Hattingh and Nupern (69) described a 10-year research program presently underway in South Africa to assess the health aspects of reusing wastewater. The studies to date showed that reclaimed wastewater was the same quality as the acceptable potable water from surface supplies. Grothman et al. (65), in investigating potential methods for reducing wastewater from in-plant hog slaughtering operations, had to eliminate many points of operations for possible water reuse because the USDA specifies the use of potable water at those points.

2.5.1 Microbiological Index

2.5.1.1 Nuisance Organisms

Nuisance organisms include planktonic algae, actinomycetes, fungi, and other organisms capable of producing objectionable odors, tastes, color and turbidity. Owing to their widely different abilities to produce the aforementioned undesirable effects, it is difficult to specify any quantitative limit on those organisms. However, they are indirectly controlled by the limits set on the physical characteristics - turbidity, taste, color - of the water.

2.5.1.2 Coliform Organisms

Bacteriologically, the coliform test remains the most sensitive and valuable, currently available tool in detecting bacterial contamination. This test is also used to evaluate the effectiveness of water treatment process in removing bacterial contamination. The coliform group of organisms is defined as: "all of the aerobic and facultative anaerobic, Gram-negative, non - sporing, rod-shaped bacilli which ferment lactose with gas formation within 48 hours at 35 °C, or those that produce sheen colonies by the MPF method." (151)

The faecal coliform group bacteria are inhabitants of the intestinal tract of man and other warm-blooded animals. They are thus a good indicator of pollution because of their predominance in sewage. Detections of coliforms in small quantities of water (50 ml or less) suggests pollution, whereas their absence is considered as indication of probable safety (32). By proper treatment, it is possible to produce a water which is free of coliform organisms. Because of the sanitary significance of the various members of the coliform group derived from the natural sources, difference of fecal from non-fecal organisms is important in evaluating raw water quality. The standard and accepted methods of enumeration are given in the "Standard Methods for the Examination of Water and Wastewater" (151).

2.5.1.3 Total Bacteria Count

There is no evidence that total bacteria count is directly related to a potential microbiological problem. The EPA originally proposed a standard plate count of 500 organisms/ml as one of the primary drinking water standards (42). However, it recently eliminated this standard from the final regulations on the basis that it was "not justified by the available data", although it still believes "that the standard plate count is a valid indicator of bacteriological quality of drinking water and recommends that it be used in appropriate cases in conjunction with coliform tests as an operational tool." (44) It is on the same basis that the FDA has declined to set standards for the total number of microorganisms available in bottled water (49). Hudson (81) included bacteria as indicated by the plate counts and by presumptive and confirmed coliform determination as one of the criteria for the production of high quality water.

2.5.1.4 Virus

Viral disease has been one of the areas of major concern about the safety of water reuse. However, water meeting the bacteriological quality standards is believed to be safe from a viral standpoint. Hudson (81) observed a lower incidence of viral disease in cities where water treatment produced a superior product rather than tolerable water. In summarizing the status of viruses in water, Clarke et al. (25) suggested that concern should be on

the recognized enteric virus groups: polioviruses, coxackie viruses, ECHO viruses, the virus(es) of infectious hepatitis, the adeno-viruses, and the reoviruses. They further calculated the coliform - virus ratio to be about 92,000 : 1 in sewage and about 50,000 : 1 in polluted surface water. Coliform organisms greatly out-number enteric viruses in sewage or polluted surface water and therefore appear to be a better indicator of pollution than enteric viruses. Also, there is presently no method for positively detecting virus in water or measuring the numbers present. Treatment procedures that are known to remove virus must therefore be used.

2.5.2 Microflora in Potato Wastewater

In studying the effect of Gamma irradiation on the aerobic microflora of potato wastewater, Sholdice (127) isolated 19 genera of organisms, and obtained the following microbial composition shown in Table 2. He found the micrococcus genus to be the most predominately occuring organisms, making up 38.8 percent of the microflora. Yeasts and molds were not significant in number. Of the 500 isolations, he obtained only one Escherichia genus.

Certain species of the genera noted in the wastewater are known to cause various tuber diseases. Erwinia carotovora incited soft rot and blackleg (8), while Corynebacterium sepedonicum incites bacterial ring rot (102). Pseudomonas solanacearum is known to cause brown rot; and Streptomyces scabies, a soil-borne filamentous

TABLE 2. MICROFLORA IN POTATO WASTEWATER (127)

GENUS	TOTAL NO. ISOLATED	PERCENTAGE OF TOTAL
Aerobacter	16	3.2
Alcalgines	3	0.6
Arthrobacter	7	1.4
Bacillus	122	24.4
Corynebacterium	10	2.0
Erwinia	12	4.4
Escherichia	1	0.2
Flavobacterium	4	0.8
Lophomonas	4	0.8
Micrococcus	194	38.8
Mold	8	1.6
No growth	16	3.2
Proteus	3	0.6
Pseudomonas	28	5.6
Sarcina	10	2.0
Staphylococcus	5	1.0
Streptomyces	16	3.2
Xanthomonas	16	3.2
Yeast	15	3.0
TOTAL	500	100.0

bacterium, is known to cause common scab or corky scab of potatoes (8). It is one of the major diseases of the U.S. potato farms. It seriously affects the appearance, grade and quality of the tubers.

2.6 Measurement of Turbidity in Water

Turbidity in water is caused by the presence of suspended matters such as clay, silt, finely divided organic and inorganic substances, plankton and other microscopic organisms. It is an expression of the optical property of a sample which causes light to be scattered and adsorbed rather than transmitted in straight lines through the sample (121). It has been an important factor in determining the quality of drinking water as well as treated wastewaters. The Safe Drinking Water Act passed in 1974 calls for the daily measurement of turbidity at the supply source (150).

Turbidity may be determined by using a candle turbidimeter, provided the suspended matter is finely divided. It may also be measured by a photometer or nephelometer that has been calibrated against prepared turbidity standards which, in turn, have been calibrated against a candle turbidimeter such as the Jackson Candle Turbidimeter.

2.7 Measurement of Oxygen Demand by the Aquarator

Chemical oxygen demand (COD) and biochemical oxygen demand (BOD) are the most important indicators of pollutants in water. Unfortunately, these standard methods require two hours (for COD) to 5 days (for BOD). This delay makes the existing methods virtually useless where prompt information is needed to initiate corrective measurements. The COD determinations, moreover, involves the use of expensive and toxic substances which subsequently cause a disposal problem. It is not until the recent years that a fast method for the COD determination has been developed (132). The Precision Aquarator is one of those newly developed instruments that are capable of performing the COD test within minutes with a minimum, if any, pretreatment of the sample. It is designed to measure oxygen demand in the range of 50 to 300 mg/1.

Theory of Aquarator Operation The following two equations illustrate the types of reactions that take place when organic material is combusted in atmospheres of oxygen and carbon dioxide respectively:

$$(1) \quad C_aH_bN_cO_d + \frac{n}{2} O_2 \longrightarrow aCO_2 + \frac{b}{2}H_2O + \frac{c}{2}N_2$$

$$(2) \quad C_aH_bN_cO_d + m\ CO_2 \longrightarrow (m+a)CO + \frac{b}{2}H_2O + \frac{c}{2}N_2$$

Equation (1) depicts the reaction in the determination of

COD. If the amount of oxygen required in equation (1) could be determined exactly, it would represent the ultimate COD of the sample.

The Aquarator method utilizes the second equation. It has been demonstrated by the originators (132) of the method that (m+a) in equation (2) is equal to n in equation (1). That is, the number of moles of carbon monoxide (CO) produced is the same as the number of moles of oxygen atoms related to the COD. Calculation is originally carried out by injecting standard solutions of sodium acetate trihydrate, for which the oxygen demand in mg/l can be calculated.

SCOPE OF INVESTIGATION

SCOPE OF INVESTIGATION

This study was directed towards the microbiological aspects - microbial reduction and subsequent effluent qualtiy - of a purification system employing powdered activated carbon to render food processing effluents for possible reuse purpose. Effluents from the rinsing of raw potato French fry slices were used in this investigation.

The study was divided into three sections under which the following areas were investigated:

(1) to determine the efficiency of powdered activated carbon on the removal of selected microorganisms commonly found in the potato slice rinse effluent, and to investigate any possible effects and selectivity by virtue of morphological differences and cell wall composition on the absorption/filtration of those test organisms by the powdered activated carbon;

(2) to investigate the factors, namely, effluent strength, microbial load, turbidity and color, in the determination of optimal dosage conditions, i.e. levels of carbon dosage, contact time and methods of application, in the purification of the effluent;

(3) to investigate the cause and methods of control of turbidity development in stored effluent.

MATERIALS AND METHODS

MATERIALS AND METHODS

4.1 Materials

4.1.1 Potatoes

The netted gem variety obtained from the Manitoba Vegetable Marketing Board was used throughout this study.

4.1.2 Powdered Activated Carbon

Aqua-nuchar powdered activated carbon was used as the adsorbant in this study. Aqua-nuchar was chosen over other commercial activated carbon because of its cheaper costs and its better adsorption (82).

4.1.3 Chemicals

The following chemicals of analytical grade [Fischer Scientific Co., Chemical Manufacturing Division, Fair Lawn, New Jersey, U.S.A.] were used in this project:

(a) d-Tartaric Acid

(b) Potassium Dihydrogen Phosphate

(c) Citric Acid

(d) Sodium Hydroxide

(e) Sodium Acetate Trihydrate

4.1.4 Bacteriological Media

The following bacteriological media [BBL, Cockeysville, Maryland 21030, U.S.A.] were used for the enumeration and/or cultivation of the selected microorganisms used in this investigation:

(a) Bacto Nutrient Broth

(b) Bacto Starch Agar

(c) Czapek Dox Broth

(d) F Agar

(e) Potato Dextrose Agar

(f) Staphylococcus Agar 110

(g) Tryptone Glucose Yeast Agar (SPC Agar)

(h) Violet Red Bile Agar

4.1.5 Bacteriological Cultures

Stock cultures were obtained from the Department of Microbiology, University of Manitoba.

The following cultures were used for the bacteriological studies in this investigation:

(a)	*Aspergillus niger*	A.T.C.C.* # 1015
(b)	*Bacillus subtilis*	A.T.C.C. # 6501
(c)	*Escherichia coli*	A.T.C.C. # 10997
(d)	*Lactobacillus casei*	A.T.C.C. # 393
(e)	*Micrococcus roseus*	A.T.C.C. # 9815
(f)	*Pseudomonas aeruginosa*	A.T.C.C. # 7700

(g) Saccharomyces cerevisiae A.T.C.C.* # 9763

(h) Staphylococcus aureus N.C.T.C.** # 9309

(i) Streptococcus faecalis # 97***.

*American Type Culture Collection, 12301 Parklawn Drive, Rockville, Maryland 20852.

**National Collection of Type Cultures, London, England.

***Culture collection number of the Department of Microbiology, University of Manitoba, Canada.

4.2 Methods

4.2.1 General Methods

4.2.1.1 Preparation of Potato French Fry Slice Rinse Effluent

Those experiments which required a relatively large quantity of potato slices used a Hobart model abrasive potato peeler. Otherwise the potatoes were hand-peeled.

The peeled potatoes were thoroughly rinsed with cold tap water and cut into slices of approximately 5/8 in. square in cross section by means of a mechanical potato chipper.

Potato slices were rinsed over a screen using a ratio of 300 grams of potato slices per liter of cold tap water. Henceforth, potato French fry slice rinse water will be referred to as effluent. The effluent was collected in a sterilized Erylenmeyer flask (1-

or 3-liter capacity). The volume of effluent required varied according to the individual studies. For multiple rinse studies, fresh potato slices were used for each rinse.

4.2.1.2 Reuse of Potato French Fry Slice Rinse Effluent

In this study, the term reuse means the repetitive use of a volume of water or effluent at the same process step, without significant purification. In this manner, a cyclic process of effluent flow at the same unit operation was simulated. In this study, the process step or unit operation was thus the rinsing stage. Effluent reuse resulted in an increase in organic strength as well as an increase in microbial load in the water.

The desired number of reuse cycles was thus obtained by the number of rinses with the same volume of effluent. The removal of suspended solids (destarching) followed by carbon treatment was performed after each reuse cycle or after a number of successive reuse cycles. Samples were taken for chemical, physical and bacteriological analyses at the desired points of the cyclic process. The effluent volume was maintained at a constant volume by the addition of sterile water (make-up water).

4.2.1.3 Effluent Treatment with Powdered Activated Carbon

Destarching Prior to effluent treatment with powdered activated carbon, it was necessary to remove as much of the sus-

pended solids as possible. The suspended solids consisted mainly of starch which would tend to interfer with the adsorption process. On a commercial process, this process is known as "destarching" and is achieved conveniently through the use of hydrocyclones or simply by gravitational sedimentation.

Because of the relatively small volume of effluent used in each experiment, centrifugation by means of a Sorvall Superspeed Automatic refrigerated centrifuge [Model RC2-B] was utilized to destarch the effluent. The effluent was dispensed in pre-sterilized 300 ml plastic centrifuge containers, capped and centrigued at about 3000g for 3 minutes. Desired volumes of the destarched effluent were measured out and subjected to carbon treatment.

Dosages of activated carbon used were expressed as grams of activated carbon per liter of water (or effluent). The dosages employed included 0.0, 0.1, 0.5, 1.0, 3.0, 5.0 and 10.0 g/l. Dosages above 1.0 g/l were arbitrarily referred to as high dosages.

Carbon Treatment Effluent volumes of either 100 ml or 250 ml were dispensed into 250 ml Erlenmeyer flasks containing the appropriate dosages of powdered activated carbon. One flask without carbon served as a control. The flasks and contents were shaken on a New Brunswick scientific model rotary shaker operating at 300 r.p.m. for approximately 3 minutes at room temperature.

After shaking the flask contents were filtered using a

Whatman No. 5 filter paper in conjunction with a Buchner funnel. A sterilized glass wool / carbon filter unit was connected to the vacuum line to prevent post-contamination of the effluent upon release of the pressure. A new sterilized funnel was always used for each sample filtration. This method was used when the volume of effluent exceeded one liter.

4.2.2 Microbiological Methods

4.2.2.1 Sterilization and Sanitization of Equipment

All equipment, including Erlenmeyer flasks containing the measured amounts of powdered activated carbon were sterilized in an autoclave at 121 °C for 15 minutes. The Buchner funnels, millipore filtration units and measuring cylinders were wrapped in aluminium foil to prevent post-contamination.

The abrasive peeler, potato chipper, strainer, collecting container and other equipment not capable of being accomodated by the laboratory autoclave were all sanitized with a chlorine solution. The equipment was thoroughly cleaned prior to sanitization, and then thoroughly rinsed with tap water to remove excess residual chlorine.

Millipore Filtration Unit Prior to use, the filtration carrier, upper funnel and its flange were loosely assembled, wrapped with aluminium foil and autoclaved at 121 °C for 15 minutes. The

membrane filter of 0.2 μ pore size and the composed asbestos pads had been commercially pre-sterilized. The unit was allowed to cool to room temperature.

All handling of the millipore filters and asbestos pads were performed aseptically with a pair of flamed forceps. Both the asbestos pads and membrane filters were discarded after each sample filtration.

4.2.2.2 Maintenance of Microbiological Cultures

The selected stock cultures were transferred to trypticase soy agar slants, which were incubated at 35 °C for 24 hours, and then stored at 4 °C. The cultures were re-streaked onto fresh slants every 14 days, in order to maintain viability.

4.2.2.3 Preparation of Microbiological Inocula

Slants of the respective cultures were washed with 5.0 ml of sterile phosphate buffer solution. The cell suspension was then transferred to a Roux bottle containing the appropriate agar. The cell suspension, aided by the use of sterile glass beads, was then distributed evenly over the agar surface. The Roux bottles were subsequently incubated for 24 hours at 35 °C.

[Roux bottles of 250 ml capacity, containing 30 ml tryptone glucose yeast extract agar were sterilized at 121 °C for 15 minutes. F Agar, Potato Dextrose Agar and Staphylococcus Agar 110

were used for the cultivation of L. casei, S. cerevisiae and S. aureus respectively. The bottles were laid flat after sterilization, allowing the agar to solidify.]

The resultant cell growth from the Roux bottles were harvested by washing the surface of the slant with 25 ml of sterile phosphate buffer solution. The cell suspension was then aseptically dispensed into a 3-liter sterilized Erlenmeyer flask containing a liter of sterile phosphate buffer water and a magnetic stirring bar. The inoculated phosphate buffer water was stirred for 15 minutes at room temperature to ensure homogeneous mixing.

One hundred ml aliquot of the inoculated buffered water were then dispensed into 250-ml sterilized Erlenmeyer flasks containing various dosages of powdered activated carbon. Carbon treatment was performed as described in the preceding section.

4.2.2.4 Enumeration of Viable Microbial Counts

Preparation of Phosphate Buffer Water In this investigation, phosphate buffer water was used as diluant and blank for serial dilutions. The phosphate buffer water was prepared as outlined in the"Standard Methods for the Examination of Water and Wastewater" (151). Its composition is given in Appendix Table 2.

Standard Plate Count (SPC) A serial dilution technique was performed using 99 ml dilution blanks containing phosphate

buffer water. Viable bacterial counts were enumerated by the Standard Plate Count (SPC) technique as given in the "Standard Methods for the Examination of Water and Wastewater" (151).

The plates were counted on a Quebec Darkfield colony counter. Those plates containing between 30 - 300 colonies were counted and then corrected for dilution factors.

Presumptive Coliform Count Violet Red Agar was used for the enumeration of presumptive coliform organisms. The method for presumptive coliform count enumeration is given in the "Standard Methods for the Examination of Water and Wastewater" (151).

Yeast and Mold Count Potato dextrose agar was used for the enumeration of yeasts and molds. The melted agar was acidified to a pH of 4.5 by adding 1.2 ml of a sterile 10 percent tartaric acid solution to each 100 ml of the medium.

The plates were incubated at room temperature. Enumeration was done after 5 - 7 days of incubation.

4.2.2.5 The Effect of Bacterial Morphology on Adsorption/Filtration

Those studies investigating the effect of cell morphology on the adsorption/filtration process used cultures of S. aureus and

E. coli in phosphate buffered water and carbon treated at various dosage levels as pure inocula and as a binary mixture.

The enumeration of the two organisms was performed on Standard Plate Count Agar and Violet Red Bile Agar. Counts obtained from the Violet Red Bile Agar represented the viable cell counts of E. coli. The Standard Plate Count represented the total viable count of the two microorganisms.

4.2.2.6 The Effect of Bacterial Cell Size on Adsorption/Filtration

Those studies investigating the effect of cell size on the adsorption/filtration process used cultures of S. aureus and M. roseus inoculated in phosphate buffered water. S. aureus is about 0.8 - 1.0 μ in diameter while M. roseus is 1.0 - 2.5 μ in diameter.

Enumeration of the viable cell count of each microorganism was based on the different pigmentation of the organisms. M. roseus colonies produced a pink pigmentation on the agar surface, while the S. aureus formed colonies that were orange in color. The two organisms were thus differentiable from the colors of their colonies on the agar surface.

4.2.2.7 The Effect of Bacterial Cell Wall Composition on Adsorption/Filtration

Major chemical compositional differences between the cell walls of eubacteria are revealed by the Gram staining pattern of the microorganisms. Consequently, the division of the eubacteria into two groups, namely, Gram-positive microorganisms and Gram - negative microorganisms, constitutes a division of profound taxonomic importance.

In this study, cultures of B. subtilis and E. coli were used to investigate the effect of bacterial cell wall composition on the process of adsorption/filtration. Enumeration of the two different rod shaped microorganisms were possible through the use of a selective medium, the Violet Red Bile Agar and a non-selective medium, the Standard Plate Count Agar. The Violet Red Bile Agar contains bile salts that inhibit the growth of B. subtilis but not E. coli.

4.2.2.8 The Effect of Motility on Adsorption/Filtration

Two Gram-positive rod shaped microorganisms, B. subtilis and L. casei were selected for this study which investigated any possible effects of bacterial motility on the process of adsorption/filtration process. B. subtilis is flagellated, while L. casei is non-flagellated.

The maximum temperature for the growth of B. subtilis is

between 45 and 55 °C, while L. casei does not grow at 45 °C or above (12). In this study, the two organisms were thus enumerated for their viable cell counts at two incubation temperatures, namely, 35 °C and 45 °C. Difference in the viable cell counts obtained at these two incubation temperatures therefore represented the viable counts of L. casei in the phosphate buffered water.

4.2.2.9 Microbial Growth In Carbon Treated Effluents

Four liters of effluent were obtained and dispensed in volumes of 500 ml each into four 1-liter Erlenmeyer flasks containing 0.0, 1.0, 2.0 and 5.0 g/l of powdered activated carbon respectively. The effluents were thus carbon treated as described previously.

The carbon treated, filtered effluents were incubated at room temperature (about 22 °C) for a period of 5 days, during which aliquots (about 5 ml) were withdrawn at 24-hour intervals for viable cell count and pH determinations. The flasks were well shaken prior to sample withdrawal.

4.2.2.10 The Effect of Aeration on Microbial Growth In Carbon Treated Effluents

The effect of aeration on microbial growth was investigated by aerating the effluent with a stream of filtered air.

Two 1-liter Erylenmeyer flasks capped with rubber stoppers, one of which contained a magnetic stirring bar, was sterilized and cooled to room temperature. Into each flask, 500 ml of effluent previously treated with 1.0 g/l of powdered activated carbon was dispensed. The flasks were incubated at 22 °C for 72 hours. One of the flasks was aerated at a rate of 5 ml/min/ml effluent using a sintered glass aerator which was positioned at a level directly above the rotating magnetic bar. The other flask served as a control. Samples were withdrawn from both flasks at 24-hour intervals and then enumerated for viable bacterial cell counts.

4.2.2.11 The Effect of Low Temperature Incubation on Turbidity Development in Carbon Treated Effluents

Four liters of effluent was prepared and subjected to ten sequential reuse cycles. The recycled effluent was dispensed in volumes of 500 ml into four sterilized 1-liter Erlenmeyer flasks capped with sponge stoppers. Carbon treatment using a dosage of 10 g/l was performed on the contents in two of the flasks. The other two flasks served as controls.

One control flask and one carbon treated flask were then incubated at room temperature (22 °C) for 72 hours. The other control and carbon treated flasks were incubated at 4 °C for 72 hours. Samples were withdrawn from each flask at 8-hour intervals . Turbidity, CO_2D values and viable bacterial cell counts were determined.

4.2.2.12 The Effect of Hydrogen Ion Concentration on Turbidity Development in Carbon Treated Effluents

A liter of cold tap water was used to rinse ten successive lots of raw potato French fry slices. The effluent was divided into two equal portions of 500 ml each. One portion of the effluent was dispensed into a sterilized 1-liter beaker containing a magnetic stirring bar. A 0.1 M citric acid solution, added in a dropwise manner, was used to acidify the effluent until a pH of 4.5 was reached.

Acidification of the effluent caused precipitation. The precipitate was removed by vacuum filtration using a Whatman No. 5 filter paper. The filtrate was collected in a 1-liter Erlenmeyer flask and then capped with a sponge stopper. A control flask containing non-acidified effluent was also included as a control.

Samples were withdrawn from the control and the acidified effluents at 8-hour intervals over a period of 96 hours. Determinations of turbidity, CO_2D valies and viable bacterial cell counts were done on the samples.

4.2.2.13 The Adsorption/Filtration of Yeast and Mold

Cultures of S. cerevisiae and A. niger were used to study the adsorption/filtration of yeast and mold by powdered activated carbon respectively. A liter of sterilized phosphate buffered water was innoculated with culture of A. niger, thoroughly stirred and

dispensed in 200-ml volumes into five sterilized 250-ml Erlenmeyer flasks. The contents of the flasks were treated with the following dosages of powdered activated carbon: 0.0, 0.5, 1.0, 2.0 and 3.0 g/l respectively, and then filtered.

4.2.2.14 The Effect of Initial Bacterial Population in the Effluent on Adsorption/Filtraton

Three batches of effluents (1 liter each) were prepared and reused ten times as described in the previous sections. Each batch of the effluents was sterilized by millipore filtration and then inoculated with one level of B. subtilis. It was dispensed in 100-ml volumes into seven sterilized 250-ml Erlenmeyer flasks containing the following carbon dosages: 0.0, 0.5, 1.0, 2.0, 3.0, 4.0 and 5.0 g/l respectively. The effluents were enumerated for the viable bacterial cell counts after carbon treatment and filtration.

4.2.2.15 Contact Time Study

A liter of sterilized phosphate buffered water was inoculated with a pure culture of B. subtilis, thoroughly stirred and divided into two equal portions in two 1-liter Erlenmeyer flasks. The contents of the flasks were treated with 1.0 and 5.0 g/l of powdered activated carbon respectively. Aliquots (20 ml) were withdrawn from the flasks at the following time intervals: 0.0, 5.0, 15, 30 seconds, 1, 3, 5 and 10 minutes while the contents

of the flasks were being shaken on a rotary shaker operating at 3000 r.p.m.

In a similar study, a liter of effluent was sterilized by millipore filtration and then inoculated with a pure culture of B. subtilis. The study was then carried out in an identical manner as described above.

4.2.3 Analytical Methods

4.2.3.1 Measurement of Turbidity

Turbidity in J.T.U. [Jackson Turbidity Unit] was determined by means of a Fisher Turbidity Meter (Model DRT 100).

The instrument was first standardized with the standard provided. Care was always taken to obtain a homogeneous sample. The glass vessel for the sample was sanitized and thoroughly rinsed before it was used for a second sample.

Turbidity in the effluents became visually noticeable at around 20 J.T.U. Hence, intermittent carbon treatments on the effluents were performed when the turbidity readings reached 20 $\pm$ 5 J.T.U.

4.2.3.2 Measurement of pH

Changes in pH of the effluents were measured by means of a Fisher Accumet pH/ion Meter (Model 520). The automatic temperature compensation probe was utilized when needed.

4.2.3.3 Oxygen Demand Determination

The oxygen demand was measured directly in terms of parts per million [ppm] of CO_2D (Carbon Dioxide Demand) by the Aquarator method.

Stock Acetate Solution. A stock acetate solution was prepared by dissolving 2.127 g sodium acetate trihydrate in distilled water and diluting to 1 liter in a volumetric flask. This solution had an oxygen demand of 1000 mg/l.

Standard acetate solutions were prepared by obtaining aliquots of the stock solution (5 to 30 ml) and diluting to 100 ml with distilled water in separate volumetric flasks.

The carbon dioxide pressure regulator was set to a reading of 10 psi. The flowmeter on the Aquarator was adjusted to obtain a rate of 130 ml/minute of carbon dioxide gas.

The temperature of the sample furnace was set at 900 °C. The carbon furnace was initially set at approximately 400 °C, and was gradually increased until the reading on the IR meter was between 5 and 6. This adjustment ensured that all the oxygen in the line had been converted to carbon monoxide.

CO_2D Determination Samples were diluted with distilled water when necessary. Aliquots (20 ml) were withdrawn by means of a syringe and injected into the Aquarator to obtain a reading on the IR meter. Duplicates were done on each sample. The values were converted to ppm of CO_2D.

