THE UNIVERSITY OF MANITOBA

Water and Wastes Management in Carrot Processing

by

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A Thesis

Submitted to the Faculty of Graduate Studies
in partial fulfillment of the requirements for the
Degree of Master of Science

Department of Food Science

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ABSTRACT

Powdered activated carbon treatment was shown to be feasible in a batch process to regulate the quality control factors in carrot processing effluents enabling possible reuse of such effluents within the process.

"Aqua Nuchar" powdered activated carbon was chosen after evaluation of several commercially available carbons. An activated carbon dosage of 0.1% (w/v) applied at every fifth reuse of the carrot rinse water was able to control the aesthetic factors such as odor, foam, color, turbidity, enzyme activity and microbial growth.

Adsorption isotherms were developed for amino acids and sugars, major chemical constituents in carrots, which could become possible components of carrot processing effluents.

A schematic for an improved carrot dehydration processing line is included in the report. A possible saving of at least 60% in the wastewater treatment cost could be achieved using activated carbon treatment and in-plant reuse of effluents, as compared to the standard secondary biological treatment.

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NOMENCLATURE

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Terms	Explanation
MGD	million gallons per day
TSS	total suspended solids
g	gram
g/l	grams per litre
rpm	revolutions per minute
ppm	parts per million
nX	successive reuses of rinse water without treatment, where n = number of rinses
gpd	gallons per day

I. INTRODUCTION

1.1 Effluent Controls Relating to the Food Industry in Canada

Since Canada's food industry -- the largest industry in Canada -- has been characterized as one which discharges highly polluting effluents to the environment, it has been selected by the Environmental Protection Service of Environment Canada, for the development of effluent controls. Higgins (1974)(1) suggested in-plant controls through minimizing water use, water re-use, by-product recovery and process modification in the development of effluent regulations and guidelines for the food industry. The intent of the controls, issued under the Fisheries Act, is to protect the fish and marine organisms across Canada from the discharge of harmful substances. The aim of the regulations and guidelines is to ensure that the food processing plants operating in Canada employ "best practicable process and treatment technology" in their plants. Installation of "best practicable process technology" will ensure that "end-of-pipe" loadings are minimized as well as affording greater opportunities for by-product recovery. Regulations are immediately effective for new plants, while guidelines are indications of a future course of action for the existing food processing plants.

The food processing industries for which effluent guidelines have been developed are fish, potato and meat processing. Future development of effluent controls within the next few years would include the dairy industry and the canned and frozen foods industry.

In summary, Canada's food industry is following a similar pattern to that initiated by the U. S. Environmental Protection Agency, in the development of regulations and guidelines for the U. S. food industry.

1.2 Water Pollution Control in the United States

According to the U. S. Environmental Protection Agency under the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500), effluent limitations guidelines for industrial discharges to municipal systems were set forth, for the degree of effluent reduction attainable through the application of "Best Practicable Control Technology Currently Available" (BPCTA) and "Best Available Technology Economically Available" (BATEA). The reductions must be achieved by existing point sources by July 1, 1977, and July 1, 1983, respectively, with the aim of zero discharge by 1985. The "Standards of Performance for New Sources" set forth the degree of effluent reduction which is achievable through the application of the best achievable demonstrated control technology, process, or other alternatives (2).

1.2.1 U. S. Food Processing Industry

In 1970, a national program was established by the Environmental Protection Agency and the U. S. Food Processing Industry in dealing with the guidelines listed in section 1.2. The First National Symposium on Food Processing Wastes (3) reported on existing projects of the Research and Demonstration Grant Program of the Federal Water Quality Administration. The objectives were to represent a cooperative, coordinated program between industry and government in mutually solving troublesome water pollution problems and reviewing some of the latest efforts to reduce water pollution from the food processing industry. The First Symposium (3) suggested that goals include the refinement of conventional methods of treatment; the development of processes capable of higher degrees of treatment or completely closed loop systems; improvement of processing methods to reduce the quantity of water required per ton of product and development of profitable by-products from the recovered processing "wastes".

In 1971, the Second National Symposium (4) was expanded to include air pollution and solid wastes.

The total systems approach was suggested by Dr. R. A. Gallop at the Fourth Symposium (1973)(5) to be the most ideal solution to water and waste management in the food processing industry in which the entire plant is viewed as a "total system" with the waste element being considered as important as the intended commercial products. The process water could be recycled with in-plant treatment such as activated carbon adsorption. Solid wastes produced at the plant could be converted into activated carbon for on site use (6). A pilot plant in Southern California (7) was reported to have converted sewage solids to activated carbon which was then used to treat the incoming wastewater, which resulted in virtual elimination of sewage solids, removal of heavy metals contained in the sewage and elimination of odors. The "spent" activated carbon could be recycled back with the solid wastes and reactivated. Some carbon and ash were the only residues in the system and the gases generated from the solid wastes could be used as a source of power.

The total system approach is now being successfully demonstrated by the Hawaii's Sugar Cane industry (8) and the pulp and paper industry (9).

SCOPE OF INVESTIGATION

This study deals with the use of activated carbon as a possible method of purification for reuse as part of the "total systems" concept approach to the carrot processing industry.

"Aqua Nuchar" powdered activated carbon was the carbon chosen for use in this study, after evaluation of six available commercial powdered activated carbons. The evaluation was based on the (x/m)Co value (maximum theoretical amount of impurities adsorbed by a unit weight of carbon).

Adsorption isotherms were developed for simulated carrot wastes and organic compounds which could be possible components of carrot processing effluents.

Instrumental measurement of oxygen demand of simulated carrot wastes using the "Aquarator" was investigated.

Recommendations are made for an improved carrot dehydration processing line which handles solid and liquid wastes as part of the "total systems" concept. Costing of incorporating a carbon treatment with reuse is compared to conventional secondary biological treatment.

II. LITERATURE REVIEW

2.1 Fundamental Processes of the Carrot Processing Industry

The individual processing steps have been described by U. S. E. P. A. (1975)(2), Copley and van Arsdel (10) and von Loescke (11).

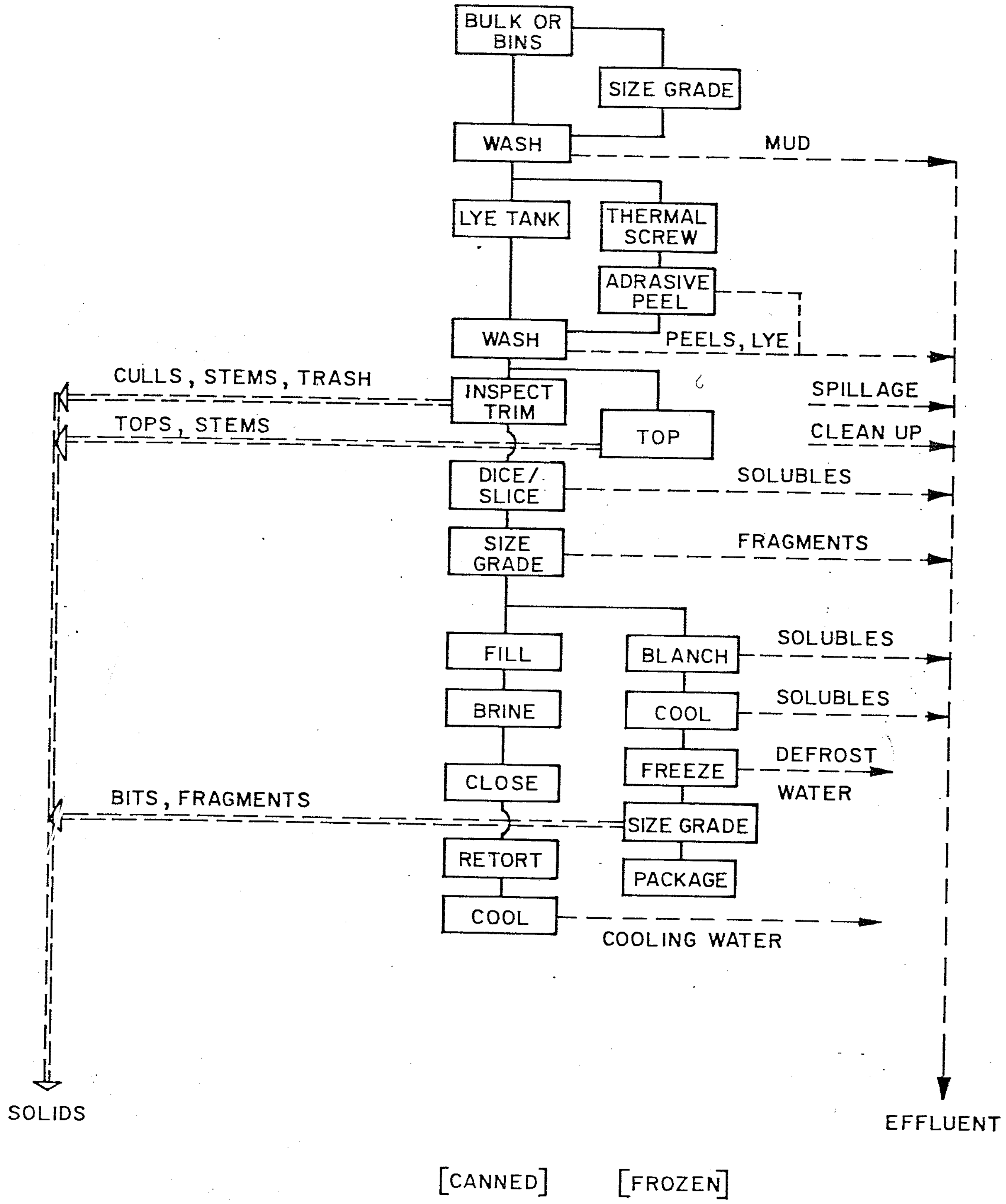
A flow diagram for a typical carrot process is shown in fig. 1.

2.2 Water Use in Carrot Processing

A considerable volume of information concerning water use for fruit and vegetable processing is available. Most of this information applies to canning and freezing operations.

Information on waste volumes from vegetable processing has been available in reference texts such as Mercer (12) of the National Canners Association. Although this data has traditionally been accepted, its reliability has recently been questioned. Soderquist (13) observed that information cited by Mercer and other accepted textbook sources is derived from studies conducted 20 - 30 years ago and based on "grab" samples gathered over sampling periods as short as a few hours or days. However, food processing effluents are subject to wide short-term and seasonal variations. Soderquist (14) has attempted to provide more meaningful data by establishing a mobile laboratory unit which has continuously monitored the processing effluents of several Oregon fruit and vegetable

Fig. 1 TYPICAL CARROT PROCESS FLOW DIAGRAM (2)



processors throughout entire processing seasons.

Total water use information for carrot processing is summarized in table (1) and water requirements for unit operations are given in table (2).

2.3 Waste Characteristics of the Carrot Processing Industry

The largest water usage is needed for cooling, plant cleanup, and product washing. Peel removal waters and blancher effluents are the main contributors to both biochemical oxygen demand (BOD) and suspended solids levels. Initial washing operations were observed to generate both large volumes of wastewater and high settleable solids levels as evidenced from the amount of mud in the effluent.

Wastewater strengths can vary considerably depending on the processing methods, conditions, and plant activities at the time of sampling. The high pH values result from the use of caustics such as lye in peeling.

Slicing and dicing operations can also contribute organics to the waste stream by generating juices and vegetable particles. The rate of leaching of the organics is initially high and decreases exponentially with time and with the number of washes (21). In-plant flumes can be recirculated and reused provided that the water is controlled and properly chlorinated.

The waste flows and loads summary of seven carrot processing plants are shown in table (3), while the waste characteristics of three unit operations from the carrot

TABLE (1) TOTAL WATER USE FOR CARROT PROCESSING

PROCESS	FRESH WATER	EFFLUENT	TOTAL WATER USE IMPERIAL GALLONS /TON RAW PRODUCT RANGE	TOTAL WATER USE IMPERIAL GALLONS /TON RAW PRODUCT AVERAGE	TOTAL WATER USE IMPERIAL GALLONS /CASE* RANGE	TOTAL WATER USE IMPERIAL GALLONS /CASE* AVERAGE	REFERENCE
CANNING		X		4163		60.4	15
CANNING		X				19.0	12
CANNING		X	1249**	3081			16
CANNING & FREEZING		X		3081			17
CANNING	X				33-46		18
CANNING (U.K.)		X		1250			19
CANNING (FRANCE)		X		1350			19
CANNING (U.S.)		X		5000			19
DEHYDRATED		X		4000			19
CANNING & FREEZING		X		3300			20

* 24 #303 cans unless specified
** standard deviation
X-data obtained for either fresh water or effluent

	UNIT WATER USE					
PROCESS EFFLUENT	IMPERIAL GALLONS /TON RAW PRODUCT		IMPERIAL GALLONS /CASE*		% OF TOTAL	REFERENCE
	RANGE	AVERAGE	RANGE	AVERAGE		
CLEAN					12-30	17
PEEL					30-40	17
CUT					20-28	17
BLANCH					0-5	17
FILL, SEAL, COOK					15-20	17
WASH-FLUME		79		1.1	1.9	15
BLANCH-TUMBLE PEEL		2057		29.9	49.4	15
ABRASION PEEL		1440		20.9	34.6	15
WHOLE GRADER		233		3.4	5.6	15
SLIVER SCREEN		212		3.1	5.1	15
SLICED GRADER		142		2.1	3.4	15
FILLER						15
TOTAL		4163		60.4		

* 24 #303 cans unless specified

TABLE (2) UNIT WATER USE FOR CARROT PROCESSING

TABLE (3) COMMODITY SURVEY - GROUP B - RAW WASTE FLOWS AND LOADS SUMMARY* (23)

ACTIVITY	NO. OF PLANTS	FLOW MGD	FLOW GAL/TON	BOD mg/L	BOD LB/TON	TSS mg/L	TSS LB/TON
Carrots	7	0.310	2762	1260	29.0	762.0	17.6

* from industry survey and EPA data.

TABLE (4) WASTE CHARACTERISTICS OF UNIT OPERATIONS FROM A CARROT PROCESSING LINE (21)

TYPES OF PROCESS	VOL. OF WATER (GAL/TON)	BOD (mg/L)	BOD (LB/TON)	SUSPENDED SOLIDS (mg/L)	SUSPENDED SOLIDS (LB/TON)
WASHING	600	243	1.4	4120	24.7
	1600	78	1.2	2190	35.0
CANNING	1250	1400	17.5	2000	25.0
	1350	1100	14.8	1830	24.7
DEHYDRATION	4000	1220	48.8	703	28.1
		(860)	(34.4)	(157)	(6.3)

Values in parenthesis relate to settled waste waters.

processing line are listed in table (4).

2.4 Amino Acids and Sugars of Carrots

The study of the amino acids and sugars composition of carrots is important because they are leached or destroyed to some degrees during washing and blanching, consequently generating high pollutional loads.

Amino acids in hot water extracts of carrots which were detected and identified were glutamic acid, valine, leucine, aspartic acid, lysine and serine (22). Carbohydrates present included sucrose, maltose and glucose. The constitution of a simulated carrot soup is shown in table (5).

2.5.1 The Quality Control Criteria in the Purification Systems of Carrot Wastewater

Quality control factors such as physical, physico-chemical, biochemical and biological (fig. 2) must be regulated in order to enhance the feasibility of recycling process wastewater as part of the "total system" concept approach (section 1.2.1.) to the food industry (24).

In the case of water purification in the carrot processing lines, the physical factors refer to factors such as solids, color and turbidity; the physico-chemical factors refer to levels of harmless or potentially troublesome dissolved organics; the biochemical factors refer to the presence of enzymes which might cause alteration of appearance, off-flavor, and reduction in nutritive value; and the biological factors refer to the number of

TABLE (5) CONSTITUTION OF SIMULATED CARROT SOUP (22)

SUBSTANCE	mg/100ml
ASPARTIC ACID	3.15
THREONINE	75.90
SERINE	140.00
GLUTAMIC ACID	60.50
PROLINE	1.86
GLYCINE	2.00
ALANINE	55.40
CYSTINE	trace
VALINE	143.60
METHIONINE	1.69
ISOLEUCINE	5.28
LEUCINE	3.28
TYROSINE	3.74
PHENYLALANINE	3.53
TRYPTOPHANE	1.60
LYSINE	1.22
HISTIDINE	1.35
ARGININE	2.73
TAURINE	20.30
GLUCOSE	75.75
MALTOSE	415.90
SUCROSE	482.98
SUCCINIC ACID	14.10

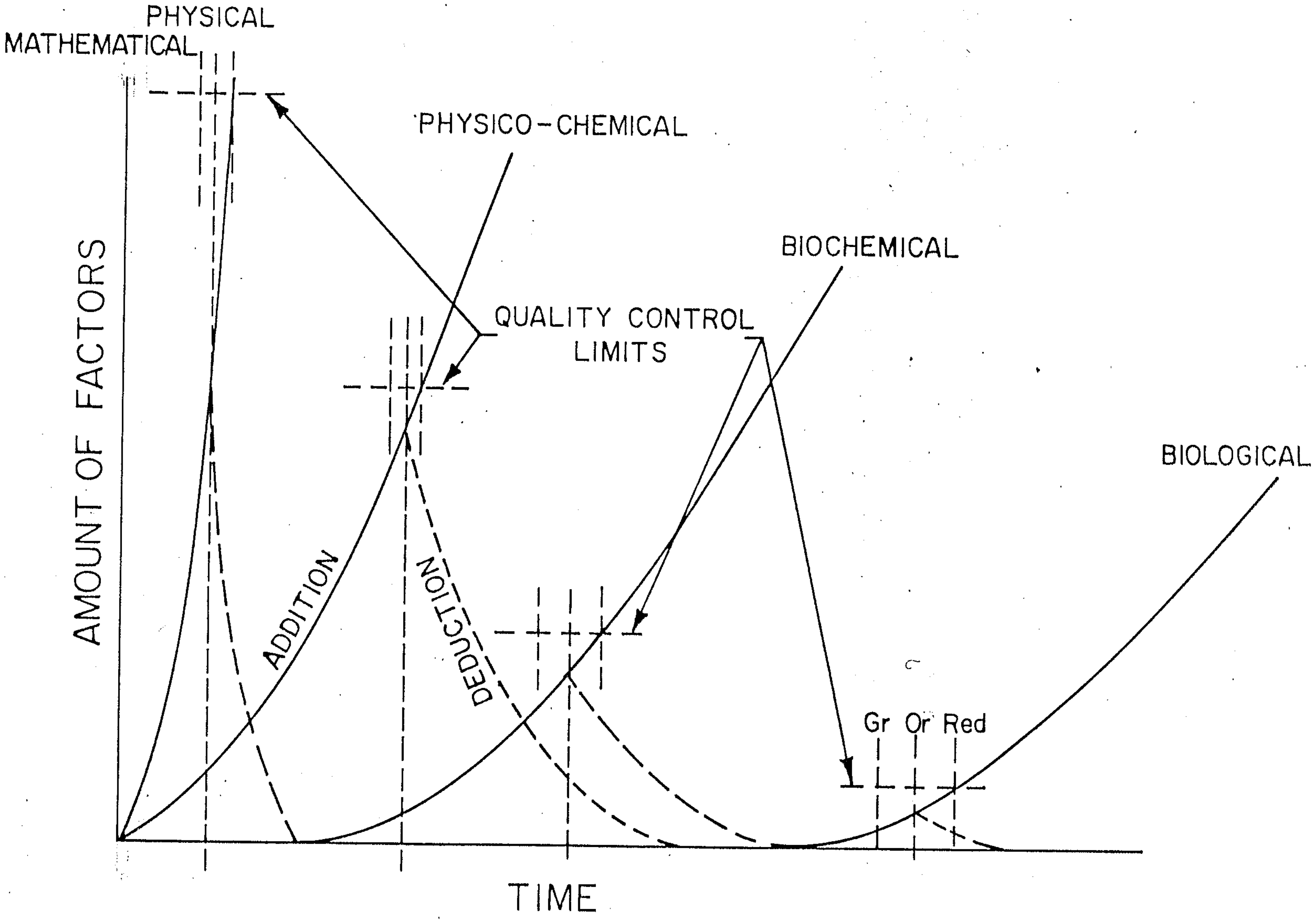


Fig. 2 Growth Rates of Types of Problems, when Recycling Process Waters (24)

potentially objectionable, and possibly dangerous organisms, viruses and bacteria.

The primary objective in wastewater purification systems is to remove the potential build-up of the physical and physico-chemical problems at rates equal to or greater than their rates of increase. The biochemical and biological problems, subsequently can be effectively controlled due to their long induction time.

2.5.2 Enzyme Activity Relating to Carrot Processing

Carrots have been reported to possess polyphenolic compounds and phenolase activity (25). Carrot browning has been a serious problem to Manitoba carrot producers. In Manitoba, unwashed carrots are placed in cold storage immediately after harvest, where they remain until premarket washing. It is suspected that abrasion by mechanical washing damages the skin surface, thereby exposing the internal tissue to oxidation. Chubey and Nylund (1969)(26) suggested that oxidative browning of carrots was caused by the oxidation of phenolic compounds. However, no direct relationships were found between potential browning and total or oxidizable phenols (27).

Water used in carrot processing will leach from the surface of the carrot tissues color-forming compounds such enzymes and enzyme substrates. The colored process water may be undesirable from an aesthetic viewpoint and it also may contain appreciable foam, microbial populations. If recirculated upon freshly exposed food tissue, it may also promote further development of browning. Browning reactions are important for quality control in terms of the alteration of appearance, flavor, nutritive value and possible toxicology (28).

2.5.3 Microbiology of Carrot Processing Effluent

An over-all standard of water quality for the food industries is not practical because so many specialized requirements prevail (29). Traditionally, water for use in food processing operations must usually meet certain required standards of quality, usually equal to those for drinking water, especially the bacteriological standard (30).

The biological characteristics of water are distinguishable by the following effects that are significant from a water quality control viewpoint (31) :

(1) bacterial, viral, protozoal, and helminthic organisms capable of transmitting infections and diseases by the water route,

(2) planktonic algae, actinomycetes, fungi, and other organisms capable of producing objectionable odors, tastes, color, and turbidity,

(3) organisms capable of producing toxic effects by the release of extracellular, metabolic end-products,

(4) nuisance organisms which interfere with water treatment processes and operations.

These four types of effects may be caused by primary or corollary pollutants.

Faecal coliform organisms may be regarded as indicators of recent pollution by enteric wastes. No reliable and routinely applicable method is currently available or differentiating the faecal coliform organisms of human and animal origin. It is necessary therefore, to consider all faecal coliform organisms as indicative of hazardous contamination. The total bacterial count of yeasts and moulds must also be considered as a quality requirement for waters used in certain food processing operations. However, it is difficult to specify quantitative limits on biological organisms which may cause problems such as odor, color, turbidity, taste, and toxic metabolites.

2.6.1 Wastewater Treatment by Activated Carbon Adsorption

It is well documented that biological waste treatment systems respond adversely to widely varying organic and hydraulic loads, and the removal of specific waste constituents cannot always be achieved effectively by biological systems (32). Adsorption processes for wastewater purification were developed which have the following advantages (33) :

(1) wide applicability of the process to many industrial problems,

(2) no additional waste products are generated by the process,

(3) adsorption is impervious to toxic wastes,

(4) the adsorption process is not easily upset by

fluctuations in hydraulic loads or contaminant concentration; and

(5) space or land requirements are minimal.

