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EVALUATION OF INDUSTRIAL WASTE CARBON SOURCES FOR BIOLOGICAL DENITRIFICATION

by

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ABSTRACT

Concern over impairment of water quality by both industrial and municipal effluents has resulted in extensive investigations into nitrogen removal processes. Biological denitrification is one of the most economical and effective means of nitrate reduction. The process involves the conversion of nitrate to dinitrogen (N_2) using organic carbon as the electron donor. Methanol appears to be the most popular electron donor. Although methanol has certain advantages over industrial or municipal wastewater carbon sources, its significant disadvantage is cost and this alone justifies consideration of alternative electron donors.

A project was initiated to identify and evaluate industrial wastes or waste by-products which could be used as replacements for methanol. The first phase of the project involved contacting a wide variety of processing and manufacturing industries (petrochemical, organic chemical, pulp and paper, food and beverage, etc.) to identify potentially suitable wastes. Forty-one waste samples were collected and chemically analyzed to determine their organic carbon and nitrogen concentrations. Bench scale testing followed, with the determination of batch denitrification rates for 30 of the characterized wastewaters.

Twenty-seven of the 30 wastes exhibited denitrification rates equal to or greater than that observed using methanol. A distillery fusel oil exhibited the highest rate of 0.331 mg NO_T-N•mg $MLVSS^{-1}•d^{-1}$ as opposed to the mean rate, using methanol, of 0.097 mg NO_T-N•mg $MLVSS^{-1}•d^{-1}$. Many of the wastes exhibited substrate consumption ratios equal to or less than that for methanol. Data analysis showed a correlation between the initial FOC:N ratio and substrate consumption ratio.

Evaluation of costs for transportation of waste carbon sources by truck indicated that, for a range of 110 km from source to point of use, a soluble COD of 60 000 $mg•L^{-1}$ would be required for a waste to compete with methanol. If the waste was sold for 1.1¢/L, the soluble COD concentration would have to be 128 000 $mg•L^{-1}$ to transport the waste economically in comparison to methanol.

RÉSUME

A cause de l'inquiétude provoquée par la dégradation de la qualité de l'eau par les effluents industriels et urbains, des vastes études des procédés de dénitrification ont été entreprises. La dénitrification biologique est un des moyens les plus efficaces et les plus économiques d'éliminer les nitrates. Elle transforme ces derniers en azote diatomique (N_2), le carbone organique servant de donneur d'électrons. Le méthanol semble être le donneur le plus utilisé; même s'il présente certains avantages par rapport aux composés du carbone des eaux usées industrielles ou urbaines, il a comme désavantage de coûter cher, ce qui à lui seul justifie qu'on veuille utiliser d'autres donneurs d'électrons.

On a entrepris d'identifier et d'évaluer les eaux usées industrielles ou leurs sous-produits résiduaires, qui pourraient remplacer le méthanol. On a commencé par prendre contact avec une grande variété d'industries de transformation et de fabrication (pétroléochimie, chimie organique, pâtes et papiers, alimentation, etc.) pour identifier leurs déchets utiles. Quarante et un de ces déchets ont été analysés pour leur teneur en carbone organique et en azote. Après leur caractérisation, on a mesuré en laboratoire la vitesse de dénitrification en discontinu de trente de ces déchets.

Vingt-sept d'entre eux permettaient une dénitrification de vitesse égale ou supérieure à celle qui est observée avec le méthanol. Le plus rapide était un fusel de distillerie (0,331 mg d'N nitrique total par mg de matières volatiles en suspension dans la liqueur mixte et par jour comparativement à moyenne de 0,097 (mêmes unités) du méthanol). Comparativement à ce dernier, beaucoup des déchets permettaient une utilisation du substrat aussi ou moins rapide. L'analyse des données a montré une corrélation entre le rapport initial de C organique filtré à N et le rapport de transformation du substrat.

L'évaluation du coût de transport du carbone de rebut par camions à partir de la source d'approvisionnement indique que si la distance entre celle-ci et le point d'utilisation ne dépasse pas 110 km, il faudrait que la DCO soluble du déchet soit de 60 000 $mg \cdot L^{-1}$ pour que ce dernier reste en concurrence avec le méthanol. Si le déchet se vendait 0,011 $/L, sa DCO soluble devrait être de 128 000 $mg \cdot L^{-1}$ pour que son transport soit plus économique que celui du méthanol.

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ABBREVIATIONS

BOD_5	=	five-day biochemical oxygen demand
C_m	=	methanol requirement for denitrification
C_r	=	consumptive ratio
CL	=	confidence limit
COD	=	chemical oxygen demand
DN	=	denitrification
DO	=	dissolved oxygen
FCOD	=	filterable chemical oxygen demand
FOC	=	filterable organic carbon
FOC:N	=	filterable organic carbon to nitrogen ratio
MLVSS	=	mixed liquor volatile suspended solids
NO_3^--N	=	nitrate ion, expressed as nitrogen
NO_2^--N	=	nitrite ion, expressed as nitrogen
NO_T-N	=	NO_2^--N plus NO_3^--N
NH_3-N	=	ammonia plus ammonium ion, expressed as nitroge
r	=	correlation coefficient
TKN	=	total Kjeldahl nitrogen

CONCLUSIONS

1. Twenty-seven of the 30 industrial waste streams evaluated as external carbon sources exhibited denitrification rates equal to or greater than those observed using methanol.
2. Most wastes exhibited substrate consumption ratios between 0.7 and 2.4 kg FOC/kg NO_T-N removed, compared to the methanol average of 1.17 kg FOC/kg NO_T-N removed. Substrate consumption ratio appears to be related to initial FOC:N ratio.
3. Approximately 50% of the wastes tested in this study had the required carbon content and were available in quantities sufficient to provide a constant supply of carbon for the denitrification of domestic sewage and industrial wastes.
4. Where a denitrification treatment facility is adjacent to a waste carbon source, the concentration of the carbon is not a significant factor in its economic evaluation as a methanol alternative. Economic analysis revealed that only those wastes having a FCOD greater than 60 000 $mg \cdot L^{-1}$ can be considered economically feasible methanol alternatives at a transportation distance of 110 km.