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

5.1 Adsorption/Filtration of Selected Microorganisms by Powdered Activated Carbon

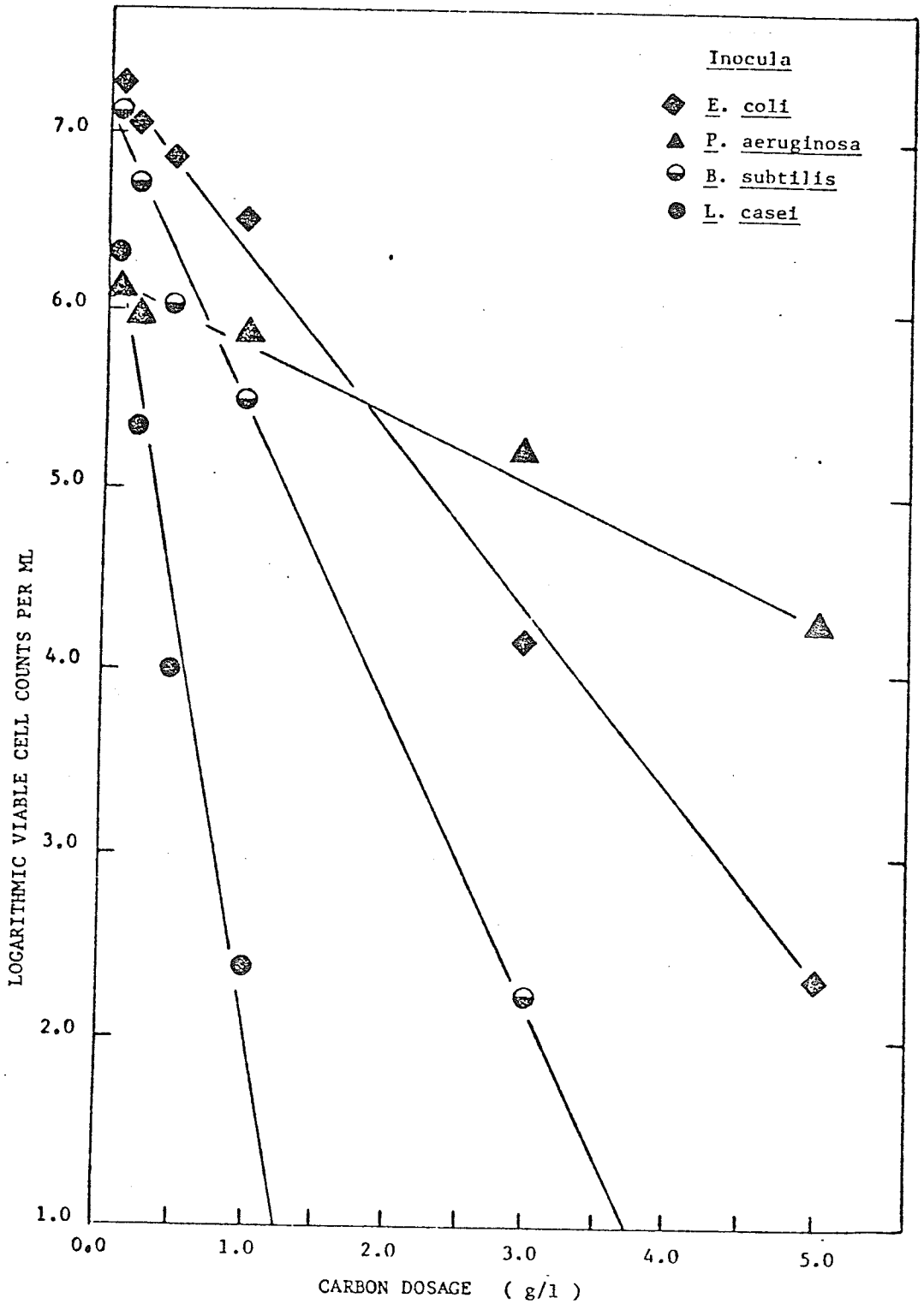
5.1.1 The Effect of Bacterial Morphology on Adsorption/Filtration

The following rod shaped microorganisms were investigated as to their removal by varying dosages of powdered activated carbon: Escherichia coli, Pseudomonas aeruginosa, Lactobacillus casei and Bacillus subtilis. Results on the removal of these rod shaped microorganisms are illustrated in Figure 3.

It was observed that powdered activated carbon could remove all of the selected rod-shaped bacteria, the extent of removal, however, was dependant on the applied dosages of activated carbon. Among the four microorganisms studied, B. subtilis was shown to be more readily adsorbed/filtered than E. coli, and L. casei much more readily removed than P. aeruginosa. From Figure 3, it would require about 1.5 g/l of powdered activated carbon to reduce the L. casei from 1.6×10^6 to less than 10 organisms/ml, compared to about 10 g/l carbon dosage for P. aeruginosa with similar initial population for similar degree of bacterial reduction. To achieve the final bacterial load of about 10 organisms/ml, it would require a carbon dosage of 4.0 and 10 g/l for B. subtilis and E. coli respectively, as extrapolated from the reduction curves in Figure 3.

The initial cell concentrations of the microorganisms in the buffered water have been shown to be important in the rate of bacterial removal by powdered activated carbon, as will be discussed in

FIGURE 3 The Effect of Bacterial Morphology on Adsorption/ Filtration [Bacilli] (Appendix Table 3)



later section. In view of this fact, only the above comparisons could be made from the available data.

In another study, three types of cocci were investigated for their adsorption/filtration by powdered activated carbon. They are Micrococcus roseus, Staphylococcus aureus and Streptococcus faecalis. Results on their removal by powdered activated carbon are illustrated in Figure 4.

Figure 4 shows that S. faecalis was more readily removed than S. aureus. To reduce the initial population of these cocci from about 10^7 to less than 10 organisms/ml, it would require carbon dosages of about 1.5 and 3.5 g/l for S. faecalis and S. aureus respectively. The more efficient removal of S. faecalis could perhaps be due to the tendency of S. faecalis to form short chains which would provide a greater surface area for filtration. A carbon dosage of between 5.0 and 10 g/l would be required to reduce the M. roseus population from 9.8×10^6 to less than 10 organisms/ml, as extrapolated from its reduction curve in Figure 4.

Figure 5 compares the results obtained for the removal of two bacilli, i.e. E. coli and B. subtilis amd two cocci, i.e. S. aureus and S. faecalis, all of which had an initial cell concentration of about 10^7 organisms/ml in phosphate buffered water. The two cocci were more readily adsorbed/filtered than the two baccili, as shown in Figure 5. This observation appears to be consistent with

FIGURE 4 The Effect of Bacterial Morphology on Adsorption/ Filtration [Cocci] (Appendix Table 4)

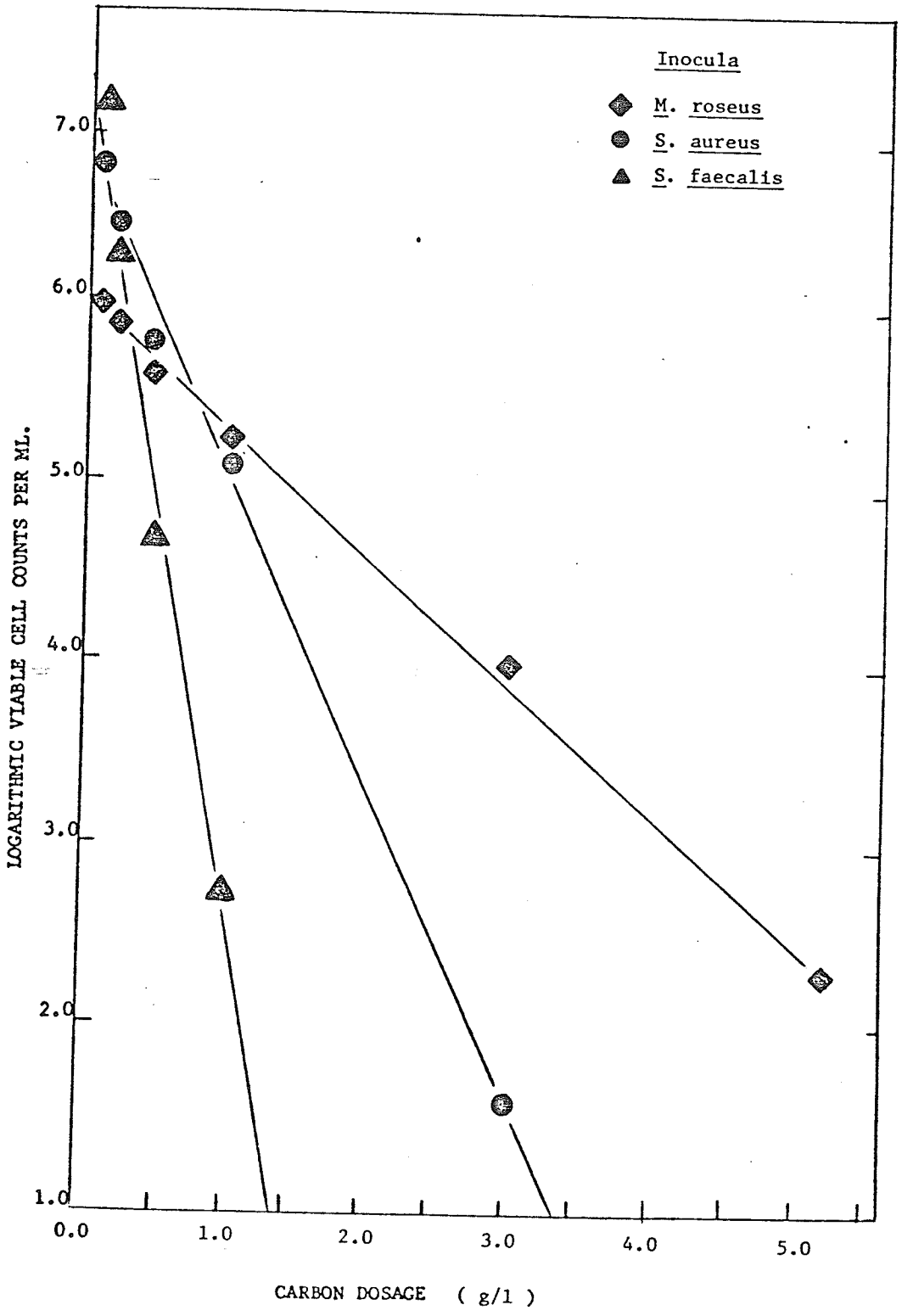
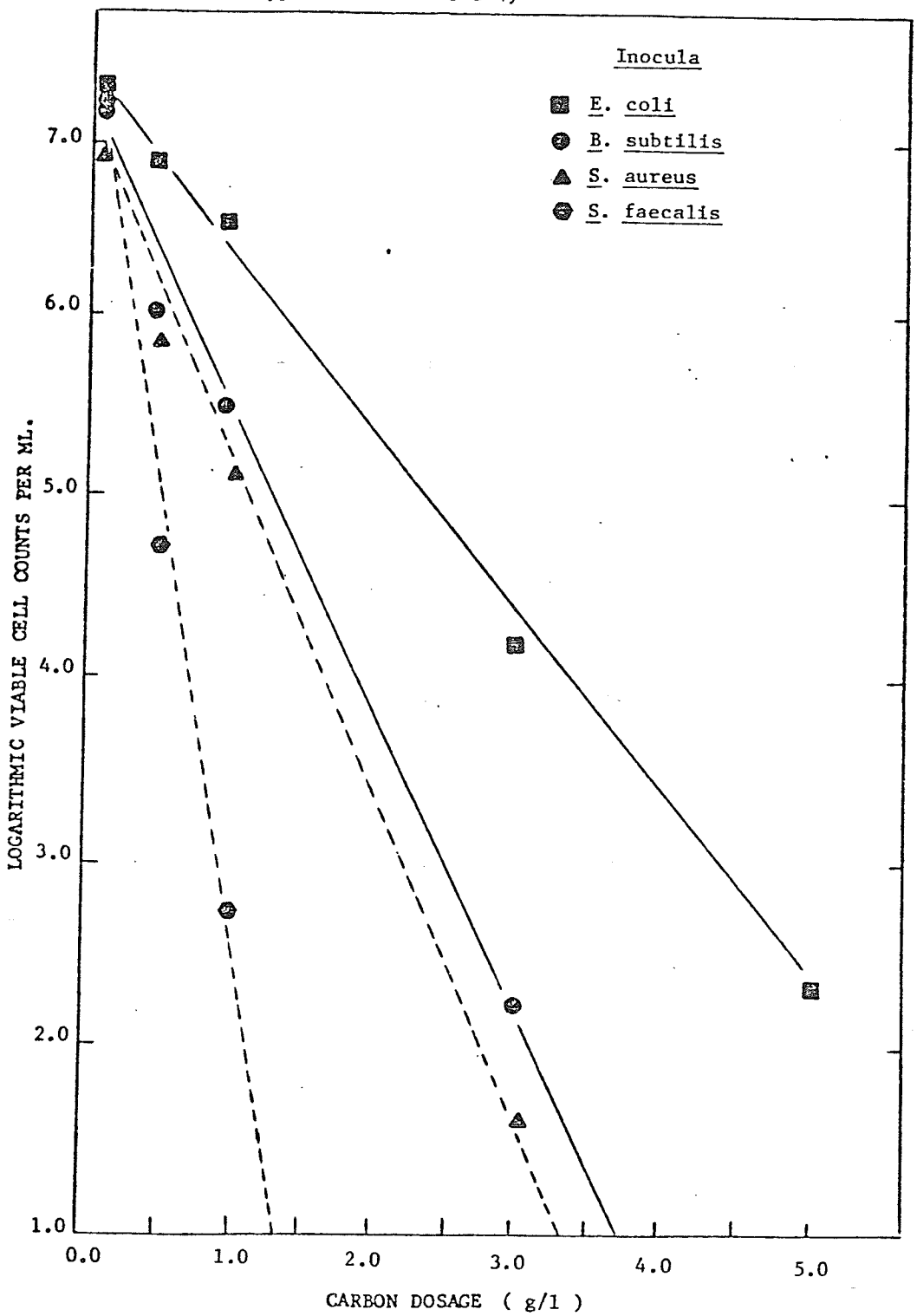


FIGURE 5 The Effect of Bacterial Morphology on Adsorption/ Filtration [Selected Cocci & Bacilli]

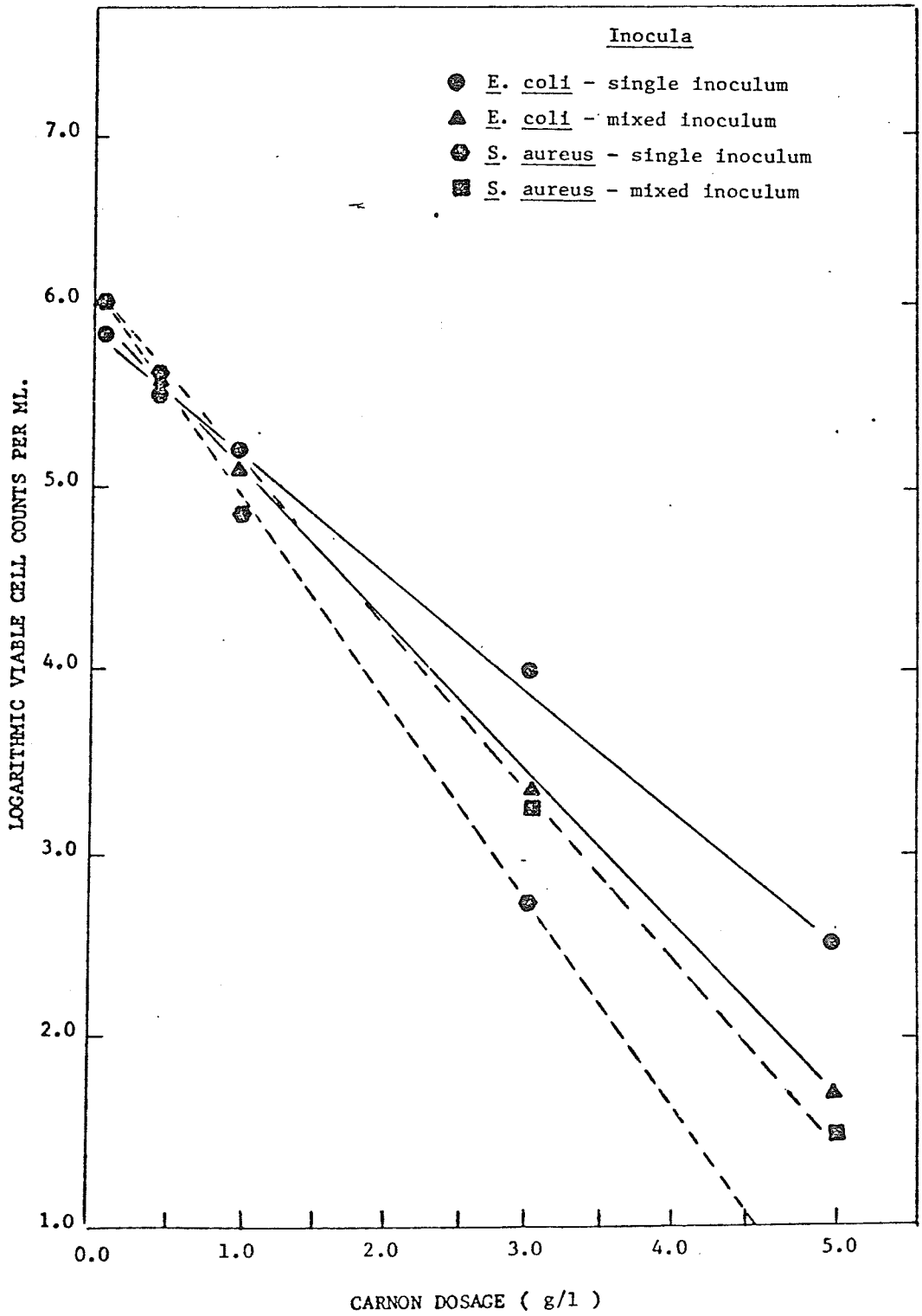
(Appendix Tables 3 & 4)



that obtained by Salus (124) who found the cocci to be most readily adsorbed than the typhoid bacteria and E. coli.

Figure 6 illustrates the adsorption/filtration of E. coli and S. aureus in two studies. In one study, they were individually inoculated into two separate volumes of buffered water and then carbon treated. In another study, they were concurrently inoculated in a volume of buffered water which was subsequently carbon treated in a similar manner. It was observed that both the microorganisms were simultaneously removed by the powdered activated carbon. This resulted in a greater residual bacterial concentrations of both the organisms in the filtrates than the case when they were individually inoculated and carbon treated. The results indicates that S. aureus was more readily adsorbed/filtered than E. coli when the two organisms were concurrently present in the buffered water. This was as predicted from the from the individual removal curves as shown in Figure 6. The steeper the slope represents greater removal. This preferential adsorption/filtration is also revealed by the increasing proportion of the E. coli in the filtrates after carbon treatment. This selectivity, however, should not be accounted for solely on the basis of cellular morphology. It is more likely to be due to a variety of factors. Furthermore, S. aureus was present in a greater proportion than E. coli in the phosphate buffered water prior to any carbon treatment.

FIGURE 6 The Effect of Bacterial Morphology on Adsorption/ Filtration [Inocula: S. aureus & E. coli]
(Appendix Table 5)



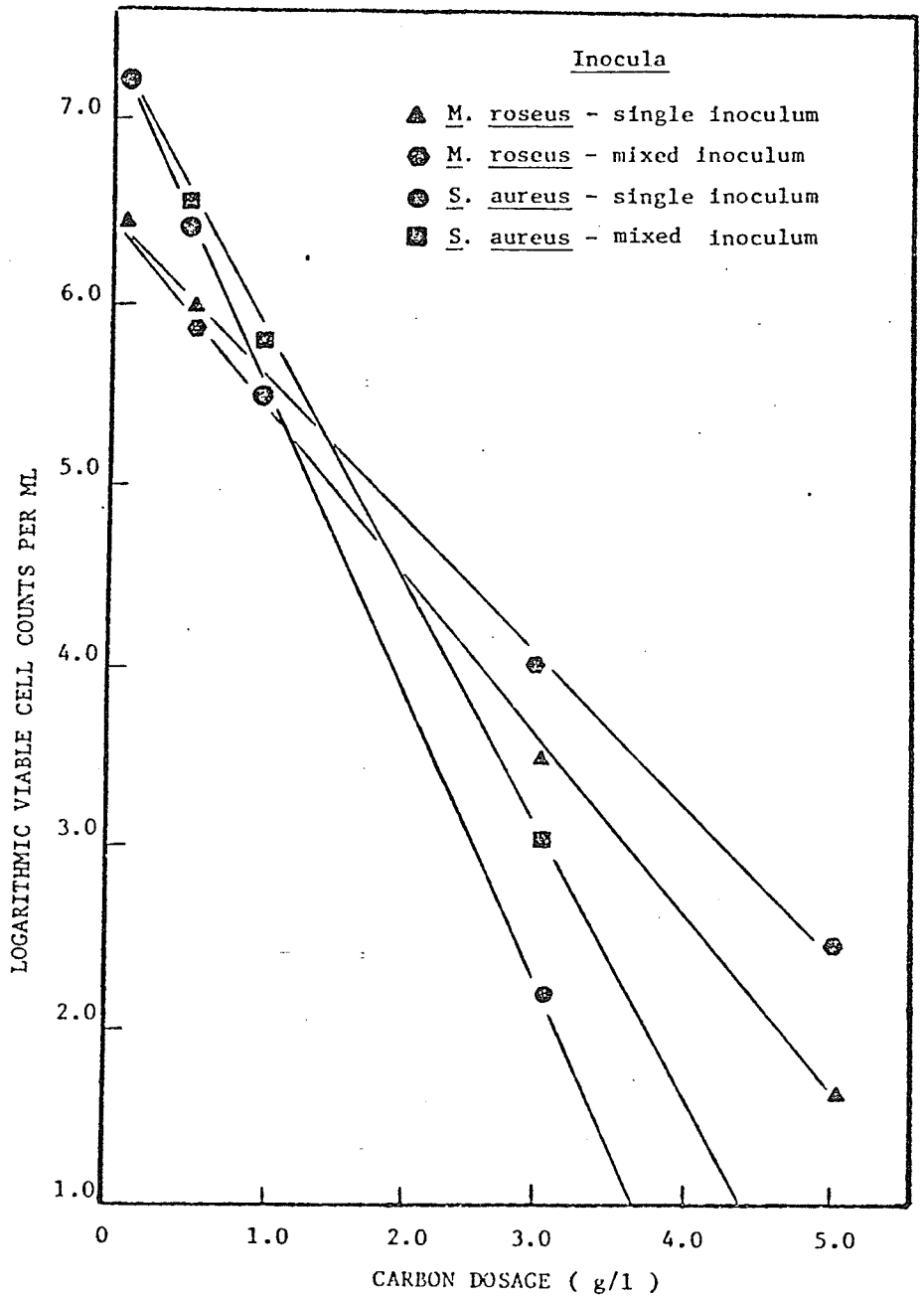
5.1.2 The Effect of Bacterial Cell Size on Adsorption/Filtration

Bacterial cell size could also be a factor in the adsorption/filtration process, since adsorption takes place most readily when the size of the adsorbates is similar to that of the pores of the activated carbon. In this study, two genera of the spherical bacteria were studied for their removal by powdered activated carbon. The microorganisms were S. aureus and M. roseus. S. aureus has a diameter of about 1.0 μ while M. roseus is about 2.5 μ in size. Results on the reduction of the bacterial populations by varying carbon dosages are illustrated in Figure 7.

S. aureus was observed to be better adsorbed/filtrated than M. roseus either as a pure inoculum in the buffered water or as a mixed inoculum with the latter. As a mixed inoculum, both organisms were simultaneously adsorbed/filtered. With increasing carbon dosages, S. aureus was observed to be preferentially removed in a greater degree than M. roseus. This resulted in its more efficient removal over M. roseus, as indicated in Figure 7.

The more efficient adsorption of S. aureus than M. roseus could perhaps be explained by its relatively small size. Of the two species, the size of S. aureus compares more favorably to the macropore size of the activated carbon particles. It is to be noted, however, that bacterial cells are much larger than most of the macropores of the activated carbon. Furthermore, the tendency of these spherical microorganisms to form clusters and short chains in some

FIGURE 7 The Effect of Bacterial Cell Size on Adsorption/Filtration [Inocula: S. aureus & M. roseus] (Appendix Table 6)



genera is also of importance. S. faecalis for example, is similar to S. aureus in size, was observed to be more efficiently removed than S. aureus (Figure 4). This could likely be due to the ability of S. faecalis to form short chains that would be more readily filtered off than other cells that exist individually.

5.1.3 The Effect of Cell Wall Composition on Filtration/Adsorption

Cell walls of many bacteria are exceptionally complex, being mosaics of several different macromolecular constituents, which include lipids and proteins, as well as a complex polymer of the type known as mucopolysaccharides. The Gram reaction is indicative of some consistent basic chemical differences between the cells of Gram-positive and Gram-negative forms. The cell wall, for example, is thinner in Gram-negative bacteria, ranging from 10 to 25 mμ in thickness. The cell wall substances are also highly individualistic in kind and amount in different bacterial species. In light of adsorption as a chemical surface phenomenon, it is of interest to investigate any difference on the adsorption of bacteria with basic cell wall compositional variations, as indicated by the Gram reaction.

Among the rod-shaped microorganisms studied in Section 4.1, L. casei and B. subtilis are the Gram-positive forms, while P. aeruginosa and E. coli are Gram-negative microorganisms. Figure 3

in Section 4.1 shows that L. casei was more readily adsorbed/filtered than P. aeruginosa while B. subtilis was more easily eliminated than E. coli. It would appear that the Gram-positive organisms were better adsorbed/filtered than the Gram-negative forms. However, studies on the Gram-positive cocci indicated also variations in their trends of removal, as illustrated in Figure 4. Cell wall composition should perhaps be considered along with other possible factors including morphological differences and extracellular components such as slime and capsules as affecting carbon adsorption/filtration of the microorganisms.