The development of granular activated carbon capable of reactivation and reuse, made adsorption an economic alternative for removal of dissolved organic contamination from wastewater including those that were difficult to remove biologically. Only a few experiments were performed before the 1960's on its application to wastewater treatment. However, the potential use of carbon has been enhanced recently by a number of regeneration processes (7, 34, 35, 36, 37). Over twenty municipal and at least two dozen industrial wastewater treatment plants in North America are reported to be using activated carbon adsorption (38).

2.6.2 Food Industry Waste Treatment by Activated Carbon

Food plant wastes offer difficult problems in many instances, because they are derived from materials rich in carbohydrates, proteins, fats and mineral salts, causing serious odor nuisances and heavy pollution of the waters into which they are discharged (29).

Conventional biological treatment is the most prevalent treatment process used to treat food industry waste effluents. However, a higher degree of purification and uniform consistency cannot be achieved by the biological treatment. In order to meet the Legislative Guidelines with deadlines set for 1977 and 1983, the food processing industry in the

U. S. will have to develop pollution control methods capable of higher degrees of treatment for reduction of waste effluents and the use of "best available technology". Activated carbon is being considered as a possible method of advanced waste treatment.

Activated carbon was first used in the sugar industry over a hundred years ago for removal of color, and organic contaminants (39). Activated carbon is also used to remove off-flavors in the soft drink industry, to remove color, odor in alcoholic beverages, in purification of oils, fats, gelatin, pectin, alginates, maple syrup, honey, candy, and to remove turbidity in fruit juices (39).

Fox (40) reported on the purification of brines for reuse using activated carbon filters to adsorb phenolics. Ralls et al. (42) also reported on this subject. Beavers et al. (43) discussed the feasibility of activated carbon renovation of maraschino cherry brine effluent. Schultz et al. (44) reported on the use of activated carbon for adsorbing volatiles in commercial apple essence. Ralls et al. (45) reported on the use of granular activated carbon for treatment of various cannery wastes. The potential of purifying several food industry wastes by activated carbon was demonstrated by Gallop et al. (6). Hager (33) reported that activated carbon adsorption was almost universally applicable as a viable treatment alternative for a number of industrial wastewaters including food processing wastes such as natural cheese; fluid milk;

canned fruits, vegetables, preserves, jams and jellies; canned specialties; biscuit, crackers and pretzels; shortening, table oils, margarine and other edible fats and oils.

In general, activated carbon adsorption is a practical and reliable unit process, applicable in preserving water quality, meeting discharge requirements, and producing reclaimed water free of color, odor, taste, microorganisms and the presence of organic pollutants.

2.6.3 Powdered Activated Carbon

Although granular activated carbon has been applied to wastewater treatment on a plant scale, powdered activated carbon is considered as a possible alternative method of purification for wastewater. Powdered activated carbon has excellent adsorptive capacities and has been used widely in water treatment plants for removal of organic materials causing taste and odor problems (46). It has the following advantages over granular activated carbon :

(1) high degree of purification required in the final product can be achieved by powdered activated carbon treatment especially for final polishing,

(2) greater flexibility of operation can be achieved e.g. when many products or grades are produced or when production schedules are irregular,

(3) contact time can be reduced,

(4) can be successfully used for high strength organic effluents.

Davies and Kaplan (1965)(47) studied a pilot-scale adsorption system for sewage effluents using powdered activated carbon. Beebe and Stevens (1967)(48) applied powdered activated carbon to chemically coagulated and settled activated sludge effluent. Cohen (1969)(49) has reported that influent T.O.C. concentrations of 15 - 25 mg/l were reduced to 1.5 - 3.0 mg/l, using a two-stage countercurrent process for application to secondary effluent. Bloom et al. (1969)(34) reported on a transport-type system which they felt could regenerate powdered carbon at a cost as low as 1.5 cents/lb. The potential use for powdered activated carbon in wastewater treatment has been enhanced by a recent process, the "Atomized Suspension Technique" (50), which regenerates and recovers powdered carbon in about 30 secs, at low costs and high yields (90% recovery and 95% of reactivation of adsorption capacity).

2.7 Instrumental Measurement of Oxygen Demand

Although the chemical method of oxygen demand (C.O.D.) is much more rapid than the biological method (B.O.D.), there remains the problem of disposal of the chemicals used in the determination of the oxygen demand of a water sample. The chemicals used are both toxic and expensive (e.g. mercuric salts, silver and chromium salts, sulfuric acid).

The 2 - 3 hour time lag in the COD determination makes it impossible to monitor the oxygen demand of wastewater instantly, and so faster instrumental methods were developed.

Goldstein et al. (51) developed an instrument which is based on the combustion of an organic sample. The oxygen demand of the sample is expressed as "T.O.D." (Total Oxygen Demand).

Fisher and Haskill (1975)(52) developed a rapid COD method for packinghouse wastes, using an autoanalyser (53) and an oxidation time of ten minutes and a temperature of 222 C.

Stenger and van Hall (54) developed an instrument that can determine the oxygen demand of a water sample two minutes after homogenization or dilution by oxidizing the sample using carbon dioxide gas, and the oxygen demand of the sample is expressed as "CO_2D" (Carbon Dioxide Demand).

The latter instrument, known as the "Aquarator", was used in this study to determine the oxygen demand of carrot waste and the theory of operation is discussed in section 3.8.

III. Methods and Materials

3.1.1 Preparation of Simulated Reuse Carrot Rinse Water

In this study, the term "reuse" means repetitive use of a volume of water at the same process step directly, without significant purification by a special engineering system. The carrots, grade No. 1, were obtained from Manitoba Vegetable Producer's Marketing Board, Winnipeg. The carrots were hand peeled, then they were sliced (3/16" thick) by a Hobart Slicer. 100 grams of carrot slices were rinsed by one litre of water over a fine mesh screen. The effluent was collected and reused to rinse successive lots of 100 grams freshly sliced carrots. This experiment was repeated for 300 grams and 450 grams lots of fresh carrot slices. After each rinse, 50 ml was taken out for COD analysis and replaced by 50 ml of make-up water before a further reuse.

3.1.2 Preparation of Simulated Blanched Carrot Wastes

Different weights, 100 grams, 300 grams and 450 grams of carrot slices (obtained as described in section 3.1.1.) were immersed in one litre of boiling water (100 C) for five minutes. The effluents thus collected were used for: adsorption isotherm study; measurement of oxygen demand by the standard method and the instrumental method using the "Aquarator"; and activated carbon selection.

3.2 Adsorption Isotherm Study on Carrot Wastes

The removal of impurities from carrot processing wastes by activated carbon is by adsorption. The empirical

Freundlich equation (55) is most widely applicable in representing adsorption as a mathematical expression. The use of this equation in evaluating adsorption isotherm data is discussed in section 3.2.5.

3.2.1 Adsorbent

The adsorbent chosen for use in this study was Aqua Nuchar powdered activated carbon. This carbon was found to be the most efficient carbon in treating carrot effluents after comparison of six available commercial powdered activated carbon (section 4.2.).

3.2.2 Equipment

The batch study experiments with activated carbon were conducted using a New Brunswick Scientific (model C-33) laboratory rotary shaker. The test liquid and the Erlenmeyer flasks containing the activated carbon were shaken at 300 rpm for one hour.

3.2.3 Effluent Purification Rate

Duplicate 0.1 gram samples of activated carbon were weighed and transferred to 250 ml Erlenmeyer flasks on a laboratory shaker. The test liquid (100 ml) was added and the flasks were shaken at 300 rpm for predetermined time intervals. Control samples containing 100 ml of the test liquid alone were also shaken for the same time intervals. The samples were filtered free from the activated carbon by passing through Whatman filter paper No. 5. The clear filtrate was then analyzed for turbidity and C.O.D.

A rate of effluent purification curve was plotted with impurity as the ordinate and time as the abscissa. The rate of effluent purification curve indicates the required contact time between the test liquid and the adsorbent to achieve the required degree of turbidity and organic removal.

3.2.4 Adsorption Isotherm Procedure

Different weights of powdered activated carbon were transferred to 250 ml Erlenmeyer flasks. The dosages of carbon were chosen to give a wide range of organic removal in order to obtain a satisfactory adsorption isotherm.

The test liquid (100 ml) was added to flasks containing the activated carbon, and to one flask without carbon. This sample served as the control. The carbon treated samples and the control were shaken on the laboratory shaker at 300 rpm for one hour. The test liquid was then separated from the carbon by filtration through Whatman filter paper No. 5. The control sample was filtered in the same manner.

The residual concentration of impurity remaining in solution was determined by the C.O.D. test. The experimental data was then calculated using the Freundlich equation to obtain adsorption isotherms. The adsorption capacity of the activated carbon for the test liquid was calculated from the adsorption isotherm plot (logarithmic).

3.2.5 Adsorption Isotherm Evaluation (55)

The adsorption isotherm is the relationship, at a given temperature, between the amount of a substance adsorbed and its concentration in the surrounding solution. In wastewater, a logarithmic isotherm plotting usually gives a straight line. The Freundlich equation for adsorption isotherms was used to calculate the experimental data measuring the adsorption capacity of the activated carbon. The equation which relates the amount of impurity in the solution to that adsorbed is written :

$$x/m = kc1/n$$

x = amount of impurity adsorbed
m = weight of carbon
x/m = amount of impurity adsorbed per unit weight of carbon
k,n = constant
c = unadsorbed concentration of impurity left in solution.

In logarithmic form :

$$\log x/m = \log k + 1/n \log c$$

in which $1/n$ represents the slope of the straight line isotherm and k represents the intercept of the line at $c = 1$.

The adsorption isotherm indicates the degree of purification that can be obtained with activated carbon treatment. By extrapolation of the isotherm plot to intersect the vertical line erected from the point on the horizontal scale corresponding to the influent concentration (Co), the adsorption capacity of the activated carbon can be determined.

This value, (x/m)Co, represents the amount of impurity adsorbed per unit weight of carbon when the carbon is in equilibrium with the influent concentration, and represents the ultimate adsorption capacity of the carbon.

3.3 Activated Carbon Adsorption of Organic Compounds

This study dealt with adsorption studies of a number of organic compounds (sugars and amino acids) which are possible organic components of the waste effluent from carrot processing lines.

Batch testing was conducted with activated carbon to develop adsorption isotherms for each constituent. The adsorption isotherms indicated the affinity of the activated carbon for these organics, and therefore the possible merit of using carbon, for purifying carrot effluents.

3.3.1 Adsorption Isotherm Study

The method for obtaining the adsorption isotherms was as described in section 3.2.4. The adsorbates used in this study were of analytical grade. The initial substrate concentration was 1 gram/litre. Most solutions of the organics were prepared by dissolving the organics in distilled water and diluting to 1 litre in a volumetric flask. For some organic substrates heat was required for dissolution. The method of evaluation of the adsorption isotherms was as described in section 3.2.5.

3.4 Evaluation of Different Activated Carbon for Treatment of Simulated Carrot Wastes

Six available commercial powdered activated carbons were evaluated as possible adsorbents in this study. The method of selecting an activated carbon was by evaluation of the adsorption isotherms of the test carbons. The method used to develop the adsorption isotherms was as described in section 3.2.4. The method of evaluation was as described in section 3.2.5.

3.5.1 Study of the Effect of Time on COD Leaching of Carrot Wastewater

Carrots were hand peeled, then they were sliced (3/16" thick) by a Hobart Slicer. These sliced carrots (100 grams and 300 grams) were then immersed in one litre of water respectively. Samples were taken at regular intervals for COD analysis to determine the organic leaching.

3.5.2 Feasibility of Reusing Carrot Rinse Water

Simulated reuse carrot rinse water, obtained as described in section 3.1.1., was analyzed for COD after each rinse to determine the organic build-up during 15 reuses. The ratios of carrot slices to water being studied were 100, 300 and 450 grams carrot/one litre water.

3.5.3 Study of the Effect of Powdered Activated Carbon on Quality Control Factors of Recycled Carrot Rinse Water

As described in section 2.5.1., there are four types of quality factors that characterize wastewater. They are :

1. Physical, 2. Physico-chemical, 3. Biochemical and 4. Biological.

Careful monitoring of these factors and differentials in the characteristics of waterflows, across processing steps will largely determine the effects of such processes and the feasibility of with in-plant recycling of the effluent produced.

The apparatus, equipments and glassware used in this study were sterilized with chlorine water before use so that analyses of the biological factors were not affected by outside contamination. The carrot slices (300g), 3/16" thick, were weighed and rinsed by one litre of water. The same litre of effluent was used to rinse successive lots of 300g carrot slices. After the fifth rinse, 40 ml was taken out for analyses. The rinse water was then filtered through Whatman No. 4 filter paper to remove the presence of discrete particles and the filtrate was treated with 1g of "Aqua Nuchar" powdered activated carbon. The samples were placed on a rotary shaker at 300 rpm for 10 minutes to ensure maximum adsorption, filtered through glass-fibre paper (Whatman GF/C) for carbon removal. A sample (40 ml) of the carbon treated effluent was taken out for analyses. A total of 80 ml of make-up water was added to replace the volume of rinse water being taken out for analyses before and after carbon treatment. Then the litre of effluent was reused to rinse another successive lot of 300g fresh carrot slices. The above procedure was repeated for 25 rinses, with intermittent powdered activated carbon treatment after every fifth rinse. Samples were taken out for analyses before and after carbon treatment and make-up water was added after each carbon treatment.

The analyses consisted of the physical factors (turbidity, total solid); physico-chemical factors (COD, reducing sugar, tannin-like compound); biochemical factor (phenolase activity); and biological factors (total bacterial counts, yeasts and moulds, and coliform counts).

3.6 Study of the Measurement of Oxygen Demand of Carrot Effluents by Standard Method and Instrumental Method using the "Aquarator"

3.6.1 Carrot Rinse Water

Sliced carrots (300 grams), obtained as described in section 3.1.1., were rinsed by one litre of water over a screen. Duplicate one gram samples of activated carbon were weighed and transferred to 250 ml Erlenmeyer flasks on a laboratory shaker. The sample effluent (100 ml) was added and the flasks were shaken at 300 rpm for one hour. The samples were then filtered free from the activated carbon by passing through Whatman filter paper No. 5. The raw effluent and the carbon treated effluent were analyzed for oxygen demand by standard method (section 3.7.1.) and the "Aquarator" (section 3.8.).

3.6.2 Blanched Carrot Waste

Blanched carrot waste was obtained as in section 3.1.2.

The ratio of carrot to water used in this study was 300 g/l. The effluent was treated with one gram of powdered activated carbon as described in section 3.6.1.

The carrot effluents were analyzed for oxygen demand before and after carbon treatment by the standard method and the "Aquarator".

3.7 Chemical Analysis

3.7.1 Chemical Oxygen Demand (COD) (56)

Reagents

1. Standard potassium dichromate solution (0.250N) : potassium dichromate (12.259g), primary standard grade, previously dried at 103 C for two hours, was dissolved in distilled water and diluted to 1000 ml in a volumetric flask.

2. Sulfuric acid - Silver Sulfate Solution : Silver sulfate (22g) was added to concentrated sulfuric acid (4.08kg) and allowed to stand for two days for dissolution.

3. Standard Ferrous Ammonium Sulfate Titrant (0.1N) : Ferrous ammonium sulfate (39g) was dissolved in distilled water. Concentrated sulfuric acid (20 ml) was added, cooled and diluted to 1000 ml in a volumetric flask.

4. Ferroin Indicator Solution : 1, 10-phenanthroline dihydrate (1.735g) and hydrated ferrous sulfate (0.695g) were dissolved in distilled water and diluted to 100 ml in a volumetric flask.

5. Mercuric Sulfate : analytical-grade crystals were used.

Procedure

Mercuric sulfate (0.4g) was placed in a 250 ml flat bottom boiling flask. The sample (20 ml) or an aliquot diluted to 20 ml with distilled water was added to the flask. Standard potassium dichromate solution (10 ml) was then added, followed by anti-bumping granules. The sulfuric acid-silver sulfate solution was then carefully added to the mixture. The flasks were swirled to ensure thorough mixing. The mixture was refluxed for two hours using "Corning" hot plates and Liebig and coil condensers. A blank consisting of 20 ml distilled water was refluxed in the same manner, together with the reagents. After the samples were allowed to cool, the condensers were washed down with distilled water to make a final volume of about 150 ml. The excess dichromate was titrated with standard ferrous ammonium sulfate, using ferroin indicator (3 drops) to a reddish-brown end point.

Addition of Mercuric Sulfate

Mercuric sulfate was added to the samples before refluxing to form a soluble mercuric chloride complex with the chloride ions present to eliminate chloride interference in the reaction. A mercuric sulfate:chloride ratio of 10:1 was maintained.

Standardization of Ferrous Ammonium Sulfate Solution

A 10 ml aliquot of standard potassium dichromate solution (0.250N) was diluted to about 100 ml with distilled water. Concentrated sulfuric acid (30 ml) was added and allowed to cool. The solution was titrated with the ferrous ammonium sulfate titrant to a reddish-brown end point, using three drops ferroin indicator.

$$\text{Normality} = \frac{\text{ml potassium dichromate} \times 0.25}{\text{ml ferrous ammonium sulfate}}$$

Calculation of COD

$$\text{mg/l COD} = \frac{(a - b)N \times 8000}{\text{ml sample}}$$

where COD = chemical oxygen demand from dichromate

a = ml of ferrous ammonium sulfate used for blank titration

b = ml of ferrous ammonium sulfate used for sample titration

N = normality of ferrous ammonium sulfate used in titration

3.7.2 Measurement of Turbidity (56)

Turbidity was measured with a Nephelometer (EEL, UNIGALVO TYPE 20, U. K.). The standard was set at 100 on the linear scale using the sensitivity control. Distilled water at 1.33 was used as the reference.

3.7.3 Measurement of Total Residue (56)

Apparatus :

1. Evaporating dish
2. Steam bath
3. Drying oven
4. Desiccator
5. Analytical balance

Procedure

Evaporating dishes were dried in the oven to constant weight. A 20 ml sample was then added to the weighed dishes. The samples were evaporated on a steam bath. After complete evaporation of the water from the residue, the dishes were transferred to the drying oven maintained at 103 C. The dishes were again dried to constant weight. The dishes were allowed to cool in a desiccator before weighing.

Calculation of Total Residue

$$\text{mg/l total residue} = \frac{\text{mg total residue} \times 1000}{\text{ml sample}}$$

3.7.4 Determination of Dextrose (Reducing Sugar)

Shaffer-Somogyi Micro Method (57)

Reagents

1. Shaffer-Somogyi carbonate 50 reagent, 5g KI : Anhydrous sodium carbonate (25g) and Rochelle salt (25g) were dissolved in 500 ml distilled water in a two-litre

beaker. 75 ml of solution of 100g $CuSO_4.5H_2O$/litre were added through funnel with tip under surface, with stirring. Sodium bicarbonate (20g) was added, allowed to dissolve; followed by 5g potassium iodide. The solution was transferred to a one litre volumetric flask. 250 ml 0.1N potassium iodate (3.567g dissolved and diluted to one litre with distilled water) were added and diluted to one litre with distilled water. The solution was filtered through fritted glass and aged overnight before use.

2. Iodide-Oxalate Solution : potassium iodide (2.5g) and potassium oxalate (2.5g) were dissolved in distilled water and diluted to 100 ml. The solution was prepared fresh weekly.

3. Thiosulfate Standard Solution (0.005N) : The solution was prepared daily from standard stock 0.1N solution which was prepared by dissolving sodium thiosulfate (25g) in 1 litre of distilled water, boiled gently for 5 minutes and transferred while hot to a storage bottle previously cleaned with hot sulfuric acid-potassium dichromate solution and rinsed with warm boiled distilled water. The solution was stored in a dark, cool place.

4. Starch indicator solution : Soluble starch (5g) was dissolved in a little cold water, then added to a litre of boiling water. The resulting solution was preserved by adding 4g zinc chloride.

Method

A 5 ml sample was pipetted into 25x200 mm test tube.

Shaffer-Somogyi carbonate 50 reagent (5 ml) was added and mixed well by swirling. Blank determination was carried out by using 5 ml distilled water and 5 ml reagent. The tubes, capped with bulb or funnel was placed in boiling water bath for 15 minutes. The tubes were then removed carefully without agitation to running water cooling bath for four minutes. The caps were removed and potassium iodide-potassium oxalate solution (2 ml) was added down side of each tube, followed by 2N sulfuric acid (3 ml). The solution was mixed thoroughly to insure that all cuprous oxide was dissolved and allowed to stand in cold water for 5 minutes, mixing twice during that time. The solution was titrated with 0.005N sodium thiosulfate using starch indicator.

Calculation of Dextrose

The titration of the sample solution was subtracted from that of the blank. The amount of dextrose in 5 ml solution was determined by the following :

$$\text{mg dextrose} = (0.1099 \times \text{ml of } 0.005\text{N sodium thiosulfate}) + 0.048$$

3.7.5 Determination of "Tannin-like" compounds (56)

Reagents

1. Tannin-lignin reagent : Sodium tungstate dihydrate (100g), molybdophosphoric acid (20g) and 85% phosphoric acid (50 ml) were dissolved in 750 ml distilled water. The liquid was boiled under reflux for two hours, allowed to cool and

made up to 1 litre with distilled water.

2. Sodium carbonate solution : Sodium carbonate (200g) was dissolved in 500 ml warm distilled water and diluted to 1 litre to form a saturated solution.

3. Stock solution : Tannic acid (1g) was weighed, dissolved in distilled water and diluted to 1000 ml.

4. Standard solution : 10 ml of the stock solution were diluted to 100 ml with distilled water to form a solution containing 100μ g active ingredient per 1.00 ml.

Method

Tannin-lignin reagent (2 ml) was added to 50 ml of clear sample and mixed well. Sodium carbonate solution (10 ml) was added after 5 minutes and mixed thoroughly. The solution was allowed to stand for 10 minutes for color development. A reagent blank was prepared by substituting distilled water for sample substrate. Absorbance measurements were made at 700 mμ using a Coleman UV-111 spectrophotometer.

Calculation of "tannin-like" compound

Although the results were reported as "tannin" or "tannin-like" compound, they more properly should be referred to as "hydroxylated aromatic" compounds. The concentration of "tannin-like" compound, expressed in mg/l was determined from a calibration graph.