1 INTRODUCTION

1.1 Principles of Biological Denitrification

The denitrification process involves the conversion of nitrate and nitrite ions into nitrogen gas by facultative heterotrophic bacteria such as Pseudomonas, Micrococcus, Archromobacter, and Bacillus under anoxic conditions. An energy source is required for this, and methanol has been the most widely used electron donor in the U.S.A. (U.S. EPA, 1975). Organics present in wastewater have also been used as the external carbon and energy source, but denitrification rates are roughly one-third of those attained with methanol (U.S. EPA, 1975).

Nitrate dissimilation with methanol is depicted as a two-step reaction of the following sequence:

$$NO_3^- + 0.33\ CH_3OH \rightarrow NO_2^- + 0.67\ H_2 + 0.33\ CO_2 \quad (1)$$

$$NO_2^- + 0.5\ CH_3OH \rightarrow 0.5\ N_2 + 0.5\ CO_2 + 0.5\ H_2O + OH^- \quad (2)$$

Overall: $$NO_3^- + 0.83\ CH_3OH \rightarrow 0.5\ N_2 + 0.83\ CO_2 + 1.17\ H_2O + OH^- \quad (3)$$

Whereas Equation 3 reveals the stoichiometric quantity of methanol required for nitrate dissimilation, additional methanol is required for deoxygenation and cell synthesis according to the following equations:

$$O_2 + 0.93\ CH_3OH + 0.056\ NO_3^- + 0.056\ H^+ \rightarrow 0.056\ C_5H_7NO_2 + 0.65\ CO_2 + 1.69\ H_2O \quad (4)$$

$$14\ CH_3OH + 3\ NO_3^- + 4\ H_2CO_3 \rightarrow 3\ C_5H_7NO_2 + 20\ H_2O + 3\ HCO_3^- \quad (5)$$

The methanol requirement can be combined and related to that required for nitrogen removal and deoxygenation. McCarty et al (1969) referred to this as the consumptive ratio, C_r, represented by the relationship:

$$C_r = \frac{\text{Total FOC utilized}}{\text{FOC required for denitrification and deoxygenation}} \quad (6)$$

In a reactor in which nitrate, nitrite and oxygen are reduced stoichiometrically by organic carbon sources, the C_r is equal to one. A supplemental quantity of organic carbon is required for cell synthesis. Consequently, the consumptive ratio is observed experimentally to be greater than unity. As the C_r of an organic compound increases, cell synthesis also increases. Thus, an organic waste that has a high consumptive ratio would tend to generate larger volumes of sludge (cells) than a waste with a lower C_r. McCarty et al (1969) listed observed C_r values for such organic substrates as acetate, ethanol, methanol, acetone and sugar. Sugar has a higher C_r value than the other organics, which have much simpler structures.

The methanol requirement, C_m, for nitrate dissimilation and deoxygenation can be written (U.S. EPA, 1975):

$$C_m = 2.47\ NO_3^-\text{-N} + 1.53\ NO_2^-\text{-N} + 0.87\ DO \quad (7)$$

A common working value is 3.0 kg methanol per kg nitrate-N removed rather than the stoichiometric amount of 2.47 kg of methanol.

Methanol has been widely used in biological denitrification (DN) as an external carbon and energy source (U.S. EPA, 1975). Reasons for this include:

1) high DN rate,
2) abundance of supply,
3) low sludge solids yield,
4) relatively low cost.

Recently, however, the price of methanol has risen dramatically following increases in world petroleum and petrochemical feedstock prices. Methanol is the largest single item in annual operating and maintenance costs at plants with denitrification facilities (Ecolotrol, Inc., 1974). Because of rising methanol prices, alternative carbon sources for denitrification have been considered. Christensen and Harremoes (1977) have listed a number of carbon sources, other than methanol, which have been used in denitrification studies.

Industrial waste effluents are frequently high in organic carbon. These wastes must undergo extensive biological treatment to reduce the oxygen demand. It is, therefore, reasonable to examine the use of industrial wastes high in organic carbon as possible replacements for methanol in the DN process. This proposal has several advantages:

1) It reduces the quantity of waste an industry is required to treat for carbon removal.
2) It may provide the industry with a saleable product.
3) It could reduce the operating and maintenance costs for DN at a sewage treatment plant.

1.2 Alternative Carbon Sources for Denitrification

The concept of utilizing waste materials as replacements for costly chemicals used in sewage treatment has alrady been implemented. As an example, industrial wastes which contain iron, aluminum and calcium have been shown to remove phosphorus from sewage successfully (Fowlie and Shannon, 1973; Wilson, 1976a).