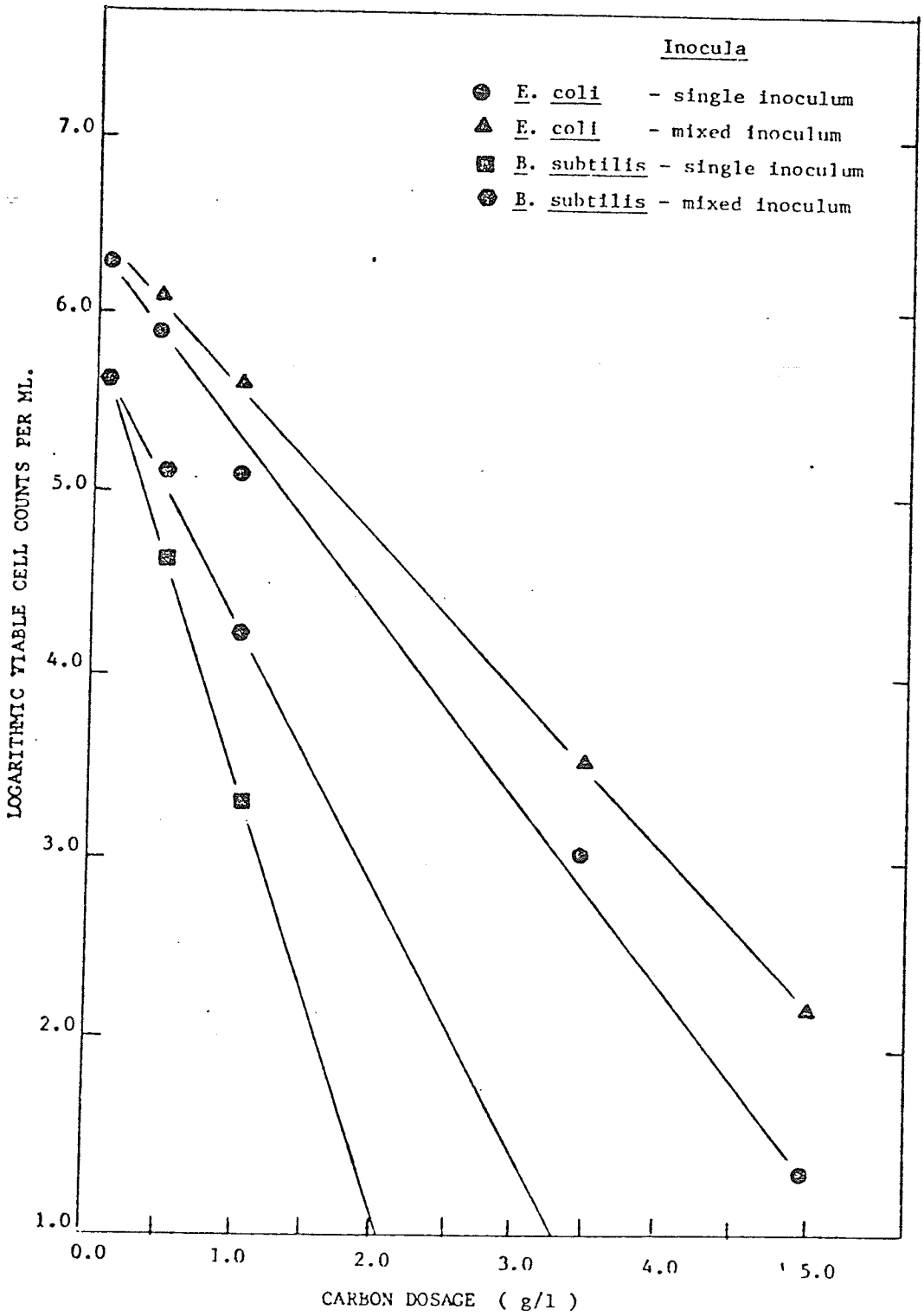
Figure 8 illustrates the adsorption/filtration of E. coli, a Gram-negative bacillus, and B. subtilis which is Gram positive. It shows that B. subtilis was adsorbed/filtered much more readily than E. coli, irrespective of the absence or presence of the latter.

5.1.4 The Effect of Motility of Selected Microorganisms on Adsorption/Filtration

The presence of flagella in a bacterium could be expected to possibly exert an effect on the adsorption of the cell by the activated carbon. Physically, it renders the bacterium in a mobile state in the aqueous environment. Biochemically, the locomotary organelle consists of flagellar proteins which are known to be important in surface chemistry (74).

Among the four microorganisms studied in Section 4.1, L. casei was the only non-flagelled species. It was most readily

FIGURE 8 The Effect of Cell Wall Composition on Adsorption/ Filtration [Inocula: E. coli & B. subtilis] (Appendix Table 7)



adsorbed/filtered than the other three genera which are motile.

Figure 9 illustrates the adsorption/filtration of B. subtilis, a peritrichous rod-shaped bacterium, and L. casei. It is noted that L. casei was more readily adsorbed/filtered than B. subtilis both as a pure inoculum and as a binary mixture with the latter in the buffered water. At dosages of 1.0 g/l and greater, the filtrate consisted almost exclusively of B. subtilis, as indicated in Figure 9.

5.1.5 Filtration/Adsorption of Yeasts and Molds by Powdered Activated Carbon

Yeasts and molds were found to be present in potato slice rinse effluent, but in much smaller numbers than the bacteria. In this study, a common yeast, Saccharomyces cerevisiae, and a bread mold, Aspergillus niger were investigated for their filtration / adsorption by powdered activated carbon. Results obtained are given in Table 3.

It was observed (Table 3) that both S. cerevisiae and A. niger were removed by the various applied levels of carbon dosages. However, the control experiment (0.0 g/l carbon dosage) revealed that the effective elimination of both microorganisms from the buffered phosphate water was attirbuted by the filter paper. With a 0.0 g/l carbon dosage, the S. cerevisiae was reduced from an initial viable count of 4.8×10^3 to 20 organisms/ml, and the A. niger,

FIGURE 9 The Effect of Motility of Selected Microorganisms on Adsorption/Filtration [Inocula: B. subtilis & L. casei] (Appendix Table 8)

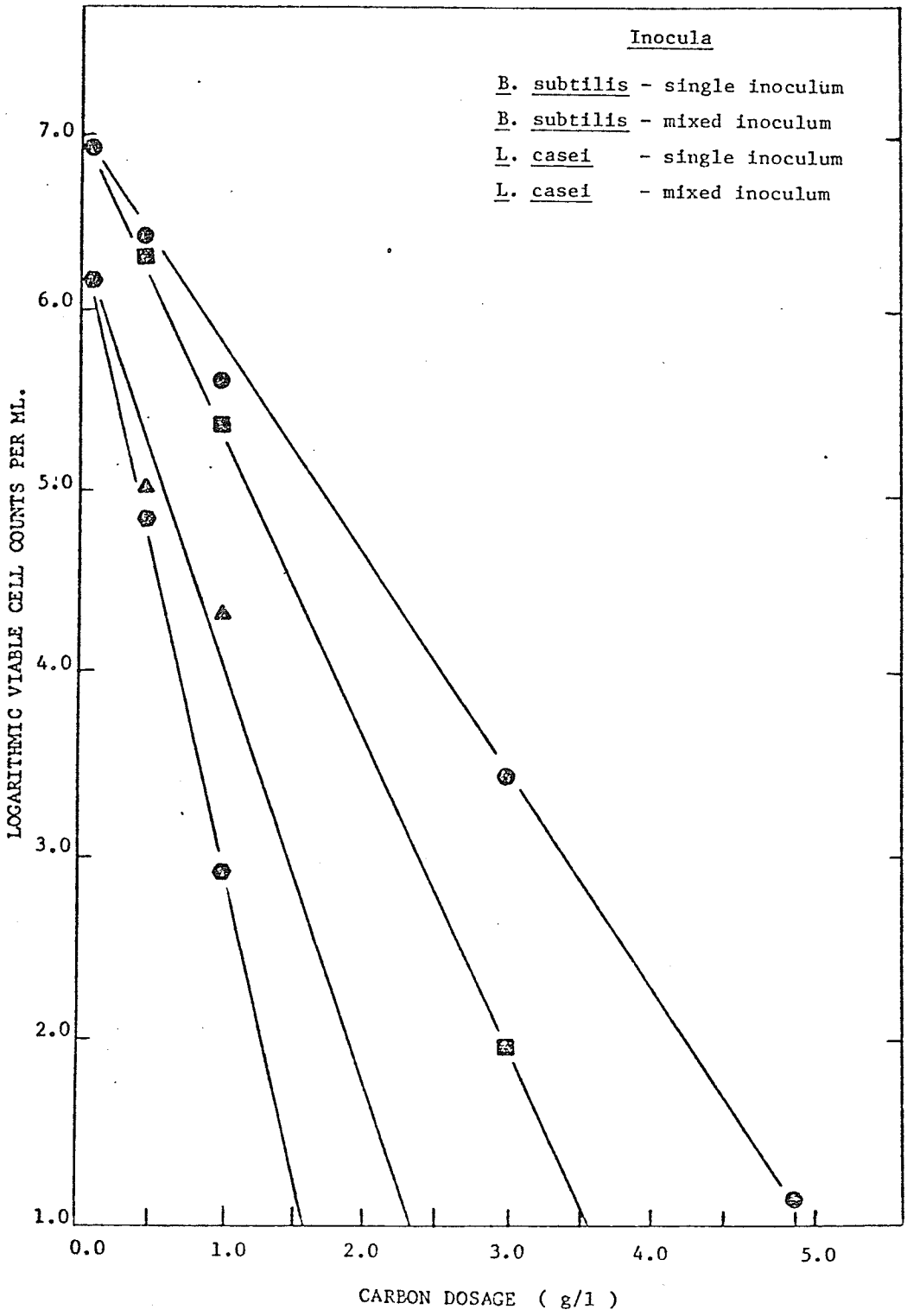


TABLE 3 Filtration/Adsorption of Yeasts and Molds by Powdered Activated Carbon [Inocula: *S. cerevisiae* & *A. niger*] (Initial Cell Concentrations: *S. cerevisiae* 4.8×10^3 org./ml; *A. niger* 6.5×10^2 org./ml)

Carbon Dosage (g/l)	Viable Cell Counts Per ml	
	S. cerevisiae	*A. niger*
0.0	20	15
0.5	16	8
1.0	10	4
3.0	6	4
5.0	5	0

from 6.5×10^2 to 15 organisms/ml.

The increasing carbon dosages appeared to exert a positive effect on the filtration process. With both the organisms, a more efficient reduction was observed with increased carbon dosages. This could be explained by the fact that the greater the applied carbon dosage, the thicker the carbon bed formed on the filter paper, and thus the better filtration observed.

At each carbon dosage, the mold was noted to be better filtered than the yeast, as indicated in Table 3. This could readily be accounted by the mycelial structure of the mold which would greatly facilitate the filtration process.

The removal of these two organisms as a simple filtration process could be accounted by the type of filter paper used. In these studies, the filter paper used has a Whatman particle retention size of 2.5 μ with a 98 percent retention efficiency. Filter paper of this grade was necessary for effective separation of the carbon particles from the treated samples. The yeast cells with cell sizes ranging from 10 to 25 μ were thus also effectively filtered out.

5.1.6 A General Discussion

This section of the investigation studied the adsorption/filtration of various genera of microorganisms by powdered activated carbon. The genera chosen, although not necessarily the species,

have been shown to be present in the potato slice rinse water (128). A total of nine microorganisms were studied, including a yeast species, S. cerevisiae and a mold, Aspergillus niger. In general, it was observed that at sufficient dosages, powdered activated carbon was capable of yielding a great reduction of the microbial populations in the water. The comparatively large size of the yeast cells and mold mycelia render these two organisms highly susceptible to effective removal from the water by simple filtration process.

Variations in the adsorption/filtration patterns of the various test organisms were observed. Some organisms were noted to be more readily filtered/adsorbed than the others. With phosphate buffered water inoculated with similar levels of the test organisms, the cocci appeared to be more readily adsorbed/filtered than the rod shaped bacteria. Among the rod shaped organisms studied, L. casei, a rod in chain, was found to be most effectively removed than the other three genera of bacilli. This could be due to, among other factors, the tendency of this organisms to form chains which could be more susceptible to mechanical trapping and filtered out. Similarly this explanation could be applied to the removal of S. facecalis. However, the aggregation of bacterial cells into clusters or chains is dependent on a number of factors, one of which being the age of the cultures. In general, a carbon dosage of 3.0 g/l would be sufficient to obtain a substantial reduc-

tion of most of the microbial populations with initial concentrations in the range of 10^6 - 10^7 organisms/ml.

Organisms with certain common characteristics appeared to show similar adsorption/filtration patterns. For example, the cocci were more readily adsorbed/filtered than the rod shaped organisms studied in this section. However, the small number of test organisms studied in this section and the design of some of the experiments did not permit a general conclusion to be made. Furthermore, the experimental design did not furnish proof for adsorption, hence the phrase adsorption/filtration is used in this investigation.

Variations in the adsorption/filtration patterns were believed to be attributed to a number of factors such as morphological differences, presence of certain capsular substances, possession of flagella or fimbriae, and aggregations of the cells into chains or irregular clusters. Many of these factors are inherent characteristics of the organisms. These studies illustrate the difficulty of isolating the effects contributed by each individual factors in the adsorption/filtration process. Furthermore, many of the flagellated organisms may loose their flagella and yet retain their viability. The formation of chains or clusters is irregular and dependent on a number of factors. It would seem reasonable to believe an interplay of these possible cellular factors, and other physical factors associated with adsorption and filtratration, that give rise to the variations in the adsorption/filtra-

tion patterns of the genera of organisms studied.

5.2 Carbon Treatment of Recycled Potato Slice Rinse Effluent

Microbiological quality of the effluent is of prime concern when the effluent is to be reused at the same processing step. Studies in Section 4.1 have shown the potential for powdered activated carbon to substantially remove the test organisms inoculated in buffered phosphate water. In the following studies, attempts were made to evaluate the efficiency of microbial removal from potato slice rinse effluent by powdered activated carbon treatment, and to establish the treatment parameters such as number of reuse cycles prior to carbon treatment, contact time, methods of carbon application and the optimal dosages for such applications.

5.2.1 Microbial Removal from Effluent by Carbon Treatment

In this study, effluent that had been reused ten times was treated with 0.0, 0.5, 1.0, 3.0, 5.0 and 10.0 g/l powdered activated carbon, filtered and enumerated for the resultant viable bacterial cell counts. Figure 10 illustrates the results obtained and the average of two such trials.

After 10 sequential reuse cycles, one batch of effluent contained 3.3×10^4 organisms/ml, while the other similar batch had a viable cell count of 7.8×10^3 organisms/ml, as shown in Table 4. Figure 10 indicates that the effluent having a higher viable

FIGURE 10 Microbial Removal From Effluent by Powdered Activated Carbon Treatment

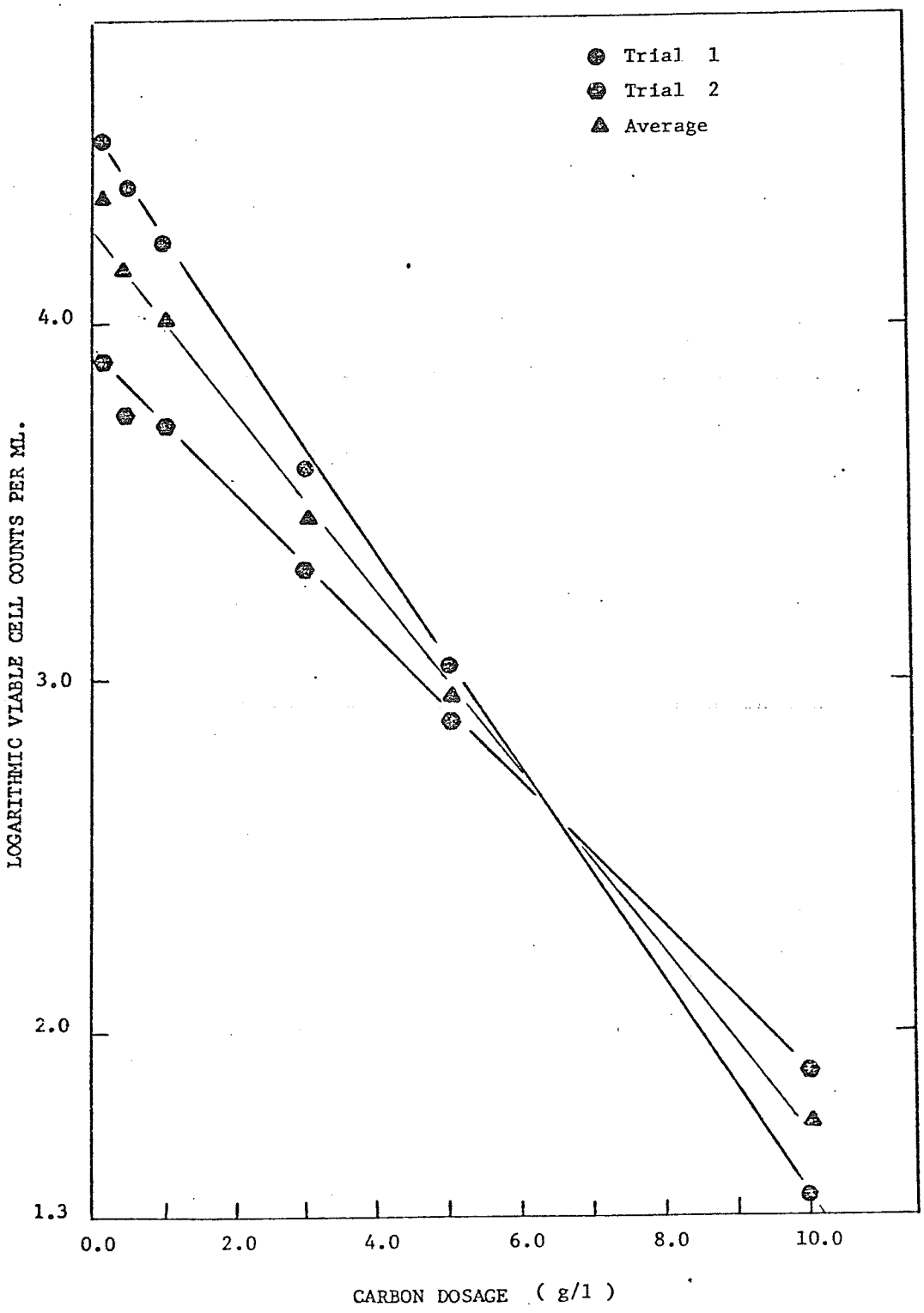


TABLE 4 Microbial Removal from Effluent by Carbon Treatments

Carbon Dosage	Viable Cell Counts Per ml		
(g/l)	Trial 1	Trial 2	Average
0.0	3.3×10^4	7.8×10^3	2.1×10^4
0.5	2.4×10^4	5.6×10^3	1.5×10^4
1.0	1.7×10^4	5.3×10^3	1.1×10^4
3.0	3.8×10^3	1.2×10^3	2.5×10^3
5.0	1.1×10^3	8.2×10^2	7.0×10^2
10.0	35	62	49
15.0	**	**	**

cell count showed a slightly better rate of microbial removal by powdered activated carbon over the other effluent which contained a lower microbial population. On the average, it would require about 12 g/l powdered activated carbon to obtain a final bacterial level of 30 organisms/ml, as extrapolated from the curve in Figure 10.

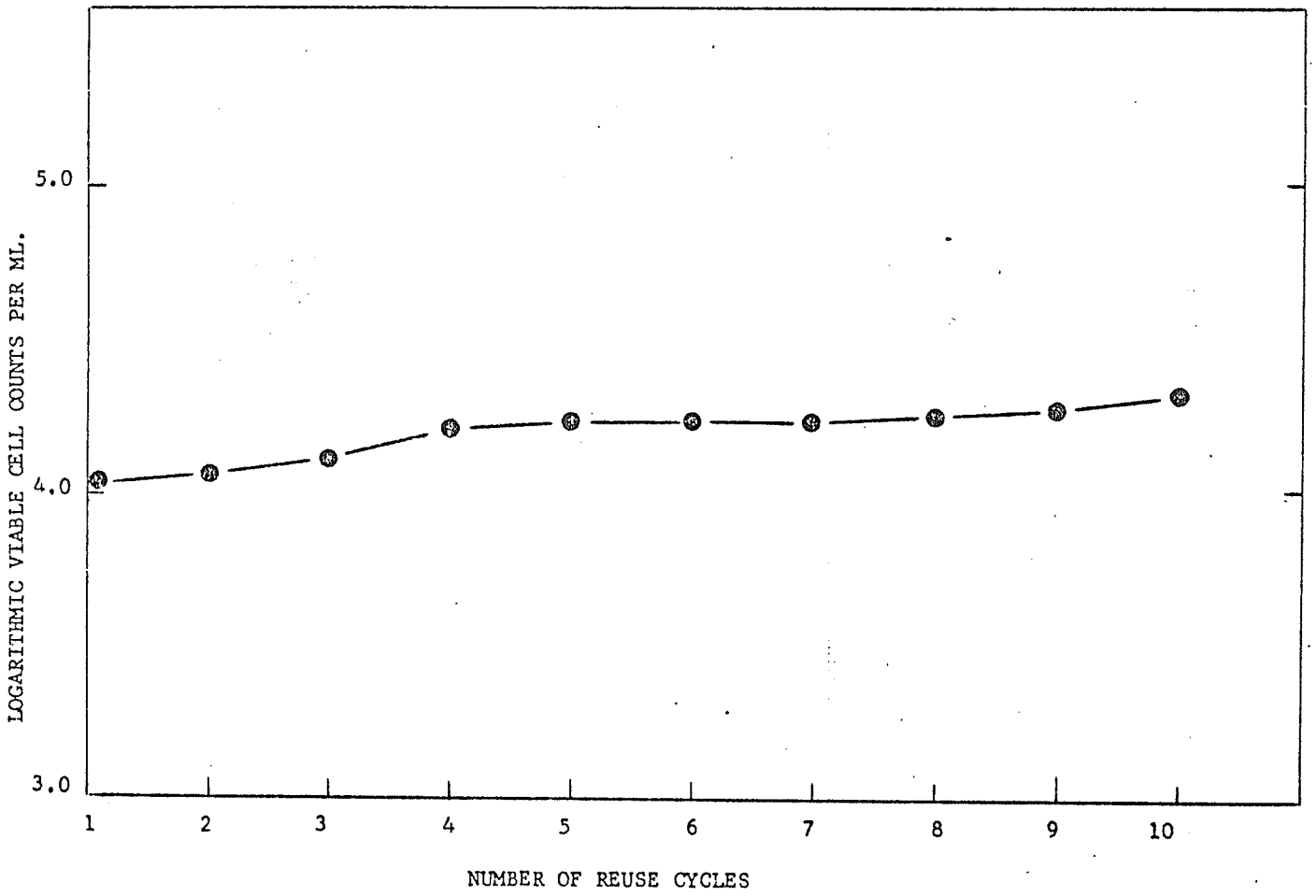
5.2.2 Build Up of Viable Bacterial Cell Count During Sequential Effluent Reuse

Figure 11 illustrates the increase in microbial population using a definite volume of effluent that was reused ten times. It was noted that each rinse cycle yielded about 10^3 - 10^4 organisms/ml, as shown in Table 5. Figure 11 indicates that the increase in viable bacterial cell count was somewhat of an arithmetic progression. In this particular run, the bacterial cell count increased from 2.1 x 10^3 to 8.1 x 10^4 organisms/ml, with an average rate of increase of about 6.0 x 10^3 organisms/ml per rinse cycle.

Unlike the build up of organics in the effluent, the microbial population did not show an equilibrium condition within the number of reuse cycles (10 reuse cycles) employed in this study. This indicated a direct physical removal of the organisms from the potato slices into the rinse water.

The arithmetic progression in bacterial build up would also enable an estimation of the desirable number of reuse cycles prior

FIGURE 11 Build-Up of Viable Bacterial Cell Counts During Sequential Effluent Reuse (Appendix Table 9)



to a carbon treatment, and the necessary dosage of powdered activated carbon, once the viable cell counts of the first intial rinses are determined. This would prevent excessive microbial load that would subject the effluent to questionable reuse possibilities.

5.2.3 The Effect of Effluent Strengths on Adsorption/Filtration

Several studies have shown activated carbon to be effective in adsorbing organic compounds in food processing wastes (60, 67, 138). The presence of organics would thus be expected to interfer with the adsorption/filtration of the microbial population in the effluent, the extent of such an interference could perhaps depend on the amount of the organics present in the effluent. However, the levels of organics in the effluent have been shown to reach an equilibrium condition after a certain number of sequential reuse cycles. Gallop et al. (61) had shown that equilibrium conditions for COD, sugars and starch in the potato slice rinse effluent were reached after seven reuse cycles. When such equilibrium conditions for the COD, sugars and starch are reached after a certain number of reuse cycles, the effects of organics on the adsorption/filtration of the microbial population in the effluent would become a constant factor despite the number of reuse cycles.

In this study, effluents at three reuse stages (i.e. first rinse, fifth rinse and tenth rinse) with effluent strengths of 421, 5922 and 7423 ppm CO_2D (Carbon Dioxide Demand) were collected,

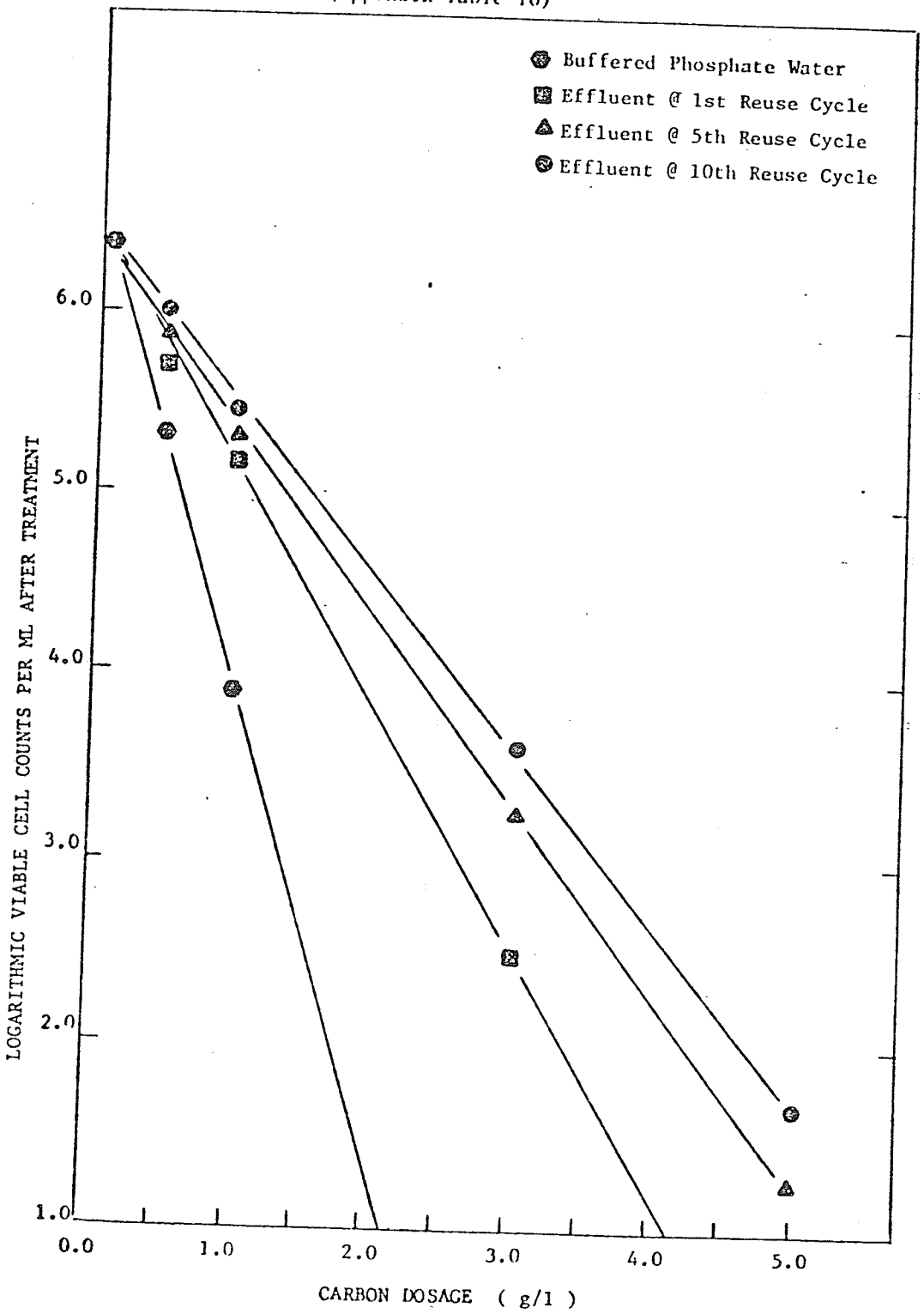
rendered sterile and inoculated with B. subtilis. They were then treated with the following dosages of powdered activated carbon: 0.0, 0.5, 1.0, 3.0 and 5.0 g/l and filtered. Results on the final viable cell counts after carbon treatments are illustrated in Figure 12.