Calibration graph (data, Appendix VI)

A calibration graph (figure 3) was prepared using aliquots of the standard solution (1 ml to 5 ml) and

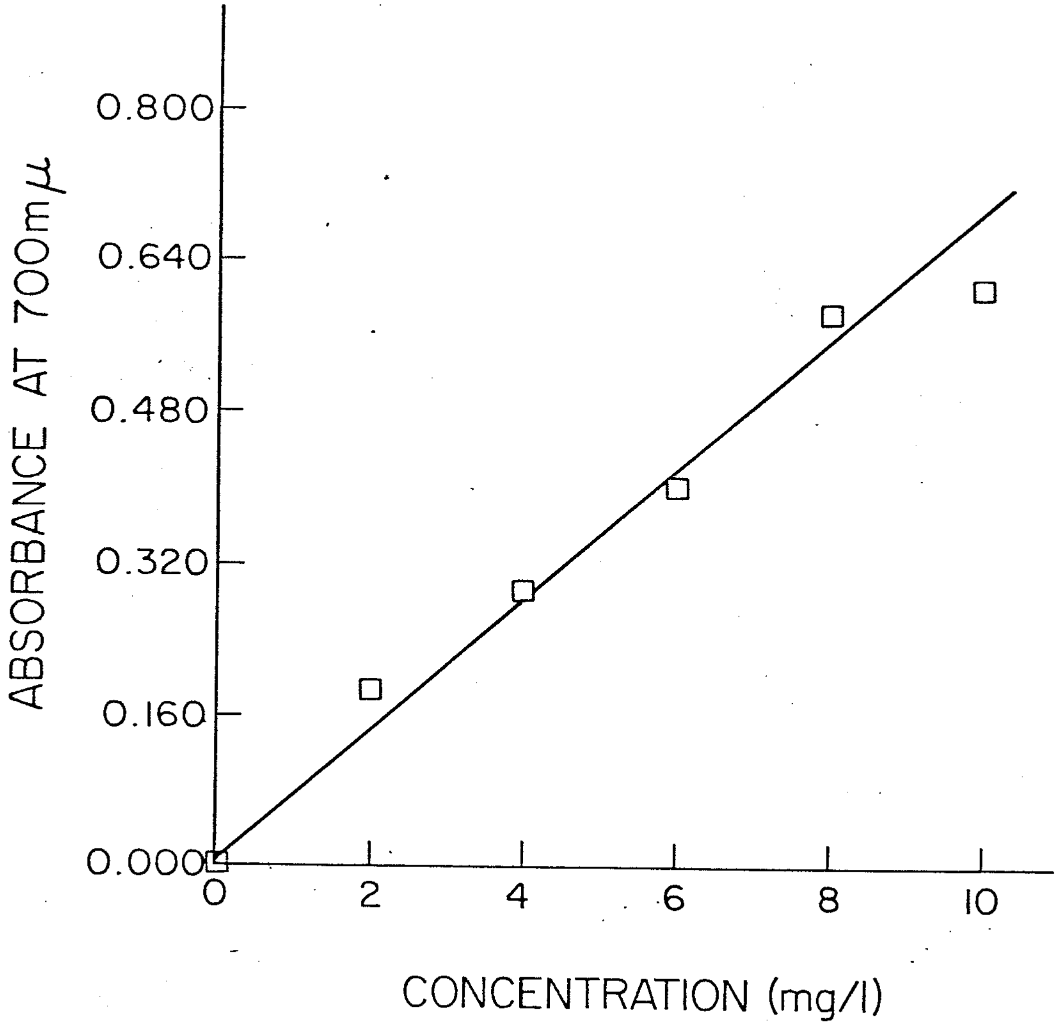


Fig. 3 Standard Curve for "tannin-like" Compound

diluting to 50 ml before using the above procedure.

3.8 Instrumental Method of Analysis

"Precision" Aquarator Method for Determination of Oxygen Demand

Theory of Operation

The "Aquarator" consists of two electric furnaces and an infra-red spectrophotometer. Extremely pure carbon dioxide gas (containing less than 7 ppm hydrocarbons and 7 ppm oxygen) passes through a quartz tube set inside the first electric furnace. The furnace is set anywhere from 370 - 555 degrees Centigrade. Its purpose is to convert any trace amounts of oxygen in the line to carbon monoxide. The gas then flows through an inlet port into a longer combustion tube set inside a second electric furnace maintained at 900 degrees Centigrade. The furnace is packed with platinum catalyst. A 20μl sample is injected into the combustion tube present in the second (sample) furnace. The organic component is oxidized by the carbon dioxide gas. To remove water vapor, the gases pass through a trap filled with "Drierite". The gases then are returned to the sample furnace where they pass through a "U" tube packed with additional platinum catalyst. The gases then flow through an "IR" unit which detects the amount of carbon monoxide present in the gas stream. If organic matter is present, the IR meter needle moves upward.

The oxygen demand of a sample is obtained from a standard curve obtained by plotting the meter reading of each standard versus its theoretical oxygen demand.

Reagents

1. Stock Acetate Solution : sodium acetate trihydrate (2.127g) was dissolved in distilled water and diluted to 1000 ml in a volumetric flask. The solution had an oxygen demand of 1000 mg/l.

2. Standard Acetate Solutions : Aliquots of the stock solution (5 to 30 ml) were diluted to 100 ml with distilled water in separate volumetric flasks.

Calibration Curve (data, Appendix VI)

Calibration was done by injecting 20 μl of the standard acetate solutions separately into the sample combustion tube. When reproducible readings on the IR meter were obtained, the meter reading of each standard was plotted against its theoretical oxygen demand on a graph (figure 4).

3.9 Determination of Phenolase Activity (58)

Equipments

1. Coleman UV-111 spectrophotometer
2. Unicam SP45 Concentration Readout Unit
3. Unicam AR25 linear recorder.

Procedure

The sample solution was filtered, under refrigeration, through Whatman No. 1 paper. The substrate used was 0.05M in

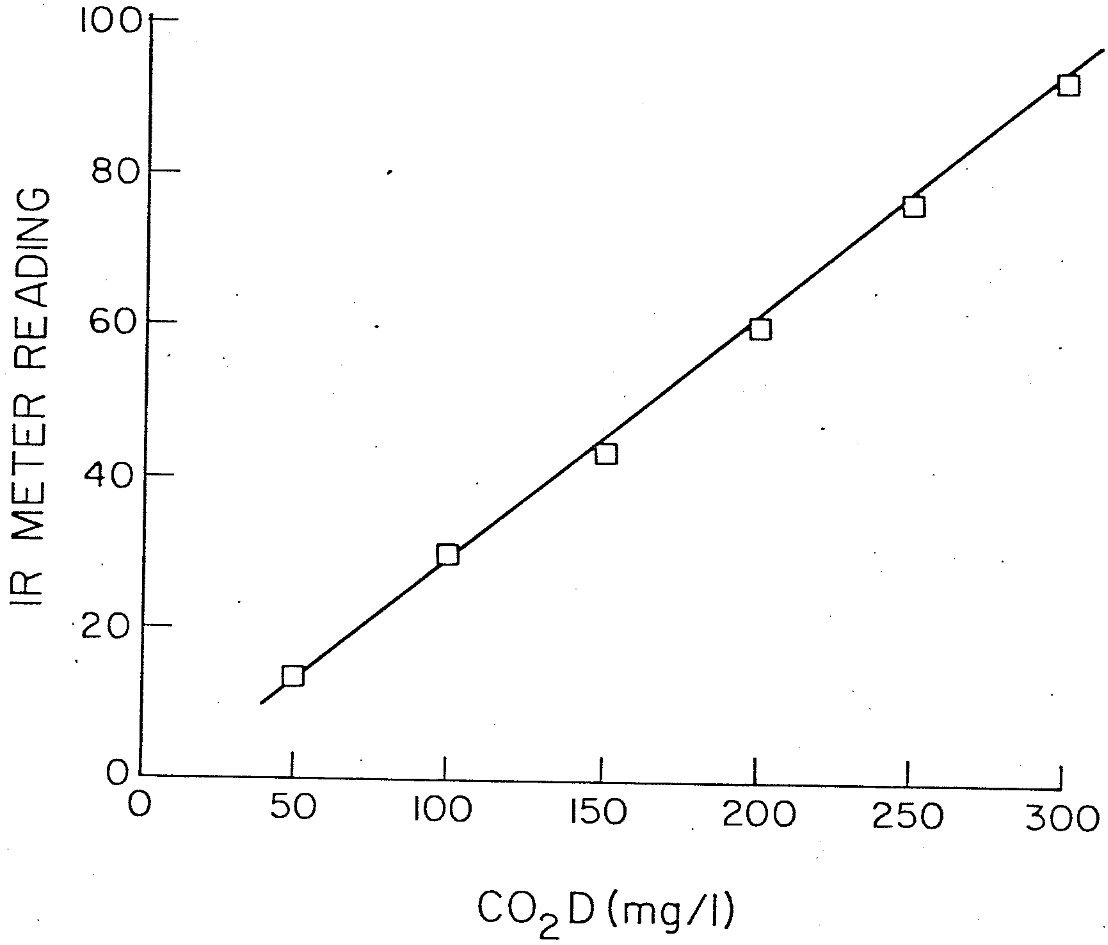


Fig. 4 Calibration Curve for "Aquarator"

catechol and 0.1M in phosphate buffer, pH 6.0 (59). Activity of phenolase was determined by placing 3.0 ml of substrate in a spectrophotometer cuvette, balancing the instrument, and then the enzyme extract (0.6 ml) was pipetted rapidly into the cuvette. After thorough mixing, the cell was immediately inserted into the spectrophotometer to enable a "progress curve" to be obtained for the enzyme at 410 mμ.

Calculation of phenolase activity

The initial rate, reported in terms of increase in absorbance per minute, was used as a measure of the enzyme activity at 25 C and was obtained by drawing a tangential line to the curve approximately 48 seconds after the reaction had begun.

3.10 Microbiological Analysis (60)

The number of viable bacteria cells, yeasts and moulds, and coliform bacteria in recycled carrot rinse water were determined by the method recommended by the A.P.H.A. (1965).

Standard Plate Count (S.P.C.)

Using a serial dilution technique, the samples were plated at time intervals on standard plate count agar. The plates were incubated at 32 C for 48 hours. The average of colony counts of a suitable dilution containing 30 - 300 colonies was selected to enumerate the viable bacteria cells per ml.

Yeasts and Moulds

Using a serial dilution technique, the samples were plated at time intervals on potato glucose agar (acidified with sterile 10% tartaric acid for the suppression of bacterial growth by adjusting the reaction of the medium to pH 3.5 ± 0.1). The plates were allowed to solidify, inverted and incubated at 23 C ± 2 C. The plates were counted after 5 days of incubation using the Quebec colony counter. If moulds and mycoderma were numerous, the plates were counted on the third day and then recounted on the fifth day if possible. If the ratio of higher to lower estimates on decimal dilutions exceeded 2 : 1, the lower computed count was reported.

Coliform Bacteria

The multiple-tube method (60) was used, and the results were reported as most probable number (MPN) of coliform organisms per ml of sample.

IV. RESULTS AND DISCUSSION

4.1 Feasibility of Reusing Carrot Rinse Water

Simulated reuse carrot rinse water was prepared as in section 3.1.1. The carrot to water ratios being studied were : 100g/l, 300g/l and 450g/l. The results are shown in table (6) and fig. 5.

From fig. 5, it may be noted that the first rinse contained 396 (C/W = 100), 854 (C/W = 300), and 1253 (C/W = 450) mg/l COD which increased up to 2245, 4726 and 5307 mg/l COD correspondingly at the fifteenth rinse, with the rinse water gradually reaching an equilibrium condition in dissolved COD in which no further significant organic leaching could be observed. Hence, the rinse water is valuable for reuse, since further reuse of the water performs the desired function of surface cleaning of the slices while the nutrients are largely left in them. The treatment requirement would be to control the aesthetic factors such as turbidity, color, odor, foam and microbial growth.

As part of the total systems concept, powdered activated carbon was used to control the aforementioned aesthetic factors as well as the quality control factors and will be discussed in section 4.6.

4.1.1 Effect of Time on COD Leaching of Carrot Slices in Flume Water

Carrot slices and/or dices are usually flumed from

TABLE (6) COD BUILD-UP IN CARROT RINSE WATER DURING REUSE

RINSE (CUMULATIVE)	C.O.D. (mg/l) C/W = 100	C/W = 300	C/W = 450
1	396	854	1253
2	640	1416	2100
3	843	1869	2879
4	994	2307	3279
5	1115	2755	3937
6	1219	2956	4347
7	1348	3175	4421
8	1563	3321	4568
9	1733	3577	4605
10	1861	3704	4642
11	2018	4160	4863
12	2122	4510	5084
13	2127	4672	5231
14	2245	4710	5273
15	2245	4726	5307

C/W = gram of carrot slices/litre of water

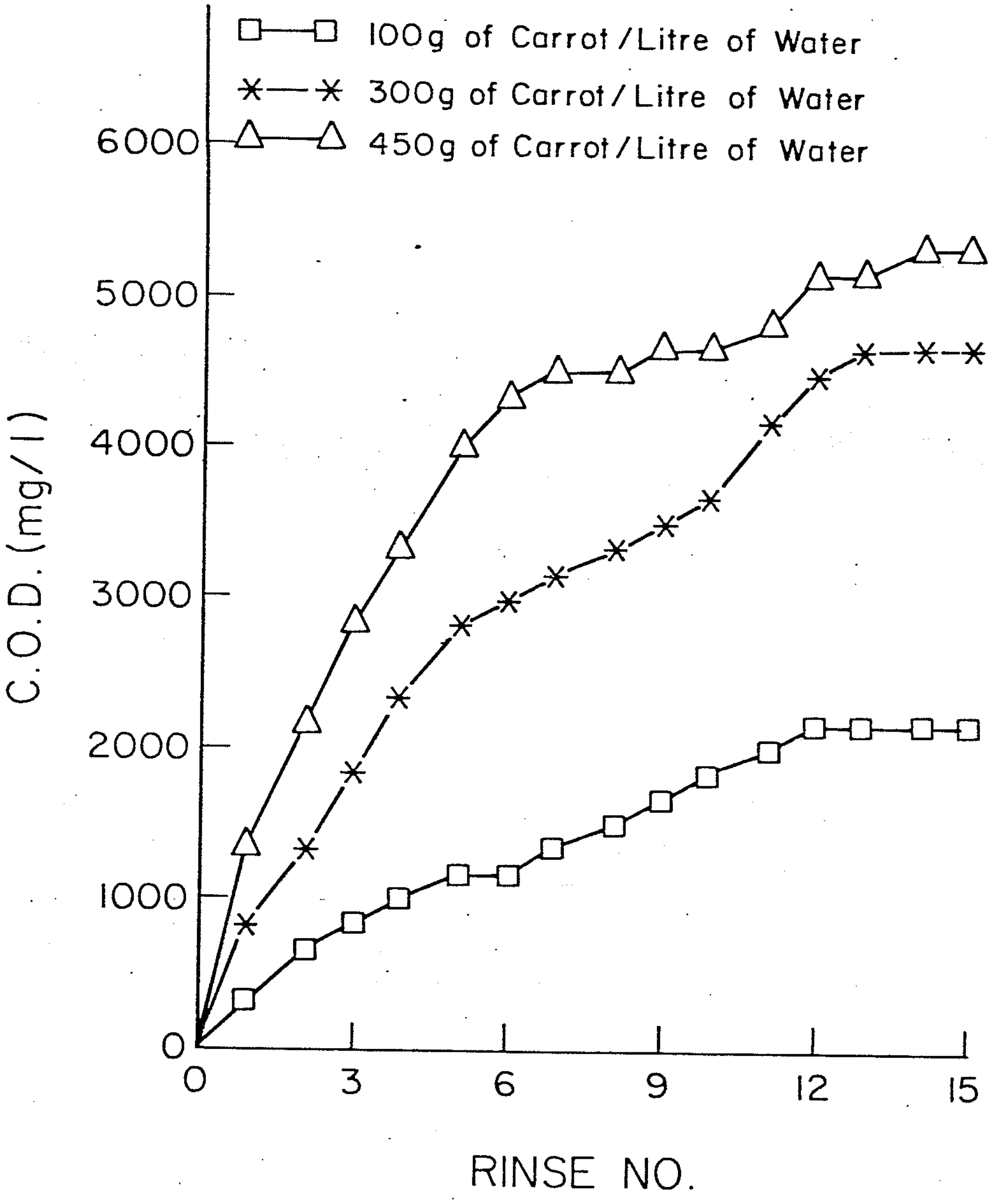


Fig. 5 COD Build-up in Carrot Rinse Water during Reuse

the cutter to the next operation in a carrot processing line, but fluming of small or thin-cut pieces of foodstuff usually causes substantial losses of soluble organics and nutrients.

The COD levels of soaking carrot slices (3/16" thick) at different times are listed in table (7) and fig. 6. For the carrot to water ratios being studied (100g/l and 300g/l), the organic leaching of the slices is shown to be proportional to both the weight of carrots and time. From fig. 6, it may be noted that most of the leaching of organics occurred in one minute. This can be attributed to the fact that the build-up of organics reduced the leaching effect. Hence, the flume water could be recirculated and reused since with repetitive use, it would suppress leaching of organics from the carrot slices while performing the function of fluming, provided that at the same time the water was protected against appreciable build-up of enzymic and microbiological activities.

4.2 Evaluation of Different Activated Carbons for Treatment of Simulated Carrot Wastes

Six available commercial powdered activated carbons were used to determine the feasibility of treating reuse carrot rinse water (5X) and blanched carrot waste with activated carbon, and to determine the most efficient carbon for the adsorption stage. Evaluation was based on results using the Freundlich adsorption isotherm equation. The activated carbon whose adsorption isotherm exhibited the

TABLE (7) EFFECT OF TIME ON COD LEACHING OF CARROT WASTEWATER

CONTACT TIME (min.)	COD (mg/l) (C/W = 100g/l)	COD (mg/l) (C/W = 300g/l)
1	706	1844
5	765	1980
10	825	2101
60	981	2339
120	1083	2420
180	1143	2532

C/W = carrot slices to water ratio

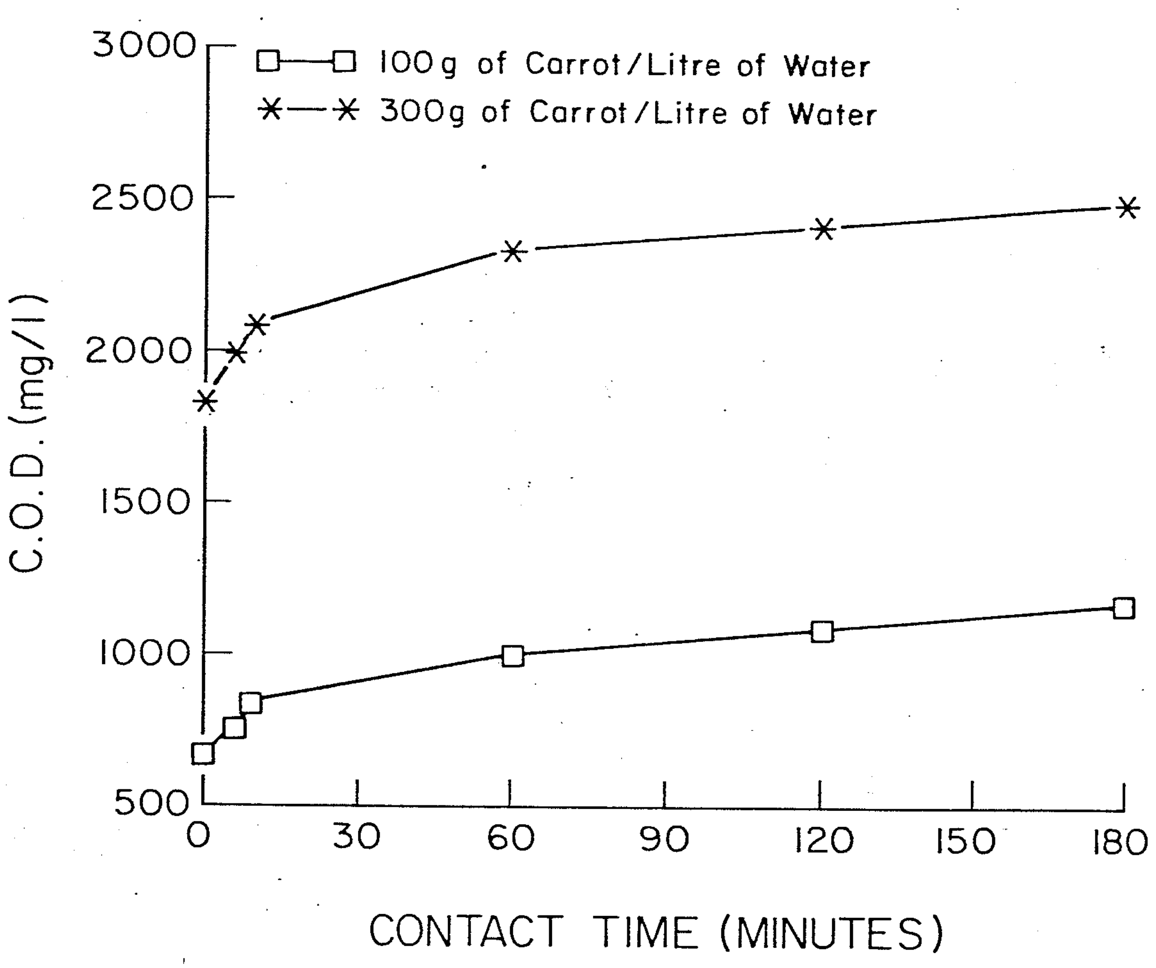


Fig. 6 Effect of Time on COD Leaching of Carrot Wastewater

highest (x/m)Co value (maximum theoretical amount of impurities adsorbed by a unit weight of carbon) was considered the most efficient carbon.

Results are shown in tables (8, 9). Graphical representations of the Freundlich adsorption isotherms for the test carbons are illustrated in figs. 7, 8. The experimental data used in evaluating the adsorption isotherm equation is listed in appendix (I, II).

The results indicated that "Aqua Nuchar" powdered activated carbon was the preferred carbon, based on the (x/m)Co value, and the degree of purification achieved from the COD test. The (x/m)Co values for Aqua Nuchar carbon were : 348 mg COD/g carbon for reuse carrot rinse water (5X) and 434 mg COD/g carbon for blanched carrot waste.

The adsorption testing also indicated the feasibility of the adsorption stage in treating the simulated carrot waste and adsorption was favored by increased concentration. Adsorption isotherm evaluation of carrot waste is discussed in section 4.4.