The best waste carbon sources for denitrification are those which:

1) have a very high concentration of soluble organic carbon;
2) are uniform in composition from day to day;
3) exhibit denitrification rates equal to or greater than that observed with methanol without a great degree of cell synthesis;
4) are available in sufficient quantities to provide a regular supply; and
5) are close enough to sewage treatment plants to be transported economically.

A number of carbon sources for denitrification, other than methanol and sewage, have been listed by Christensen and Harremoës (1977). Specific instances where industrial wastes have been used as external carbon sources have been described by Wilson and Newton (1973) who used brewery wastes, and Climenhage and Stelzig (1973) who used an organic acid waste from nylon production. Tan and Martin (1975) also examined denitrification using several industrial wastes including a brewery stream, distillery waste, and several dairy products or wastes.

This report identifies waste streams from industries which have potential as carbon and energy sources in denitrification. It is by no means a complete compilation of all industries and their wastes. Characteristics of waste streams from industries surveyed should be representative of wastes generated by industries with similar processing. This report should help those planning the installation of denitrification facilities by making them aware of alternatives to methanol.

1.3 Study Objectives

The objectives of this project were:

1) to identify industrial wastes which could be used as replacements for methanol as an external carbon and energy source in the biological denitrification process; and
2) to determine whether it would be economically feasible to use industrial wastes in place of methanol for denitrification.

2 PROCEDURES

2.1 Waste Survey and Characterization

Waste streams that could replace methanol as carbon and energy sources for denitrification were identified by the procedure shown in Figure 1. Sectors of the industrial community with potentially high BOD_5 streams were identified in Fraser's Canadian Trade Directory (1976). Government offices (regional offices of the Department of the Environment and/or provincial government agencies) were then contacted to obtain names and telephone numbers of industry personnel familiar with their industry's waste streams. Enquiries were also made at this time in an attempt to identify local industries with concentrated waste carbon sources which might be suitable replacements for methanol. Subsequent conversations with company officials revealed whether they had high strength organic waste (BOD_5 greater than 8000 $mg \cdot L^{-1}$) available on a continuous basis. Industries with suitable wastes were either visited for sample pickup or requested to send samples to the Wastewater Technology Centre (WTC), Burlington, Ontario for nitrogen and carbon analyses. Waste samples that were acceptable by the screening procedure were then tested in batch denitrifying reactors to compare them with methanol as a carbon source. The screening criteria, similar to those of Wilson (1976b), were that the BOD_5 should be greater than 8000 $mg \cdot L^{-1}$, and TKN concentrations less than 2.5% of the BOD_5.

The criterion of greater than 8000 $mg \cdot L^{-1}$ BOD_5 was somewhat arbitrary, but required, in order to eliminate all but high strength organic wastewaters. Less concentrated wastes would be uneconomical to transport and tend to hydraulically overload the sewage treatment system. The low nitrogen criterion was essential to minimize the quantity of reduced nitrogen added to the nitrogen removal system.

Waste samples from industries were received or picked up in plastic or glass containers. Samples susceptible to biological change (especially from food and beverage industries) were frozen between characterization and denitrification studies. The following parameters were analyzed in unfiltered samples: BOD_5, COD, TKN, total solids, and pH. Filtered samples were analyzed for BOD_5, COD, FOC, NO_3^--N, NO_2^--N, NH_3-N, TKN and total dissolved solids. The same parameters were analyzed in the