Figure 12 shows that the presence of organics lowered the efficiency of the adsorption/filtration of the microorganisms from the effluents. Adsorption/filtration was most efficient in the inoculated phosphate buffered water. It also appears that the greater the amount of organics present in the effluent, the less efficient the adsorption/filtration of the organisms. However, with sufficient carbon dosages the microbial population could be substantially reduced. Figure 12 indicates a carbon dosage of about 4.0 - 6.0 g/l would be required to reduce the viable cell count from 3.5×10^6 to less than 10 organisms/ml, for the three effluents of different effluent strengths.

5.2.4 The Effect of Initial Bacterial Population in Effluent on Adsorption/Filtraton

The previous study has shown the somewhat arithmetic increase of viable bacterial cell count with increasing number of reuse cycles. It would thus be expected to require different dosages of powdered activated carbon to obtain the same level of microbiological quality of the effluents which have different initial microbial populations. In this study, effluent after ten

FIGURE 12 The Effect of Effluent Strengths on Adsorption/ Filtration [Test Organism: B. subtilis] (Appendix Table 10)

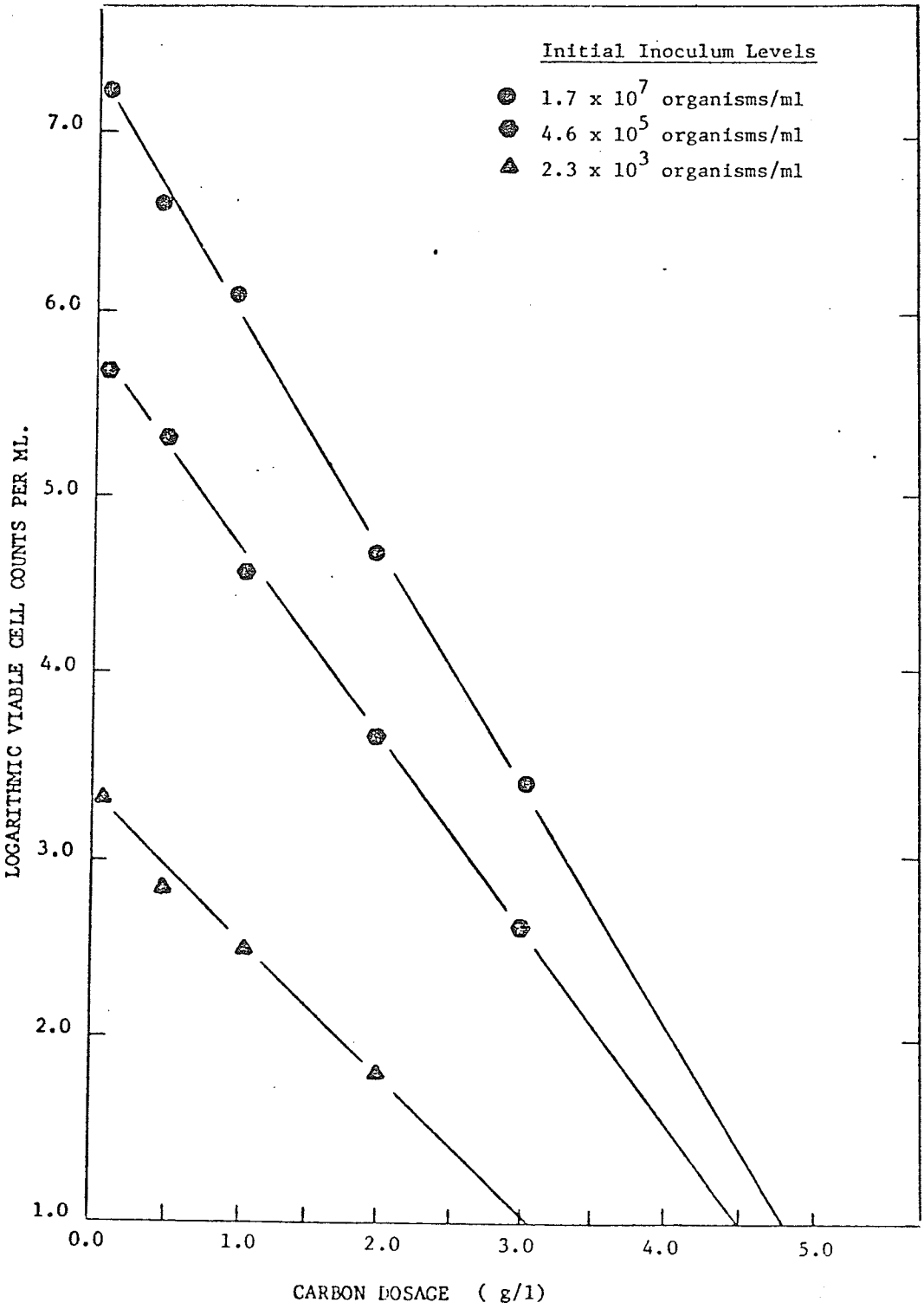


reuse cycles were sterilized, inoculated with different levels of B. subtilis, carbon treated and then filtered, as described in Section 3.2.2.14. The resultant viable cell counts after carbon treatments are illustrated in Figure 13.

Figure 13 shows that initial bacterial concentration had an effect on the efficiency of microbial reduction by powdered activated carbon. Effluents with a higher bacterial cell count appeared to have a greater rate of microbial removal, as indicated by the slopes of the reduction curves. However, to obtain a desirable low viable bacterial count such as 10 organisms/ml, effluent with a higher microbial content requires comparatively higher carbon dosages, as illustrated by Figure 13. Thus, to arrive at a final viable cell count of 10 organisms/ml, it would require about 3.0, 4.5 and 5.0 g/l powdered activated carbon for effluents with an initial viable cell count of 2.3×10^3, 4.6×10^5 and 1.7×10^7 organisms/ml respectively, as extrapolated from the curves in Figure 13.

The desirable level of viable bacterial count in the effluent would therefore depend on both the carbon dosage and the initial microbial population in the effluent. However, in the rinsing process with a treatment frequency of ten reuse cycles per carbon treatment, the effluent would usually contain from 10^3 to 10^4 organisms/ml without any significant variations. It would thus require almost the same carbon dosage for each treatment.

FIGURE 13 The Effect of Initial Bacterial Population In Effluents on Adsorption/Filtration [Inoculum: B. subtilis] (Appendix Table 11)



5.2.5 Contact Time Study

In one study, phosphate buffered water inoculated with B. subtilis was treated with 1.0 and 5.0 g/l powdered activated carbon. In another study, sterilized effluent was used instead.

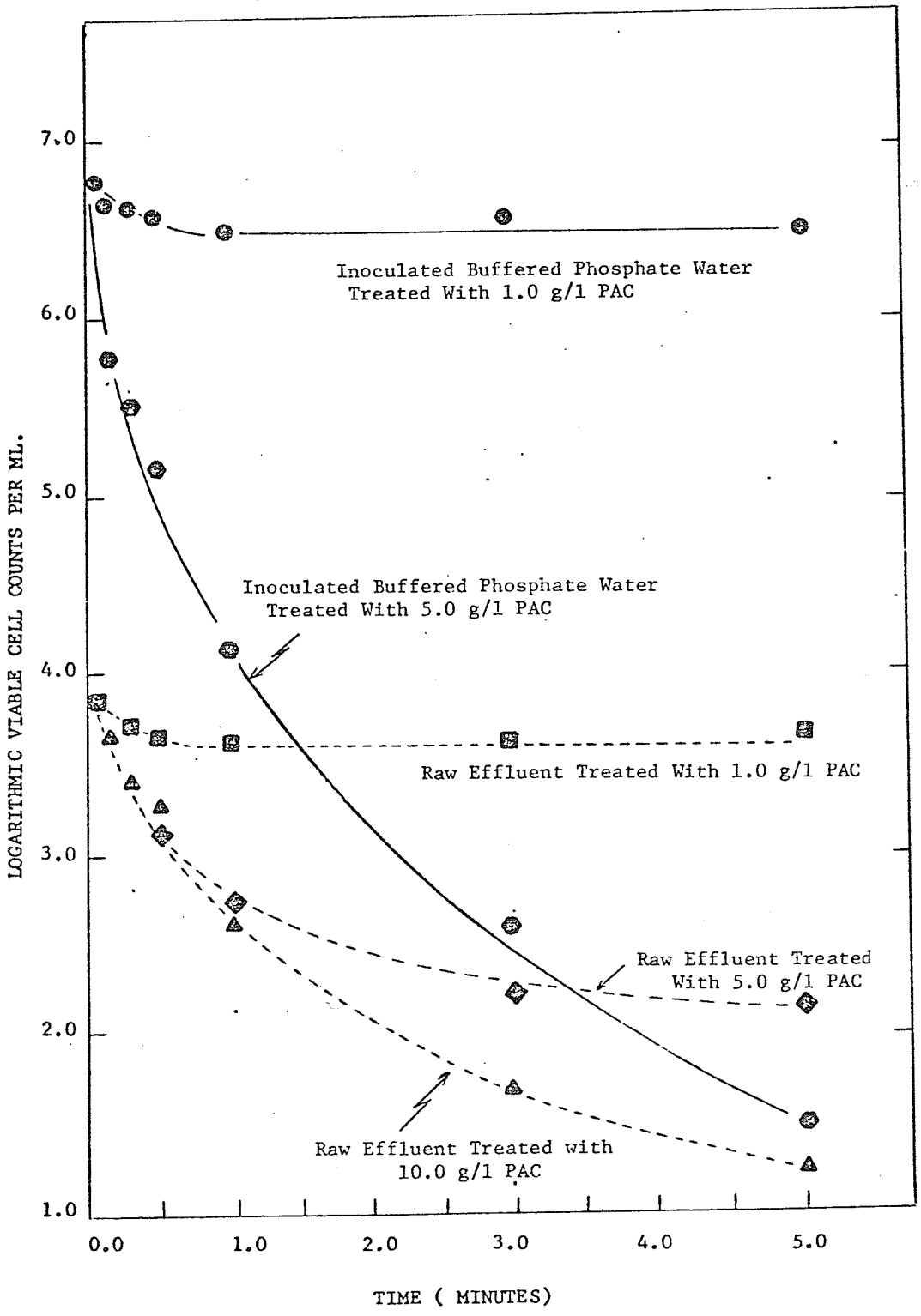
It was observed (Figure 14) that low dosages of powdered activated carbon (1.0 g/l) in posphate buffered water showed minimal removal of viable bacterial cell count through all the contact time studies. Increasing the dosages of powdered activated carbon to 5 g/l showed increasing amounts of bacterial removal with increasing contact time. A contact time of 5 minutes using 5.0 g/l was shown to reduce a sample of buffered phosphate water containing an initial bacterial level of 5.7×10^6 to about 30 organisms/ml.

Effluent samples containing 1.0 g/l powdered activated carbon also showed minimal removal of bacteria through all contact time studies. However, as the dosages of powdered activated carbon was increased to 5.0 and 10 g/l through all contact time studies a reduction in bacterial numbers was observed. Using effluent samples containing 1.0 g/l powdered activated carbon an initial concentration of 8.2×10^3 organisms/ml, the viable cell count was reduced to approximately 200 organisms/ml.

5.2.6 The Effect of Split Applications of Powdered Activated Carbon

Single-stage batch contact may require the use of a

FIGURE 14 Contact Time Study (Appendix Table 12)



greater amount of carbon than is practical when impurities that are difficult to remove are present in large quantities. To meet this difficulty, countercurrent application and split application have been developed (74). Split treatment is preferred when processes are operated intermittently. In split treatment, the carbon is divided into two portions. One portion is added to the raw effluent and is filtered from the effluent after treatment. The filtrate is then treated with the other separate portion of carbon to yield a more purified filtrate.

The study in Section 4.2.1 demonstrated the requirement of a high dosage to treat effluents containing a varied genera of microorganisms. Further studies indicated some organisms were less readily adsorbed/filtered than the others. This prompted an investigation into the applicability of split treatments of the rinse effluents.

Table 5 illustrates the effect of carbon treatment with 2.0 g/l applied as single and split treatment methods using same cumulative amounts of powdered activated carbon. With a single application of 2.0 g/l, the viable bacterial cell count was reduced from 6.2×10^3 to 8.4×10^2 organisms/ml. However, split applications of the carbon gave a final bacterial level of 95 organisms/ml, illustrating a greater efficiency of the treatment than single application. Previous study in Section 4.2.1 (Figure 10) indicates a carbon dosage greater than 10 g/l to obtain this amount of removal by a single application method.

TABLE 5 The Effect of Split Applications of Powdered Activated Carbon

Mode of Application	Dosage (g/1)	Viable Cell Counts Per ml
Before Treatment	0.0	6.2×10^3
Single Treatment	2.0	8.4×10^2
Split Treatment:		
1st Application	1.0	1.1×10^3
2nd Application	1.0	94

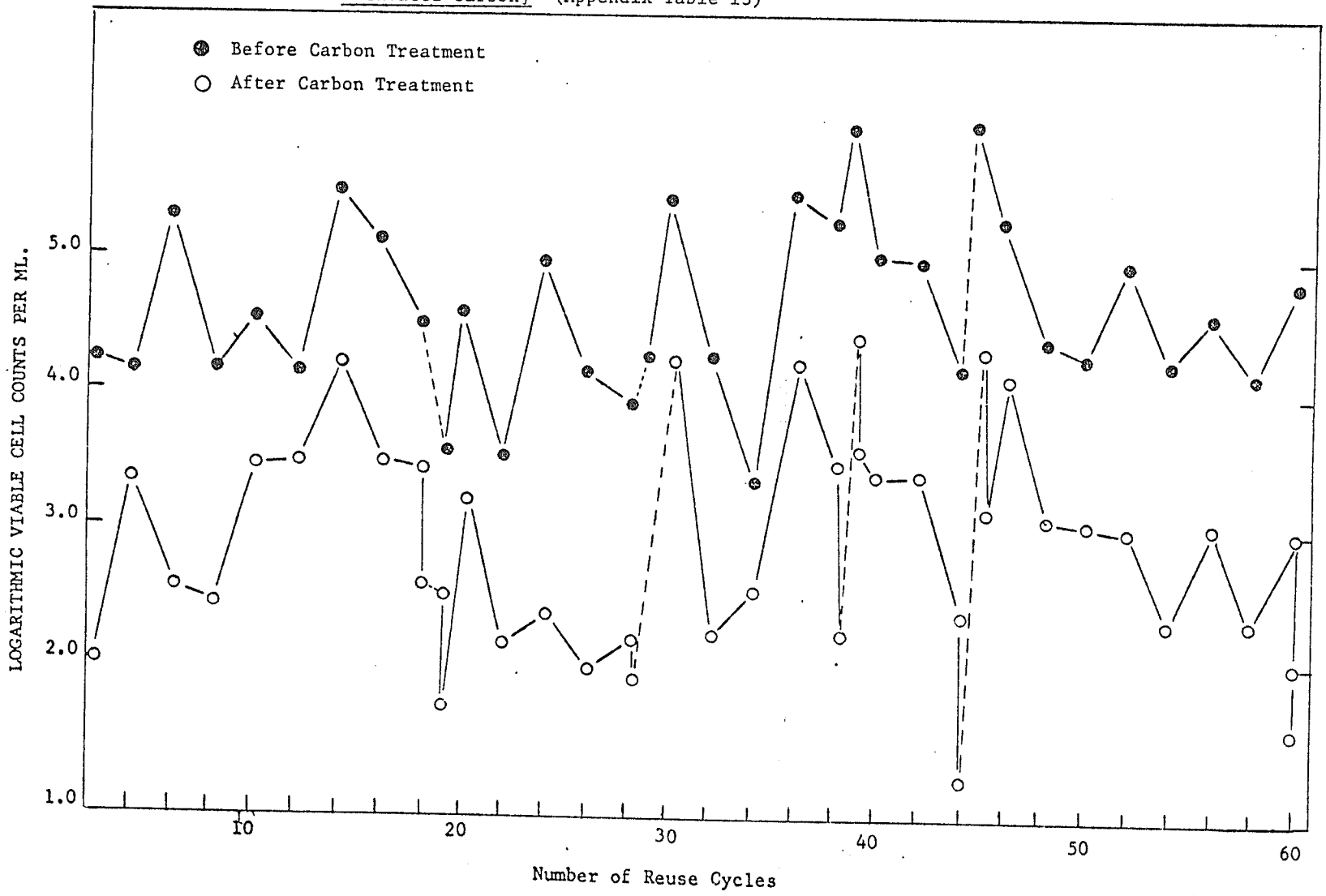
Split application is thus demonstrated to be more efficient and more economically feasible as far as efficiency of use of powdered activated carbon than single application. It would be most applicable when an effluent is expected to contain a high level of viable bacterial count.

5.2.7 Simulation of An Effluent Recycling Process

Figure 15 illustrates the viable bacterial cell counts of an effluent that was reused for a total of 60 rinse cycles over a 5 day period with carbon treatment at 1.0 g/l after every second reuse cycle. The effluent could have been reused for ten rinse cycles before carbon treatment was deemed necessary, as recommended previously.

The bacterial level after each reuse cycle fluctuated between 10^3 - 10^5 organisms/ml; subsequent carbon treatment using 1.0 g/l powdered activated carbon redueced these levels to the range of 10^1 - 10^3 organisms/ml. The viable bacterial count was noted to increase very noticeably when the effluent was stored overnight. However, a double carbon treatment using 1.0 g/l dosage per treatment effectively rendered the viable bacterial cell counts within 10^1 - 10^3 organisms/ml during a day's operation. This study illustrated the possibility of recycling effluent at an indefinite number of times with its microbiological quality assured by powdered activated carbon treatment.

FIGURE 15 Simulation of An Effluent Recycling Process [Changes In Viable Cell Counts Before and After Carbon Treatments Using 1.0 g/l Powdered Activated Carbon] (Appendix Table 13)



5.2.8 A General Discussion

Studies in this section illustrated the applicability of powdered activated carbon in treating recycling rinse effluents. Effluent strengths in terms of ppm CO_2D and initial microbial population in the effluent have been demonstrated to affect the efficiency of microbial reduction by carbon treatment. However, the effluent strength would have attained equilibrium conditions after 10 reuse cycles, as shown by Gallop et al. (61) With a treatment frequency of 10 reuse cycles per treatment, the effect of effluent strength would therefore be a constant factor. The only possible variable would be the compositional make-up of the microflora in the effluent. Nevertheless, with sufficient carbon dosage, substantial reduction in the viable bacterial cell count of the effluent has been demonstrated.

The effluent was observed to contain between 10^3 - 10^4 organisms/ml per reuse cycle. The microbial load was further noted to increase in an somewhat arithmetic manner with increasing numbers of reuse cycles. A frequency of 10 reuse cycles per carbon treatment has been suggested. This would prevent excessive build-up of the microbial load which mean poor microbiological quality of the effluent. A high bacterial load, moreover, would call for greater dosages of powdered activated carbon in order to achieve the desirable effluent quality.

Before any optimal carbon dosage and treatment conditions could be established, it was necessary to define the allowable

level of viable organisms in the effluent; that is, the microbiological quality of the effluent. Studies conducted in this project found that fecal coliform organisms were absent in a majority of the cases. If fecal coliforms are found to be absent in the effluent, the viable bacterial cell count could be used as a direct indicator of the microbioloigcal quality of the effluent. For drinking water, the EPA has not included viable total count as one of the quality criteria. FDA originally set a limit of 500 organisms/ml for bottled drinking water, and this was later elimiated(49). Dr. Clise of the Maryland State Department of Health and Mental Hygiene commented a total viable bacterial count of 500 organisms/ml to be a reasonable maximum in municipal water supply (4). Tap water in certain city water supplies had been shown to contain 10^3 to 10^5 organisms/ml (51). The tap water used in this investigation at times contained a maximum of about 40 - 90 organisms/ml. Thus, a total viable cell count of about 10^2 - 10^3 organisms/ml as the allowable microbial density in the recycling rinse effluent would seem to be reasonable, on the condition that fecal coliform organisms are absent from the effluent.

To achieve a reduction in the microbial level from about 10^4 to about 100 organisms/ml would require a single dosage of 5 g/l powdered activated carbon, as illustrated by Figure 10. However, a split application of 2.0 g/l had been shown to attain the same quality level and would thus be preferred, as illustrated in

Table 5 [Section 5.2.6]. In terms of total carbon usage, split application would appear to be more feasible than single application. Split treatment was also shown to be particularly useful in treating effluents upon termination of a daily operation and prior to reuse of the effluent on the following day.

5.3 Microbial Growths and Turbidity Development in Stored Effluents

5.3.1 Microbial Growths in Stored Effluents

Potato slice rinse effluent is rich in reducing sugars and starch, providing the carbon source necessary for microbial growth. It also contains amino acids which furnish the nitrogen requirements of growth. In potato waste solids, the total carbon content has been determined to be 42 percent. The total organic nitrogen is 1.002 percent (136). Carbon adsorption of reducing sugars and some amino acids has been shown to be relatively poor (82, 138). Carbon treatment of the effluent thus did not appear to be detrimental to most, if not all, of the organisms present, as will be discussed later.

Deterioration of the effluent despite carbon treatment was evident by the development of turbidity and odor. In raw effluent, turbidity is mainly due to the presence of colloidal substances and in particular, the insoluble starch. Destarching followed by carbon treatment at sufficient dosages, effectively rendered the rinse effluent crystal clear. However, this clarity

was not maintained when the effluent was stored overnight at room temperature (22 °C). The development of turbidity and odor could pose a quality problem in effluent which had to be stored overnight, over the weekend, or during a mechanical breakdown in the plant.

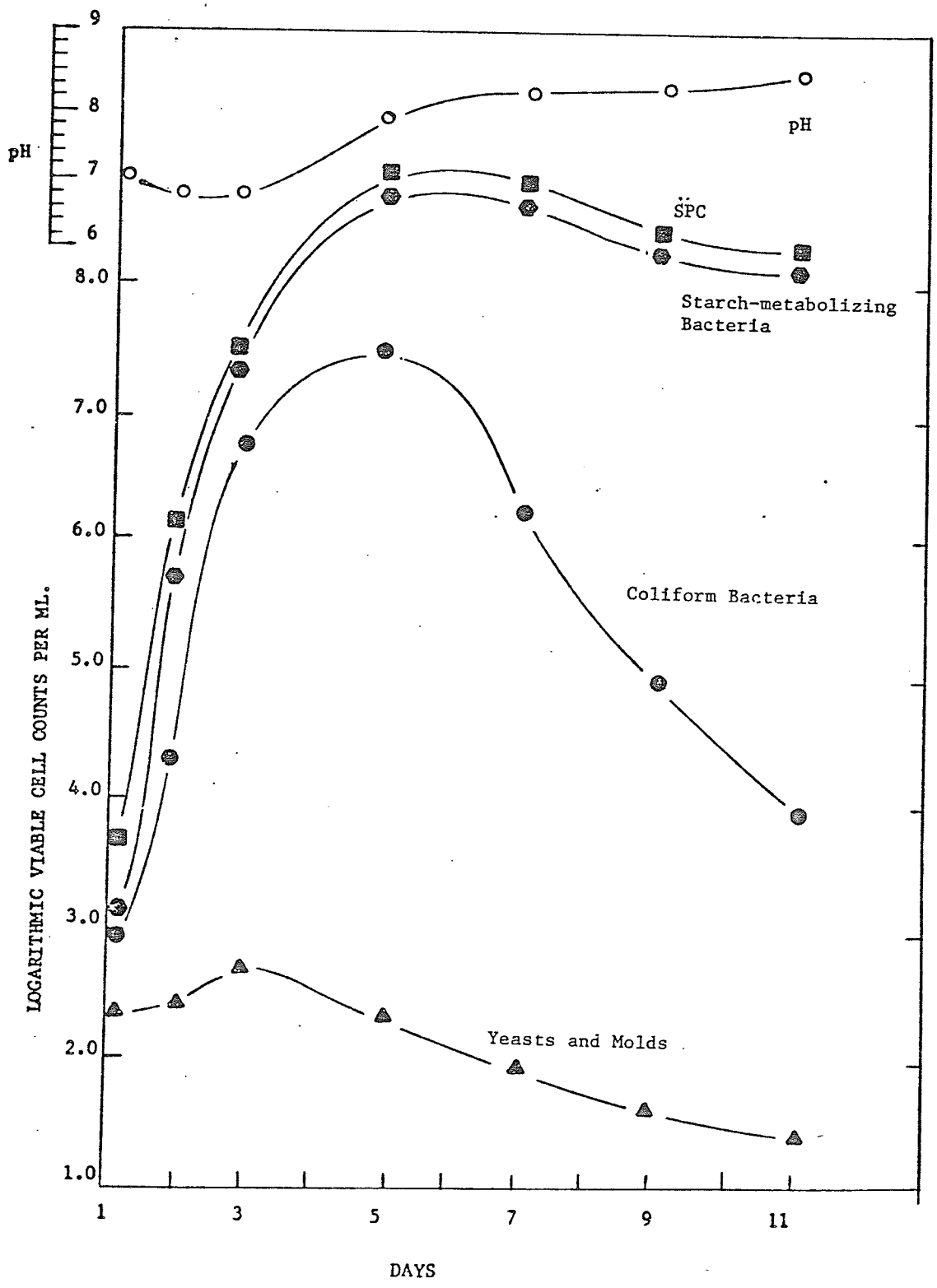
In this part of the project, studies were therefore initiated to investigate the exact cause of turbidity in the stored effluents, and further investigate the possible means of control in order to render the effluent reusable after it had been held overnight or over a weekend.

The effluent was first studied for its capacity to sustain microbial growth after a carbon treatment using 1.0 g/l powdered activated carbon. Enumeration of the total viable bacterial cell count, coliforms, yeasts and molds, and starch - metabolizing microorganisms were performed over a 11 day period. Results on the growth of these groups of microorganisms are illustrated in Figure 16 .

It was observed that the effluent was capable of sustaining microbial growth for about a week, with rapid increase in the microbial population during the first three days of incubation at room temperature (22 °C). The total viable cell count increased from 6.4×10^3 to 3.6×10^7 organisms/ml during that 3 day period. A stationary growth phase was attained on the fifth day, when the viable cell count was 8.3×10^8 organisms/ml. The bacterial popu-

FIGURE 16 Microbial Growths In Stored Effluents

(Appendix Table 14)



lation entered its death phase on the seventh day of incubation. This could possibly be attributed to the deprivation of nutrients and the build-up of toxic metabolites in the effluent.

It was noted that most of the microorganisms present were capable of metabolizing starch, as shown by the growth curve of the starch-metabolizing bacteria which parallel closely to the growth curve of total viable bacteria. These organisms would have the capacity to break down the starch in the effluent into various types of complex and simple sugars, part of which could be utilized by the non-starch metabolizing organisms.

Coliform organisms were found to be present at a level lower than that of the total viable bacteria. It should be noted, however, that in most of the studies fecal coliforms were found to be non-existent. The coliform group showed an initial rapid logarithmic growth phase similar to the other organisms. But the group reached a lower level of maximum growth and exhibited an earlier and faster die-off rate after the fifth day, as indicated by Figure 16.