4.3.1 Activated Carbon Dosage

The activated carbon dosage was determined to be 0.1% (w/v). This figure is based on the minimum amount of carbon required to produce a clear effluent virtually free of color, turbidity and foam. As shown in fig. 11, 80% of the turbidity of the carrot effluent was removed by 0.1g of activated carbon. Complete removal of the turbidity is

TABLE 8

ADSORPTION ISOTHERMS

TEST CARBONS FOR REUSE

CARROT RINSE WATER (5X)

TREATMENT	COD INITIAL (mg/l)	1/N	K	(x/m)Co
AQUA NUCHAR CARBON	7199	11.118	0.000	348
CARBON A	7199	9.466	0.000	243
CARBON B	7199	10.417	0.000	158
CARBON C	7199	9.503	0.000	291
CARBON D	7199	9.818	0.000	249
CARBON E	7199	3.676	0.000	104

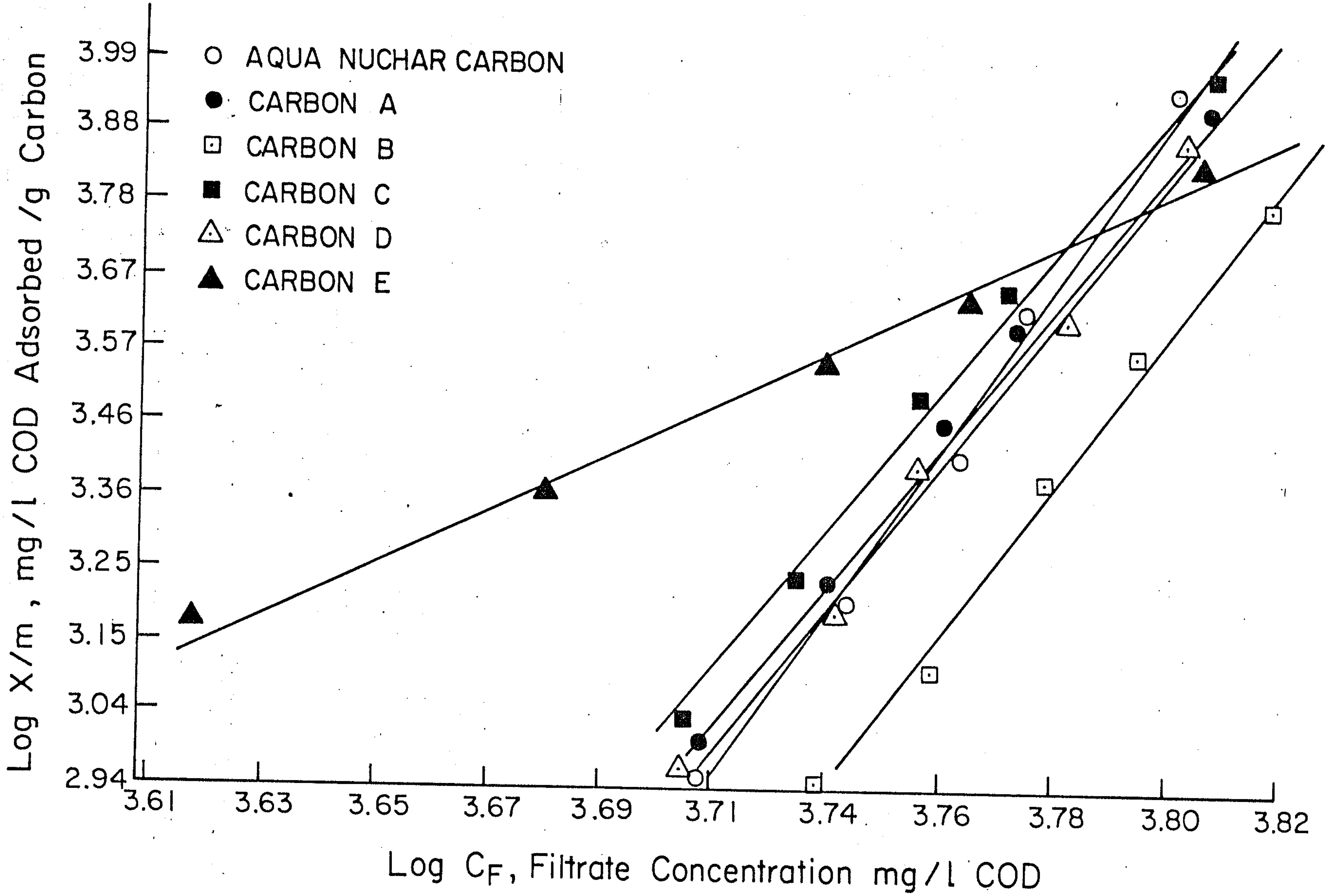


Fig. 7 Adsorption Isotherms of Test Carbons for Reuse Carrot Rinse Water (5X)

TABLE 9

ADSORPTION ISOTHERMS
TEST CARBONS FOR
BLANCHED CARROT WASTE

TREATMENT	COD INITIAL (mg/l)	1/N	K	(x/m)Co
AQUA NUCHAR CARBON	10625	14.833	0.000	434
CARBON A	10859	11.781	0.000	308
CARBON B	10859	15.341	0.000	369
CARBON C	10859	7.485	0.000	157
CARBON D	10625	9.646	0.000	235
CARBON E	10625	5.552	0.000	151

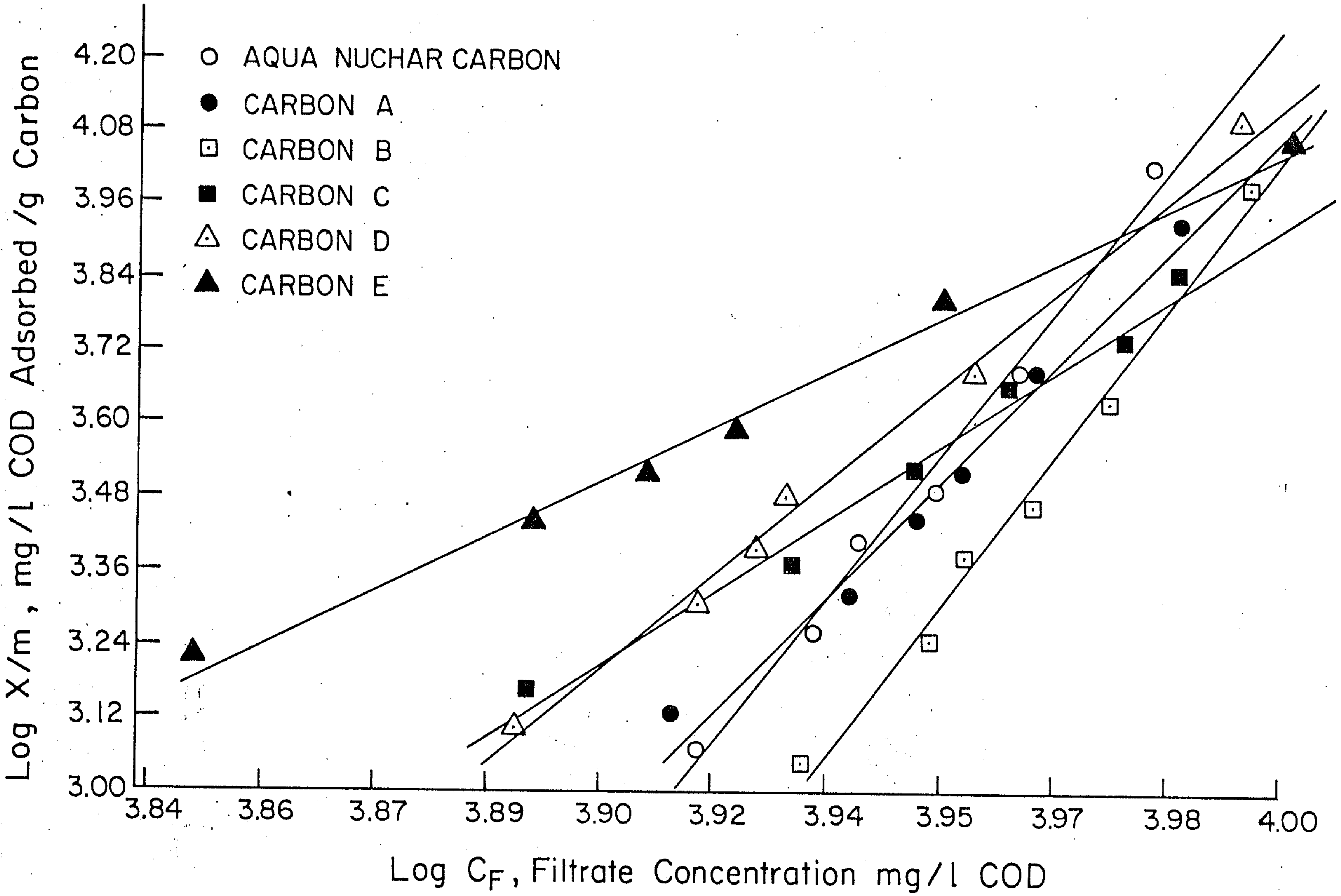


Fig. 8 Adsorption Isotherms of Test Carbons for Blanched Carrot Waste

uneconomical and would not be practicable or necessary in commercial practice. In addition, the use of minimal carbon dosage would allow the factors (physical, physico-chemical, biochemical, biological) to gradually build up to equilibrium levels at which stage a "saw-tooth" effect would result showing suppression of leaching from the carrot, while repeatedly producing a quality of water suitable for the particular unit operation.

4.3.2 Effluent Purification Rate Studies

The rate of removal curves for turbidity control and COD were obtained for reuse carrot rinse water (5X). The rate curves,figs. 9, 10, were used to determine the time required for the purification system to reach equilibrium conditions (i.e. maximum removal). Equilibrium conditions determine the treatment time required for the system. Effluent purification is indicated by the decreasing turbidity and concentration of impurity in the liquor as measured by the COD test.

The rate curves indicated a contact time of approximately one minute would be required to remove the physical factors such as turbidity to make the water aesthetically feasible for reuse. Longer contact time reduced the COD and turbidity only slightly, and would neither be necessary nor worthwhile in commercial practice.

4.4 Adsorption Isotherm Evaluation

Adsorption isotherms were obtained for a series of

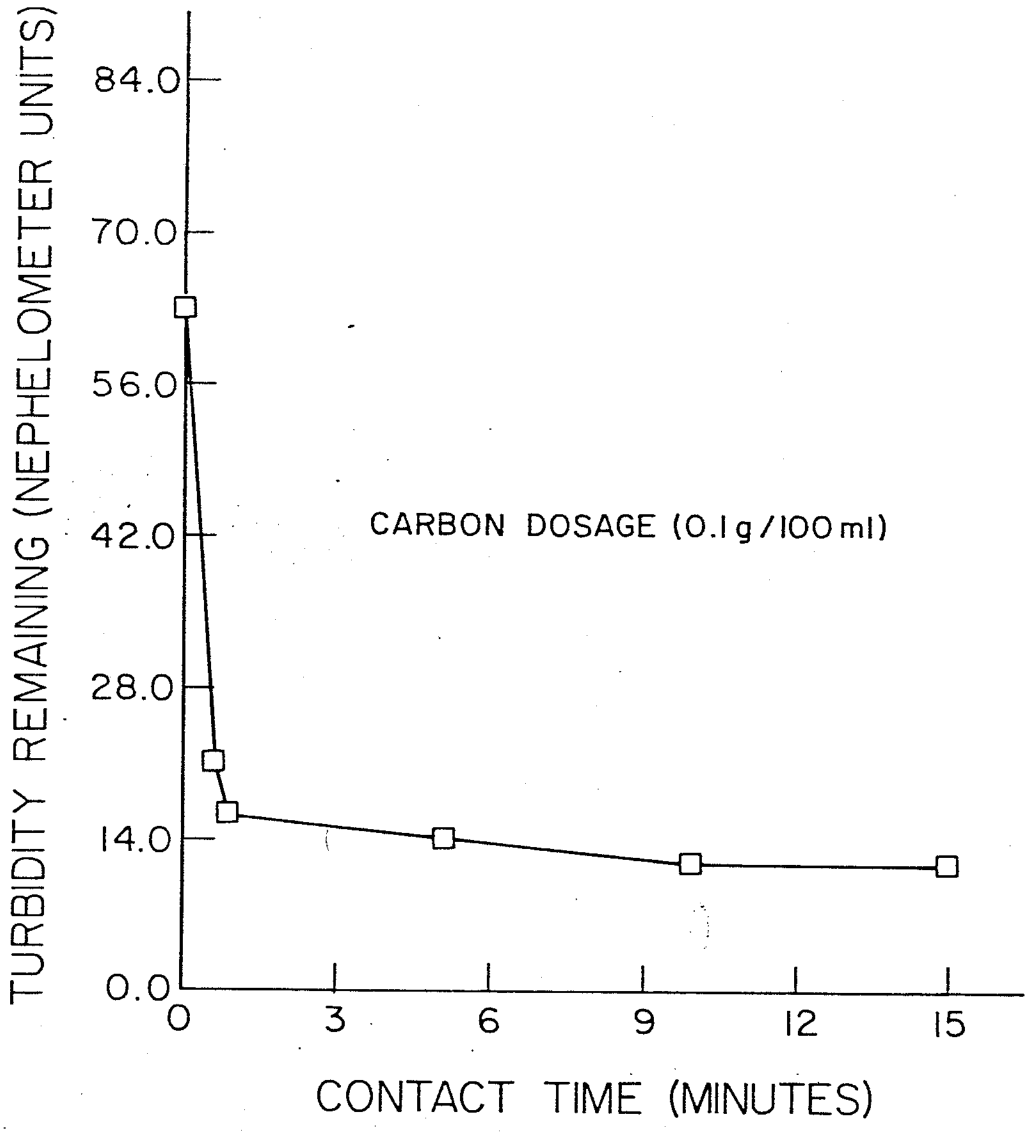


Fig. 9 Rate of Removal of Turbidity for Reuse Carrot Rinse Water (5X)

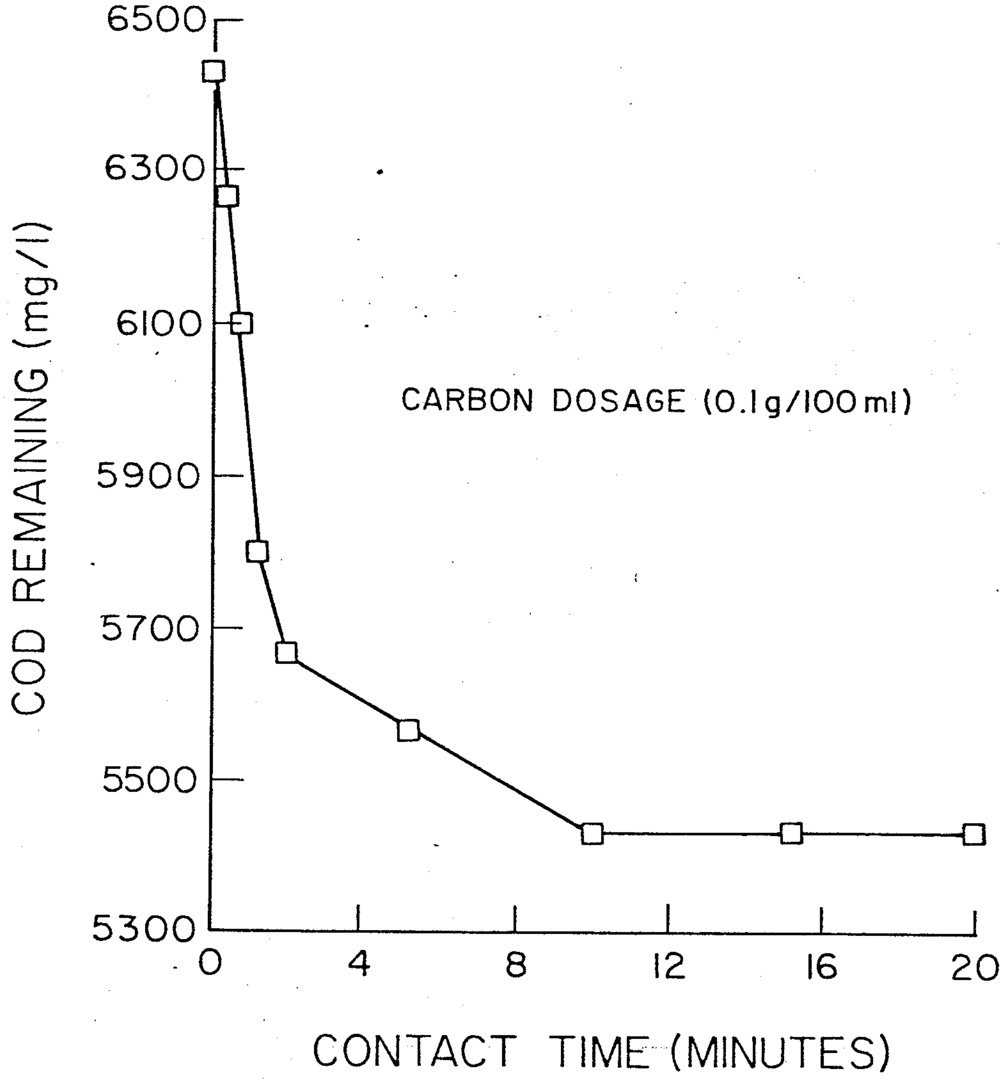


Fig. 10 Rate of Removal of COD for Reuse Carrot Rinse Water (5X)

reuse carrot rinse water and blanched carrot wastes. The object of this experiment was to evaluate the effect of carbon adsorption treatment of the simulated carrot wastewater.

The experimental data was evaluated using the Freundlich adsorption isotherm equation (section 3.2.5.). The results of the experiment are shown in table (10). Graphical representation of the adsorption isotherms is shown in fig. 12. The experimental data used to develop the isotherms is listed in appendix III.

The activated carbon removed turbidity from the simulated carrot waste yielding a relatively clear effluent, as shown in fig. 11.

The optimum adsorption capacity (x/m)Co found by extrapolation of the adsorption isotherms were in the range of 13 - 37 percent COD removed per unit weight of carbon. An (x/m)Co value greater than 10 percent indicates that a carbon adsorption system is likely to be feasible (61). The (x/m)Co value was found to be higher for wastes with higher organic concentrations. This is in agreement with the literature (33), which states that adsorption efficiency and economics are favored by increased concentration. However, the (x/m)Co value is only an approximation of the amount of organics adsorbed since the COD value does not indicate the actual concentration, but the weight of oxygen consumed in the standard COD test.

In summary, the treatment of carrot waste with

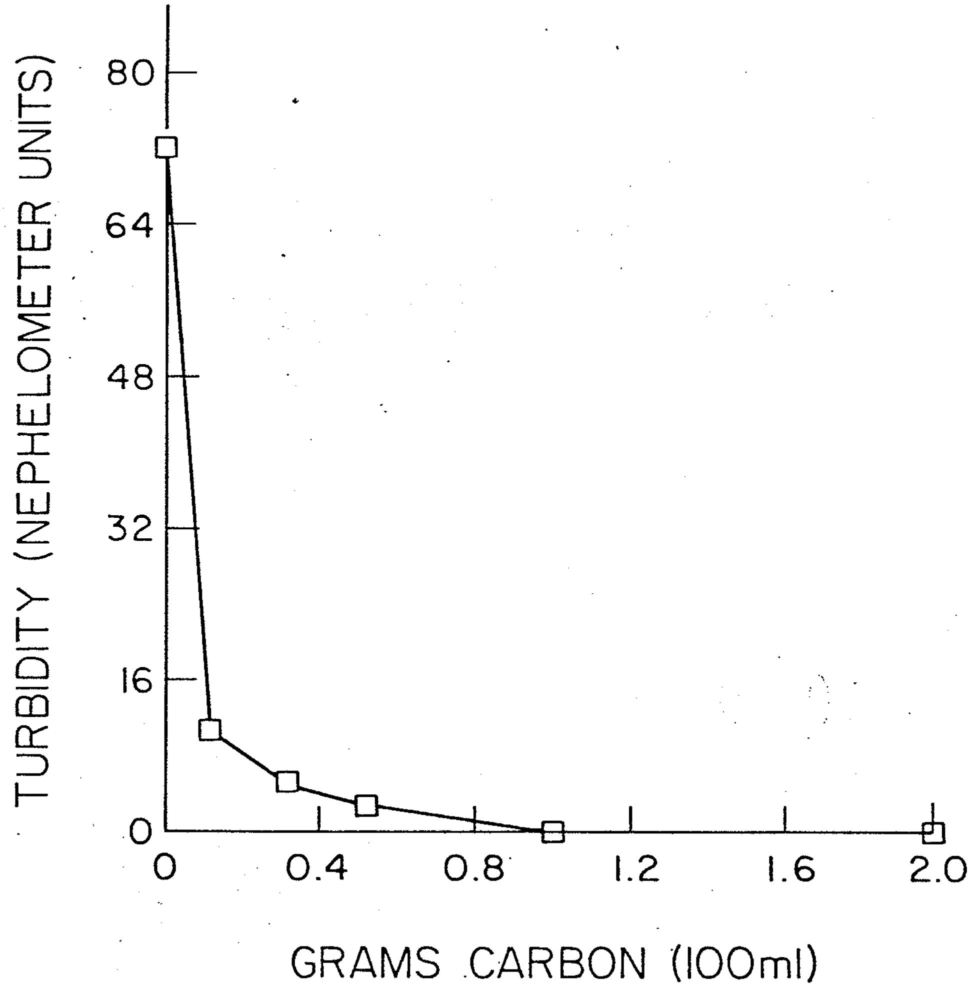


Fig. 11 Effect of Activated Carbon on Turbidity of Reuse Carrot Rinse Water (5X)

TABLE 10

ADSORPTION ISOTHERMS

REUSE CARROT RINSE WATER

AND BLANCHED CARROT WASTE

TREATMENT	C/W* (g/l)	COD INITIAL (mg/l)	1/N	K	(x/m)Co
1ST RINSE	100	349	1.376	0.404	128
6TH RINSE	100	1429	1.282	0.203	225
15TH RINSE	100	4428	1.195	0.112	253
1ST RINSE	300	941	6.175	0.000	219
15TH RINSE	300	5146	1.553	0.004	254
BLANCHED	300	12125	0.786	1.665	269
BLANCHED	450	13708	1.402	0.006	371

* C/W = carrot slices to water ratio

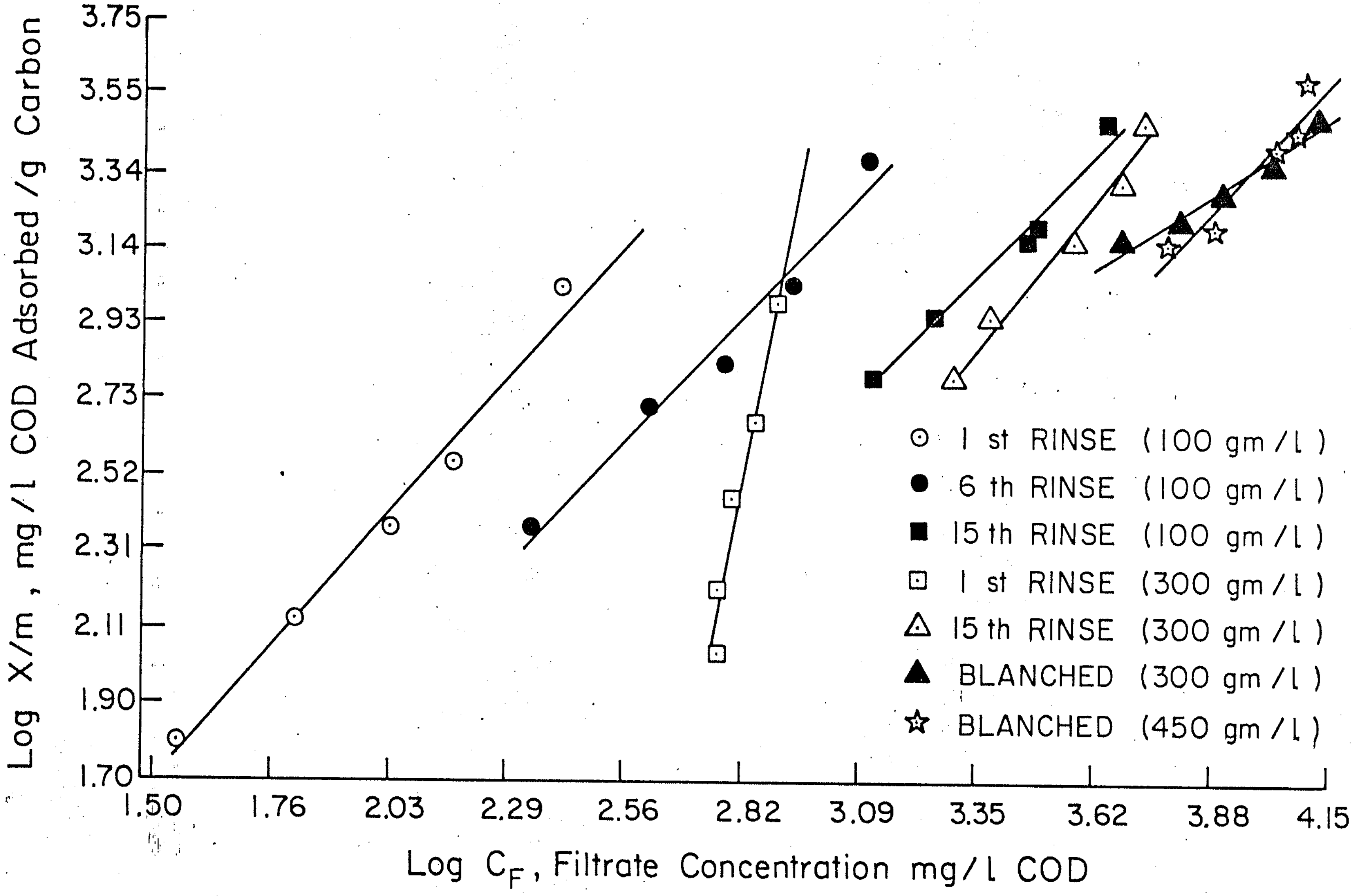


Fig. 12 Adsorption Isotherms for Reuse Carrot Rinse Water and Blanched Carrot Waste

activated carbon indicated the possibility of water reuse. The benefits include lower pollution abatement costs, savings in water, and valuable food solids, to give a better product yield, of better average solids content.