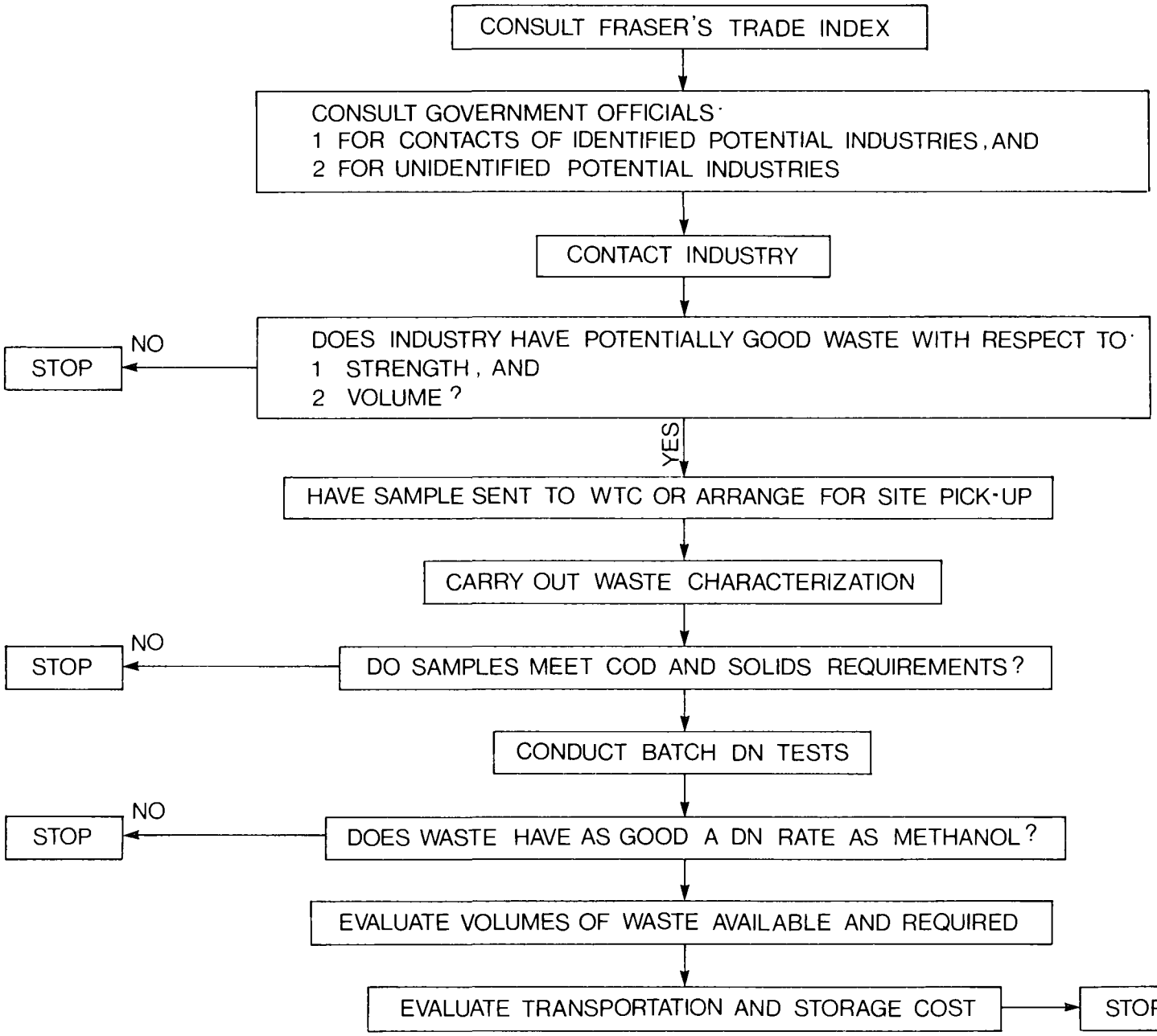

FIGURE 1. SEQUENCE OF SELECTING INDUSTRIAL WASTE SAMPLES FOR DENITRIFICATION

batch reactor tests, but additional measurements were taken for dissolved oxygen (DO), reactor pH, temperature, and mixed liquor volatile suspended solids (MLVSS).

The procedures used for measuring oxygen demand, organic carbon and nitrogen forms are described elsewhere (Sutton et al, 1976). Dissolved oxygen, pH, temperature and MLVSS determinations were carried out according to Standard Methods (1971).

2.2 Batch Denitrification Rate Studies

The sludge used in the batch reactor studies was obtained from a combined sludge nitrification-denitrification pilot plant system. Denitrification was promoted using methanol as an external carbon source.

In the batch reactors, each of ten-litre capacity, the sludge was diluted with tap water to provide trace elements essential for microorganism growth. Stock solutions of methanol and sodium or potassium nitrate were also made up with tap water. The denitrifying sludge was acclimated for at least two full days using the stock nitrate and methanol solutions. On the third day the external carbon source was switched from methanol to the industrial waste. The reactors were stirred with mechanical mixers at a rate sufficient to keep the microorganisms in suspension. Although the reactors were uncovered, the mixing rate was slow enough to maintain anoxic conditions in the mixed liquor.

In the batch runs, three or more reactors were run in parallel, with one reactor operated as a methanol control. Industrial wastes were added to the reactors in volumes dependent on the organic carbon content of the wastes. A sufficient quantity was added to keep the system nitrogen-limited rather than carbon-limited.

Samples for COD and nitrogen analyses were collected every half an hour for the first two and one-half hours and then once every hour for another three or four hours to determine kinetic rate constants. The mixed liquor volatile suspended solids concentration was taken as the mean of samples collected at the beginning, middle and end of the batch runs. Reactor pH, temperatures and DO were monitored once every two hours. If the reactor pH rose above 7.7 due to the alkalinity production, concentrated sulphuric acid was added dropwise to adjust the pH back to 7.0.

Samples for nitrogen and carbon analyses were frozen if they were not measured within twenty-four hours of collection.

Batch denitrification rates were determined by linear regression of nitrate-N concentration (y) on time (x). In cases where the nitrate reduction curve showed a distinct decrease in rate, the first part of the line was assumed as the correct denitrification rate. The second part of the curve (with slower rate) was assumed as approaching a carbon-limiting situation, and was disregarded for rate calculation.

When nitrite-N production was significant, the actual denitrification rate was calculated by subtracting the nitrite-N rate of production from the apparent nitrate-N depletion rate.

3 RESULTS AND DISCUSSION

3.1 Waste Survey and Characterization

The complete list of industries that were contacted and wastes sampled in this project appears in Appendix I. Of the 41 companies that were contacted, 27 had wastes which appeared promising enough for sample pickup or delivery. Wastes from companies which were not considered for further study were rejected because:

1) waste streams were too dilute to be feasible as a carbon source;
2) the company was a product distributor without manufacturing at the site; or
3) the company was shut down for the period of this study.

In almost all cases, wastes were sampled as individual streams within a plant, before they were combined with other effluents for final discharge. Frequently, more than one waste stream within a company was sampled (e.g., distillery wastes), resulting in 43 wastes that were received for characterization. Of these, two were considered unsuitable as a carbon source for biological denitrification and they were not submitted to the laboratory for analyses. After characterization of the 41 wastes, a further 11 were rejected and the remaining 30 tested in the batch reactors as possible replacements for methanol in denitrification. Most of the characterized wastes rejected were too low in organic carbon for further consideration.