Yeasts and molds appeared to be the least competitive with the other microorganisms. Their population showed a slight increase during the first three days, thereby started the die-away. This could perhaps be attributed to the unfavorable pH environment to these two organisms. The hydrogen ion concentration of the effluent increased from a pH of 7.1 to 6.8 during the first 3 days. However, the pH value started to rise to 8.6 on the 11th day. The pH

condition was evidently unfavorable to the growth of yeasts and molds which strive best at low pH of about 4.5.

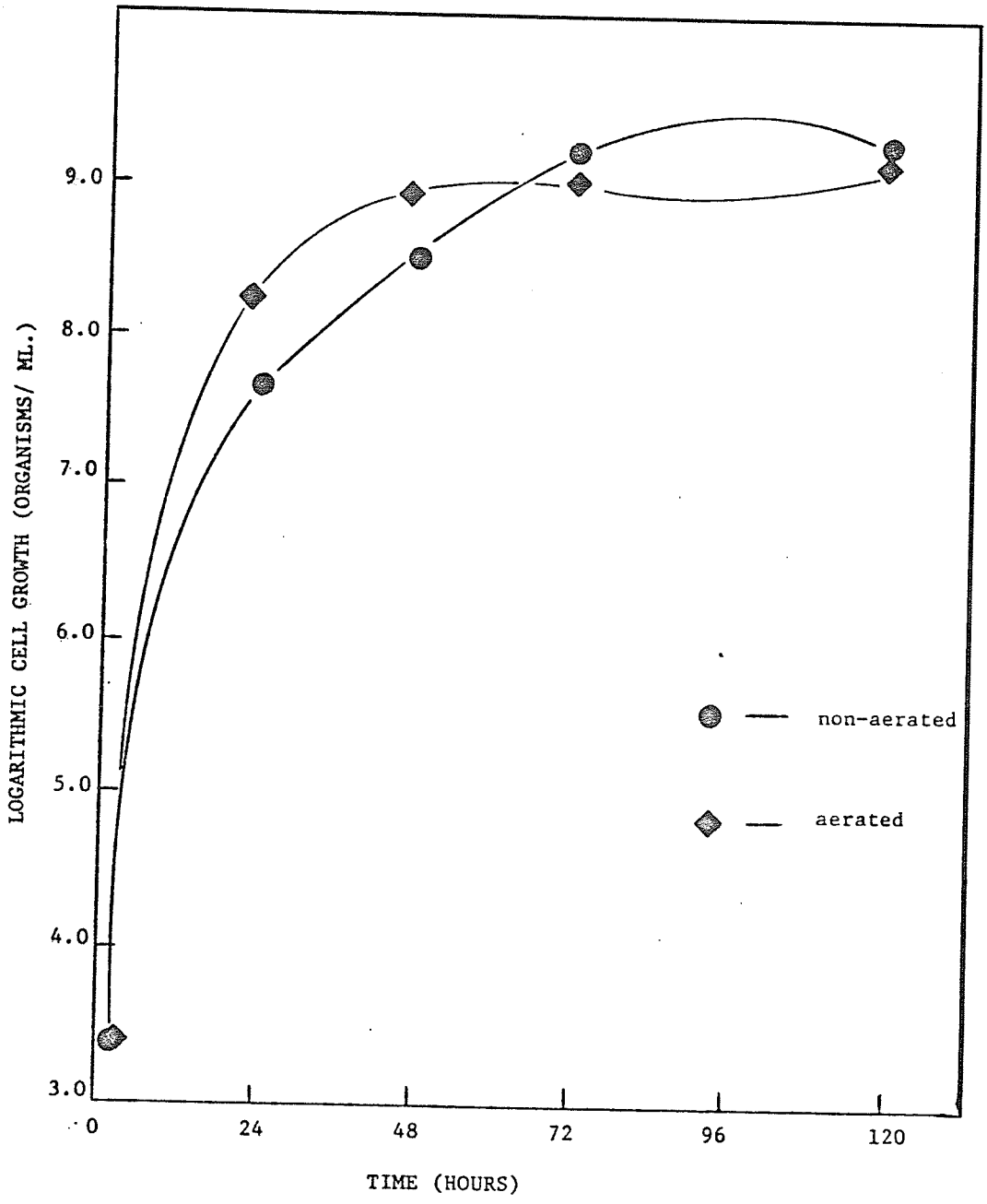
Turbidity and odor development in the effluent were most noticeable after the third day of storage. Further studies on turbidity development were conducted and will be discussed in the following sections.

5.3.2 The Effect of Aeration on Microbial Growth

The development of turbidity and odor in undisturbed effluent incubated at room temperature (22 °C) prompted the suggestion that such physical deterioration of the effluent could be caused by the activities of the facultative anaerobes. In this study, therefore, the effect of aeration on microbial growth was investigated. Figure 17 illustrates the growth curves of the bacterial populations in two effluents, one of which was constantly aerated by an air stream.

As shown in Figure 17 aeration did not produce any appreciable effect on the microbial growth. Turbidity and odor development were also noted in both cases. Aeration did not appear to have any beneficial effects in controlling the microbial growth or preventing the deterioration of the effluent.

FIGURE 17 The Effect of Aeration On Microbial Growth (Appendix Table 15)



5.3.3 Turbidity Development in Treated Effluents

Rinse effluents treated at varying carbon dosages would result in different waste characteristics in quantitative terms. Such effluents would thus be expected to develop turbidity at different rates. In this study, effluents were treated with 0.0, 1.0, 10.0 and 20.0 g/l powdered activated carbon and investigated for the trends in turbidity development as a result of varying carbon treatment levels. Microbial growths and decrease in organic carbons were followed concurrently with the increase in turbidity in the effluents over a 4 day period. Data obtained are illustrated in Figures 18, 19 and 20 for turbidity, bacterial count and CO_2D values respectively.

As shown in Figure 18, a carbon dosage of 1.0 g/l was as effective as the relatively high levels of 10.0 and 20.0 g/l in the elimination of turbidity. The initial turbidity of 35 J.T.U. was reduced to 14, 10 and 6 J.T.U. with carbon treatments at 1.0, 10.0 and 20.0 g/l respectively, all of which yielded virtually excellent clarity.

An arbitrary value of 20 J.T.U. was set for the observable turbidity. Effluents subjected to the varying carbon dosages appeared to become turbid at different rates. To attain the level of 20 J.T.U. turbidity, it took 8 hours for the effluents treated with 1.0 g/l carbon, and 12 hours for the other two effluents treated with 10.0 and 20.0 g/l carbon, as indicated in Figure 18.

FIGURE 18 Turbidity Development In Carbon Treated Effluents
[Changes In Turbidity Readings]
(Appendix Tables 16 - 19)

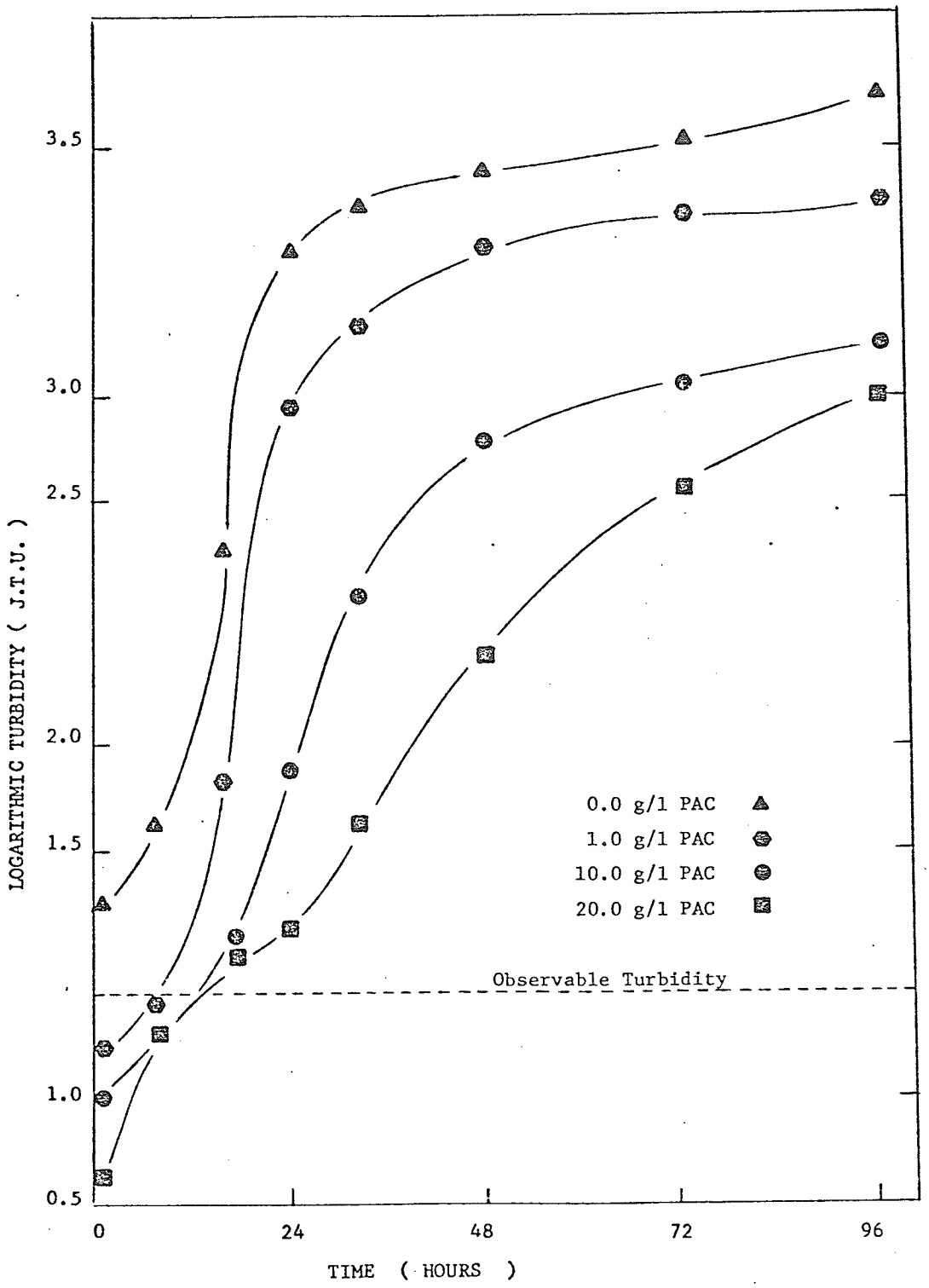


FIGURE 19 Turbidity Development In Carbon Treated Effluents
[Changes In Viable Bacterial Cell Counts]
(Appendix Tables 16 - 19)

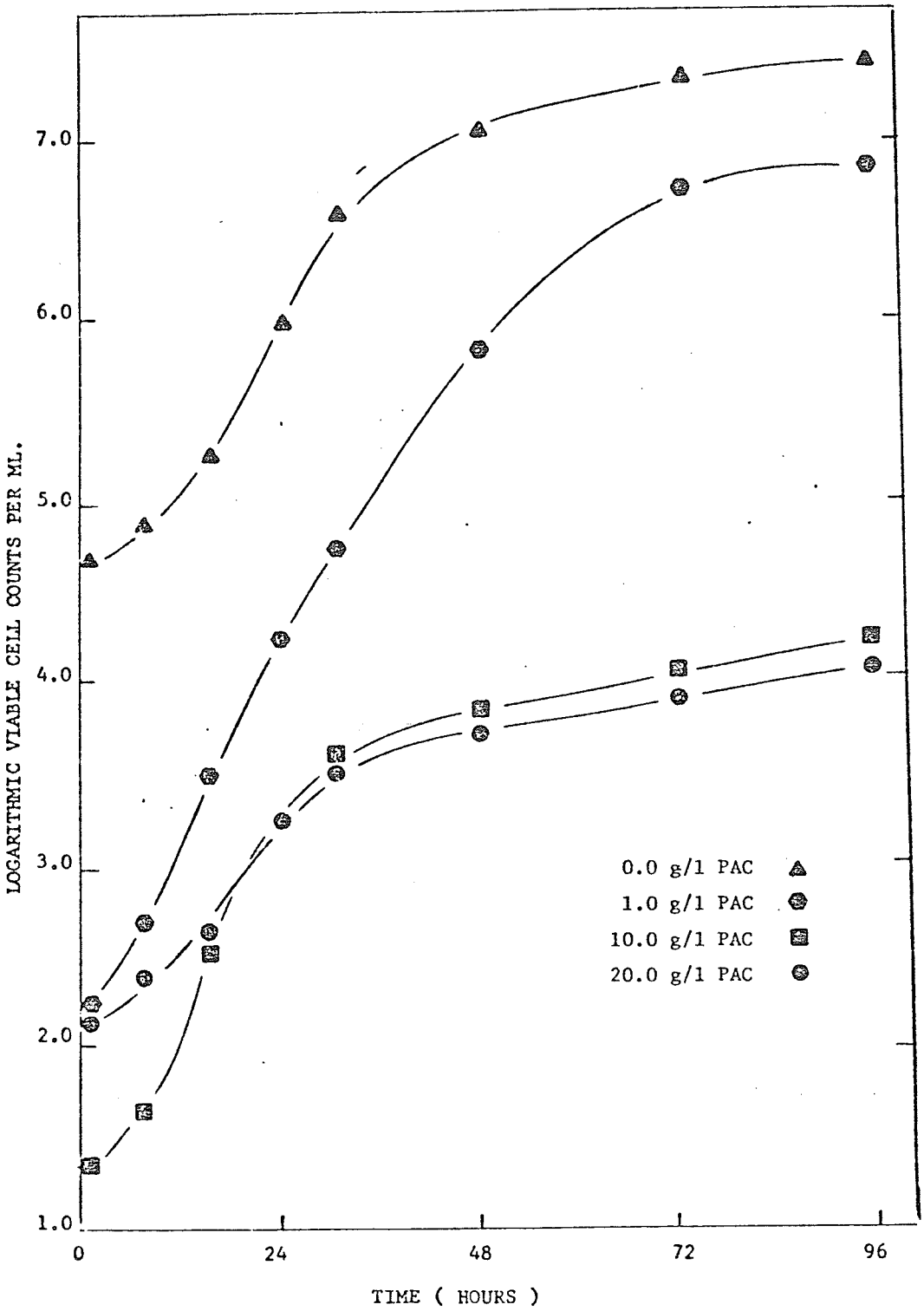
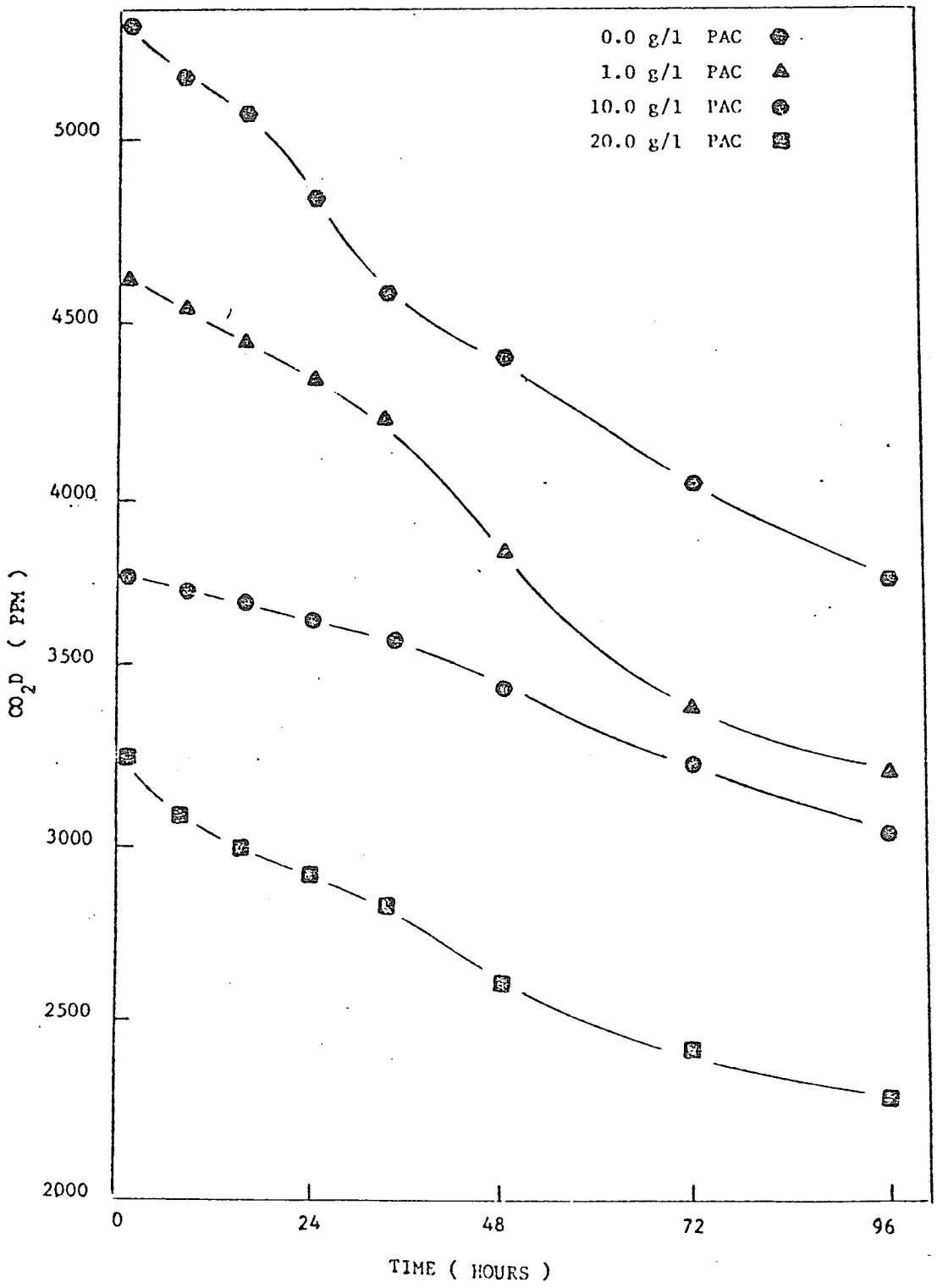


FIGURE 20 Turbidity Development In Carbon Treated Effluents
[Changes In CO_2D] (Appendix Tables 16 - 19)



Turbidity was observed to occur in a logarithmic manner, as illustrated in Figure 18. Turbidity and cell growth thus followed a similar trend, as revealed by a comparison of Figures 18 and 19. Moreover, the degree of turbidity appeared to be related to the cell density in the effluent. Effluent with lower cell growth correspondingly showed lower turbidity readings over the 4 day period. It was observed that during the stationary phase of the microbial growth, turbidity continued to increase in an appreciable rate, as indicated by the Figures. This is particularly marked with effluents that had been initially treated with 10.0 and 20.0 g/l of activated carbon. Such observations tend to indicate that turbidity development correlates to more than cell growth. From the fact that the stationary phase indicates a counterbalance of cell growth by cell death, it is likely that turbidity could be due to those dead cells that autolysed and discharged their cellular colloids in the effluents.

Bacterial activities were reflected partially by the depreciation of organic carbon content of the medium. The cell growth curve in Figure 19 and CO_2D reduction curve in Figure 20 revealed a similar but antagonistic trends of the two curves. In other words, increase in cell growth was accompanied by a decrease in the organic carbon content of the effluents. This is accountable by the aerobic oxidation of nutrient by the microorganisms. During the initial 48 hours when microbial growth proceeded exponentially, there was a correspondingly greater rate of CO_2D decrease, as

indicated by the slope of the reduction curve at that time period. Towards the 72 - 96 hour period when growth approached cessation, the rate of CO_2D reduction decreased. In all the following studies, CO_2D values per se were thus determined to serve as an partial indication of the rate of microbial activities.

5.3.4 Bacterial Activities As Cause of Turbidity

Results from the previous sections indicated a likelihood of microbial activities as the cause of turbidity in the effluents. If this is so, suppression of bacterial activities could thus be expected to reduce the extent of turbidity in the effluents. Moreover, exclusion of microoganisms from the effluents should completely prevent the appearance of turbidity.

Metabolic activities of most microorganisms fall off very rapidly around freezing point of water, as evident by the general increase in G_{10} values (a measure of the rate at which reaction rate changes with temperature) with decreasing temperature. Simple exposure to low temperatures does not kill bacteria effectively. The majority die off, the rest survive but with minimal metabolic activities.

In this section, two studies were performed to verify bacterial activities as the cause of turbidity in accordance to the aforementioned facts. In one study, a 10-rinse effluent was treated with 1.0 g/l powdered activated carbon and filtered. The filtrate

was divided into two equal portions, and incubated at 4 °C and 22 °C respectively for 72 hours. Data on the changes in turbidity and CO_2D values at these two temperatures are illustrated in Figures 21 and 22 respectively.

At the refrigeration temperature (4 °C) an almost complete cessation of bacterial activities was noted. This is reflected partially in the CO_2D values [Figure 21] which showed very slight depreciation over the incubation period.

However, it was also noted that turbidity still occured at a noticeable rate, as revealed by Figure 22. This could perhaps be due to the destructive effect of simple chilling on some bacteria. Simple chilling to near freezing temperature has been known to exert a destructive effect on some bacteria particularly when they are in the logarithmic growth phase (17).

In another study, the effluent was rendered sterile, divided into two equal portions, and incubated at room temperatue (22°C) and refrigeration temperature (4 °C) respectively. Figure 21 illustrates the changes in turbidity at these two temperatures and similarly, Figure 22 illustrates the decrease in CO_2D values.

The effluents were noted to remain in a sterilized condition for the first 48 hours. Positive viable cell count was noted after 48 hours of incubation. This could possibly be due to post - contamination of the effluent.

Figure 22 shows an extreme insignificant depreciation in

FIGURE 21 Bacterial Activities As Cause of Turbidity [Changes In Turbidity Readings] (Appendix Tables 20 & 21)

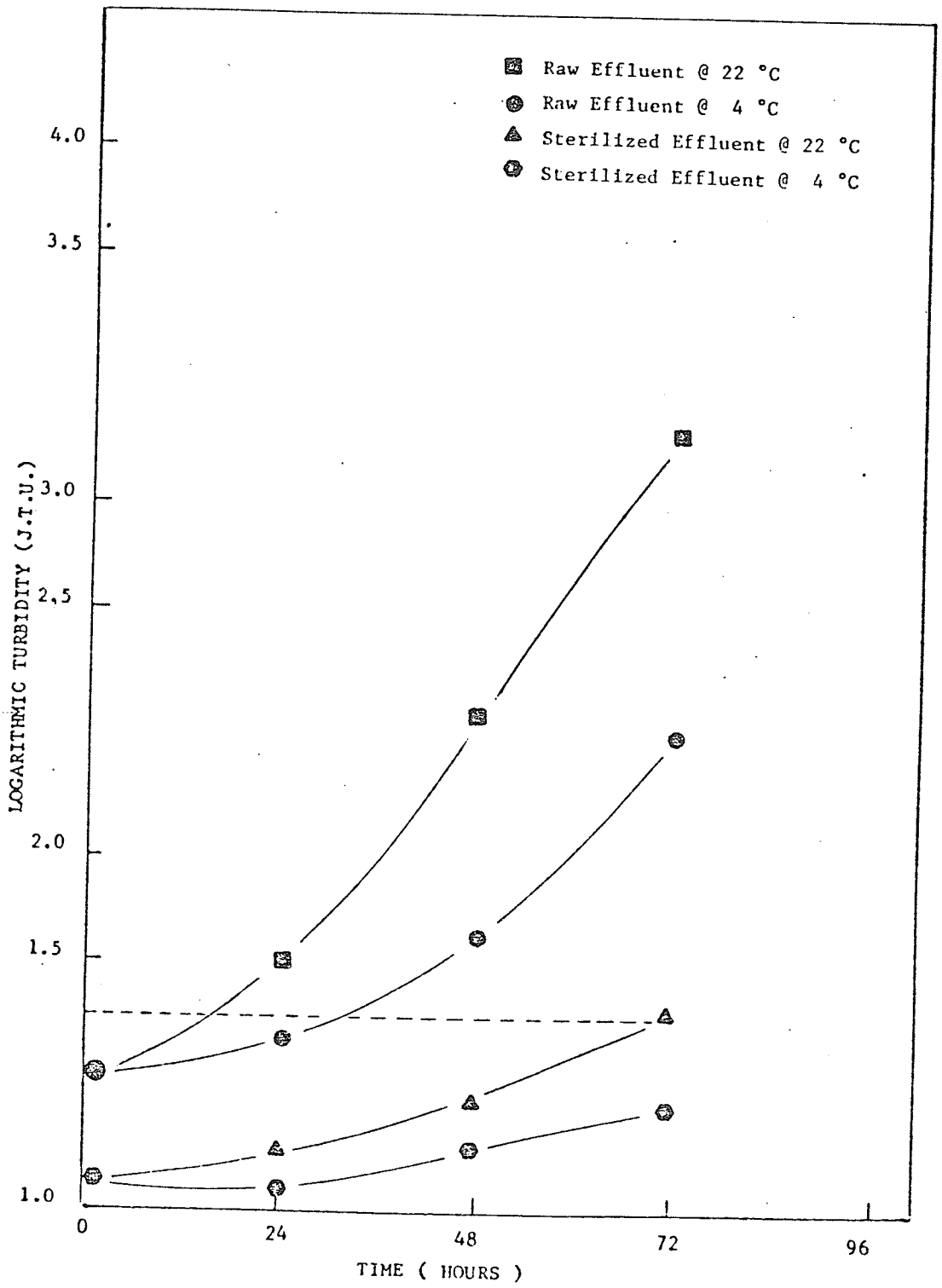
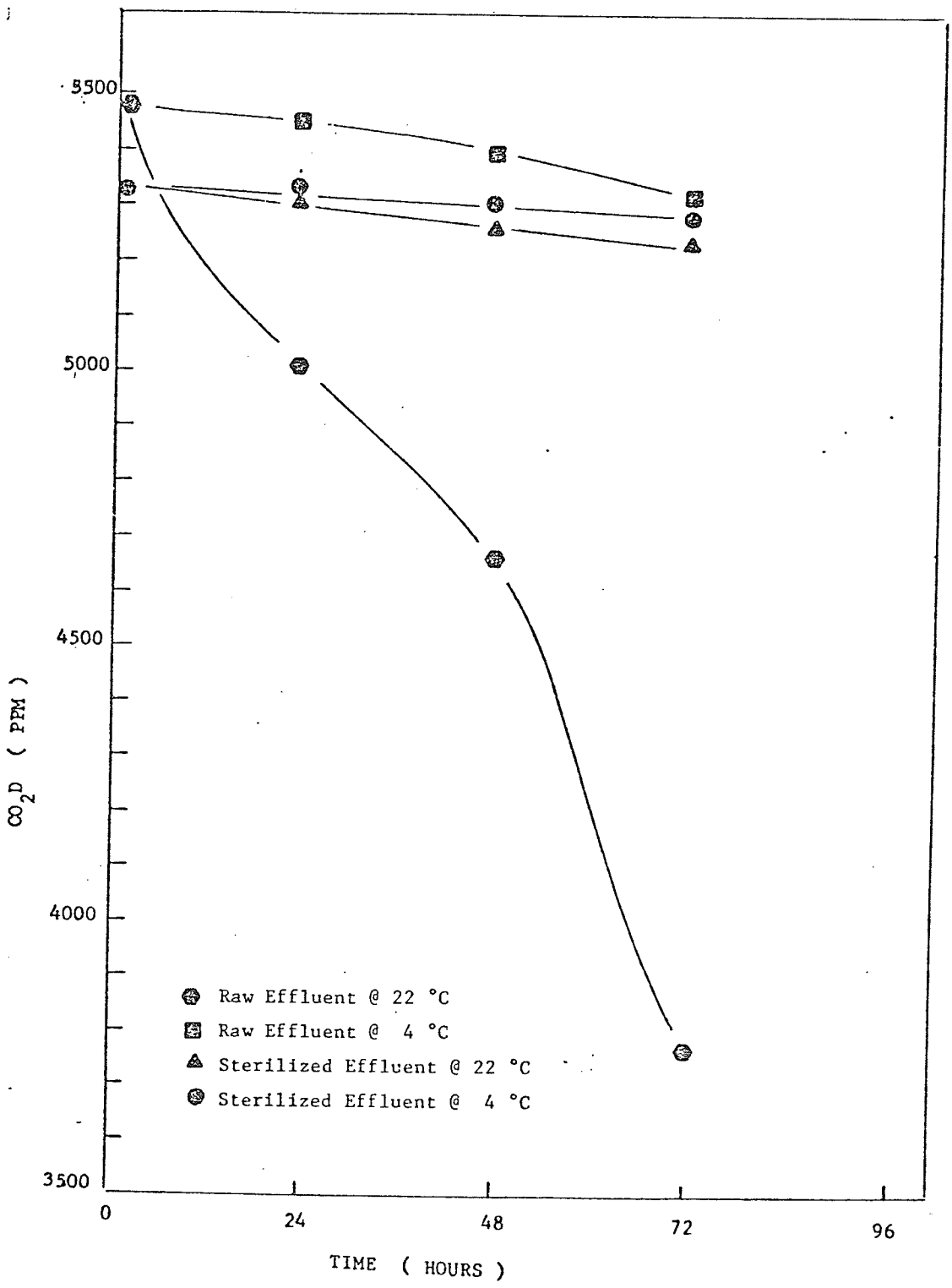


FIGURE 22 Bacterial Activities As Cause of Turbidity [Changes In CO_2D] (Appendix Tables 20 & 21)



the organic carbon content of the effluents at both temperatures, indicating virtual absence of any bacterial activities during the first 48 hours of incubation. Insignificant increase in turbidity was also noted, as illustrated in Figure 21. Over the 72 hour incubation period, effluent at 22 °C showed an increase of 13 J.T.U., while effluent at 4 °C indicated an increase of 9 J.T.U.