4.5 Activated Carbon Adsorption of Organic Compounds

Adsorption isotherms were obtained for a number of organic compound -- sugars and amino acids -- which are possible organic constituents present in the waste effluents of a carrot processing line. The results are listed in table (11). Graphical representation of the adsorption isotherms are illustrated in figs. 13, 14. Experimental data used to derive the adsorption isotherms are listed in appendix IV.

Maltose and sucrose showed high adsorption on powdered activated carbon. The adsorption capacities of the activated carbon for maltose and sucrose were 261 mg COD/g carbon and 197 mg COD/g carbon respectively. Glutamic acid, threonine, valine and glucose were considerably less adsorbed exhibiting adsorption capacities on activated carbon of 45 - 73 mg COD/g carbon. Alanine and serine were poorly adsorbed on the activated carbon, as indicated by the low (x/m)Co values (13 - 14 mg COD/g carbon).

In general, this study confirmed that higher molecular weight dissolved organic molecules adsorb preferentially to lower molecular weight molecules and that molecules possessing three or more carbon atoms usually

TABLE 11

ADSORPTION ISOTHERMS

SUGARS AND AMINO ACIDS

TREATMENT	COD INITIAL (mg/l)	1/N	K	(x/m)Co
GLUTAMIC ACID	869	0.382	54.973	73
ALANINE	1057	1.961	0.000	14
SERINE	759	55.333	0.000	13
THREONINE	1075	5.765	0.000	51
VALINE	1391	2.284	0.000	45
GLUCOSE	1086	0.714	4.127	61
MALTOSE	1036	0.312	298.996	261
SUCROSE	1053	0.261	320.078	197

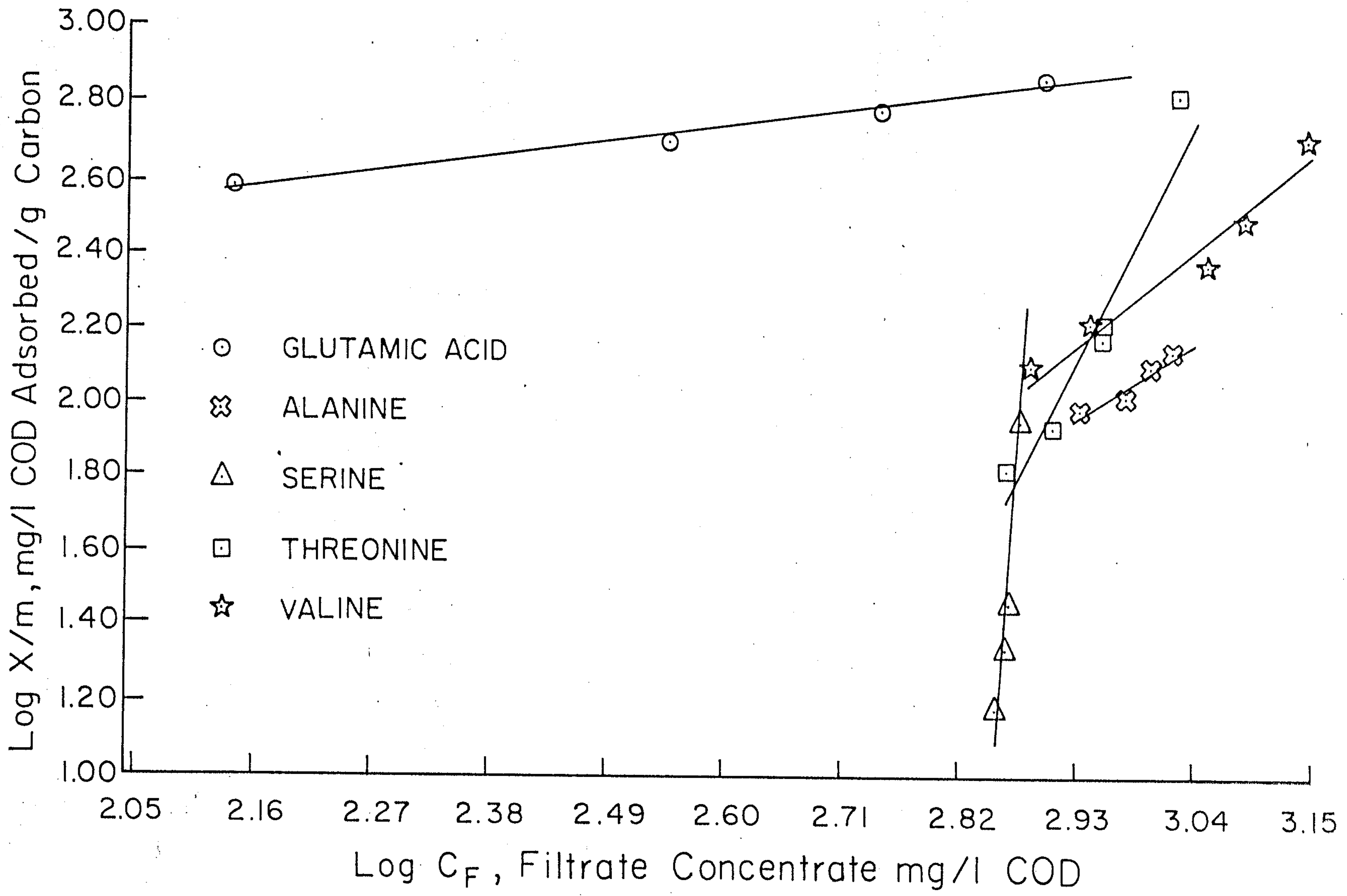


Fig. 13 Adsorption Isotherms for Amino Acids and Organic Acid

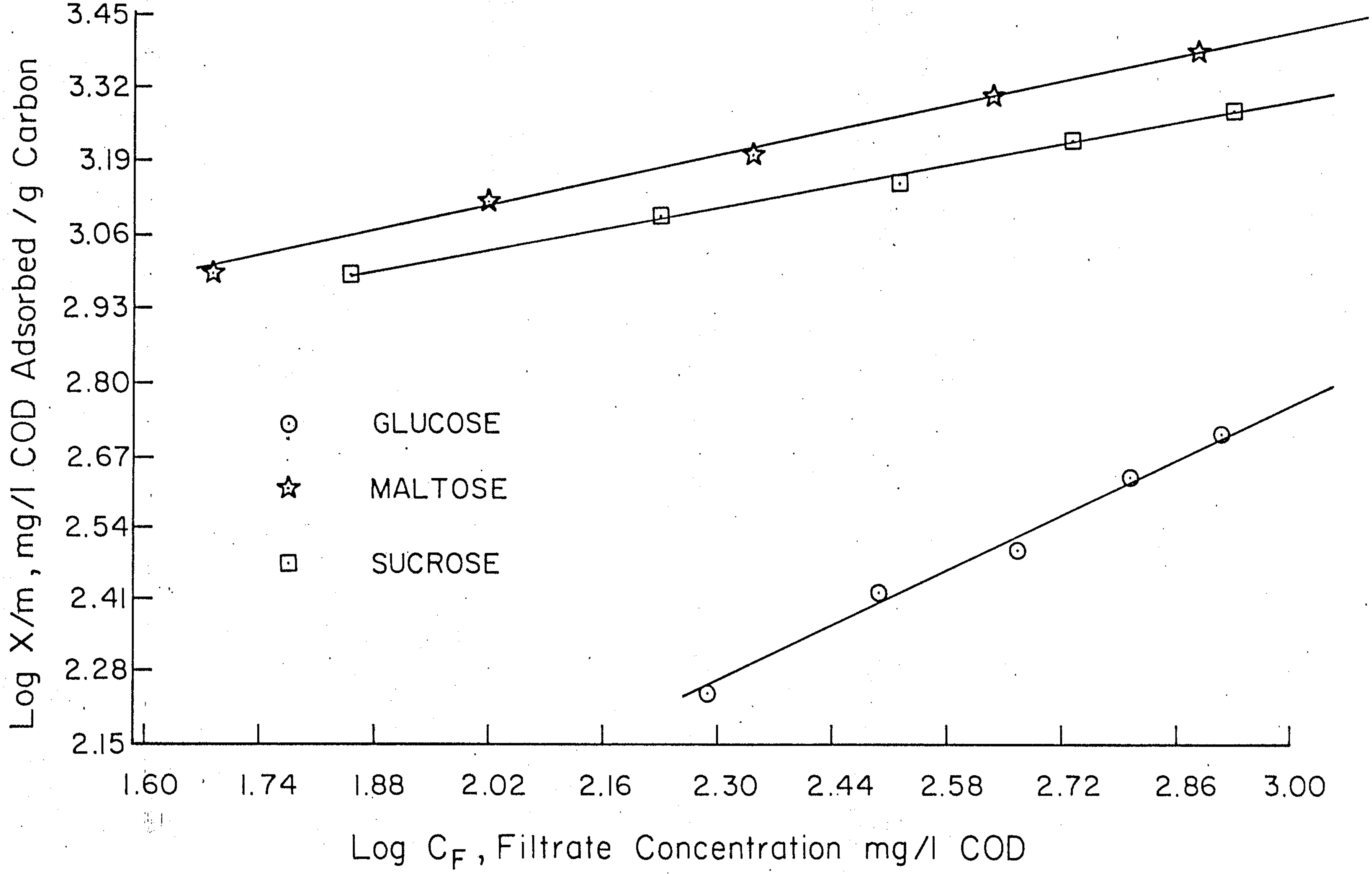


Fig. 14 Adsorption Isotherms for Sugars

respond favorably to adsorption treatment before approaching polymer size (33).

4.6 Effect of Powdered Activated Carbon on Quality Control Factors of Recycled Carrot Rinse Water

As described in section 2.5.1., it is important to control the quality factors that characterize wastewater, they are : 1. Physical, 2. Physico-chemical, 3. Biochemical and 4. Biological.

In this study, powdered activated carbon was incorporated into the recycle system at the rinse stage of carrot processing as part of the "total systems" concept approach to the food industry. The rinse stage is important, especially in dehydration of carrots, by providing a uniform spread on the drying surfaces and producing a loose, non-clumped, free-flowing dried product. The factors analysed in this study included turbidity, total solids (physical factors) ; COD, reducing sugar, tannin-like compound (physico-chemical factors) ; phenolase activity (biochemical factor) ; total bacterial counts, yeast and moulds, coliform counts (biological factors).

The activated carbon (Aqua Nuchar) used in this study was chosen by the adsorption isotherm evaluation of several available commercial powdered activated carbons (section 4.2.), and was introduced at the fifth rinse level to control the aesthetic factors such as color, taste, odor, foam, turbidity and microbial growth. The results are shown in table (12) and figs. 15 to 21.

The optimal ratio of the carbon to the effluent treated was found to be 1 g/l (0.1% w/v). This is the minimum dosage of carbon to produce aesthetically acceptable water (section 4.3.1.).

Physical Factors (turbidity, total solids)

The intermittent treatment of activated carbon is able to remove turbidity (fig. 15) from the reuse carrot rinse water, yielding a relatively clear effluent with a tint of background color. Over-purification of water before, and after use, in large volumes, is a major cause of inefficiency, in water-management. In virtually "Closed-Loop" cyclic systems, purification needs and volumes/cycle are minimal. With repetitive use, all factors build up to equilibrium, background levels, at appropriate rates (24).

From fig. 16, it may be noted that after the 25th rinse, the total solids level following carbon treatment began to give a gradual approach to an equilibrium level. As mentioned in section 4.1., rinse water saturated with soluble organic nutrients is valuable for recycling, resulting in better product quality and better product yield.

Physico-Chemical Factors (COD, reducing sugar, tannin-like compound)

From figs. 17, 18, it can be seen that COD and reducing sugar showed proportional increases between the 1st, 2nd, 3rd, 4th and 5th carbon treatment as did total

	TURBIDITY (nephelometer units)	TOTAL SOLIDS (mg/l)	C.O.D. (mg/l)	REDUCING SUGAR (mg/l)	TANNIN (mg/l)	ENZYME ACTIVITY (phenolase activity Δ absorbance per min.)	S.P.C. (viable cell count/ml)	YEAST & MOULD (viable cell count/ml)	FECAL COLI
(1)BT	59	6520	5895	1615	30	0.047	50×10^3	120	- ve
(1)AT	13	6070	5403	1505	15	0.024	45×10^2	44	- ve
(2)BT	55	10310	9895	2660	42	0.084	20×10^3	240	- ve
(2)AT	11	8250	7649	2160	20	0.043	12×10^2	80	- ve
(3)BT	61	13000	12070	3315	48	0.102	88×10^3	260	- ve
(3)AT	12	11670	10912	3015	30	0.048	15×10^2	25	- ve
(4)BT	62	14890	13825	3700	55	0.130	52×10^3	260	- ve
(4)AT	13	13180	12105	3315	30	0.049	12×10^2	11	- ve
(5)BT	68	15250	14175	3865	53	0.164	18×10^3	240	- ve
(5)AT	14	13840	12772	3590	33	0.047	12×10^2	15	- ve

TABLE 12 EFFECT OF POWDERED ACTIVATED CARBON ON QUALITY CONTROL FACTORS OF RECYCLED CARROT RINSE WATER *

(cont'd)

* (1) BT = 5th rinse before carbon treatment

(1) AT = 5th rinse after carbon treatment

(2) BT = 10th rinse before carbon treatment

(2) AT = 10th rinse after carbon treatment

(3) BT = 15th rinse before carbon treatment

(3) AT = 15th rinse after carbon treatment

(4) BT = 20th rinse before carbon treatment

(4) AT = 20th rinse after carbon treatment

(5) BT = 25th rinse before carbon treatment

(5) AT = 25th rinse after carbon treatment

TABLE 12 (cont'd)

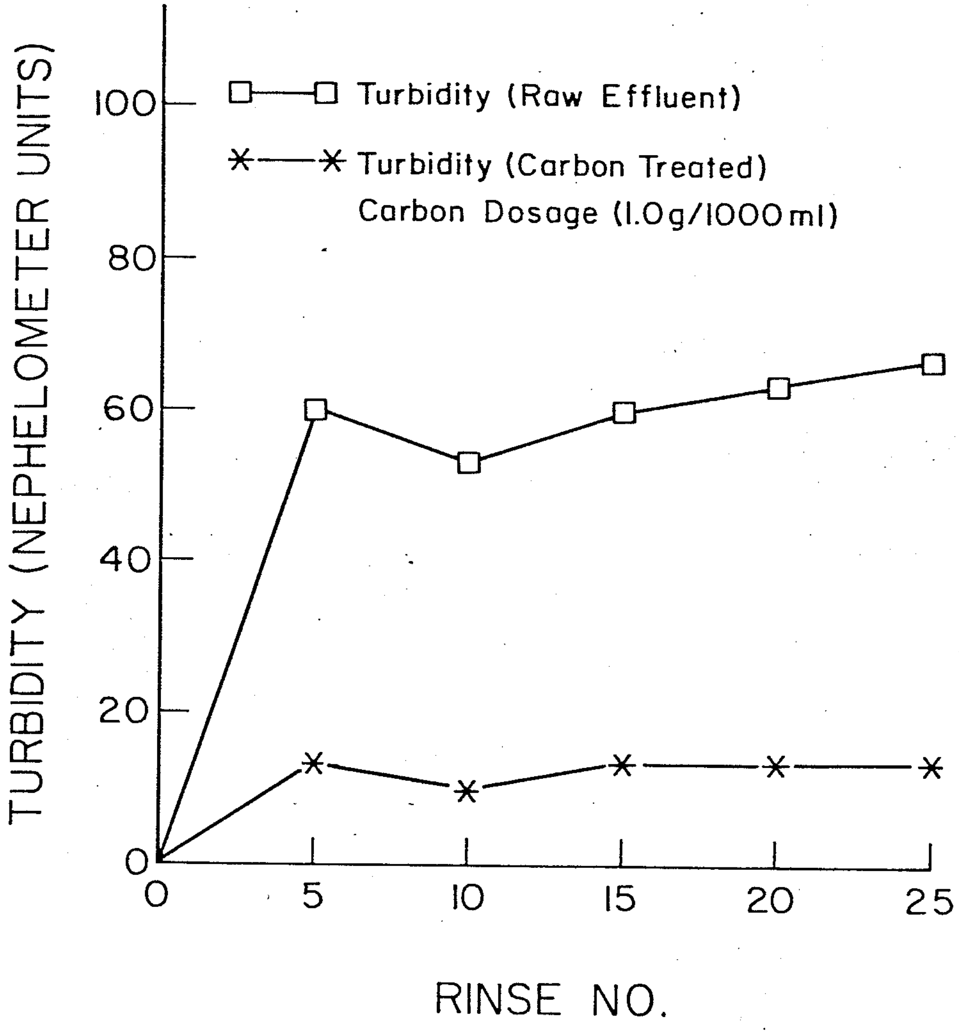


Fig. 15 Effect of Powdered Activated Carbon on Turbidity of Recycled Carrot Rinse Water

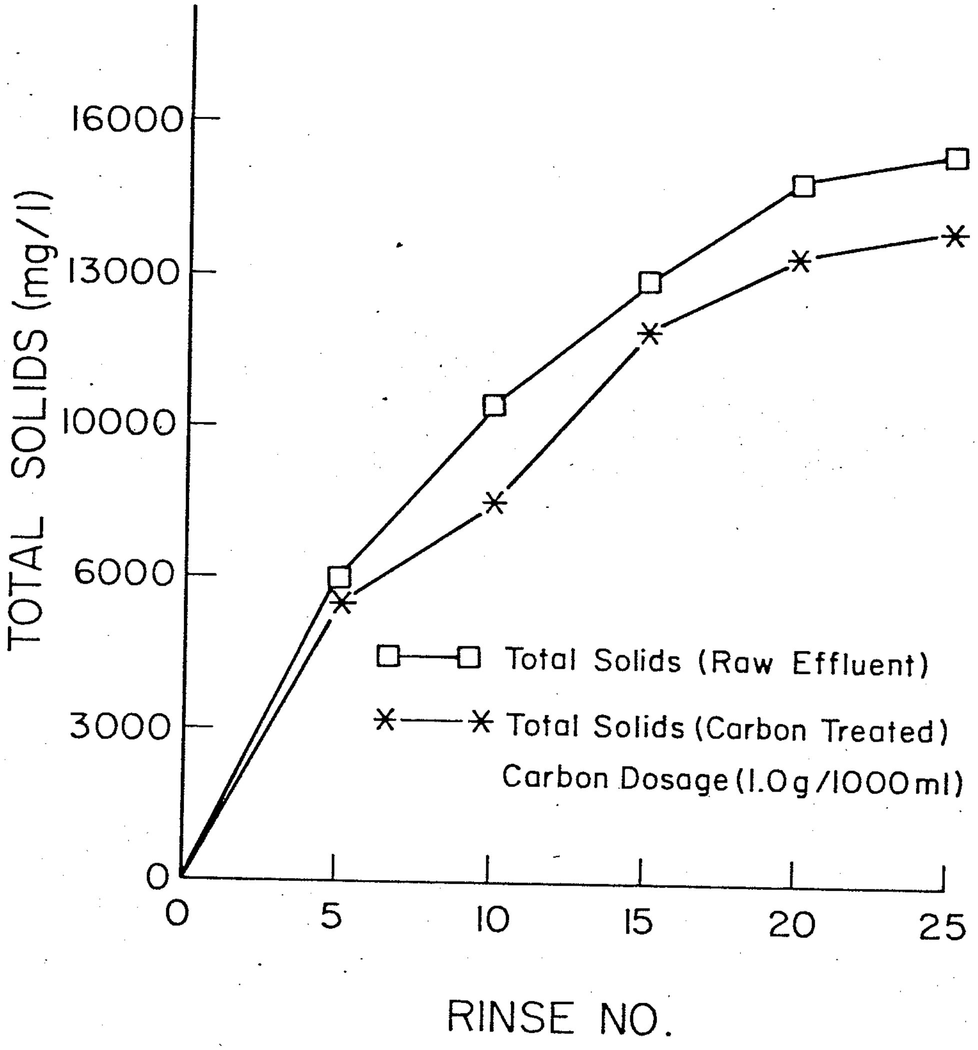


Fig. 16 Effect of Powdered Activated Carbon on Total Solids of Recycled Carrot Rinse Water