A complete summary of the waste characterization results is contained in Appendix II. Waste strengths varied in COD from several hundred $mg \cdot L^{-1}$ in pulp mill evaporator condensates to over one million $mg \cdot L^{-1}$ in streams reaching almost pure solvent proportions, such as distillery fusel oils or light distillates.

3.2 Batch Denitrification Rate Studies

In the batch denitrification studies, two or more reactors using industrial wastes as carbon sources were run in parallel with a methanol control reactor. The batch runs completed using methanol as the carbon source resulted in a distribution of denitrification rates, as shown in

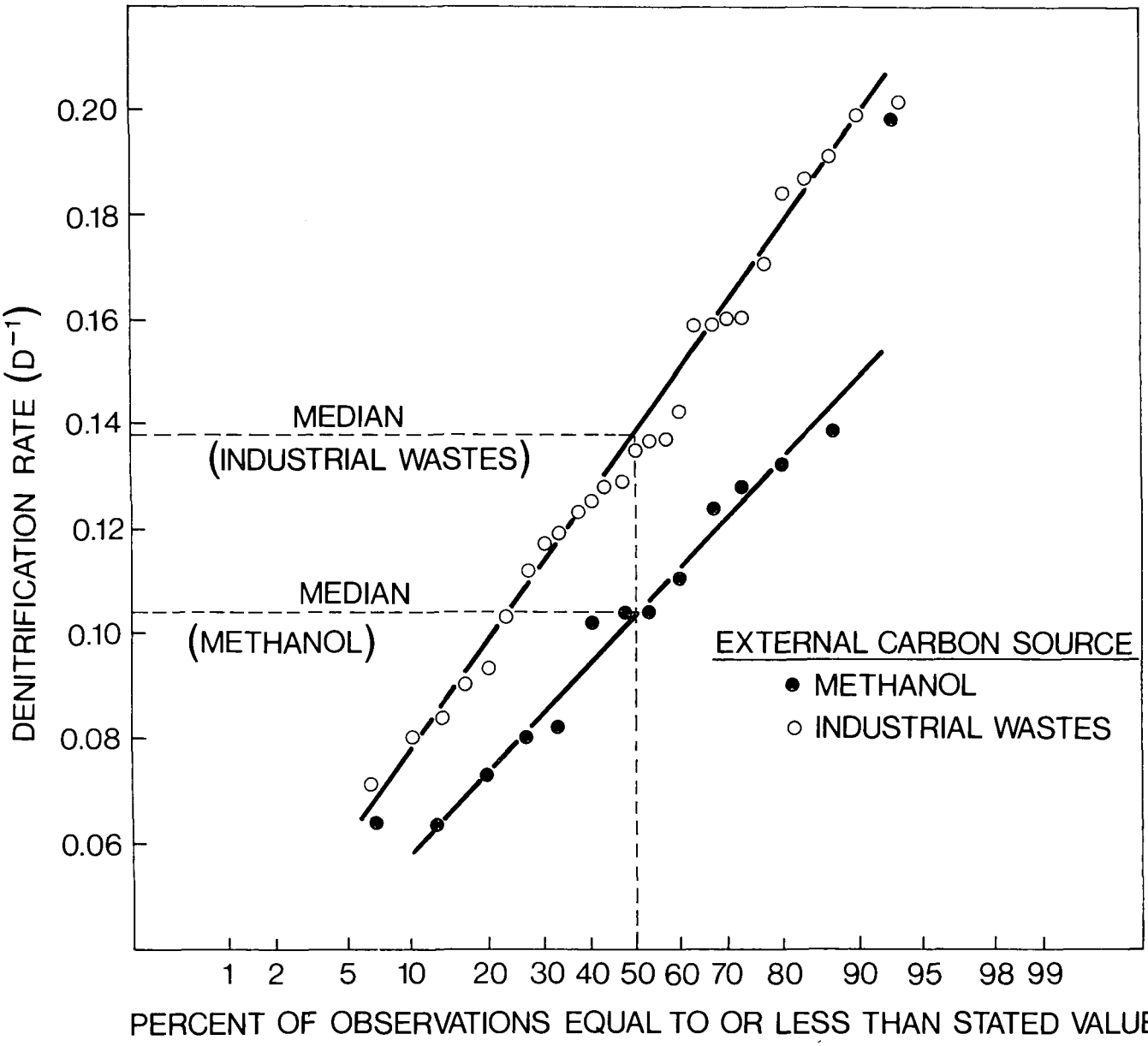

FIGURE 2. DISTRIBUTION OF DENITRIFICATION RATES

Figure 2. The result closely resembles a normal distribution with the exception of one very high value. Mean denitrification rates with methanol as the carbon source were calculated first using all 15 points and then using 14 points, having discarded the high value (Table 1). The mean rate of 0.097 mg NO_T-N removed·mg $MLVSS^{-1}·d^{-1}$ was chosen as the value best representing the methanol controls.

TABLE 1. ANALYSIS OF DATA FROM BATCH TESTS USING METHANOL AS CARBON SOURCE

Number of Points	Mean Rate mg NO_T-N·mg $MLVSS^{-1}·d^{-1}$	Standard Deviation	95% CL	99% CL
15	0.104	0.037	±0.022	±0.030
14	0.097	0.027	±0.016	±0.022

The degree of variation in rates observed may be expected from batch runs done on different days. Denitrification rates for suspended growth reactors using methanol have been summarized elsewhere (U.S. EPA, 1975). The range of DN rates achieved with methanol in this study are of the same magnitude as those given in the EPA Nitrogen Control Manual (U.S. EPA, 1975).