These two studies thus affirmed that turbidity is caused by microbial activities. Exclusion of microorganisms was shown to prevent the development of turbidity. Furthermore, in the presence of microorganisms, suppression of their activities at refrigeration temperature effectively retarded the rate of turbidity development. Since metabolic activities, namely cellular reproduction, had been halted, the observed turbidity could more likely be due to the destructive effect of the low temperature on most of the organisms. Turbidity could perhaps be further speculated to be caused by discharge of cellular colloids from lysis of the cells.

5.3.5 Control of Turbidity by Lowering the Hydrogen Ion Concentration

Frequently the hydrogen ion concentration is one of the principal factors controlling microbial development in foods. The concentration of hydrogen ion is practically always low in the natural habitats of microorganisms. Strong acids and strong alkalis alike inhibit the development of bacteria, most of which thrive best not too far from neutrality.

In this study, rinse effluent was adjusted to a pH of 4.5 by the addition of 0.1 M citric acid. Generally, most bacteria cannot tolerate a pH less than this value. It was hoped that, by controlling bacterial growth at this pH level, one could thus control the development of turbidity in the effluent, as bacterial activities have been determined to be responsible for the occurrence of turbidity.

Figure 23 illustrates the changes in bacterial population and turbidity of an acidified effluent incubated over a 4 day period at room temperature (22 °C). It was noted that initially when the citric acid was added to the effluent, a thick floc was formed. It was readily removed, however, by filtration through a Whatman No. 5 filter paper. Removal of the floc resulted in an immediate reduction of CO_2D, viable bacterial cell counts and turbidity, as shown in Table 6.

The instantaneous increase in turbidity of the effluent resulted in a net decrease in the total viable bacterial cell count during the first 16 hours, as shown in Figure 23. However, the figure also indicates that while this pH environment affected the increase in the population of the general microflora, it did not inhibit the growth of all the microorganisms. This could be due to the fact that some of the genera of the microflora such as the Actinomycetes, and especially the yeasts and molds are somewhat acid-tolerant. Also, methodologically the Standard Plate Count

FIGURE 23 Control of Turbidity by Raising Hydrogen Ion Concentration [Changes in Viable Bacterial Cell Counts and Turbidity Readings] (Appendix Table 22)

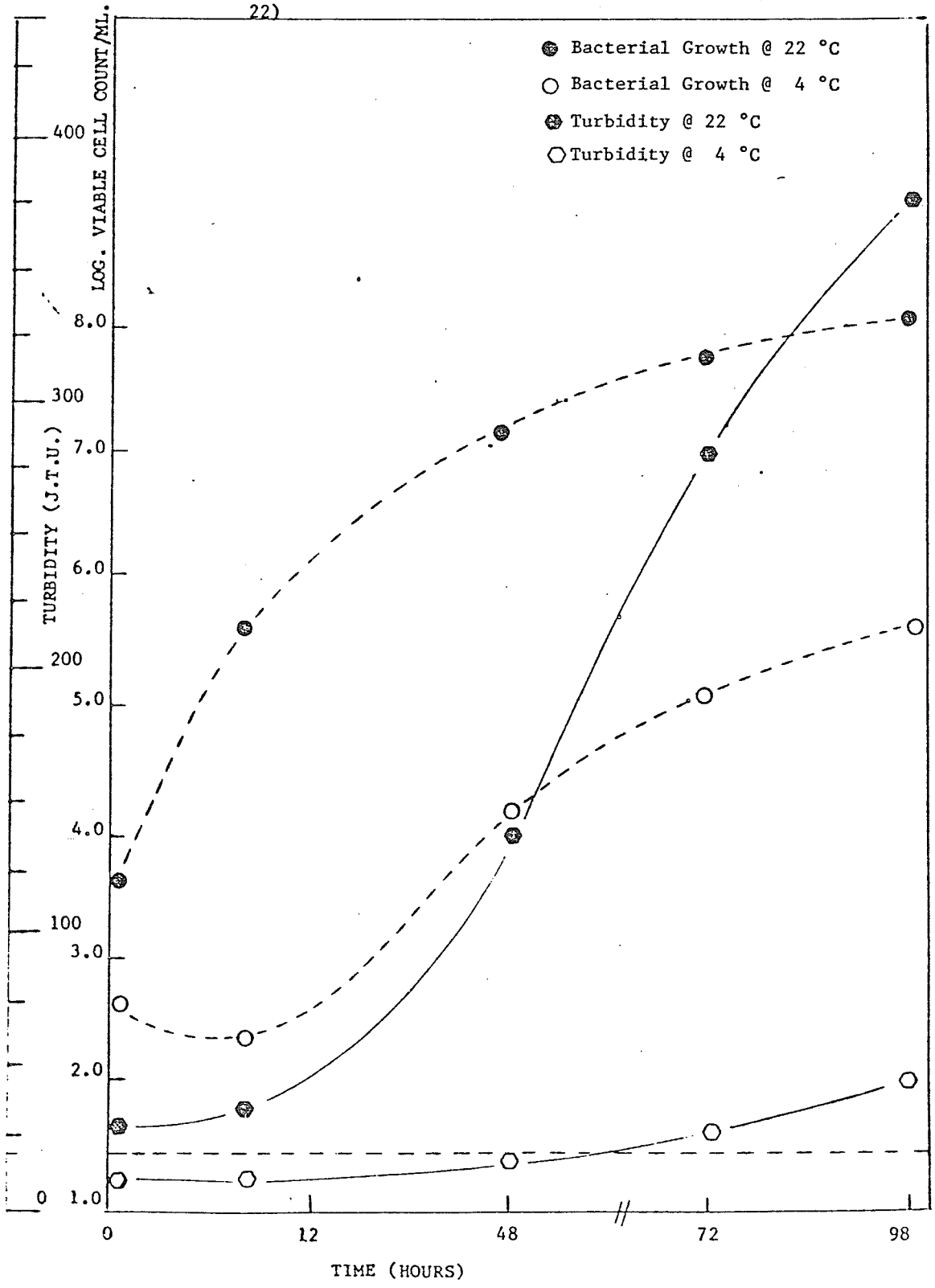


TABLE 6 Control of Turbidity by Raising Hydrogen Ion Concentration

Factors	Before Filtration	After Filtration
pH	6.9	4.5
Turbidity (J.T.U.)	30.0	1.4
CO_2D (p.p.m.)	1687	1359
Viable Cell Count/ml	4.7×10^4	4.2×10^3

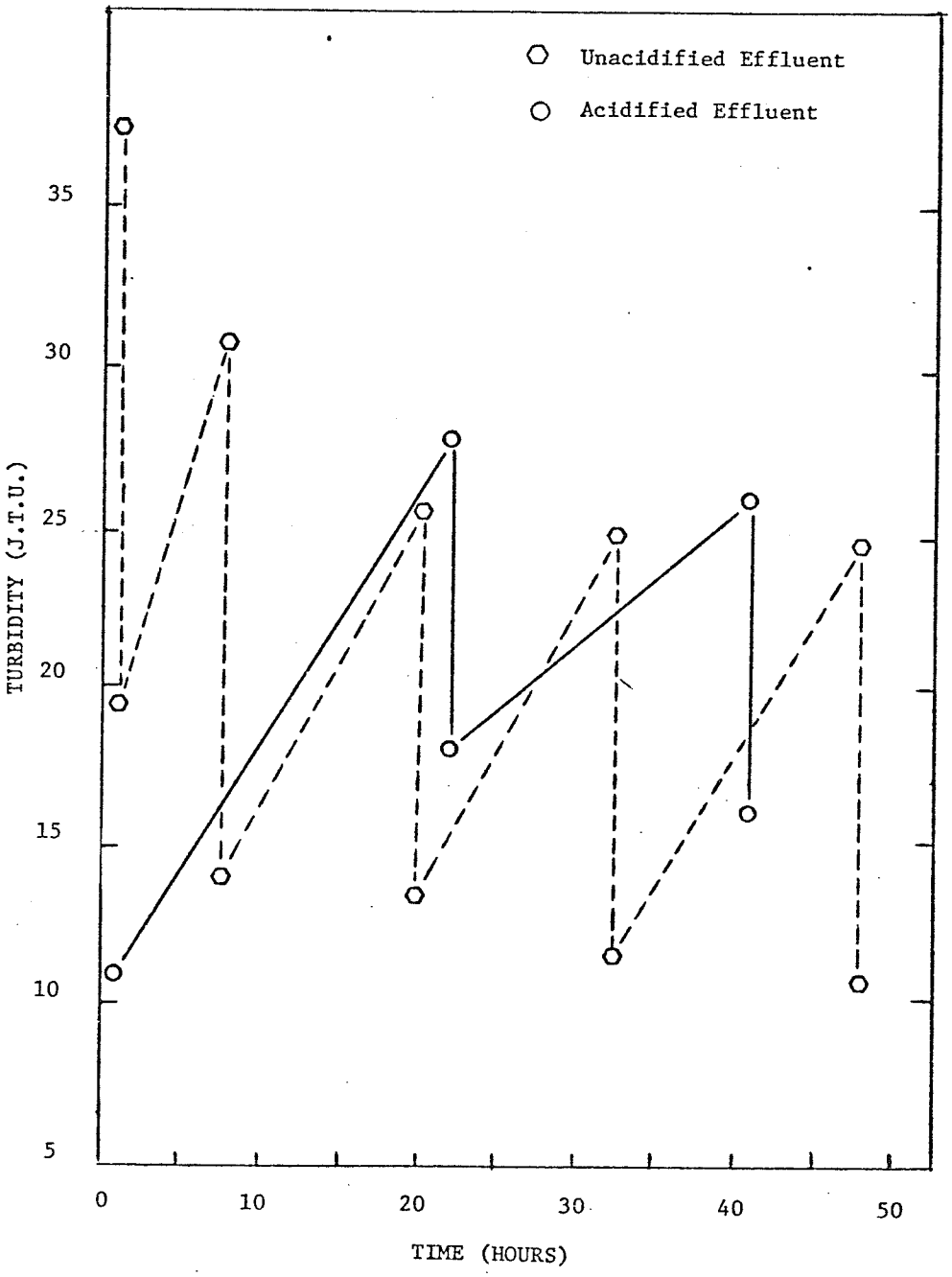
does not necessarily exclude viable cell counts from the yeasts and molds. Moreover, during the incubation period, pH of the effluent was noted to increase, making the environment more favorable than before. After 72 hours, the pH attained a value approaching neutrality. The decrease in hydrogen ion concentration could perhaps be caused by the autolysis of the dead cells, as observed with the unacidified effluent.

Acidification of the effluent, however, was noted to improve the keeping quality of the effluent - defined by an observable value of 20 J.T.U. - in about 24 hours. Previous studies indicated a keeping quality of 8 - 12 hours with carbon treatment of dosages varying from 0.1 to 10 g/l .

Addition of citric acid to the effluent has been shown to control browning coloration without affecting the quality product (136). Citric acid was thus used in these studies to control the turbidity development in the effluent for a period of about 24 hours. However, its feasibility should also be considered in terms of the volume of effluent to be treated in this manner. Material cost arising from the use of the acid may prove prohibitive.

Acidification also appeared to affect the efficiency of turbidity removal by the powdered activated carbon. As illustrated in Figure 24, after carbon treatment, the acidified effluent consistently showed a higher turbidity reading than the unacidified effluent. This could perhaps be due to the formation of larger colloids perhaps by coalescence that were less adsorbable by the

FIGURE 24 Control of Turbidity by Raising Hydrogen Ion Concentration [Changes in Turbidity Readings]
(Appendix Tables 23 & 24)



carbon. Nonetheless, the treated effluents appeared to be visually clear after carbon treatment.

Microbiologically, acidification followed by carbon treatment effectively produced a better quality effluent, as illustrated in Figure 25. This procedure reduced the bacterial population more efficiently than direct carbon treatment at the same dosage level. After two days of storage, the acidified and carbon treated effluent showed a viable bacterial cell count of 1.7×10^4 organisms/ml, as compared to the carbon treated but unacidified effluent which gave a rather high viable bacterial cell count of 3.7×10^7 organisms/ml. It is evident that citric acid coupled with intermittent carbon treatment is highly effective in microbial control of the effluents.

5.3.6 Control of Turbidity by Intermittent Carbon Treatments

Studies were made to control turbidity by treating the effluents with activated carbon only. The application of these studies was to compare the frequencies of intermittent treatment by varying the dosage levels.

An initial study was carried out to investigate any substantial gain in the keeping quality of effluents treated with relatively high dosages of 10.0, 20.0 and 30.0 g/l of powdered activated carbon. Changes in turbidity readings were followed with the treated effluents incubated at room temperature (22 °C) for a two day period. Results are illustrated in Figure 26 .

FIGURE 25 Control of Turbidity by Raising Hydrogen Ion Concentration [Changes in Viable Bacterial Cell Counts] (APPENDIX TABLES 23 & 24)

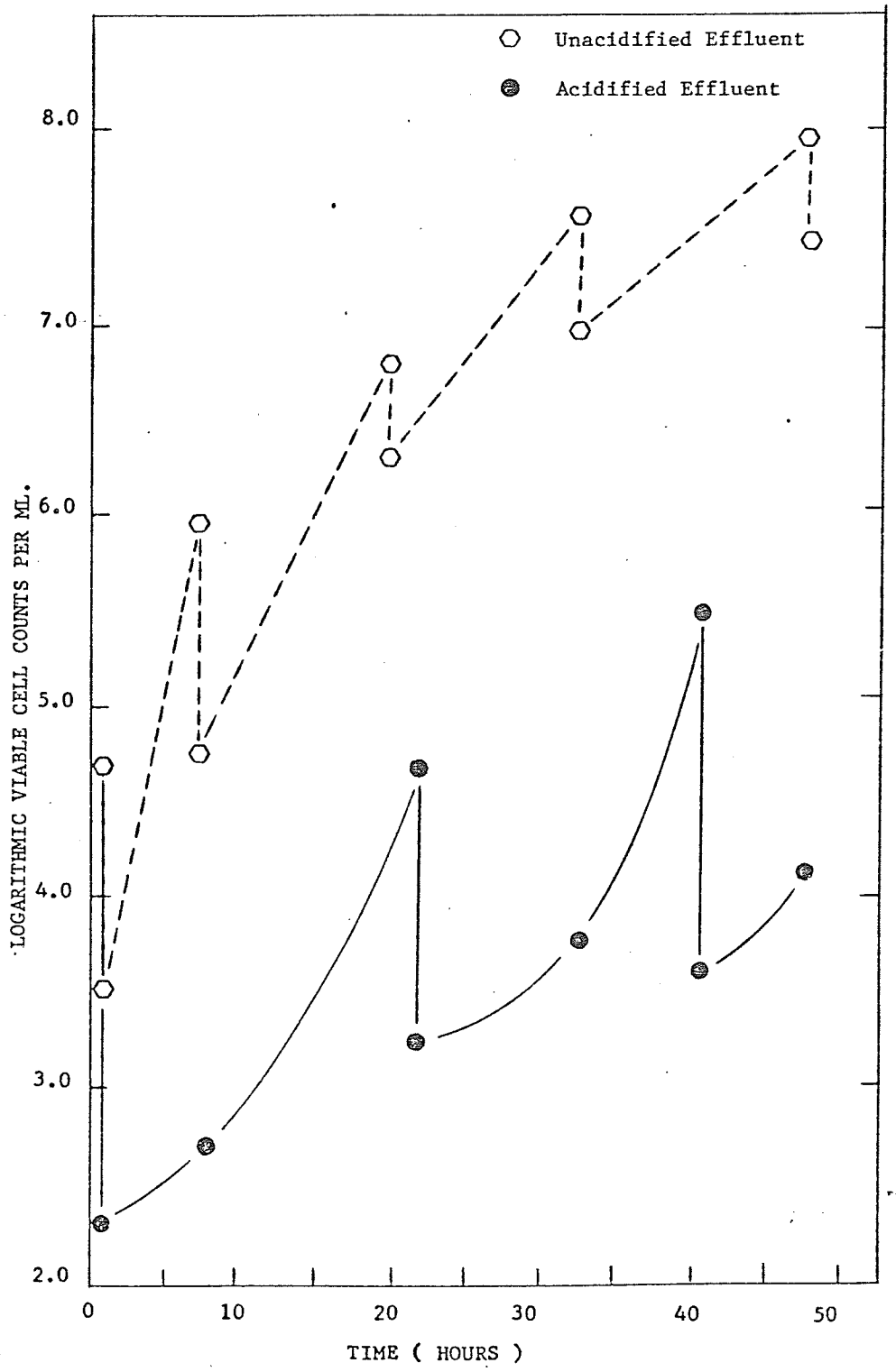
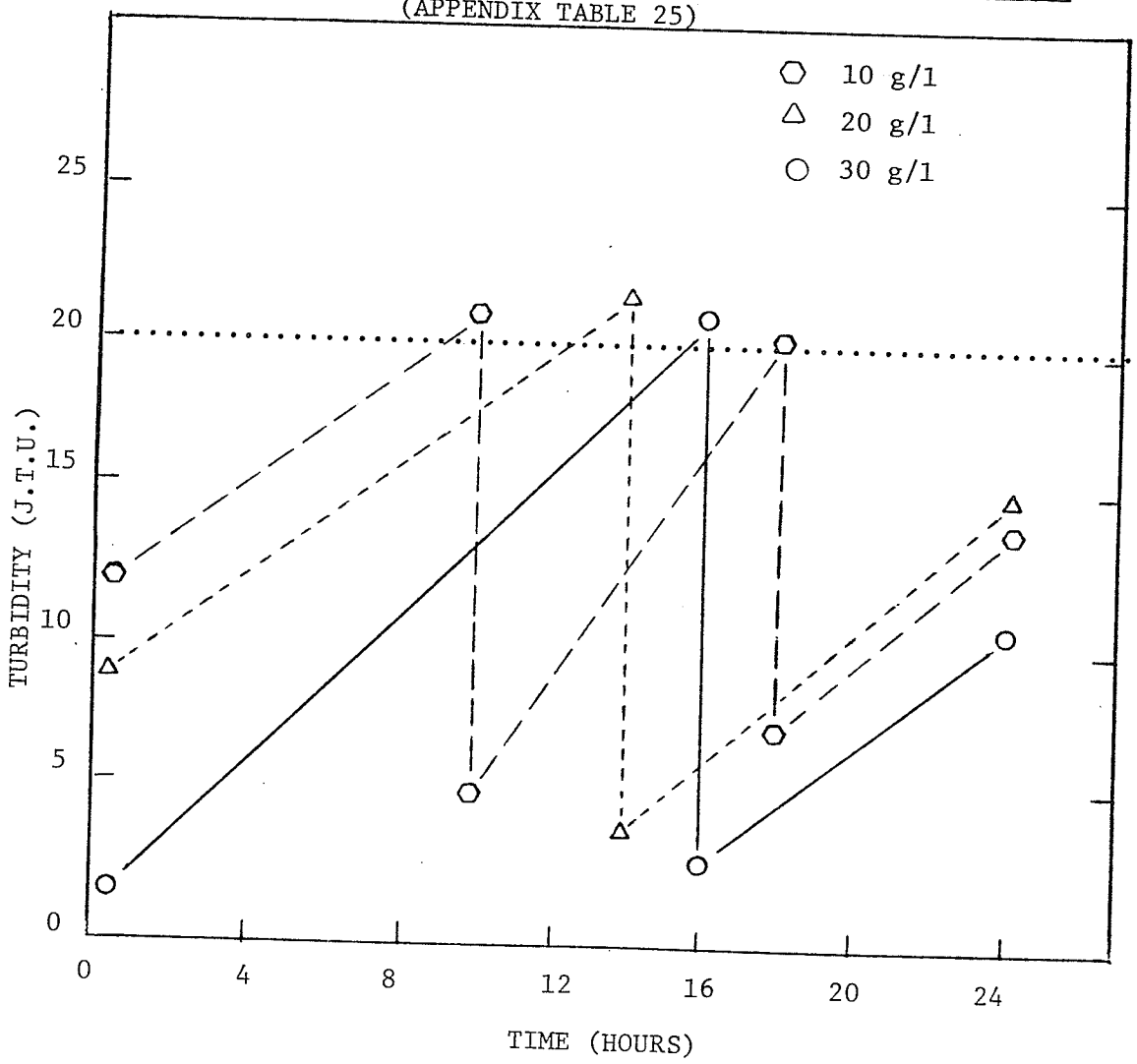


FIGURE 26 Control of Turbidity by Intermittent Carbon Treatments [Changes In Turbidity Readings] (APPENDIX TABLE 25)



As shown in Figure 26 , re-treatment was required after 10, 14 and 16 hours for the effluents with an initial treatment of 10.0, 20.0 and 30.0 g/l powdered activated carbon respectively. The gain of 4 and 6 hours in the keeping quality by a two and three -fold increase in carbon dosages evidently does not seem to be feasible. Over the two day period, it required a total of 3 treatments at 10.0 g/l, or 2 treatments at 20.0 and 30.0 g/l. Again, no apparent feasibility could be established to justify the high carbon dosages employed. The study was therefore discontinued.

In another study, the effluents were respectively subjected to multiple treatments in the following manners: one treatment at 1.0 g/l, split treatments at 1.0 g/l per application (a total of 2.0 g/l) and triple treatment at 1.0 g/l per application (a total of 3.0 g/l). Results obtained are illustrated in Figure 27 for the changes in turbidity readings.

The figure showed that with multiple treatments substantial gain in the keeping quality of the effluent over single treatment was achieved. There was a gain of 4 and 6 hours by the application of split and triple treatments respectively. However, it is noted that the triple treatment did not provide any significant advantage over the split treatment in that the third application did not substantially reduce the microbial load any further, as shown in Table 7. Over a two day period, it required a total of three treatments with single application, or two treatments with split and triple applications of 1.0 g/l per treatment.