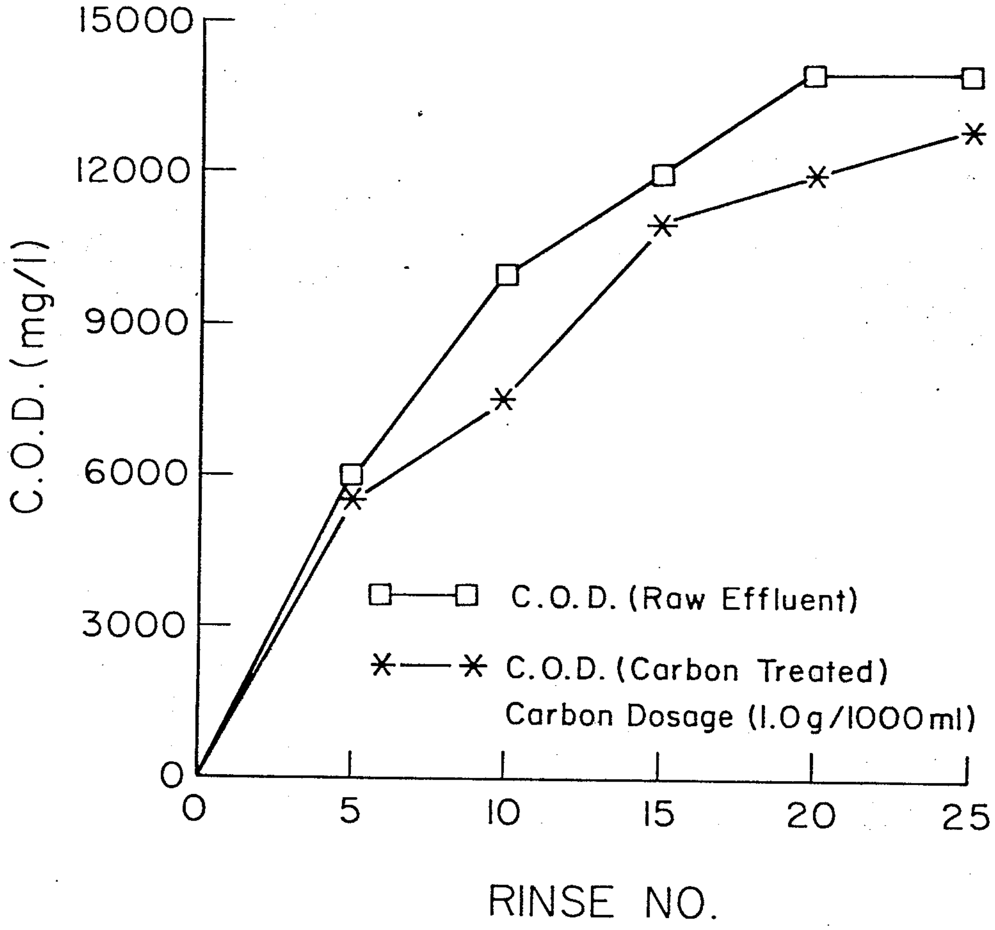


Fig. 17 Effect of Powdered Activated Carbon on COD of Recycled Carrot Rinse Water

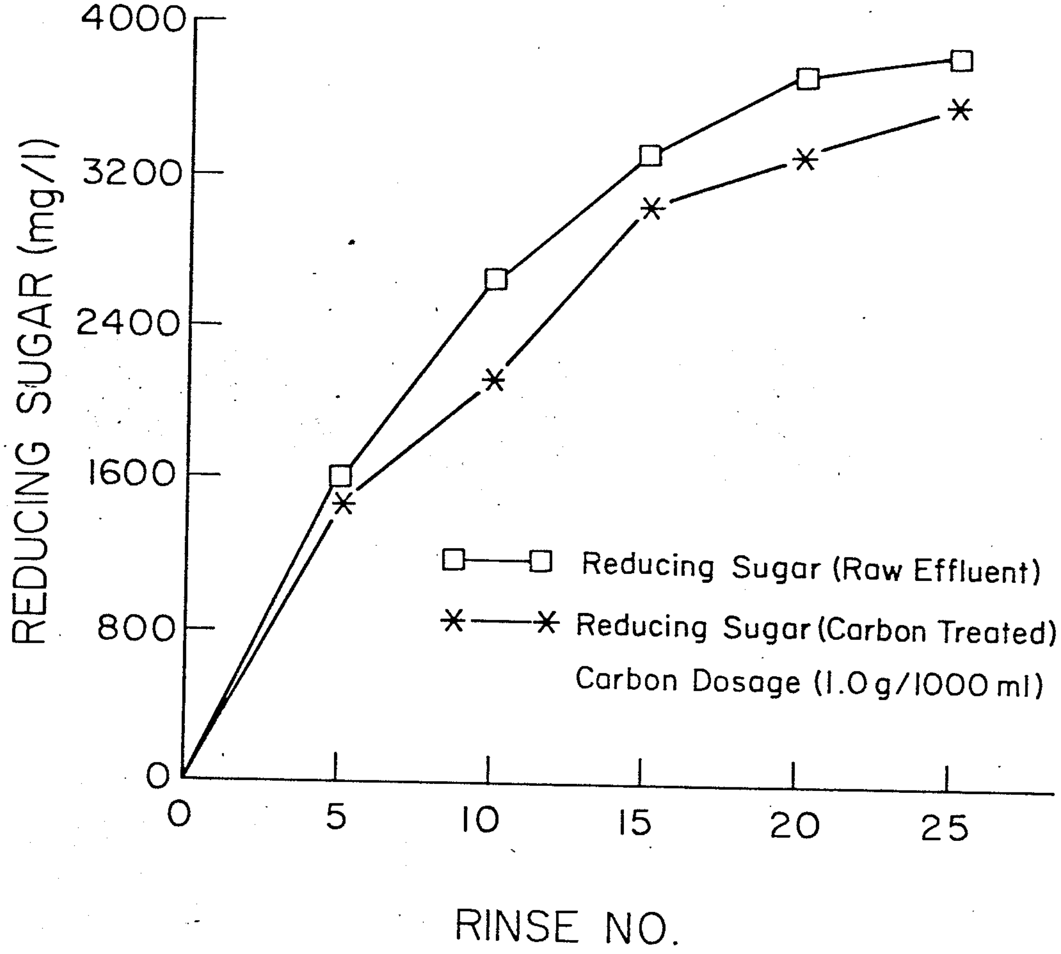


Fig. 18 Effect of Powdered Activated Carbon on Reducing Sugar of Recycled Carrot Rinse Water

solids. This indicates that approximately 80% of the organics present in the rinse water are not removed by the carbon treatment, due to the presence of reducing sugar and amino acids. The amount of carbon used in small dosage, was just enough to remove firstly the physical factors to render the water aesthetically feasible for reuse. Secondly, the small dosage of carbon did remove some soluble organics such as shown in figs. 17, 18. Soluble organics were left in the carrot on purpose to conserve these nutrients during the recycling. However, the presence of reducing sugar and amino acids in the effluent should not pose problems to the carrot processing in the surface washing of carrots. In addition, the presence of the aforementioned compounds in the rinse water helps to conserve these compounds in the surface and inner regions of carrot tissues, resulting in better product quality and yield.

From fig. 19, it can be noted that after about the 15th rinse, the tannin-like compound concentration begins to remain at a constant level following carbon treatment. This indicates that further reuse of the rinse water is feasible, provided that the aesthetic factors are properly controlled.

Biochemical Factor (phenolase activity)

From fig. 20, it can be seen that after the 10th rinse, carbon treatment reduces the enzyme activity to a constant level and the rate of removal is higher for the more

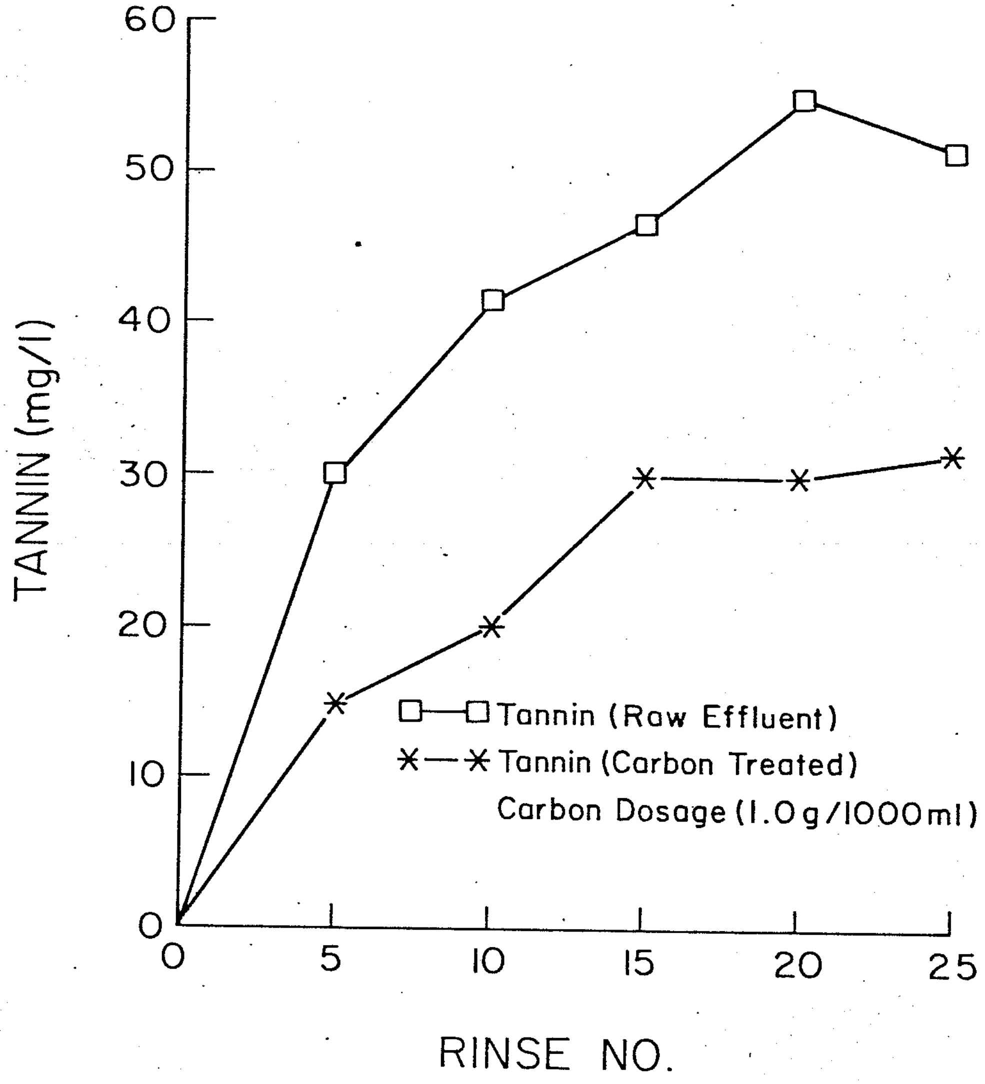


Fig. 19 Effect of Powdered Activated Carbon on "tannin-like" Compound of Recycled Carrot Rinse Water

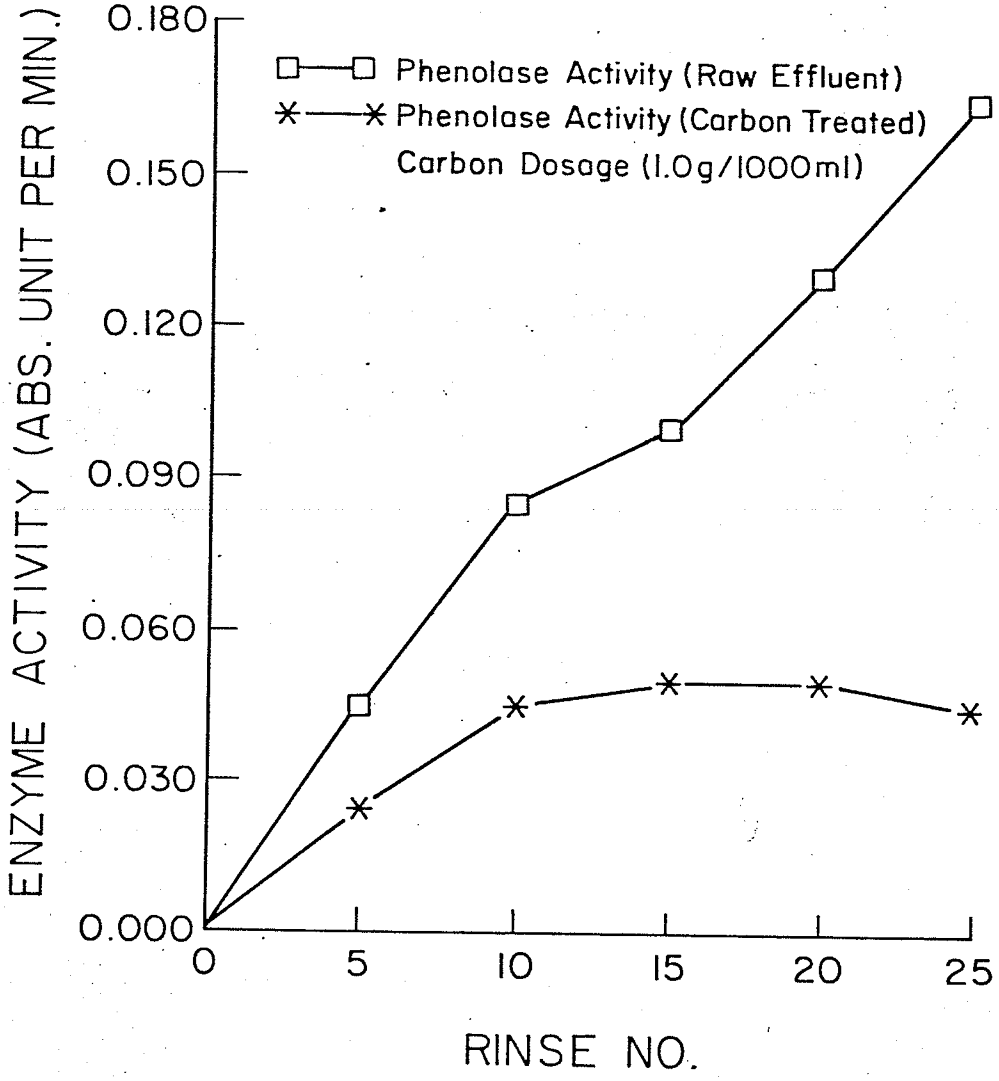


Fig. 20 Effect of Powdered Activated Carbon on Phenolase Activity of Recycled Carrot Rinse Water

concentrated carrot rinse water. This indicates that carbon treatment is feasible in controlling browning reactions, by removing enzyme from solution. In addition, it was observed that the result was in agreement with the literature (27) which states that no direct relationships were found between potential browning and "tannin-like" compounds, in the absence of sufficient phenolase activity.

Biological Factors (total bacterial counts, yeast and mould, coliform counts) (fig. 21)

The reuse carrot rinse water was found free from coliform counts, but showed positive results for total bacterial counts and yeast and mould. The source of the bacterial contamination was suggested by Wildes and Neales (63) to be the "endogenous" bacteria present in the carrot root. Tervet and Hollis (1948)(64) and Bacon, MacDonald, and Knight (1965)(65) also observed this endogenous population of bacteria. The reuse rinse water increased in bacterial counts at each trial reuse. Powdered activated carbon treatment reduced the bacterial counts to relatively low levels. This indicates the feasibility of reuse of carrot rinse water, with respect of bacteriological standards. However, as discussed in section 2.5.3., it is difficult to specify quantitative limits on biological organisms which may render the water aesthetically unacceptable.

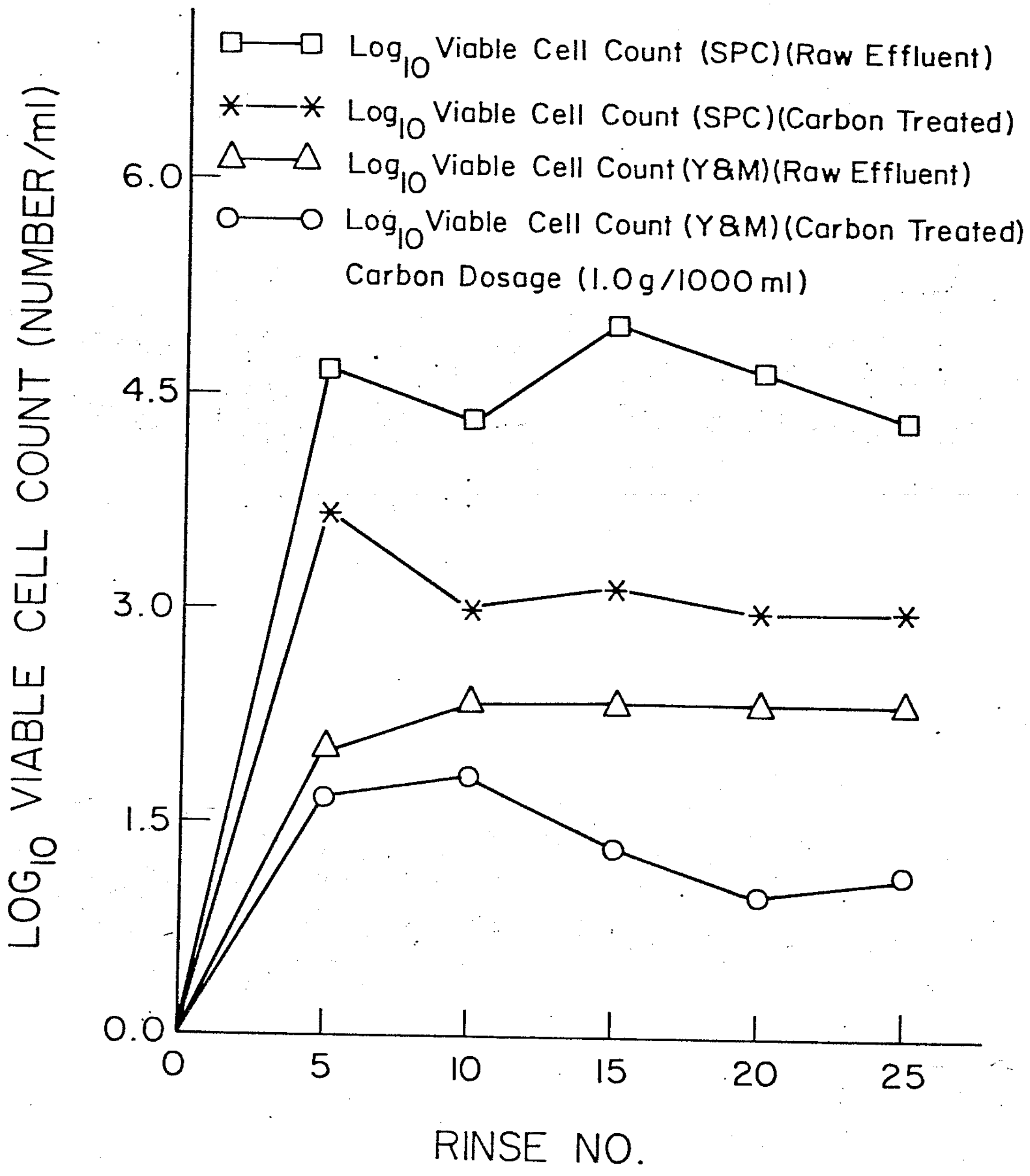


Fig. 21 Effect of Powdered Activated Carbon on SPC and Yeasts and Moulds (Y & M) of Recycled Carrot Rinse Water

4.7 Study of the Measurement of Oxygen Demands of Carrot Effluents by Standard Method and Instrumental Method using the "Aquarator"

Oxygen demands of carrot rinse water and blanched carrot waste before and after powdered activated carbon treatment were determined by the standard method and instrumental method using the "Aquarator". As indicated in section 2.7., the oxygen demand of the sample determined by the "Aquarator" is expressed as "CO_2D" (Carbon Dioxide Demand).

CO_2D/COD ratios of the effluents being studied were obtained. The results are listed in table (13) and fig. 22.

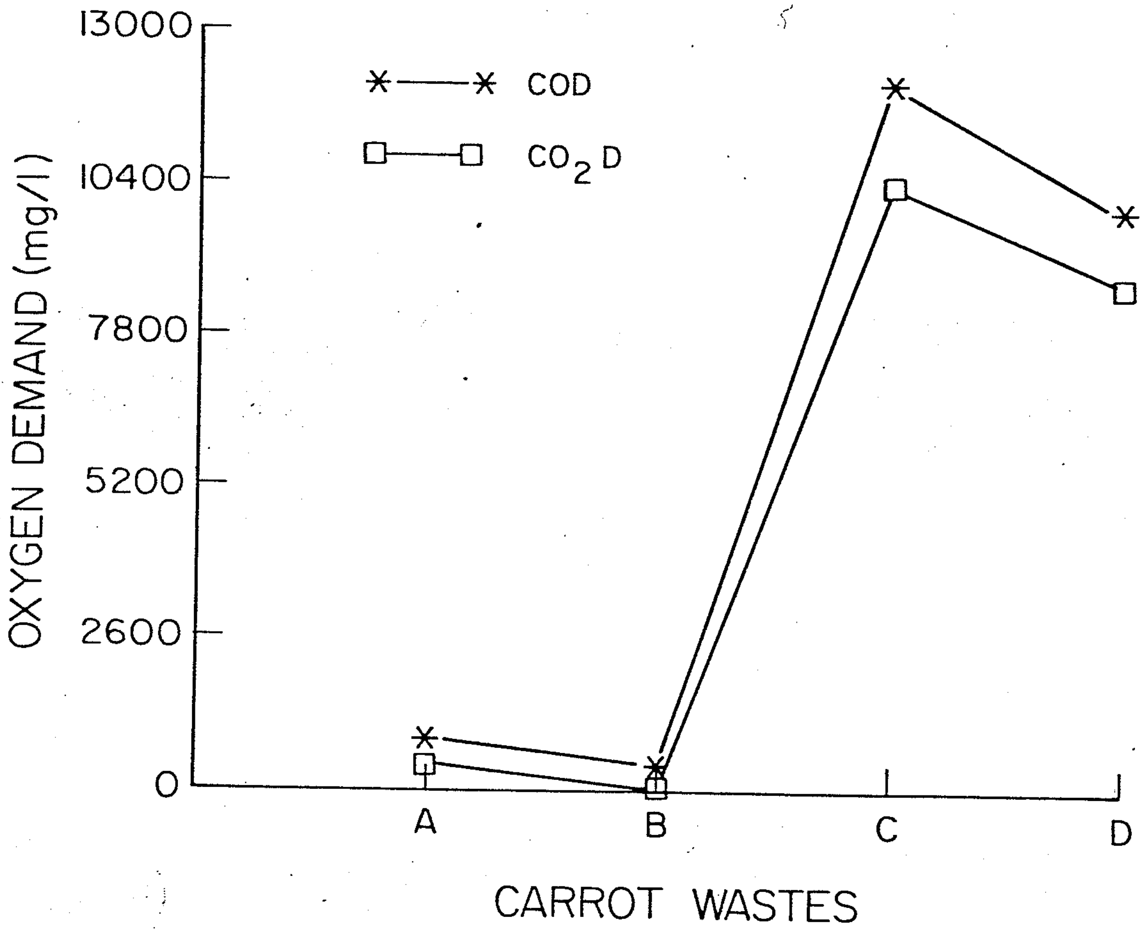
CO_2D/COD ratios were also obtained for different concentrations of blanched carrot waste and reuse carrot rinse water. The results are presented in appendix V.