The sludge used in these DN rate studies exhibited variable characteristics as it was derived from a denitrification pilot scale reactor operating under varying control parameters such as sludge age and temperature. To assess the effect of this factor, during one run three batch reactors were operated in parallel using methanol as the carbon source. The rates obtained were 0.104, 0.102 and 0.132 mg NO_T-N·mg $MLVSS^{-1}·d^{-1}$, reducing to a mean rate of 0.113 mg NO_T-N·mg $MLVSS^{-1}·d^{-1}$ with a standard deviation of 0.017. Statistical comparison of the within-day variance and day-to-day variance indicated no significant difference at the 95% confidence limits. This suggests that deriving the sludge from the pilot scale reactor, which operated under varying conditions, did not affect the variability of the rates observed in the batch studies.

In a further attempt to explain the observed variability in the batch DN rates, two other possible correlations were examined. Batch denitrification rates using methanol as external carbon sources were correlated (using simple linear regression) with reactor MLVSS concentrations and with initial FOC:N ratios. In both cases, no correlation resulted.

The rates derived from the batch reactor studies using industrial wastes as external carbon sources are shown in Figure 2. As can be seen, these rates also exhibit a normal distribution with a mean of 0.144 mg NO_T-N•mg MLVSS^{-1}•d^{-1}.

The results for the industrial wastes appear in Table 2 in order of decreasing rate, classified according to whether the DN rate lay within or outside the 95% CL of the methanol control mean value. Process effluents in Group 1 (Table 2) had rates that were above the confidence interval for methanol in the control reactors. These streams and similar effluents would be the choice as methanol alternatives, although many wastes from Group 2 (Table 2) would also be acceptable replacements for methanol.

Nitrite formation was frequently observed in the denitrifying reactors. The rate of nitrite production is important because it decreases the overall rate of denitrification. Because both NO_3^--N and NO_2^--N forms were measured in the reactor samples collected, the true rate of denitrification was determined by subtracting the nitrite production rate from the measured nitrate removal rate. Examples of rate curves for the wastes with and without nitrite production are shown in Figure 3. A complete tabulation of data generated from the batch denitrification studies is contained in Appendix III.

Exactly half (15) of the wastes examined caused nitrite generation during the denitrification process. These are noted in Table 2. As long as the reaction is nitrogen-limited, nitrite production does not represent a problem. Microorganisms will use nitrite as the electron acceptor in denitrification.

Information in addition to the magnitude of the denitrification rates specified in Table 2 must be used to evaluate the batch test results. The majority of the highest rates measured were twice the magnitude of that resulting from the methanol control run on the same day. On

TABLE 2. DENITRIFICATION RATES USING INDUSTRAL WASTES AS THE CARBON SOURCE

Waste	Initial FOC:N	Temp. (°C)	DN Rate (d^{-1})	DN Rate Relative to MeOH Control Run on Same Day	Substrate Consumption Ratios		Comments*
					kg FCOD Consumed / kg NO_T-N Removed	kg FOC Consumed / kg NO_T-N Removed	
GROUP 1: The following wastes exhibited rates above the 95% confidence interval for methanol:							
Rieder Distillery Fusel Oils	3.19	20.5	0.331	2.38	2.22	0.77	
Pea Blanchwater (Food Processor 'A')	3.27	18.5	0.261	2.08	5.71		
Jordan Wines Sludge Centrate	2.70	20.5	0.207	1.62	7.30	2.28	1
Labatt's Brewery Spent Grain Extract	3.18	20	0.197	2.40	5.48	2.46	1
Molson's Brewery Last Runnings	2.53	20.5	0.191	1.49	6.67	1.83	
Molson's Brewery Wort	4.29	21	0.187	2.27	6.17	1.35	1
McGuinness Distillers Thin Stillage	2.71	21	0.184	1.44	6.07	2.18	1
Methanol Still Bottoms (Org. Manuf. 'A')	1.49	20	0.170	0.86	3.66	0.71	1
National Starch Process Effluent	2.97	18	0.160	1.54	3.26		
Tomato Sludge (Food Processor 'A')	1.72	18	0.160	1.31	2.54	0.80	
McGuinness Distillers Fusel Oils	3.17	20	0.159	1.29	5.32	1.46	1
Molson's Brewery Beer	4.16	20.5	0.159	1.41	8.57	2.54	1
Du Pont Organic Acids Waste	2.61	21	0.142	1.29	5.14	1.65	1
Spent Sulphite Liquor (Can. Int. Paper)	1.77	19	0.137	1.24	3.94	0.79	2,3
Domtar Packaging Whitewater	3.72	21	0.137	2.13	5.74	1.48	1,3
Vulcan-Cincinnati Methyl Fuel	4.07	21	0.135	1.22	6.18	1.83	
Celanese Light Ends (Tray 25)	3.48	21	0.129	1.17	5.23	1.36	
Methanol Heads (Ontario Paper Co.)	1.53	18	0.128	1.06	2.45	0.82	
Rieder Distillery Grape Slops	3.21	20	0.125	1.94	5.00	1.42	1
Acetic Acid Waste (Dow Chemical Co.)	1.76	20	0.123	0.62	3.87	1.71	1
Du Pont High Boiling Organic Waste	2.53	19	0.119	1.07	6.02	1.36	2
McGuinness Distillers Light Distillate	9.91	20	0.117	1.61	10.16	1.52	
GROUP 2: The following wastes exhibited rates within the 95% confidence interval for methanol:							
Jordan Wines Pomace Extract	3.43	19	0.112	1.74	5.69	2.6	1
Millhaven Fibres Glycol Waste	2.94	20	0.103	1.60	5.98	0.92	(DN is
METHANOL CONTROL	2.87	20	0.097†	-	5.41†	1.17†	-(Mean of
Molson's Brewery Trub	4.73	20	0.093	1.28	6.40	3.7	(14 Runs
Isopropanol Waste (Norwich)	4.40	20	0.090	1.40	3.64	1.82	2
Gos and Gris Cheese Whey	2.50	20	0.084	1.31	9.65	0.91	1
GROUP 3: The following wastes exhibited rates below the 95% confidence interval for methanol:							
Domtar Packaging Black Liquor	2.24	18	0.080	1.25	6.02	1.76	1,3
Waste Dextrose (Baxter Travenol Labs)	2.65	20	0.071	0.57	8.19	2.57	1
Formaldehyde Waste (University of Guelph)	3.62	20	0.042	0.37	6.21	1.38	