FIGURE 27 Control of Turbidity by Intermittent Carbon Treatments [Changes In Turbidity Readings]
(APPENDIX TABLE 26)

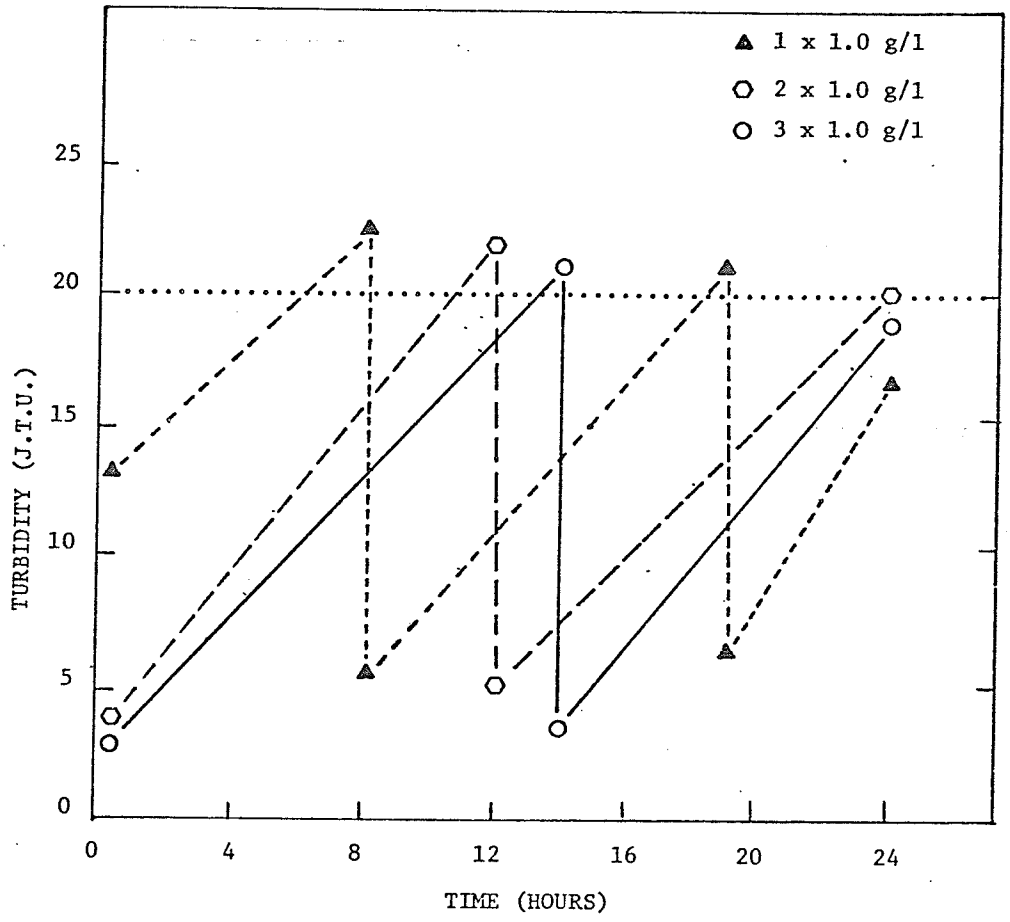


TABLE 7 Control of Turbidity by Intermittent Carbon Treatments [Multiple Treatments]

TIME		1 x 0.1 g/100 ml		2 x 0.1 g/100 ml		3 x 0.1 g/100 ml	
HOUR	INT.*	BEFORE TR.	AFTER TR.	BEFORE TR.	AFTER TR.	BEFORE TR.	AFTER TR.
0	0	6.1×10^4	4.6×10^2	6.1×10^4	53	6.1×10^4	31
8	8	5.5×10^3	1.3×10^2	2.9×10^2	--	1.4×10^2	--
12	12	9.5×10^2	--	4.1×10^4	63	6.8×10^3	--
14	14	7.4×10^3	--	79	--	4.6×10^4	94
18	10	9.7×10^4	3.1×10^2	5.8×10^3	--	2.1×10^3	--
24	--	3.4×10^2	--	6.5×10^3	--	8.9×10^3	--

*Interval Between Re-treatments

-- No Re-treatment

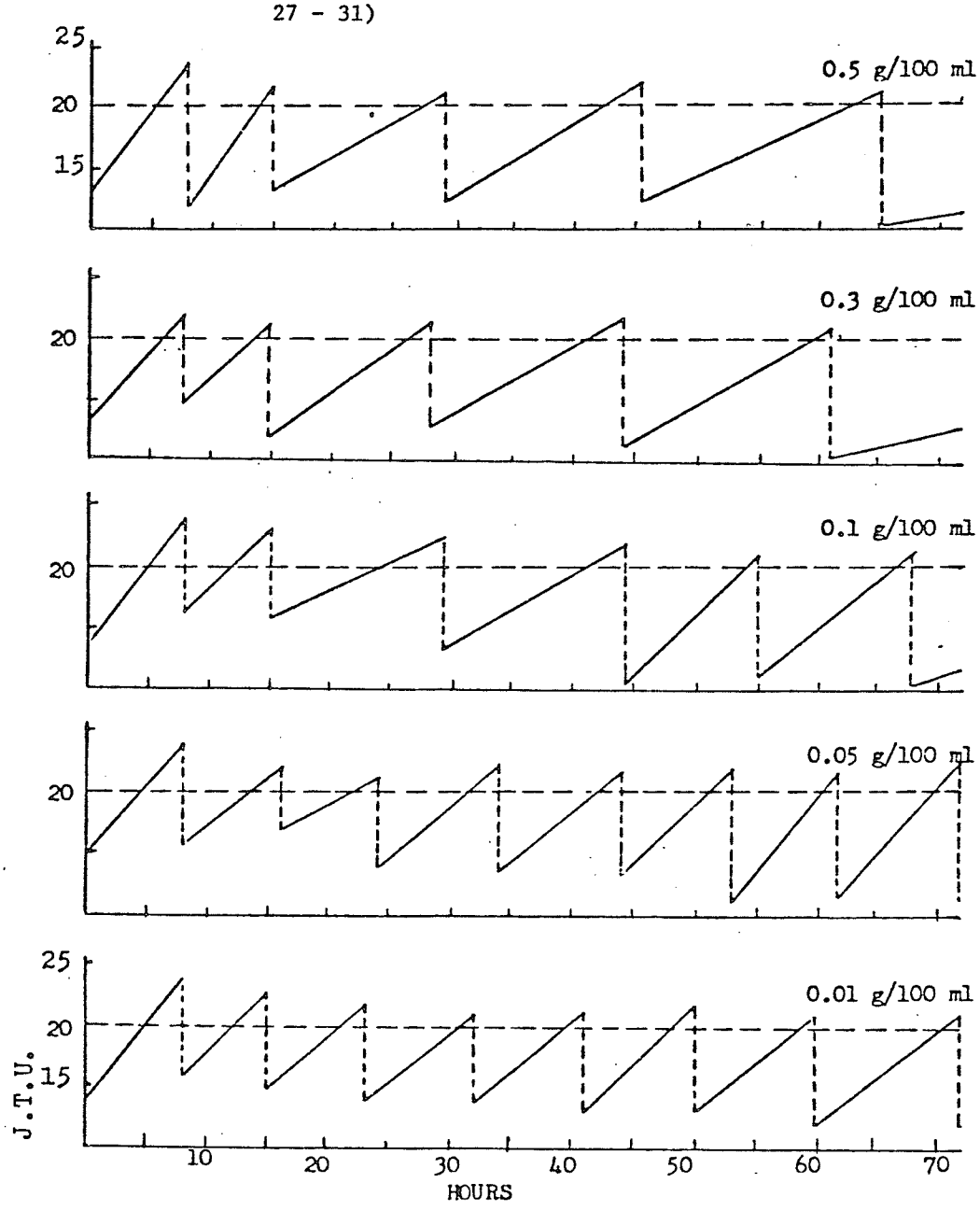
A single carbon treatment of 1.0 g/l was shown to be efficient in removing the turbid appearance of the effluents. A sequential second or third treatment would not be necessary in terms of turbidity removal. The virtue of split treatment in this case lies solely on the further reduction of the microbial density, and thus increasing the keeping quality of the treated effluents.

5.3.7 Intermittent Carbon Treatment of Stored Effluents

This study attempted to investigate any significant effects of intermittent treatment over a long period on the keeping quality of the effluents. Effluents were stored at room temperature for a 3 day period. They were treated, at points of visible turbidity [20 $\pm$ 5 J.T.U.] using carbon dosages of 0.1, 0.5, 1.0, 3.0 and 5.0 g/l respectively. Results for changes in turbidity and viable bacterial cell counts are illustrated in Figures 28 and 29 respectively.

Figure 28 reveals two consistent trends. First, as carbon treatment was repeated over the three day period, clarity of the effluent, though visually undetectable, appeared to improve. This was especially noticeable instrumentally after the third treatment with a dosage range of 1.0 to 5.0 g/l. More importantly, as the number of treatments was increased, the keeping quality of the effluent appeared to improve, that is, the effluent retained its clarity for a longer period after each carbon treatment. Table

FIGURE 28 Intermittent Carbon Treatments of Stored Effluents [Changes In Turbidity Readings] (APPENDIX TABLES 27 - 31)



8 summarizes the economics of carbon usage for the 3 day period.

On the average, the interval between successive treatments is 8 hours for dosages of 0.1 and 0.5 g/1, compared to 12 hours for higher dosages of 4.0 and 5.0 g/1. A reduction of 3 treatments was gained at the expense of a 20-fold increase in carbon dosage. Considering only the material cost, therefore, the lowest dosage of 0.1 g/1 would be preferred. Theoretically, a total of 0.9 g/1 was needed, as compared to 18.0 g/1 at 3.0 g/1 per treatment.

Although the effluents could be aesthetically rendered acceptable, their microbiological quality would impose considerable concern, as indicated in Figure 29. Over the 3 day period, the microbial contents of all the effluents, on the average, appeared to increase. This is more marked with effluents subjected to dosage of 0.1 g/1.

With dosages of 0.1 and 0.5 g/1, the bacterial counts after each carbon treatment fluctuated within the range of 10^3 - 10^5 organisms/ml. The range is 10^1 - 10^3 organisms/ml for dosages of 3.0 and 5.0 g/1. Upon termination of the 3 day period, the final bacterial counts in the effluents were as given in Table 9.

The overall increase in the bacterial population despite successive carbon treatments could perhaps be due to the growth of those microorganisms that were less adsorbable by the activated carbon. Secondly, the number of carbon treatments did not appear

TABLE 8 Intermittent Carbon Treatments of Stored Effluents [Carbon Usage]

Carbon Dosage Per Treatment (g/l)	Total Number of Treatments	Total Carbon Usage	Ratio To 1 g/l
0.1	9	0.9	1X
0.5	9	4.5	5X
1.0	7	7.0	7X
3.0	6	18.0	20X
5.0	5	30.0	33X

FIGURE 29 Intermittent Carbon Treatments of Stored Effluents
[Viable Bacterial Cell Counts After Carbon Treatments]
(APPENDIX TABLES 27 - 31)

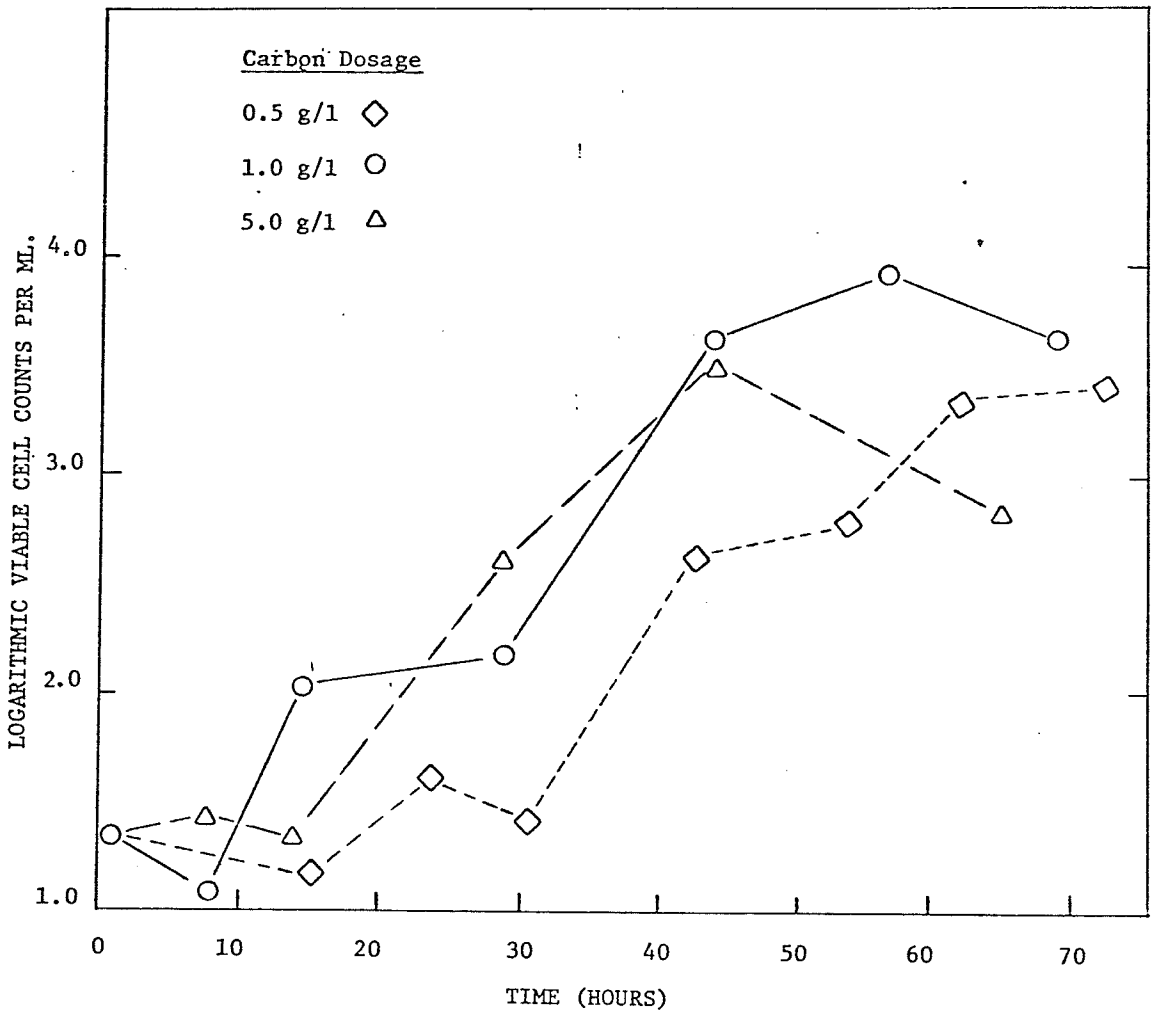


TABLE 9 Intermittent Carbon Treatments of Stored Effluents [Final Viable Bacterial Cell Counts In Effluents]

Carbon Dosage (g/1)	Viable Cell Counts Per ml
0.1	4.2×10^5
0.3	2.5×10^4
1.0	4.6×10^3
3.0	3.2×10^2
5.0	6.3×10^2

to cause an deprivation of nutrients to the extent of suppressing microbial growth. Thirdly, microbial growth could perhaps be enahanced by successive carbon treatments to eliminate the toxic metabolites.

5.3.8 A General Discussion

Turbidity has always been one of the physical criteria for the establishement of standards for surface water as well as industrial water supplies (35,42,50,150). In potato slice rinse water, turbidity was mainly due to the accumulation of insoluble starch and other solid particles. This had been shown to be effectively and efficiently removed by centrifugation (destarching) followed by carbon dosages as low as 0.1 g/1. This dosage also effectively eliminated another objectional factor, namely, brown coloration of the effluent.

Upon storage of effluents, however, turbidity was observed to re-occur. Studies conducted attributed the reappearance of turbidity in the stored effluent to microbial activities and in particular, autolysis upon microbial death. In general, the initially clear effluents became cloudy within 8 - 12 hours of storage at room temperatue (22 °C).

Occurrence of turbidity in the effluent was determined to be caused, at least in part, by bacterial metabolism. Biological activities were reflected partially in the reduction of CO_2D values

that indicate the amount of organic carbons in the effluent, and subsequent release of carbon dioxide resulting in an depreciation of the CO_2D values. In these studies, reduction in CO_2D values was thus used as an partial indication of biological activities.

Direct elimination of microorganisms by millipore filtration of the effluent gave a keeping quality that theoretically would remain indefinitely excellent unless post-contamination or other chemical changes occured in the effluent. Millipore filtration would appear to be potential means of controlling turbidity development in the effluent. However, actual industrial processing wastes will be high in colloidal materials that, along with the build-up of microorganisms on the filtration unit, would be likely to introduce operational complications such as blockage to the millipore unit.

Turbidity was further attributed to the bacteria cells per se and the subsequent discharge of cellular contents from the dead cells. The following evidences were obtained. Firstly, elimination of bacteria effectively prevented turbidity development. Secondly, a parallel exponential trend was observed between cellular growth and turbidity development which continued to rise beyond the stationary phase of cell growth. Both were also time - dependent. Thirdly, refrigeration temperature (4 °C) which could slow down or stop bacterial reproduction also greatly reduced the development of turbidity in the effluent.

Products resulting from bacterial autolysis are suggested

as the main cause of turbidity. These results are based on the following observations. Firstly, turbidity was much more readily removed than the bacteria cells. This tended to indicated that turbidity was attributed to fine colloids that would be much more readily adsorbed than the relatively large bacterial cells. A dosage as low as 0.1 g/l effectively eliminated turbidity, but not viable bacterial cells. Secondly, turbidity continued to rise in an exponential manner during the period of stationary cell growth when cell death was counterbalanced by cell growth. This showed that turbidity was related to a phenomenon that proceeds further than cell growth. Thirdly, temperatures which halted or slowed down bacterial growth gave only slight increases in turbidity. This could only be explained by the discharge of cellular colloids upon autolysis of the bacterial cells. The near freezing temperature caused most of the bacteria to die off and subsequent lysis was very likely to occur.

Fourthly, in effluents that were intermittently treated with powdered activated carbon to remove turbidity, there still remained a net increase in the viable cell counts. Therefore, it seemed that turbidity could not be attributed solely to the physical presence of the viable bacterial cells. Intermittent treatments with activated carbon would effectively remove the colloidal discharge as well as toxic metabolites, thus rendering the environment more favorable to microbial growth which accounted for

the observed increase in cell numbers in the stored effluents.

Beside sterilization by filtration, other methods of control of turbidity include lowering storage temperature, acidification of the effluent and intermittent carbon treatments. Considering the large volumes of effluents used in industrial operations, refrigeration of bulk effluent would appear to be uneconomical both in cost and space.

Citric acid was found to prevent the darkening of potato chips without affecting the product quality. Smith et al. (136) showed that this could be achieved by using citric acid or citrate solutions heated to temperature between 150 and 200 °F. The use of citric acid in treating potato slice rinse effluent would thus appear to be beneficial in product quality beside controlling turbidity development in the effluent. Acidification of the effluent also appeared to be more effective microbiologically than powdered activated carbon. Low pH caused a direct detrimental effect on the bacterial growth and was unfavorable to most organisms except the acid-tolerant species. However, the bulk of effluents to be treated in this manner would appear to involve a large cost factor. Moreover, the acidic nature of the effluent would pose concern of its effect on the equipment.

Treatment with powdered activated carbon was finally attempted. The efforts were centered on optimizing the frequency of applications and the total carbon usage. Treatments with

relatively high dosages of 10.0, 20.0 and 30.0 g/l did not give any significant advantages over the use of lower dosages such as 0.1, 0.3 and 0.5 g/l in providing better keeping quality of the effluent. Multiple treatment, in particular, split treatments were again demonstrated to be highly efficient in retaining clarity of the effluent and lowering the bacterial load therein. A split application of 2.0 g/l gave a clarity retention interval of 14 hours as compared to 8 hours obtained from a single application of 2.0 g/l powdered activated carbon.

Turbidity development in the stored effluents could be checked by direct carbon treatments using varying dosages. In the study conducted, the lowest dosage of 0.1 g/l was deemed to be more economical in the treatment of an effluent to be stored over a 3 day period, based on the total carbon usage only.

Powdered activated carbon, though effective in maintaining the clarity of effluent, did not appear to successfully prevent the growth of microorganisms in the effluent. Also, the effluent was treated at points of visible turbidity. This criterion was therefore not microbiologically effective in checking turbidity. Other indicators that would correlate more closely to bacterial density should be investigated. Continuous instead of intermittent carbon treatment would scientifically be a more rational approach in controlling biological activities. The microbial population would be continuously reduced at a rate greater than that of cell increase.

SUMMARY

SUMMARY

Powdered activated carbon was investigated for its effectiveness in the removal of microorganisms that would or could be commonly found in potato slice rinse effluent. The removal pattern of nine selected microorganisms inoculated into sterile phosphate buffered water was investigated in the first part of this investigation. It was found that powdered activated carbon, at a sufficient dosage, greatly reduced the viable cell counts of these microorganisms in the phosphate buffered water. Among the microorganisms studied, Pseudomonas aeruginosa in phosphate buffered water appeared to be least readily adsorbed/filtered, while Lactobacillus casei on the other hand, was most readily removed. The latter population was reduced from 10^4 organisms/ml to about 100 organisms/ml with a carbon dosage of 1.0 g/l. In general, a carbon dosage of 3.0 g/l was found to be sufficient in obtaining an optimal removal of the microorganisms studied. Yeasts and molds were shown to be effectively eliminated from the phosphate buffered water; the removal of these organisms, however, was attributed to the filtration properties of the filter paper rather than the powdered activated carbon.

Attempts were made to study the effects of cell size, cell morphology and cell wall composition on the bacterial removal by the powdered activated carbon. However, these effects could not be definitely determined. It was further noted that powdered activated carbon showed some degree of selective removal towards some of the microorganisms studied. This small degree of selective removal could

be due the effects of bacterial morphology, cell size and other physical factors that are known to affect adsorption. In most cases selective removal could not be firmly established at least with the parameters used in this investigation.

The second part of this investigation studied the removal pattern of the general microfloral population in potato slice rinse effluent. It was noted that, in general, a higher carbon dosage was necessary to obtain the same degree of microbial reduction from the effluent than from phosphate buffered water inoculated with a similar level of viable bacterial cells. This could perhaps be attributed by those microorganisms that were less readily adsorbed/filtered than the other members of the microflora. Furthermore, interference by the organics in the effluent could be expected. In terms of adsorption, microorganisms would be expected to be at a competitive disadvantage over the organics which compared more favorably to the pore sizes of the carbon particles.

The efficiency of bacterial removal by powdered activated carbon appeared to be dependent on a number of factors, mainly the effluent strengths and initial bacterial population in the water or effluent. The presence of organics lowered the efficiency of the adsorption/filtration; the greater the amounts of organics present, the lower the efficiency observed. On the other hand, the higher the initial microbial population in the effluent, the more efficient the reduction was noted. Nonetheless, for any degree of bacterial reduction, a greater amount of powdered activated carbon was needed

with a larger microbial population in the effluent. The extent of microbial removal from the water or effluent also appeared to be dependent on the contact time used. Studies showed that for maximum removal of B. subtilis (initial viable cell counts: 5.7×10^6 org./ml) a contact time of 1/2 minutes and 5 minutes was required for carbon dosages of 1.0 g/l and 10.0 g/l respectively.

Split application of powdered activated carbon was shown to be more efficient than single application in achieving the desired level of bacterial removal. It is particularly useful when the bacterial population is markedly high, which would be in the range of 10^6 - 10^7 organisms/ml. Split treatment also realized substantial savings in material cost since less activated carbon would be required.

In treating recycling effluent, a certain treatment frequency would be required. Recycling an effluent resulted in a gradual build up of both the organics and the viable bacterial cell counts. Physical chemistry would account for a possible equilibrium condition in the build up of organics. Physical processes such as diffusion and osmosis evidently, could not be expected to contribute to the build up of microorganisms in the effluent. Each reuse cycle was noted to contain an extra 10^3 - 10^4 organisms/ml. Excessive microbial build up should be prevented for aesthetic, microbiological and operational reasons. A treatment frequency of ten reuse cycles per carbon treatment would be recommended in the in-plant treatment of the potato slice rinse effluent.

Intermittent powdered activated carbon treatments using a carbon dosage of 1.0 g/l was demonstrated to be capable of maintaining the viable bacterial cell counts within 10^1 - 10^3 organisms/ml in a batch of effluent which was recycled 60 times over five operation days. At the termination of a daily operation and the beginning of next operation day, the viable bacterial cell levels were noted to be particularly high. Split applications of 2.0 g/l powdered activated carbon was found to be effective in reducing these high bacterial levels to the desired range.

The idea of indefinite water reuse necessitated the effluent being held over a number of non-operation days. The effluent, however, was noted to deteriorate upon storage. The final part of this investigation therefore studied the cause of effluent deterioration, as evident by the development of turbidity and odor; and attempted to study possible means of control of turbidity development.

The potato slice rinse effluents, irrespective of the initial carbon dosages applied, were noted to retain sufficient nutrients to support the microbial population for about a week. Yeasts and molds were found to be least competitive with the other microorganisms. Also, the coliform organisms were found to be less competitive with the other bacteria. Aeration did not appear to affect the growth of the bacterial population in the effluents.

The previously carbon treated, clarified effluents were noted to become turbid after 8 - 12 hours of storage at room temperature. This turbidity was largely attributed to the activities

of the microorganisms. Sterilizing the effluent effectively prevented the development of turbidity. At refrigeration temperature (4 °C) where microbial activities were greatly slowed, turbidity was noted to developed at a slower rate than at room temperature (22 °C) Evidences further indicated that turbidity could be due to the autolytic discharge of colloidal cell contents. Possible evidences include the readiness in the elimination of turbidity but not the viable bacterial cells in the effluents; continuing increase in turbidity during the stationary phase of cell growth in the effluents; gradual development of turbidity in the absence of bacterial growth at refrigeration temperature (4 °C); and a net increase in the viable bacterial cell counts in effluents subjected to intermittent carbon treatments which improved the clarity of the effluent.

Possible controls of turbidity include direct physical elimination of the microorganisms by millipore filtration, and/or the creation of unfavorable growth conditions such as low pH and low storage temperature. Lowering the pH of the effluent to 4.5 by the addition of citric acid was noted to decrease the bacterial growth rate in the effluent. However, operational complications would be expected with the use of millipore filtration. Also, the cost factor would render the use of citric acid non-feasible. Space availability would restrict the practicality of refrigerating the bulk of rinse effluent.

Intermittent treatments of the stored effluents with powdered activated carbon at points of observable turbidity (20 - 25 J.T.U.) resulted in an effluent with improved clarity but net

increase in viable bacterial cell counts. This method of intermittent powdered activated carbon treatments at points of observable turbidity is thus not reliable. The criterion should be modified by perhaps lowering the turbidity readings that warrant re-treatment of the effluent, or the use of other possible indices that would provide a closer relationship or correlation between turbidity development and bacterial growth. Above all, a continuous treatment process would be highly recommended. Such a process would continuously reduced the bacterial level at a rate faster than that of increase in bacterial population.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

The "total system" approach with extensive water reuse has been demonstrated in a few industries. In food processing, however, the principle of water reuse and effluent recycling has been demonstrated only to a limited extent, confined mostly to certain unit operations such as the fluming and washing stages. Reuse of effluent through the application of sound scientific principles to define proper engineering parameters is thus undisputedly regarded as the most efficient and the ultimate means of combating the most stringent regulations on food waste discharge as well as the escalating cost accompanied with increased demand for quality water. Powdered activated carbon, by virtue of its low cost and feasible regeneration, its enormous adsorptive capacity and versatility, is particularly suited for treating food process effluents which are unique in high organic strength and extreme variability both in kind and amount. Moreover, the application of powdered activated carbon is basically a reductive physico-chemical process in that the undesirable components, notably the bacterial load in the effluents are removed without any addition of chemical agents that might impose potential health hazards due to possible chemical complexing with certain refractory compounds in the wastes.

The first concern in recycling food processing effluents is apparently, the microbiological quality of the effluent. This

work illustrated that, with sufficient carbon dosages and proper treatment frequency, powdered activated carbon was capable of maintaining the viable bacterial cell counts of the recycling potato slice rinse effluent within a desireable limit. Activated carbon was also shown to be capable of removing the selected microorganisms inoculated in buffered phosphate water. With the potato slice effluent, generally excellent reduction in the viable bacterial counts could be obtained with a powdered activated carbon dosage of 5.0 g/l. This dosage could be lowered if split or multiple application was utilized. In the stored effluent, intermittent treatments utilizing appropriate treatment frequency and carbon dosages would maintain the viable bacterial cell counts of the effluents within a desirable limit.

In this investigation, the microbiological quality of the recycling rinse effluent was partially and indirectly reflected by the viable bacterial cell counts. It appears more sensible that in further studies the presence of possible pathogenic microorganisms and other index organisms such as faecal and confirmed coliforms should be monitored closely in conjunction to the viable bacterial counts. Only then could one define the microbiological quality of the effluents.

Application of powdered activated carbon in treating other types of food processing wastes should exhibit similar feasibility. Many pilot-plant studies could thus be recommended to affirm the potential usefulness of carbon treatments on other

food processing effluents and the possible complications unique to the treatment of any particular waste.

This study utilized Aqua-nuchar as the adsorbant. However, other grades of powdered activated carbon, such as one with a greater proportion of macropores of greater effective radii than the other sizes of pores, might prove superior than the Aqua-nuchar in the adsorption/filtration of microorganisms in the effluents. Comparative studies on different types of powdered activated carbon on this aspect could also be further recommended.

A continuous cyclic treatment process would prove much more effective and efficient than the intermittent batch-type method employed in this investigation. A continous treatment process would eliminate the microorganisms at a rate that would effectively prevent their build-up in the effluent. Further research should perhaps be emphasized on continuous treatment process. Other indices that would correlate closely to the microbial density in the effluent should also be investigated.

Increasing concern has been focussed on the occurrence of viruses in potable water. Adsorption of viruses by activated carbon has be demonstrated by some workers. However, the presence of viruses in food processing wastes has not been studied to any great extent. Also, activated carbon should be investigated for its effectiveness in eliminating water-borne and food-borne bacteria in particular. The advocation of activated carbon for treating food processing effluents should revive the interest and research

efforts on the removal of microorganisms by the filtration adsorption process.