The CO_2D/COD ratios for carrot effluents were found to be in the range of 0.85 - 0.86. COD values, being an important parameter for wastewater studies and control of waste treatment methods, could be readily estimated from the CO_2D/COD ratio after the CO_2D value was determined by the instrumental method using the "Aquarator". Therefore quality control of the process water in a carrot processing line can be rapidly and effectively carried out. Expensive chemicals (such as mercuric salts, silver and chromium salts, as well as sulfuric acid) used in the standard method can be replaced by less expensive carbon dioxide gas using the "Aquarator". Elimination of the problem of disposal

TABLE (13) CO_2D/COD RATIOS FOR CARROT RINSE AND BLANCH WATER BEFORE AND AFTER POWDERED ACTIVATED CARBON TREATMENT

	C/W* (g/l)	CARBON DOSAGE (gram)	CO_2D (mg/l)	COD (mg/l)	CO_2D/COD
RINSE WATER	300	0.0	594	694	0.86
RINSE WATER	300	1.0	214	248	0.86
BLANCH WATER	300	0.0	10430	12125	0.86
BLANCH WATER	300	1.0	8750	10183	0.86

* C/W = carrot slices to water ratio



A — Carrot Rinse Water (300g/l) (Carbon Dosage = 0.0g)

B — Carrot Rinse Water (300g/l) (Carbon Dosage = 1.0g)

C — Blanched Carrot Waste (300g/l) (Carbon Dosage = 0.0g)

D — Blanched Carrot Waste (300g/l) (Carbon Dosage = 1.0g)

Fig. 22 Comparison of COD and CO_2D for Carrot Wastes of toxic chemicals could also be achieved.

This method may be adaptable to a variety of other wastes and should warrant consideration in cases where speed of result with respect to known effluents out-weighs the time and expense required to achieve extreme accuracy.

With suitable dilution, the oxygen demand of any strength of waste can be determined.

V. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The carrot processing industry must accept a radical change in the design of their processing lines, including their processing equipment, water usage systems and effluent management systems, in order to meet the intended government guidelines and regulations being proposed by Environment Canada. Policies already exist in the U. S. on the absolute control of the pollutant discharged and the absolute zero discharge with regulations proposed for 1977, 1983 and 1985.

The use of powdered activated carbon has proven to be feasible in a batch process to control or reduce the four major quality control criteria, namely -- physical, physico-chemical, biochemical and biological factors, in carrot processing effluents.

Adsorption isotherms on the evaluation of different commercially available powdered activated carbons indicated that "Aqua Nuchar" powdered activated carbon was the preferred carbon based on the optimum adsorption capacity and cost.

An activated carbon dosage of 0.1% (w/v) applied at every fifth reuse of the carrot rinse water was able to control the aesthetic factors such as odor, foam, color and turbidity. A small portion of the nutrients of the carrot slices (present in the form of dissolved organics in the rinse water) was removed by activated carbon. However, the undesirable factors (enzyme activity and microbial growth) in the rinse water were suppressed to a constant low level even after 25 reuses. Therefore, major savings in water, in extractions of soluble solids, in effluent loads and volumes, and thus in treatment requirements can be achieved. The only requirement for water would be a small percentage of make-up water (5 - 10%) at each cycle.

For reuse, the carrot effluents in most cases need only be physically clean (clear, free from suspended solids), while still maybe high in dissolved matter. However, the presence of the dissolved matter in the rinse water helps to conserve the nutrients in the carrot by suppressing organic leaching. This in turn increases the yield of product, and its overall quality, while greatly reducing the soluble COD load extracted into sewers, for subsequent costly treatment.

Adsorption of pure compounds such as amino acids and sugars by activated carbon indicated the feasibility of the purification of carrot processing effluents which contain considerable amount of the aforementioned organic compounds.

Instrumental measurement of oxygen demand of simulated carrot wastes using the "Aquarator" was found to be much more rapid than the conventional standard method, while eliminating the problem of disposal of toxic chemicals and providing better possible quality control of the process water within the processing line.

The recommended flow sheets (section 5.2.) provide segregation of the effluents from each unit operation of the carrot processing line, with the segregated effluent being cyclically reused within the operation and providing make-up for a less-demanding function systematically down the line. Make-up water, equal to 10-15% of cyclic flows, will be needed for the bleed-off losses. Carbon treatment and disinfection are used to limit the potential build-up of the aesthetic factors, when required. Solid wastes could be utilized as fuels or as substrates for the manufacture of activated carbon. In-plant controls such as dry caustic peeling and individual quick blanching (IQB) could be used to reduce water consumption and pollution loads while improving quality and product yield (peeling losses reduced from 37% to 26% and 15% reduction in effluent generation in the blanching operation).

A possible saving of at least 60% in the wastewater treatment cost could be achieved using activated carbon treatment and in-plant reuse of effluents, as compared to the standard secondary biological treatment.

5.2 Recommendations

Proposed Design of Improved Carrot Processing Line

The total system approach (section 1.2.1.) changes the food processing industry from its "Linear Flowsheet" operation into a largely cyclic process, where valuable resources are conserved and used repeatedly instead of being discarded, to cause pollution.

In addition, in-plant controls can reduce the waste load by a factor well over 50% and are also employed to improve processing efficiency and product quality. LaConde and Schmidt (66) reported several unit processes and/or technologies that were identified as having an impact on raw waste load reductions. Dry Caustic Peeling and Individual Quick Blanching (IQB) were mentioned.

Based on these, a design for an improved carrot processing line is suggested as shown in figs. 23, 24, 25.

Solid and liquid wastes are mainly created during washing, peeling, topping, inspecting, trimming, size grading and blanching operations. As part of the total system concept, the effluents are usually segregated and recycled after sufficient purification to permit each class of water to be extensively reused at the same or a related stage of the process sequence, while the solid wastes can be reclaimed (e.g. muds into valuable top soil, and organic wastes converted into animal feeds or activated carbon).

In-plant Controls

Lee and Downing (1973)(67) reported that replacement of a conventional lye peeling system with dry caustic peeling of beets and carrots will increase production yields and substantially reduce pollution loads. Dry caustic peeling essentially eliminates the high-pressure water sprays used in conventional lye peeling and relies solely upon mechanical abrasion to remove the peel, which has been softened by being dipped in a lye solution. Peeling loss was reduced from over

35% to 26%, and COD was reduced substantially as shown in table (14).

Individual Quick Blanching (IQB)(68) was found suitable for blanching vegetables prior to canning. Effluent generation was significantly reduced (table 15) and product quality tests indicated that IQB blanched, canned products were as good as pipe blanched, canned products. For carrots, IQB could be effectively used to inactivate enzyme activity, while minimizing inequity of heat treatment received by the surface and center of the product.

Water Systems

The major functions of water in carrot processing are for the transport of solids and heat around the process. After the dry cleaning process, water is used for the removal of mud and skins from the carrots. Fresh high-quality water (grade 1) would not be appropriate for this operation but should be replaced by water of lower grade (grade 4) as shown in fig. 23. This grade 4 water is "topped up" by the water (grade 3) used to wash the carrots after the lye peeling process, which in turn is partially provided from the grade 2 water used to wash the diced/sliced carrots. This systematic, counterflow pattern is recommended, with the effluents from each step of the line being cyclically used for one operation, without much purification, except by simple means (e.g. screening, settling, cycloning, carbon treatment and chlorination) for stabilizing this water flow,

Measurement	Conventional lye peeling	Dry caustic peeling[a]
Raw carrot input (ton/hr)	7.7	-
Peeling loss (%)	37	26
Water flow rate on peeling lone (gal/ton)	585	150[b]
Total solids (lb/ton)	136	18
Chemical oxygen demand (lb/ton)	101	3.1
Biochemical oxygen demand (lb/ton)	43	1.5

[a] Pilot-plant scale

[b] Estimated

TABLE (14) CARROT PEELING LOSS AND WASTE EFFLUENT CHARACTERISTICS FOR CONVENTIONAL LYE PEELING AND DRY CAUSTIC PEELING (67)

TABLE (15) SUMMARY OF CARROT BLANCHING DATA[a] (68)

Blanching Treatment[b]	Effluent generation (l./kkg)	BOD_5 (kg /kkg)	Total Organic N (kg/kkg)	Total P (kg/kkg)	Product Yield (%)	Solids Lost as Product (%)
IQB-0	192	2.0	0.10	0.016	91.8	1.93
Deep bed	225	2.6	0.14	0.023	88.4	2.77

[a] Expressed per kkg of blanched product.

[b] IQB-0 means IQB without predrying.

Deep bed means bed steam blanching.

until it becomes unfit for its current purpose. Then it is used similarly for a less-demanding function for which it is still suitable, and so on, systematically down the line.

Small volumes of high-quality water (grade 1) which is legally-aesthetically, chemically, biologically-microbiologically, and physically acceptable, are used to finally wash the sliced/diced carrots; and as make-up for the blanching operation.

Activated carbon is used to treat the screened carrot effluents from the unit operations to remove the undesirable factors such as foam, color, turbidity and bacteria, so that continuous reuse of the process water could be feasible.

Exhausted carbon is sent to the regeneration system and recycled within the system. Single or double stage counterflow carbon contactor systems would be advisable.

Make-up water (dV), equal to 10 - 15 % of cyclic flows, will be needed for the bleed-off losses, dV_1, dV_2, dV_3, dV_4, dV_5, dV_6, and dV_7, as shown in figs. 23, 24.

Intermittent chlorination or other means of disinfection is to control the microbial factors, when required.

Published data on water reductions in the fruit and vegetable industry, attributable to changes in cleanup systems, are sparse. However, Crosswhite et al. (1971)(62) reported a cleanup water reduction from 112,000 gpd to 46,000 gpd in a poultry plant by converting to a high pressure system and using a foaming agent. Manufacturers of high pressure - low volume cleanup systems indicate that better sanitation is an added benefit. This method of water reduction assumed that 25% of the cleanup flow could be saved by utilizing this option. This effluent would then have to be managed well on-site (e.g. by appropriate treatment) prior to discharge, or put into a municipal sewage line, for treatment elsewhere.

This almost closed-looped recycling and advanced process design with in-plant automatic control of water quality grades, will (1) have small in-plant reclamation modules for maintaining quality control, instead of major ex-plant treatment plants; (2) greatly reduce water consumption; (3) have a small dependence on local water supply and local Environment for low discharges; (4) reduce the costs of water supply; (5) maximize the utilization of solid wastes; and (6) raise product yields and quality considerably (about equivalent to the solids which are not extracted from the tissues, once the cyclic system is operating steadily).

Solid Wastes

Solid wastes generated from the food processing have a potential for uses ranging from the production of fine chemicals to the feeding of livestock (69).

Caustic potash is recommended for the peeling operation, as the recovered potassium is valuable as a fertilizer, in contrast to the sodium lye.

As part of the total system concept, solid wastes of the carrot processing line could be utilized as fuels or as

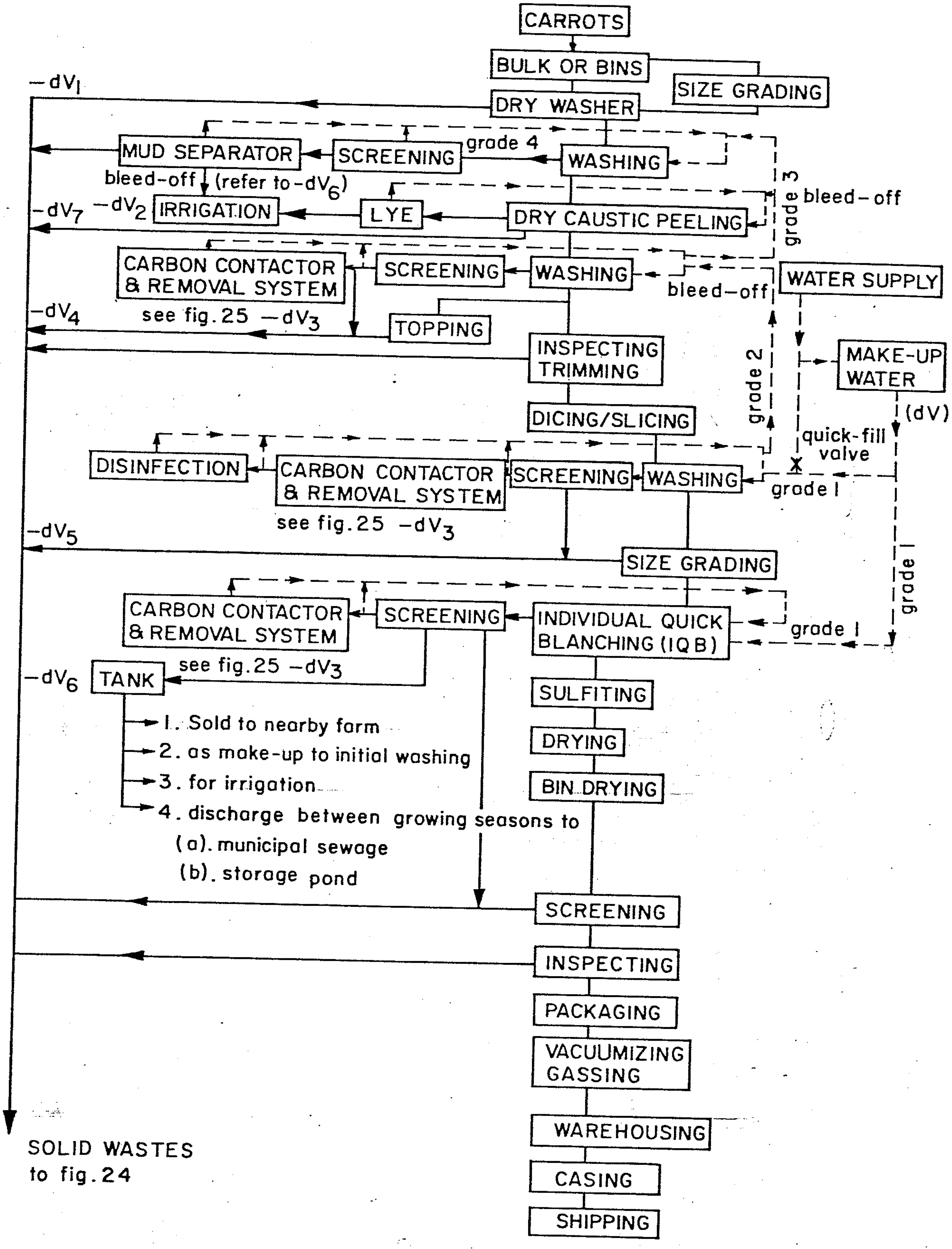


Fig. 23 Proposed Design of Improved Carrot Dehydration Processing Line

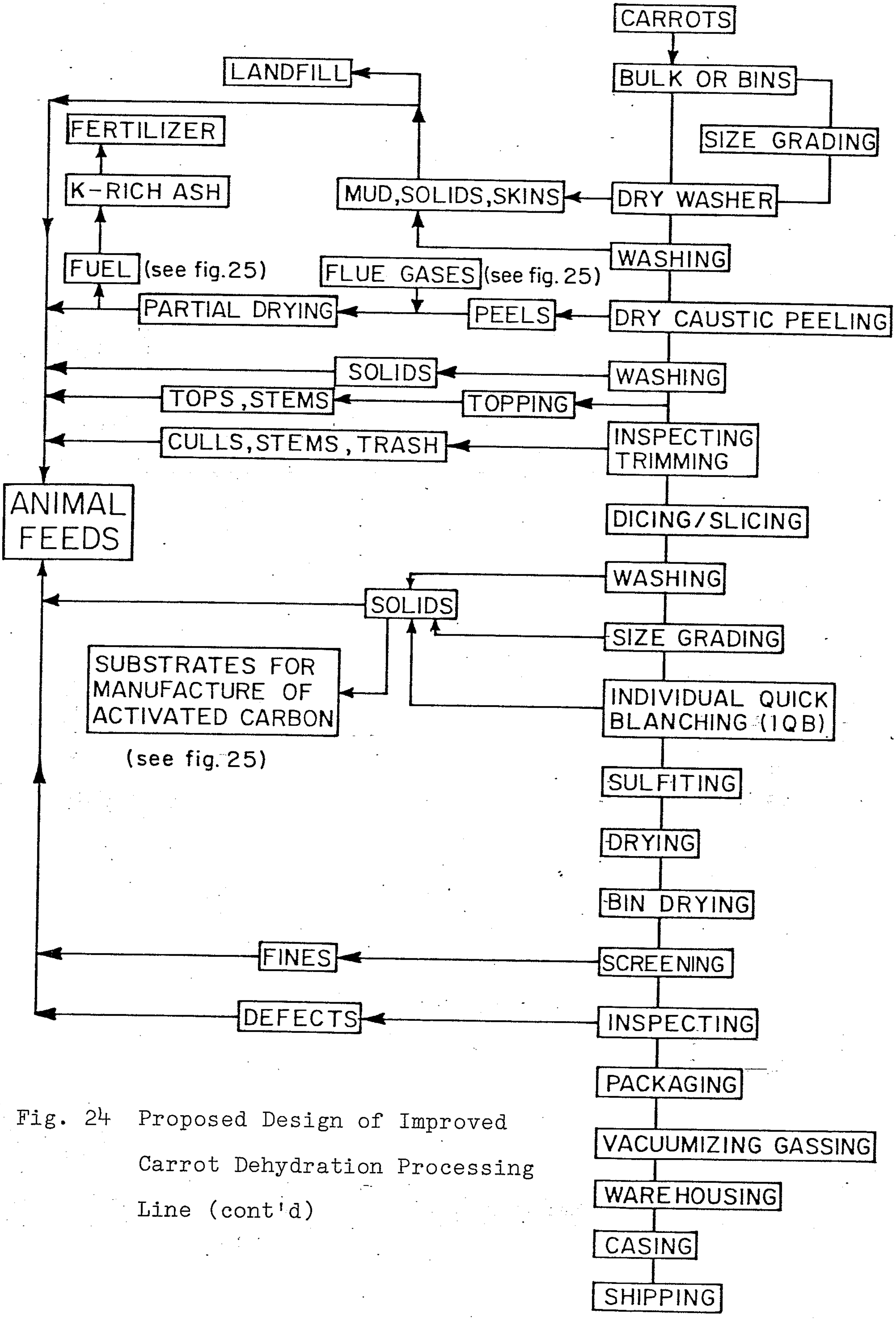


Fig. 24 Proposed Design of Improved Carrot Dehydration Processing Line (cont'd)

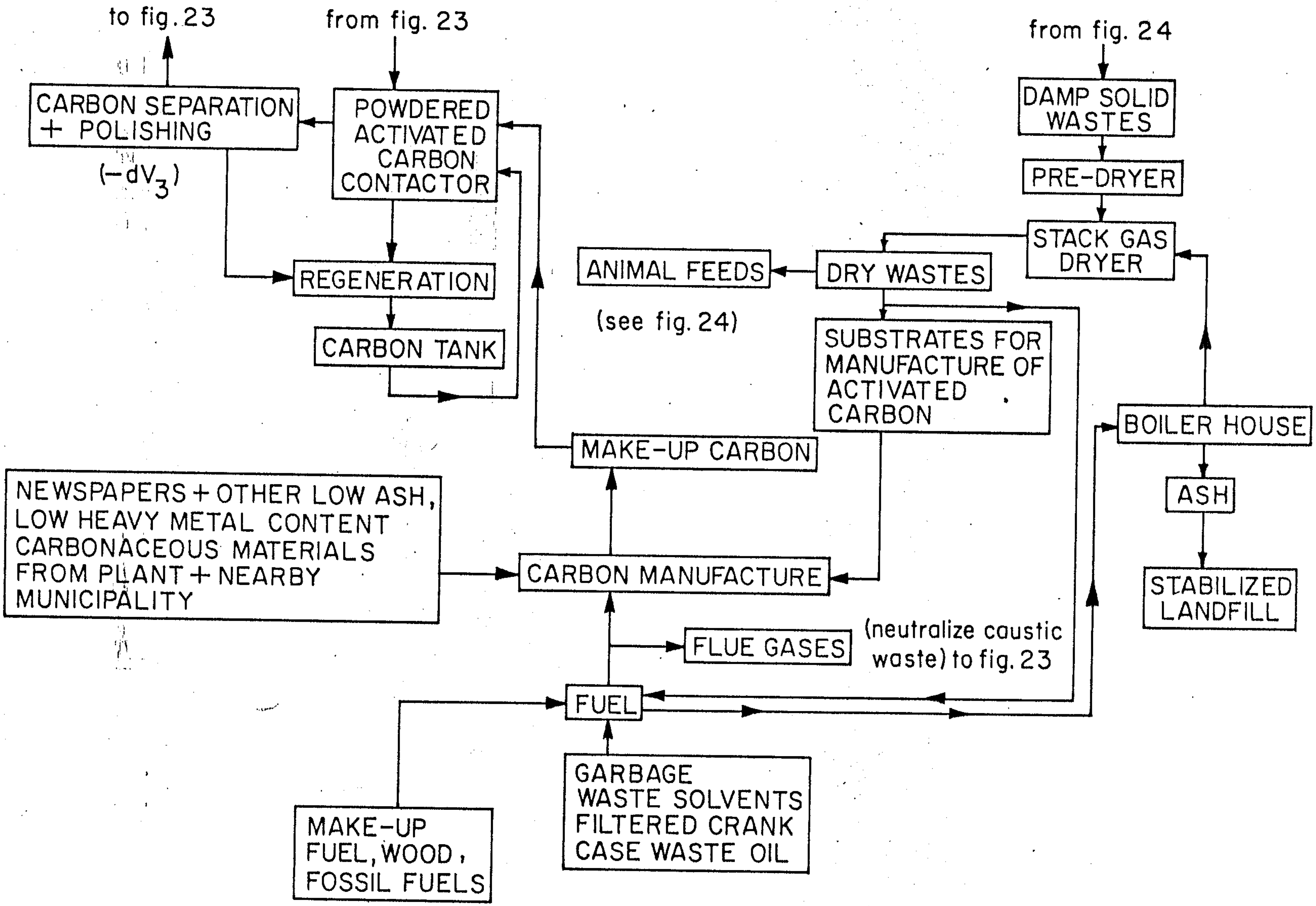


Fig. 25 Proposed Design of Improved Carrot Dehydration Processing Line (cont'd)

the substrates for the manufacture of activated carbons.

Activated Carbon Systems

To make activated carbon economically feasible for wastewater treatment, the exhausted carbon must be regenerated and reused. Closely controlled heating is presently the best procedure for removing adsorbed organics from activated carbon and is being chosen as being most appropriate to the overall design of this total system.

The carbon from this system is also recycled by continuously thermal regeneration on-site. The thermal regeneration process itself involves three steps (70) :

(1) drying,
(2) baking (pyrolysis of adsorbates), and
(3) activating (oxidation of the residue from the adsorbate).

Various substrates are used as fuels, such as straws, grain, pits, waste oils, newspapers, garbage and dry solid wastes generated from the processing line. However, air pollution control equipment should be included in the design of the carbon regeneration furnace, since some of the more volatile adsorbate is removed from the carbon and carried into the atmosphere without being completely oxidized.

Feasibility of Activated Carbon Systems for Carrot Processing Plants

Results from this thesis have shown that an activated carbon system can serve as an essential part of the almost closed loop recycling system to achieve excellent control of possible pollutants in a carrot processing plant.

Some carbon costing estimates can be obtained from the U. S. Environmental Protection Agency's Research and Development Programs (Chem. Engineering Progress Vol. 69 no. 11 Nov., 1973). In 1973, cost of carbon ranged from a low of 9 cents/lb for powdered carbon to 35 cents/lb or more granular. The regeneration costs (cents/lb) for granular carbon were 5.7 with 2 ton/day capacity, 3.3 with 10 ton/day capacity and 2.8 with 30 ton/day capacity in the multiple hearth granular carbon regeneration. In the fluidized bed powdered carbon regeneration, the total costs (cents/lb) was 9.0, 6.5 and 6.2 with 2, 10 and 30 ton/day capacity correspondingly.