† Mean Value.

* LEGEND: 1. Waste caused nitrite production.
2. Waste added to TKN concentration.
3. Waste added colour to clarified effluent.

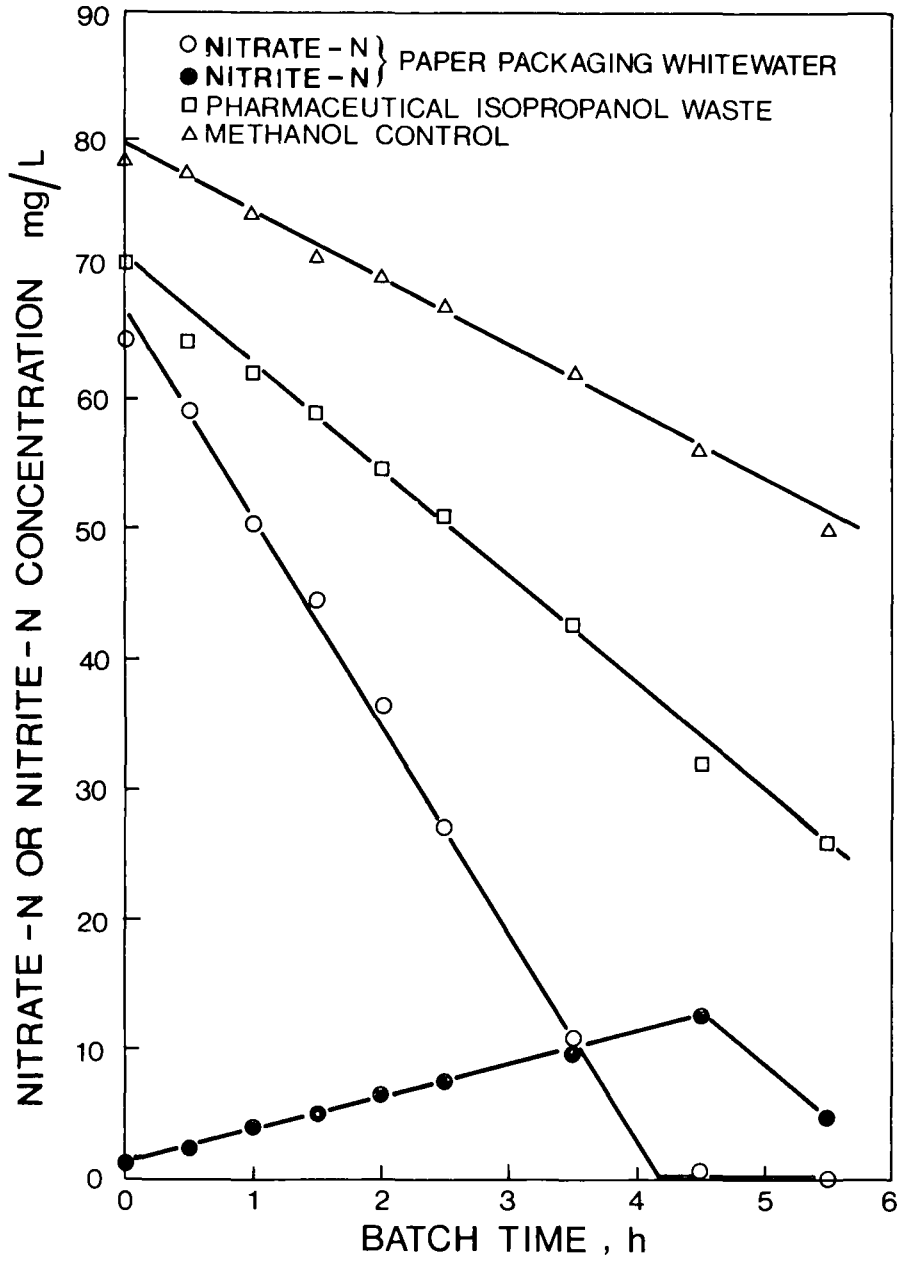

FIGURE 3. COMPARISON OF DENITRIFICATION RATES FROM ONE RUN USING WASTE CARBON SOURCES

one day, however, the methanol control displayed an extremely high DN rate. The two industrial samples used as carbon sources on this day (methanol still bottoms and acetic acid waste) consequently gave poor rates relative to the control. The individual rates, however (0.170 and 0.123, respectively), make them attractive methanol alternatives when compared to the mean methanol rate. Similarly, when a methanol control reactor gave a DN rate that was lower than usual, wastes run at that time appeared to have good relative rates. Compared with other wastes, however, these particular samples had lower individual rates. Examples of wastes in this category include distillery light distillate, winery pomace extract, and glycol waste. In summary, individual and relative DN rates should be examined together to assess the true rate of DN that may be expected.