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APPENDICES

APPENDIX TABLE 1. NATIONAL CANNERS ASSOCIATION WATER ECONOMY CHECK LIST**

OPERATION OR EQUIPMENT	BE RECOVERED WATER BE USED?	MAY WATER FROM THIS EQUIPMENT BE REUSED ELSE-WHERE IN PLANT?	SOURCE OF WATER FOR REUSE IN EQUIPMENT*
1. Acid dip for fruit	yes	no	Can coolers
2. Washing of product			
A. First wash followed by 2nd wash	yes	yes*	Can coolers
B. Final wash of products	no	yes*	
3. Flumes			
A. Fluming of unwashed or unprepared product (peas, pumpkin, etc.)	yes	yes*	Can coolers
B. Fluming partially prepared product	yes	yes*	
C. Fluming fully prepared product	no	yes	
D. Any fluming of wastes	yes	no	Any wastewater
4. Lye peeling	yes	no	Can coolers
5. Product-holding vats; product covered with water or brine	no	no	
6. Blanchers - all types			
A. Original filling water	no	no	
B. Replacement or make-up water	no	no	

APPENDIX TABLE 1. (Continued)

OPERATION OR EQUIPMENT	BE RECOVERED WATER BE USED?	MAY WATER FROM THIS EQUIPMENT BE REUSED ELSE-WHERE IN PLANT?	SOURCE OF WATER FOR REUSE IN EQUIPMENT
7. Salt brine quality graders followed by a fresh water wash	yes	Only in this Equipment	
8. Washing pans, trays, etc.			
A. Tank washers - original water	no	no	
B. Spray or make-up water	no	no	
9. Lubrication of product in machines such as pear peelers, fruit size graders, etc.	no	yes*	Can Coolers
10. Vacuum concentrators	yes	in this equipment after cooling and chlorination	
11. Washing empty cans	no	no	
12. Washing cans after closing	yes	yes	Can coolers
13. Brine and syrup	no		
14. Processing jars under water	yes	for processing	Can coolers and processing waters

APPENDIX TABLE 1 . (Continued)

OPERATION OR EQUIPMENT	MAY RECOVERED WATER BE USED?	MAY WATER FROM THIS EQUIPMENT BE REUSED ELSEWHERE IN PLANT?	SOURCE OF WATER FOR REUSE IN EQUIPMENT*
15. Can Coolers			
A. Cooling canals			
1. Original water	no		Waters from these coolers may be reused satisfactorily for cooling cans after circulating over cooling towers, if careful attention is paid to proper control of replacement water, and to keeping down bacterial count by chlorination and frequent cleaning.
2. Make-up water	yes		
B. Continuous cookers where cans are partially immersed in water			
1. Original water	no		
2. Make-up water	yes		
C. Spray coolers with cans not immersed in water	yes		
D. Batch cooling in retorts	yes	This water may be reused in other places as indicated.	
16. Clean-up purposes			
A. Preliminary wash	yes	yes*	Can coolers
B. Final wash	no	no	
17. Box washers	yes	no	Can coolers

*A certain amount of water may be reused for make-up water and in preceding operations if the counterflow principle is used with the recommended precautions.

**Townsend, C.T. and Somers, I.I. "How to Save Water in Canneries", Food Industries, 21, W11-W12.

APPENDIX TABLE 2 Preparation of Phosphate Buffered Water

Stock Phosphate Buffer Solution:	
Potassium dihydrogen phosphate	34.0 g
Water	1.0 liter
Adjusted to pH 7.2 with 1N NaOH	
Buffered Water:	
Stock Buffer Solution	1.25 ml
Distilled Water	1.0 liter

APPENDIX TABLE 3 The Effect of Bacterial Morphology on Adsorption/Filtration [Bacilli]

Carbon Dosage (g/100 ml)	VIABLE CELL COUNTS PER ML.			
	E.coli	*B. subtilis*	*L. casei*	*P. aeruginosa*
0.00	1.5×10^7	1.1×10^7	1.6×10^6	1.1×10^6
0.01	5.6×10^6	3.2×10^6	2.4×10^5	9.8×10^5
0.05	4.5×10^6	9.8×10^5	1.0×10^4	9.6×10^5
0.10	2.1×10^6	3.0×10^5	2.3×10^2	7.0×10^5
0.30	1.4×10^4	1.5×10^2	11	1.5×10^5
0.50	1.8×10^2	10	4	1.8×10^4
1.00	17	5	1	93

APPENDIX TABLE 4 The Effect of Bacterial Morphology on Adsorption/Filtration [Cocci]

Carbon Dosage (g/100 ml.)	VIABLE CELL COUNTS PER ML.		
	S. aureus	M. roseus	S. faecalis
0.00	7.1×10^6	9.9×10^5	1.1×10^7
0.01	1.7×10^6	8.2×10^5	1.8×10^6
0.05	6.7×10^5	4.4×10^5	5.3×10^4
0.10	1.5×10^5	1.7×10^5	6.3×10^2
0.30	38	1.2×10^4	**
0.50	**	2.4×10^2	**
1.00	**	**	**

**Less than 30.

APPENDIX TABLE 5 The Effect of Bacterial Morphology on Adsorption/Filtration

[Inocula: E. coli & S. aureus]

Carbon Dosage	E. coli		S. aureus		Binary Mixture
(g/100 ml)	Single	Mixture	Single	Mixture	Total Count
0.00	6.6×10^5	6.8×10^5	1.2×10^6	1.5×10^6	2.2×10^6
0.05	3.8×10^5	3.2×10^5	4.6×10^5	5.1×10^5	9.5×10^5
0.10	1.3×10^5	1.7×10^5	7.3×10^4	1.6×10^5	2.6×10^5
0.30	2.2×10^3	1.0×10^4	$5,9 \times 10^2$	1.8×10^3	1.1×10^4
0.50	56	3.7×10^2	**	31	3.8×10^2
1.00	**	**	**	**	**

**Less than 30 organisms/ml.

APPENDIX TABLE 6 The Effect of Bacterial Cell Size on Adsorption/Filtration

[Inocula: S. aureus & M. roseus]

Carbon Dosage	S. aureus		M. roseus		BINARY MIXTURE
(g/100 ml)	Single	Mixture	Single	Mixture	Total Count
0.00	1.2×10^7	1.5×10^7	2.6×10^6	2.1×10^6	1.6×10^7
0.05	2.3×10^6	3.4×10^6	7.1×10^5	9.2×10^5	4.6×10^6
0.10	2.6×10^5	6.2×10^5	3.2×10^5	3.4×10^5	1.7×10^6
0.30	5.5×10^2	1.8×10^3	2.1×10^3	1.0×10^4	1.3×10^4
0.50	**	**	42	2.5×10^2	3.1×10^2
1.00	**	**	**	**	**

**Less than 30 organisms/ml.

APPENDIX TABLE 7 The Effect of Cell Wall Composition on Adsorption/Filtration

[Inocula: *E. coli* & *B. subtilis*]

Carbon Dosage	E. coli		B. subtilis		BINARY MIXTURE
(g/100 ml)	Single	Mixture	Single	Mixture	TOTAL COUNT
0.00	1.8×10^6	1.6×10^6	3.3×10^5	4.0×10^5	2.6×10^6
0.05	7.4×10^5	1.2×10^6	3.8×10^4	1.2×10^5	1.7×10^6
0.10	1.3×10^5	4.1×10^5	2.2×10^3	1.7×10^4	4.3×10^5
0.30	1.5×10^3	3.8×10^3	**	**	3.2×10^3
0.50	2.3×10^2	1.7×10^2	**	**	1.8×10^2
1.00	**	**	**	**	**

**Less than 30 organisms/ml.

APPENDIX TABLE 8 The Effect of Motility of Selected Microorganisms on Adsorption/Filtration [Inocula: B. subtilis & L. casei]

Carbon Dosage	B. subtilis		L. casei		BINARY MIXTURE
(g/100 ml)	Single	Mixture	Single	Mixture	Total Count
0.00	6.8×10^6	6.6×10^6	1.3×10^6	2.0×10^6	8.1×10^6
0.05	1.6×10^6	2.5×10^6	1.1×10^5	3.2×10^4	2.5×10^6
0.10	2.3×10^5	4.7×10^5	2.3×10^4	**	4.7×10^5
0.30	95	2.6×10^3	**	**	2.6×10^3
0.50	**	**	**	**	**

**Less than 30 organisms/ml.

APPENDIX TABLE 9 Build-Up of Viable Bacterial Cell Count During Sequential Effluent Reuse

Number of Reuse Cycles	Viable Cell Counts Per Ml.	Microbial Increase Per Rinse
1	2.1×10^4	2.1×10^4
2	2.2×10^4	1.0×10^3
3	2.3×10^4	1.0×10^3
4	5.5×10^4	3.2×10^4
5	5.9×10^4	4.0×10^3
6	6.1×10^4	2.0×10^3
7	6.2×10^4	1.0×10^3
8	6.4×10^4	2.0×10^3
9	6.6×10^4	2.0×10^3
10	8.1×10^4	2.5×10^4

APPENDIX TABLE 10 The Effect of Effluent Strengths on Adsorption/Filtration

[Test Organism: B. subtilis]

Carbon Dosage (g /100 ml)	Control (B. Water)	Number of Reuse Cycles 1X	5X	10X
0.00	3.4×10^6	3.6×10^6	3.4×10^6	3.5×10^6
0.05	2.1×10^5	4.8×10^5	7.3×10^5	1.2×10^6
0.10	8.3×10^3	1.5×10^5	2.3×10^5	2.9×10^5
0.30	**	2.8×10^2	1.7×10^3	4.3×10^3
0.50	**	**	31	49

**Less than 30 organisms/ml.

APPENDIX TABLE 11 The Effect of Initial Bacterial Population in Effluent

[Test Organism: B. subtilis]

Carbon Dosages (g/100 ml.)	Viable Cell Counts Per Ml.		
	Effluent 1	Effluent 2	Effluent 3
0.00	1.7×10^7	4.6×10^5	2.3×10^3
0.05	3.6×10^6	1.9×10^5	6.6×10^2
0.10	1.3×10^6	3.7×10^4	3.1×10^2
0.20	4.5×10^4	4.6×10^3	60
0.30	2.6×10^3	3.8×10^2	**
0.40	91	32	**
0.50	**	**	**

**Less than 30 organisms/ml.

APPENDIX TABLE 12 Contact Time Study

Contact Time	Spiked Buffered Water		Potato Slice Rinse Effluents		
	0.10*	0.50*	0.10*	0.50*	1.00*
0 Sec.	5.7×10^6	5.7×10^6	8.2×10^3	8.2×10^3	8.2×10^3
5 "	4.3×10^6	5.8×10^5	5.9×10^3	4.2×10^3	4.0×10^3
15 "	4.1×10^6	3.0×10^5	5.7×10^3	2.4×10^3	2.3×10^3
30 "	3.8×10^6	1.4×10^5	4.3×10^3	1.6×10^3	1.5×10^3
1 Min.	3.0×10^6	1.2×10^4	4.1×10^3	5.0×10^2	3.7×10^2
3 "	3.0×10^6	3.6×10^2	4.0×10^3	1.7×10^2	48
5 "	2.9×10^6	32	4.0×10^3	1.5×10^2	**
10 "	3.1×10^6	30	4.0×10^3	1.5×10^2	**

*Carbon Dosage In g/100 ml

**Less than 30 organisms/ml.

APPENDIX TABLE 13 Simulation of An Effluent Recycling Process [Viable Bacterial Cell Counts]

Number of Reuse Cycles	Viable Cell Counts Per Ml.	
	Before Treatment	After Treatment
1	2.0×10^4	1.4×10^2
2	2.1×10^5	1.9×10^3
4	1.6×10^4	2.8×10^3
6	1.8×10^4	1.1×10^3
8	3.4×10^5	5.5×10^2
10	6.9×10^3	5.7×10^2
12	1.6×10^4	5.1×10^3
14	3.3×10^3	4.2×10^2
16	2.3×10^5	5.2×10^3
18	6.0×10^4	5.2×10^3
		$6.0 \times 10^{2**}$
(DAY 2)	7.3×10^4	5.2×10^3
		$7.4 \times 10^{2**}$
20	7.4×10^5	2.3×10^3
22	2.8×10^4	5.0×10^2
26	9.3×10^4	4.0×10^2
28	1.2×10^4	2.1×10^2
		90^{**}

** Re-treatment at 0.1 g/100 ml.

APPENDIX TABLE 13 (Continued)

Number of Reuse Cycles	Viable Cell Counts Per Ml.	
	Before Treatment	After Treatment
(DAY 3)	1.6×10^4	2.2×10^2
30	2.6×10^5	2.4×10^4
32	2.8×10^4	2.4×10^2
34	3.9×10^3	4.5×10^2
36	4.2×10^5	2.7×10^4
38	2.1×10^5	5.2×10^3
		23^{**}
(DAY 4)	2.4×10^6	5.2×10^4
40	9.6×10^5	1.7×10^4
42	9.0×10^5	3.5×10^4
44	2.1×10^4	2.4×10^3
		33^{**}
(DAY 5)	9.1×10^5	3.5×10^4
		$2.0 \times 10^{3**}$
46	2.9×10^5	3.3×10^4
48	2.7×10^4	2.4×10^3
50	2.3×10^4	3.4×10^3
52	8.6×10^4	1.9×10^3
54	1.3×10^4	5.0×10^2
56	6.1×10^3	5.2×10^3
58	1.4×10^4	5.3×10^2
60	9.1×10^4	2.0×10^2

APPENDIX TABLE 14 Microbial Growths In Stored Effluents

Day	pH	Viable Cell Counts Per Ml.			
		Total Plate Count	Starch - Metabolising Bacteria	Coliforms	Yeast and
1	7.1	6.4×10^4	9.3×10^2	8.8×10^2	2.5×10^2
2	6.9	1.3×10^6	6.7×10^5	2.1×10^4	3.3×10^2
3	6.8	3.6×10^7	2.5×10^7	8.0×10^6	4.4×10^2
5	7.9	8.3×10^8	5.4×10^8	5.0×10^7	1.8×10^2
7	8.3	5.6×10^8	5.1×10^8	2.0×10^6	1.1×10^2
9	8.4	2.7×10^8	2.4×10^8	2.0×10^5	76
11	8.6	2.4×10^8	2.2×10^8	1.1×10^4	30

APPENDIX TABLE 15 The Effect of Aeration on Microbial Growth

TIME	AERATED EFFLUENT		NON-AERATED EFFLUENT	
(Hours)	Total Plate Count	Yeasts and Molds	Total Plate Count	Yeasts and Molds
0	2.4×10^4	0	2.8×10^4	0
24	7.2×10^7	0	1.5×10^8	0
48	4.1×10^8	2	8.0×10^8	1
72	1.3×10^8	14	9.2×10^8	2
120	2.1×10^9	8	1.2×10^9	4

APPENDIX TABLE 16 Turbidity Development In Treated Effluent [Raw Effluent]

TIME (HOURS)	TURBIDITY (J.T.U.)	CO_2D (PPM)	VIABLE CELL COUNTS PER ML.
0	35	5423	4.2×10^4
8	60	5227	7.3×10^4
16	372	5124	1.7×10^6
24	1600	4865	9.7×10^6
36	2500	4602	3.8×10^7
48	4500	4325	1.1×10^8
72	5600	4243	2.1×10^8
96	7100	3984	2.2×10^8

APPENDIX TABLE 17 Turbidity Development In Treated Effluent

[Initial Carbon Treatment: 1.0 g/l]

TIME (HOURS)	TURBIDITY (J.T.U.)	CO_2D (PPM)	VIABLE CELL COUNTS PER ML.
0	14	4567	1.6×10^2
8	19	4524	2.2×10^3
16	81	4470	5.3×10^4
24	920	4398	2.4×10^5
36	1600	4254	5.9×10^5
48	2500	3950	4.7×10^6
72	3300	3847	2.6×10^7
96	3500	3782	5.1×10^7

APPENDIX TABLE 18 Turbidity Development In Treated Effluent

[Initial Carbon Treatment: 10.0 g/l]

TIME (HOURS)	TURBIDITY (J.T.U.)	CO_2D (PPM)	VIABLE CELL COUNTS PER ML.
0	10	3876	1.3×10^2
8	15	3763	2.7×10^2
16	28	3717	2.9×10^2
24	85	3629	1.8×10^3
32	270	3592	4.2×10^3
48	740	3515	5.1×10^3
72	1100	3474	7.4×10^3
96	1500	3429	1.1×10^4

APPENDIX TABLE 19 Turbidity Development In Treated Effluent

[Initial Carbon Treatment: 20.0 g/1]

TIME (HOURS)	TURBIDITY (J.T.U.)	CO_2D (PPM)	VIABLE CELL COUNTS PER ML.
0	6.0	3275	30
8	16.2	3250	62
16	26.4	3186	2.9×10^2
24	31.0	3133	1.7×10^3
48	62.0	3064	2.3×10^3
72	560.0	2953	1.2×10^4
96	990.0	2912	1.4×10^4

APPENDIX TABLE 20 Bacterial Activities As Cause of Turbidity

[Raw Effluent Treated With 1.0 g/1 PAC]

Time	Effluent at 22 °C			Effluent at 4 °C		
(Hours)	Turbidity (JTU)	CO_2D (PPM)	Viable Cell Count Per ml	Turbidity (JTU)	CO_2D (PPM)	Viable Cell Count Per ml
0	15	5482	4.6×10^3	15	5482	4.6×10^3
24	52	5030	6.3×10^6	18	5453	5.4×10^2
48	320	4652	1.5×10^7	60	5224	5.2×10^2
72	1100	3733	7.6×10^8	310	5376	3.5×10^2

APPENDIX TABLE 21 Bacterial Activities As Cause of Turbidity [Sterilized Effluent]

TIME	EFFLUENT AT 22 °C			EFFLUENT AT 4 °C		
(HOURS)	TURBIDITY (J.T.U.)	CO_2D (PPM)	VIABLE COUNT PER ML.	TURBIDITY (J.T.U.)	CO_2D (PPM)	VIABLE COUNT PER ML.
0	12	5318	0	11	5318	0
24	13	5314	0	12	5316	0
48	16	5278	11	14	5036	0
72	25	5221	640	20	5279	73

APPENDIX TABLE 22 Control of Turbidity by Raising Hydrogen Ion Concentration

TIME	RAW EFFLUENT				ACIDIFIED EFFLUENT			
(HOUR)	pH	TURBIDITY (JTU)	CO_2D (PPM)	VIABLE CELL COUNT/ML.	pH	TURBIDITY (JTU)	CO_2D (PPM)	VIABLE CELL COUNT/ML.
0	6.9	30	1687	4.7×10^4	4.5	11.4	1359	4.2×10^2
8	6.6	36	1585	3.6×10^5	4.5	11.8	1336	2.1×10^2
24	7.1	72	1484	3.1×10^7	4.6	14.0	1286	7.5×10^3
48	7.2	140	642	1.2×10^8	6.7	23.0	1229	1.6×10^4
72	8.0	380	301	9.0×10^8	6.7	43.0	1006	4.1×10^5

APPENDIX TABLE 23 Control of Turbidity by Raising Hydrogen Ions Concentration [Unacidified Effluent Intermittently Carbon Treated @ 1.0 g/1]

TIME		pH		TURBIDITY		CO_2D		VIABLE CELL COUNTS PER ML.	
HOUR	INT.*	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
0	0	6.6	7.1	33	14	1049	705	4.7×10^4	3.2×10^3
8	8	6.9	7.1	27	8	557	591	9.0×10^5	6.2×10^4
20	12	7.0	7.2	22	9	486	467	6.6×10^6	1.3×10^6
32	12	6.9	7.1	20	7.2	385	370	4.1×10^7	7.0×10^6
48	16	6.8	7.2	23	7.0	294	271	9.6×10^7	2.7×10^7

*Interval Betwen Two Treatments

APPENDIX TABLE 24 Control of Turbidity by Raising Hydrogen Ions Concentration [Acidified Effluent Intermittently Carbon Treated @ 1.0 g/l]

TIME		pH		TURBIDITY		CO_2D		VIABLE CELL COUNTS / ML.	
HOUR	INT.*	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
0	0	7.1	4.6	35	600	1049	783	4.3×10^4	29
8	8**	4.5	---	7.0	---	770	---	2.0×10^4	---
16	8**	4.5	---	11	---	755	---	8.6×10^4	---
22	22	4.6	5.4	23	13	667	564	1.3×10^5	1.6×10^3
32	10**	6.1	---	16	---	458	---	6.0×10^3	---
42	20	6.5	6.6	21	11	387	355	1.8×10^6	4.0×10^3
48	6**	6.6	---	13	---	305	---	7.6×10^4	---

*Interval Between Two Treatments

**No Carbon Treatment

APPENDIX TABLE 25 Control of Turbidity by Intermittent Carbon Treatments [High Carbon Dosages]

TIME	CARBON DOSAGES (G/100 ML.)		
(HOUR)	1.0	2.0	3.0
0	12	9	2.0
4	16	11	2.5
8	17	12	4.5
10	22	14	7.3
--	4.5**	--	--
14	6.0	22	11.5
--	--	3.6**	--
16	11	4.5	21
--	--	--	2.6**
18	20	5.1	2.7
--	7.1**	--	--
20	7.3	7.5	5.0
24	15	16	11.5

** Re-treatment with same carbon dosage

APPENDIX TABLE 26 Control of Turbidity by Intermittent Carbon Treatments
[Multiple Treatments @ 1.0 g/l Per Application]

TIME		1 x 0.1 g/100 ml		2 x 0.1 g/100 ml		3 x 0.1 g/100 ml	
HOUR	INT.*	BEFORE TR.	AFTER TR.	BEFORE TR.	AFTER TR.	BEFORE TR.	AFTER TR.
0	0	32	14	32	4.5	32	2.8
4	-	17	--	7.0	--	5.5	--
8	8	22	5.6	12.5	--	6.2	--
12	12	7.4	--	21.5	4.8	16	--
14	14	8.0	--	7.5	--	21	3.0
16	--	12.5	--	9.6	--	4.1	--
18	10	21	6.0	10.5	--	6.2	--
20	--	7.6	--	14	--	10.5	--
24	--	16	--	20	--	18	--

*Interval between re-treatments, if any

-- No re-treatment

APPENDIX TABLE 27 Intermittent Powdered Activated Carbon Treatments of Effluent [Carbon Dosage: 0.1 g/1]

TIME		TURBIDITY (JTU)		CO_2D (PPM)		VIABLE CELL COUNTS/ML	
HOUR	INT.*	BEFORE TR.	AFTER TR.	BEFORE TR.	AFTER TR.	BEFORE TR.	AFTER TR.
0**	0	24	18	5264	3606	7.2×10^5	3.0×10^3
		18	14	3606	3374	3.0×10^3	2.5×10^2
8	8	24	15	3262	3050	5.7×10^4	2.1×10^4
15	7	22	17	2893	2737	2.3×10^5	7.3×10^4
23	8	23	14	2223	2192	9.8×10^5	1.1×10^5
32	9	24	13	2032	1997	5.2×10^5	2.5×10^4
41	9	21	15	1885	1839	2.1×10^6	6.2×10^5
50	9	22	12	1763	1545	5.0×10^5	2.4×10^4
60	10	21	10	1220	1156	8.8×10^6	5.9×10^5
72	12	34	6.6	943	883	8.1×10^6	4.2×10^5

*Interval between re-treatments with same dosage

**First treatment with 0.5 g/100 ml powdered activated carbon

APPENDIX TABLE 28 Intermittent Powdered Activated Carbon Treatments of Effluents [Carbon Dosage: 0.5 g/1]

TIME		TURBIDITY (JTU)		CO_2D (PPM)		VIABLE CELL COUNTS/ML	
HOUR	INT.*	BEFORE TR.	AFTER TR.	BEFORE TR.	AFTER TR.	BEFORE TR.	AFTER TR.
0	0**	28	18	5263	3606	7.2×10^5	3.0×10^3
		18	12	3606	3083	3.0×10^3	1.3×10^2
8	8	24	16	2987	2877	4.3×10^4	8.7×10^2
16	8	22	17	2813	2612	1.3×10^4	1.5×10^2
24	8	23	14	2492	2395	2.1×10^3	4.2×10^2
31	7	21	10	2359	2267	6.2×10^3	2.4×10^2
43	12	22	12	2138	1975	3.7×10^4	4.3×10^3
53	10	20	8.2	1850	1688	9.2×10^4	6.2×10^3
62	9	21	11	1605	1442	3.6×10^5	2.1×10^3
72	10	24	6.4	1206	913	6.7×10^5	2.5×10^4

*Interval between re-treatments with same dosage

**First treatment with 0.5 g/100 ml powdered activated carbon

APPENDIX TABLE 29 Intermittent Powdered Activated Carbon Treatments of Effluents [Carbon Dosage: 1.0 g/l]

TIME		TURBIDITY (JTU)		CO_2D (PPM)		VIABLE CELL COUNTS / ML	
HOUR	INT.*	BEFORE TR.	AFTER TR.	BEFORE TR.	AFTER TR.	BEFORE TR.	AFTER TR.
0	0**	28	18	5263	3606	7.2×10^5	3.0×10^3
		18	14	3600	3075	3.0×10^3	2.1×10^2
8	8	24	16	2983	2787	3.2×10^2	12
15	7	25	16	2662	2487	9.7×10^3	1.0×10^2
29	14	22	12	2035	1747	2.1×10^4	1.5×10^2
44	15	23	11	1619	1588	4.3×10^4	3.9×10^2
56	12	24	7.2	1384	995	6.2×10^4	8.2×10^3
68	12	21	6.0	965	835	9.4×10^4	4.6×10^3
72	4	8	--	829	--	5.1×10^3	--

*Interval between re-treatments with same dosage

**First treatment with 0.5 g/100 ml powdered activated carbon

-- No treatment

APPENDIX TABLE 30 Intermittent Powdered Activated Carbon Treatments of Effluents [Carbon Dosage : 3.0 g/l]

TIME		TURBIDITY (JTU)		CO_2D (PPM)		VIABLE CELL COUNTS PER ML.	
HOUR	INT.*	BEFORE TR.	AFTER TR.	BEFORE TR.	AFTER TR.	BEFORE TR.	AFTER TR.
0	0**	28	18	5263	3600	7.4×10^5	3.0×10^3
		18	8	3600	2787	3.0×10^3	25
8	8	24	15	2744	2487	4.1×10^3	63
15	7	23	12	2420	2383	9.6×10^3	7.2×10^2
28	13	20	9	2315	1852	2.3×10^4	4.4×10^2
44	16	23	10	1675	1250	1.5×10^5	1.7×10^3
61	17	24	7.6	1127	935	1.2×10^4	1.1×10^2
72	11	15	--	835	--	3.2×10^2	--

*Interval between re-treatments

**First treatment with 0.5 g/100 ml powdered activated carbon

--No treatment

APPENDIX TABLE 31 Intermittent Powdered Activated Carbon Treatments of Effluents [Carbon Dosage: 5.0 g/1]

TIME		TURBIDITY (JTU)		CO_2D (PPM)		VIABLE CELL COUNTS/ML	
HOUR	INT.*	BEFORE TR.	AFTER TR.	BEFORE TR.	AFTER TR.	BEFORE TR.	AFTER TR.
0	0	28	18	5263	3600	7.2×10^5	3.0×10^5
		18	10	3554	2135	3.0×10^5	25
8	8	24	12	2080	1625	2.7×10^3	2.5×10^2
15	7	23	13	1562	1437	8.7×10^3	22
29	14	20	10	1375	1251	7.6×10^3	4.3×10^2
45	16	22	6.2	1117	894	3.5×10^4	3.8×10^3
65	20	20	6.0	743	550	4.6×10^4	6.3×10^2
72	6	11	--	485	--	6.3×10^2	--

*Interval between re-treatments

-- No treatment