Another process, called the Atomized Suspension Technique (AST)(50) reportedly takes less than 30 seconds to regenerate powdered carbon with a recovery rate of more than 90%, with 95% reactivation of adsorption capacity. This process has been successfully tested in pilot plant operations, on sugar refining and other fields. Economics of the process show a cost reduction of 50-70% from the cost of replenishing powdered carbon. Also, saving of 40% can be realized compared to the cost of using and reactivating granular activated carbon.

With this proposed design, existing and new carrot processing plants could meet the effluent guidelines and regulations which have been developed for the food processing industries.

VI. COSTING

The study undertaken in this thesis was on a laboratory scale, so that full evaluation of the economic feasibility of an activated carbon treatment system versus a biological treatment system could not be determined.

Costing data was obtained from the U.S. Environmental Protection Agency for the cost of biological treatment of a typical carrot processing plant, and for costing for an activated carbon system (2). Regeneration cost for carbon was based on the "A.S.T." system (71). In some cases, the costing figures were adjusted upwards to approximate 1976 costs. Thesis data was used to obtain the carbon dosage required for treating the carrot processing effluents.

Comparison of Water Plus Wastewater Treatment Costs from a Carrot Processing Plant

Assumptions : BASED ON E.P.A. DATA (2)

1,000,000 gpd of combined effluent of maximum

total B.O.D. = 1260 mg/l (table 3)

C.O.D. = 1890 mg/l

(A) Biological Secondary Treatment (without sludge disposal)*

Total annual cost for activated sludge

= $102,000 (table 16)

Total C.O.D. in lb/year = 3,157,600 = 15790 lb/day

(on the assumption of 200 operating days per year - from table 16)

Therefore, cost/lb C.O.D. applied = $102,000/3,157,600
= $0.0323

The daily treatment cost by biological methods would be (15790 x $0.0323) = $510

The fresh water cost per day would be

($0.30/1000 x 1,000,000) = $300

Total cost = $510 + $300 = $810/day

* no sludge disposal est. 6300 lbs sludge/day based on 0.6 - 0.8 lbs sludge produced per lb B.O.D. applied.

(B) Activated Carbon Treatment with Maximal Recycling

Assumptions:

(a) 1,000,000 gpd (V) in circuits, with 10 - 15 % maximum bleed-off + make-up (dV).

(b) Major flows, segregated, with new water at last stage, with bleed-offs being counter-flowed.

(c) Major flows, carbon treated minimally, to maintain good quality control everywhere (average of one treatment/five uses).

Therefore, the volume for carbon treatment would be about 200,000 gpd, with only excess C.O.D. being removed/treatment.

The recommended carbon dosage is approximately 3.8 g/U.S. gal. (section 4.3.1.).

The daily carbon requirement = (200,000 x 3.8/454) lb

= 1670 lb/day

The estimated cost of a carbon supply with "A.S.T." (i) regeneration (71) would then be : $(1670 x 16/100) (ii) = $270/day and the cost of a carbon feed + retrieval system (72) at an estimated cost $0.10/1000 gal. (iii) would be : 200,000 x $0.10/1000 = $20/day.

Total carbon system cost = $270 + $20 = $290/day

Water cost (10 - 15 % of 1,000,000) at $0.30/1000gal.

= $(100,000 x 0.3/1000) = $30/day.

Therefore, under this system, the total cost would be $290 + $30 = $320/day.

CONCLUSIONS:

SECONDARY BIOLOGICAL TREATMENT = $810/day

CARBON TREATMENT AND REUSE = $320/day

(i) "A.S.T." Atomized Suspension Technique (30 seconds of time required). Included in the A.S.T. system is the cost of pyrolysing the organic matter.

(ii) Since a carbon regenerating plant producing less than 5000 lbs/day would be needed, the A.S.T. costs for a 10,000 lbs/day plant have been doubled.

(iii) cost doubled for a carbon treatment and retrieval system.

TABLE (16)

ESTIMATED TREATMENT COSTS ($1000) FOR A TYPICAL CARROT PLANT
(200 Day Operating Season at 109 kkg/day)

	TREATMENT ALTERNATIVE							
	A	B	C	D	E	F	G	H
TOTAL CAPITAL COST	-	125	364	188	131	370	243	482
Unit Cost		93	290	110	98	295	188	385
Land Cost		9	2	50	9	2	9	2
Engr. & Cont.		23	72	28	24	73	46	95
TOTAL ANNUAL COST	-	34	95	31	41	102	65	126
Capital Recovery		18	59	22	19	60	37	78
O&M Cost		16	36	9	22	42	28	48
EFFLUENT QUALITY								
BOD5 (kg/kkg)	19.5	1.1	1.1	0.0	0.5	0.5	0.5	0.5
TSS (kg/kkg)	12.0	2.2	2.2	0.0	1.0	1.0	0.5	0.5

ALTERNATIVE A: Screening
ALTERNATIVE B: Average Aerated Lagoon Treatment and In-plant Controls
ALTERNATIVE C: Average Activated Sludge Treatment and In-plant Controls
ALTERNATIVE D: Land Treatment via Spray Irrigation
ALTERNATIVE E: Improved Aerated Lagoon Treatment Plus Additional In-plant Controls Plus Chlorination
ALTERNATIVE F: Improved Activated Sludge Treatment Plus Additional In-plant Controls Plus Chlorination
ALTERNATIVE G: Alternative E Plus Multi-Media Filtration
ALTERNATIVE H: Alternative F Plus Multi-Media Filtration

Other Advantages of an Activated Carbon System with In-plant Water Reuse

(1) lower chlorine demand,

(2) easy compliance with requirements of Water/Environmental Authorities and in consequence lower pollution abatement costs - solid, liquid, gaseous,

(3) lower unit production costs, increasing product yields/ unit cost, at high quality,

(4) advanced processes and machinery, with more automation and better quality control,

(5) greater production/plant with fewer water supply or discharge problems,

(6) greater return from liquid/solid wastes as by-products.

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Explanation of Abbreviated Terms for Appendix

G CARBON = g/100 ml

CODF = final concentration COD in effluent

X = amount of COD adsorbed

X/M = amount of COD adsorbed/unit weight of carbon

1/N = slope

K = intercept at $C_f = 1$

X/M OPTIMUM = ultimate carbon capacity for organic substrate value obtained from extrapolation of graph

APPENDIX I.

ADSORPTION ISOTHERM DATA FOR TEST CARBONS FOR REUSE CARROT RINSE WATER (5X)

AQUA NUCHAR CARBON

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	7199.			3.857	
0.10	6285.	914.	9140.0	3.798	3.961
0.30	5931.	1268.	4226.7	3.773	3.626
0.50	5833.	1366.	2732.0	3.766	3.437
1.00	5558.	1641.	1641.0	3.745	3.215
2.00	5165.	2034.	1017.0	3.713	3.007

1/N=11.118 K= 0.000 OPTIMUM X/M= 3475.7
CORRELATION COEFFICIENT=0.98 % REDUCTION=95.%

CARBON A

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	7199.			3.857	
0.10	6383.	816.	8160.0	3.805	3.912
0.30	6004.	1195.	3983.3	3.778	3.600
0.50	5726.	1473.	2946.0	3.758	3.469
1.00	5447.	1752.	1752.0	3.736	3.244
2.00	5165.	2034.	1017.0	3.713	3.007

1/N= 9.466 K= 0.000 OPTIMUM X/M= 2427.4
CORRELATION COEFFICIENT=0.99 % REDUCTION=98.%

CARBON B

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	7199.			3.857	
0.10	6579.	620.	6200.0	3.818	3.792
0.30	6069.	1130.	3766.7	3.783	3.576
0.50	5990.	1209.	2418.0	3.777	3.384
1.00	5912.	1287.	1287.0	3.772	3.110
2.00	5421.	1778.	889.0	3.734	2.949

1/N=10.417 K= 0.000 OPTIMUM X/M= 1582.2
CORRELATION COEFFICIENT=0.92 % REDUCTION=85.%

CARBON C

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	7199.			3.857	
0.10	6383.	816.	8160.0	3.805	3.912
0.30	5833.	1366.	4553.3	3.766	3.658
0.50	5578.	1621.	3242.0	3.747	3.511
1.00	5460.	1739.	1739.0	3.737	3.240
2.00	5106.	2093.	1046.5	3.708	3.020

1/N= 9.503 K= 0.000 OPTIMUM X/M= 2907.4
CORRELATION COEFFICIENT=0.97 % REDUCTION=95.%

CARBON D

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	7199.			3.857	
0.10	6226.	973.	9730.0	3.794	3.988
0.30	6069.	1130.	3766.7	3.783	3.576
0.50	5912.	1287.	2574.0	3.772	3.411
1.00	5533.	1666.	1666.0	3.743	3.222
2.00	5115.	2084.	1042.0	3.709	3.018

1/N= 9.818 K= 0.000 OPTIMUM X/M= 2489.8
CORRELATION COEFFICIENT=0.92 % REDUCTION=85.%

CARBON E

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	7199.			3.857	
0.10	6351.	848.	8480.0	3.803	3.928
0.30	5919.	1280.	4266.7	3.772	3.630
0.50	5531.	1668.	3336.0	3.743	3.523
1.00	4826.	2373.	2373.0	3.684	3.375
2.00	4164.	3035.	1517.5	3.620	3.181

1/N= 3.676 K= 0.000 OPTIMUM X/M= 1039.4
CORRELATION COEFFICIENT=0.96 % REDUCTION=92.%

APPENDIX II.

ADSORPTION ISOTHERM DATA
FOR TEST CARBONS
FOR BLANCHED CARROT WASTE

AQUA NUCHAR CARBON

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	10625.			4.026	
0.10	9375.	1250.	12500.0	3.972	4.097
0.30	9219.	1406.	4686.7	3.965	3.671
0.50	9063.	1562.	3124.0	3.957	3.495
0.70	8906.	1719.	2455.7	3.950	3.390
1.00	8711.	1914.	1914.0	3.940	3.282
2.00	8223.	2402.	1201.0	3.915	3.080

1/N=14.833 K= 0.000 OPTIMUM X/M= 4343.6
CORRELATION COEFFICIENT=0.88 % REDUCTION=78.%

CARBON A

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	10859.			4.036	
0.10	9609.	1250.	12500.0	3.983	4.097
0.30	9453.	1406.	4686.7	3.976	3.671
0.50	9219.	1640.	3280.0	3.965	3.516
0.70	8906.	1953.	2790.0	3.950	3.446
1.00	8711.	2148.	2148.0	3.940	3.332
2.00	8203.	2656.	1328.0	3.914	3.123

1/N=11.781 K= 0.000 OPTIMUM X/M= 3084.7
CORRELATION COEFFICIENT=0.91 % REDUCTION=83.%

CARBON B

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	10859.			4.036	
0.10	9687.	1172.	11720.0	3.986	4.069
0.30	9531.	1328.	4426.7	3.979	3.646
0.50	9375.	1484.	2968.0	3.972	3.473
0.70	9219.	1640.	2342.9	3.965	3.370
1.00	9063.	1796.	1796.0	3.957	3.254
2.00	8516.	2343.	1171.5	3.930	3.069

1/N=15.341 K= 0.000 OPTIMUM X/M= 3693.0
CORRELATION COEFFICIENT=0.88 % REDUCTION=77.%

CARBON C

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	10859.			4.036	
0.10	9687.	1172.	11720.0	3.986	4.069
0.30	9453.	1406.	4686.7	3.976	3.671
0.50	9141.	1718.	3436.0	3.961	3.536
0.70	8906.	1953.	2790.0	3.950	3.446
1.00	8555.	2304.	2304.0	3.932	3.363
2.00	7734.	3125.	1562.5	3.888	3.194

1/N= 7.485 K= 0.000 OPTIMUM X/M= 1574.5
CORRELATION COEFFICIENT=0.88 % REDUCTION=77.%

CARBON D

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	10625.			4.026	
0.10	9375.	1250.	12500.0	3.972	4.097
0.30	9141.	1484.	4946.7	3.961	3.694
0.50	8984.	1641.	3282.0	3.954	3.516
0.70	8672.	1953.	2790.0	3.938	3.446
1.00	8438.	2187.	2187.0	3.926	3.340
2.00	7773.	2852.	1426.0	3.891	3.154

1/N= 9.646 K= 0.000 OPTIMUM X/M= 2353.4
CORRELATION COEFFICIENT=0.88 % REDUCTION=78.%

CARBON E

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	10625.			4.026	
0.10	9453.	1172.	11720.0	3.976	4.069
0.30	9063.	1562.	5206.7	3.957	3.717
0.50	8672.	1953.	3906.0	3.938	3.592
0.70	8281.	2344.	3348.6	3.918	3.525
1.00	7852.	2773.	2773.0	3.895	3.443
2.00	7031.	3594.	1797.0	3.847	3.255

1/N= 5.552 K= 0.000 OPTIMUM X/M= 1513.7
CORRELATION COEFFICIENT=0.93 % REDUCTION=86.%

APPENDIX III.

ADSORPTION ISOTHERM DATA FOR REUSE CARROT RINSE WATER AND BLANCHED CARROT WASTE

CARROT RINSE WATER 100G/L 1ST RINSE

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	349.			2.543	
0.10	244.	105.	1046.5	2.388	3.020
0.50	172.	177.	353.5	2.236	2.548
1.00	110.	238.	238.4	2.043	2.377
2.00	67.	281.	140.7	1.829	2.148
5.00	37.	312.	62.3	1.571	1.795

1/N= 1.376 K= 0.404 OPTIMUM X/M= 1277.1
CORRELATION COEFFICIENT=0.98 % REDUCTION=96.%

CARROT RINSE WATER 100G/L 6TH RINSE

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	1429.			3.155	
0.10	1178.	251.	2510.0	3.071	3.400
0.50	888.	541.	1082.0	2.948	3.034
1.00	753.	676.	676.2	2.877	2.830
2.00	425.	1004.	502.1	2.628	2.701
5.00	232.	1197.	239.5	2.365	2.379

1/N= 1.282 K= 0.203 OPTIMUM X/M= 2250.6
CORRELATION COEFFICIENT=0.95 % REDUCTION=90.%

CARROT RINSE WATER 100G/L 15TH RINSE

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	4428.			3.646	
0.10	4034.	394.	3936.1	3.606	3.595
0.50	3788.	640.	1279.2	3.579	3.107
1.00	3007.	1421.	1420.7	3.478	3.153
3.00	1808.	2620.	873.3	3.257	2.941
5.00	1310.	3118.	623.6	3.117	2.795

1/N= 1.195 K= 0.112 OPTIMUM X/M= 2531.9
CORRELATION COEFFICIENT=0.84 % REDUCTION=71.%

CARROT RINSE WATER 300G/L 1ST RINSE

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	941.			2.974	
0.10	841.	100.	1000.0	2.925	3.000
0.50	716.	225.	450.0	2.855	2.653
1.00	662.	279.	279.0	2.821	2.446
2.00	618.	323.	161.5	2.791	2.208
3.00	595.	346.	115.3	2.775	2.062

1/N= 6.175 K= 0.000 OPTIMUM X/M= 2190.7
CORRELATION COEFFICIENT=0.99 % REDUCTION=99.%

CARROT RINSE WATER 300G/L 15TH RINSE

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	5146.			3.711	
0.10	4770.	376.	3760.0	3.679	3.575
0.50	4516.	630.	1260.0	3.655	3.100
1.00	3723.	1423.	1423.0	3.571	3.153
3.00	2540.	2606.	868.7	3.405	2.939
5.00	2036.	3110.	622.0	3.309	2.794

1/N= 1.553 K= 0.004 OPTIMUM X/M= 2536.1
CORRELATION COEFFICIENT=0.85 % REDUCTION=72.%

BLANCHED CARROT WASTE 300G/L

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	12125.			4.084	
0.10	11795.	330.	3300.0	4.072	3.519
0.50	10916.	1209.	2418.0	4.038	3.384
1.00	10183.	1942.	1942.0	4.008	3.288
3.00	7265.	4860.	1620.0	3.861	3.210
5.00	4896.	7229.	1445.8	3.690	3.160

1/N= 0.786 K= 1.665 OPTIMUM X/M= 2690.1
CORRELATION COEFFICIENT=0.87 % REDUCTION=75.%

BLANCHED CARROT WASTE 450G/L

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	13708.			4.137	
0.10	13200.	508.	5080.0	4.121	3.706
0.50	12367.	1341.	2682.0	4.092	3.429
1.00	11268.	2440.	2440.0	4.052	3.387
3.00	8792.	4916.	1638.7	3.944	3.215
5.00	6341.	7367.	1473.4	3.802	3.168

1/N= 1.402 K= 0.006 OPTIMUM X/M= 3714.7

CORRELATION COEFFICIENT=0.86 % REDUCTION=74.%

APPENDIX IV.

ADSORPTION ISOTHERM DATA FOR SUGARS AND AMINO ACIDS

GLUTAMIC ACID

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	869.			2.939	
0.10	797.	72.	719.9	2.901	2.857
0.50	564.	304.	608.8	2.752	2.785
1.00	356.	513.	513.2	2.551	2.710
2.00	139.	730.	365.0	2.142	2.562

1/N= 0.382 K=54.973
CORRELATION COEFFICIENT=1.00

OPTIMUM X/M= 729.9
% REDUCTION=100.%

ALANINE

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	1057.			3.024	
0.10	1044.	13.	133.1	3.019	2.124
0.50	992.	66.	131.5	2.996	2.119
1.00	955.	103.	102.7	2.980	2.012
2.00	866.	191.	95.5	2.938	1.980

1/N= 1.961 K= 0.000
CORRELATION COEFFICIENT=0.91

OPTIMUM X/M= 137.8
% REDUCTION=82.%

SERINE

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	759.			2.880	
0.10	750.	9.	90.0	2.875	1.954
0.50	744.	15.	30.0	2.872	1.477
1.00	737.	22.	22.0	2.868	1.342
2.00	728.	31.	15.5	2.862	1.190

1/N=55.333 K= 0.000
CORRELATION COEFFICIENT=0.97

OPTIMUM X/M= 128.8
% REDUCTION=93.%

THREONINE

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	1075.			3.031	
0.10	1004.	71.	707.8	3.002	2.850
0.50	989.	86.	171.7	2.995	2.235
1.00	902.	173.	172.6	2.955	2.237
3.00	817.	258.	85.9	2.912	1.934
5.00	732.	342.	68.5	2.865	1.836

1/N= 5.765 K= 0.000 OPTIMUM X/M= 514.3
CORRELATION COEFFICIENT=0.84 % REDUCTION=71.%

VALINE

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	1391.			3.143	
0.10	1338.	53.	530.0	3.127	2.724
0.50	1240.	151.	302.0	3.093	2.480
1.00	1149.	242.	242.0	3.060	2.384
3.00	884.	507.	169.0	2.947	2.228
5.00	775.	616.	123.2	2.889	2.091

1/N= 2.284 K= 0.000 OPTIMUM X/M= 452.6
CORRELATION COEFFICIENT=0.95 % REDUCTION=90.%

GLUCOSE

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	1086.			3.036	
0.50	832.	254.	508.1	2.920	2.706
1.00	654.	432.	432.0	2.815	2.635
2.00	464.	622.	310.9	2.666	2.493
3.00	314.	772.	257.4	2.496	2.411
5.00	194.	892.	178.3	2.288	2.251

1/N= 0.714 K= 4.127 OPTIMUM X/M= 607.8
CORRELATION COEFFICIENT=1.00 % REDUCTION=99.%

MALTOSE

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	1036.			3.015	
0.10	795.	240.	2402.5	2.901	3.381
0.30	439.	596.	1987.6	2.643	3.298
0.50	226.	809.	1618.6	2.355	3.209
0.70	106.	929.	1327.6	2.027	3.123
1.00	49.	987.	986.8	1.689	2.994

1/N= 0.312 K=298.996 OPTIMUM X/M= 2614.0
CORRELATION COEFFICIENT=1.00 % REDUCTION=100.%

SUCROSE

GRAMS CARBON	CODF	X	X/M	LOG CODF	LOG X/M
0.00	1053.			3.022	
0.10	866.	187.	1867.7	2.938	3.271
0.30	546.	507.	1688.6	2.737	3.228
0.50	337.	716.	1432.4	2.527	3.156
0.70	175.	878.	1253.9	2.243	3.098
1.00	73.	979.	979.5	1.865	2.991

1/N= 0.261 K=320.078 OPTIMUM X/M= 1973.7
CORRELATION COEFFICIENT=1.00 % REDUCTION=100.%

APPENDIX V.

CO_2D/COD RATIOS FOR BLANCHED CARROT WASTE AND REUSE CARROT RINSE WATER

BLANCHED CARROT WASTE

C/W* (g/l)	CARBON DOSAGE (gram)	COD (mg/l)	CO_2D (mg/l)	CO_2D/COD
100	0.0	5128	4242	0.83
100	0.1	4762	4008	0.84
100	0.5	4212	3623	0.86
100	1.0	3453	2910	0.84
100	3.0	1856	1615	0.87
100	5.0	1255	1052	0.84
450	0.0	13708	11650	0.85
450	0.1	13200	11417	0.86
450	0.5	12367	10333	0.84
450	1.0	11268	9750	0.87
450	3.0	8792	7767	0.88
450	5.0	6341	5603	0.88

* C/W = carrot slices to blanch water ratio

AVERAGE $CO_2D/COD = 0.86$

REUSE CARROT RINSE WATER

RINSE	COD(mg/l)	CO_2 D(mg/l)	CO_2 D/COD
1	396	340	0.86
2	640	550	0.86
3	843	700	0.83
4	994	830	0.84
5	1115	937	0.84
6	1219	1012	0.83
7	1348	1152	0.85
8	1563	1360	0.87
9	1733	1440	0.83
10	1861	1562	0.84
11	2018	1716	0.85
12	2122	1797	0.85
13	2127	1838	0.86
14	2245	1893	0.84
15	2245	1900	0.85

carrot slices to water ratio = 300 g/l

AVERAGE CO_2 D/COD = 0.85

APPENDIX VI.

CALIBRATION DATA FOR THE "AQUARATOR" AND "TANNIN-LIKE" COMPOUNDS

CALIBRATION DATA FOR THE "AQUARATOR"

CO_2D (mg/l)	IR Meter Reading Trial 1	Trial 2	Trial 3	Average
50	13	13	13	13
100	30	29	29	29
150	45	44	46	45
200	61	61	61	61
250	77	77	76	77
300	92	94	93	93

CALIBRATION DATA FOR "TANNIN-LIKE" COMPOUNDS

Conc. (mg/l)	Absorbance at 700 $m\mu$ Trial 1	Trial 2	Trial 3	Average
0	0	0	0	0
2	0.195	0.196	0.195	0.195
4	0.295	0.295	0.295	0.295
6	0.395	0.396	0.395	0.395
8	0.585	0.580	0.575	0.580
10	0.620	0.610	0.605	0.610