A comparison of denitrification rates using brewery wastes as a a carbon source was possible by relating results from this study with those of Wilson and Newton (1973). The rates determined in both studies are summarized in Table 3. The Molson Trub sample was the only waste that exhibited a low rate of denitrification. The methanol control displayed a lower rate during this run and, therefore, the Trub sample results should not be disregarded. The DN rates relative to methanol were higher in this study than in the study of Tampa brewery wastes (Wilson and Newton, 1973).

The sludge used in this study was a combined sludge consisting of carbonaceous oxidizing organism, nitrifying organisms which convert ammonia to nitrate, and denitrifying organisms. The rate of denitrification expressed per weight of MLVSS is less with a combined sludge than a separate sludge containing only a denitrifying culture. The denitrification rates in this study were lower than those observed by Sutton et al (1974) in a separate sludge system.

Many of the industrial wastes examined in this study contained a number of complex organic compounds. Because of this complexity it was not possible in most cases to calculate the consumptive ratios of the wastes. In a few cases, the industrial effluents did contain one organic compound as the major component (e.g., acetic acid waste and glycol waste). Stoichiometric equations for nitrate reduction by organic compounds were developed in order to calculate the consumptive ratios. Equations similar

TABLE 3. COMPARISON OF DN RATES USING BREWERY WASTES

Brewery Wastes	Rate of Denitrification mg N removed/mg MLVSS·d	$\frac{\text{DN Rate Using Brewery Waste}}{\text{DN Rate Using Methanol}}$	Source
Schlitz Trub	0.17	0.94	Wilson & Newton (1973)
Schlitz Combined	0.22	1.2	
Busch Schoene	0.18	1.0	
Busch Spent Grain	0.17	0.94	
Busch Spent Beer	0.15	0.83	
Labatt's Spent Grain	0.20	2.4*	This study.
Molson's Last Runnings	0.19	1.5	
Molson's Trub	0.09	1.3	
Molson's Wort	0.19	2.3	
Molson's Ale	0.16	1.4	

* Methanol control reactors were not all run on the same day for this study.

to Equation 3 for methanol in Section 1.1 were derived. The equations are as follows:

For glycol:

$$1/2\ (CH_2OH)_2 + NO_3^- \rightarrow 1/2\ N_2 + CO_2 + H_2O + OH^- \quad (8)$$

For formaldehyde:

$$5/4\ HCHO + NO_3^- \rightarrow 1/2\ N_2 + 5/4\ CO_2 + 3/4\ H_2O + OH^- \quad (9)$$

For acetic acid:

$$5/8\ CH_3COOH + NO_3^- \rightarrow 1/2\ N_2 + 5/4\ CO_2 + 3/4\ H_2O + OH^- \quad (10)$$

For isopropanol:

$$5/18\ C_3H_7OH + NO_3^- \rightarrow 1/2\ N_2 + 5/6\ CO_2 + 11/18\ H_2 + OH^- \quad (11)$$

For fusel oil (as amyl alcohol):

$$1/6\ C_5H_{11}OH + NO_3^- \rightarrow 1/2\ N_2 + 5/6\ CO_2 + 1/2\ H_2 + OH^- \quad (12)$$

For dextrose:

$$5/24\ C_6H_{12}O_6 + NO_3^- \rightarrow 1/2\ N_2 + 5/4\ CO_2 + 3/4\ H_2O + OH^- \quad (13)$$

For these equations, the stoichiometric quantities of organic carbon required for nitrate reduction in the batch reactors were calculated. The observed depletions of organic carbon in the batch tests were used to determine the consumptive ratios. The C_r for wastes such as these were calculated and are shown in Table 4.

TABLE 4. EXPERIMENTAL CONSUMPTIVE RATIOS OF SOME INDUSTRIAL ORGANIC WASTES

Material	Cr
Methanol (Commercial)	1.65
Methanol Heads (Ontario Paper Co. Ltd.)	1.15
Methanol Still Bottoms (Organic Chemical Mfg. 'A')	1.00
Methyl Fuel (Vulcan-Cincinnati Ltd.)	2.58
Glycol Waste (Millhaven Fibres Ltd.)	1.07
Formaldehyde Waste (University of Guelph)	1.29
Acetic Acid Waste (Dow Chemical of Canada Ltd.)	1.60
Fusel Oil as $C_5H_{11}OH$ (L.J. McGuinness and Co. Ltd.)	2.04
Waste Dextrose Solution (Baxter Travenol Labs. of Canada Ltd.)	2.40
Isopropanol Waste (Norwich Pharmaceutical Co.)	2.53

The mean C_r for methanol run in the control reactors was 1.65, a value higher than expected. McCarty et al (1969) found an average C_r of 1.30 for methanol in semi-continuous field experiments. Wastes which were high in methanol in this study were the methanol heads from a paper company (C_r = 1.15), methanol still bottoms from an organic chemical manufacturer (C_r = 1.00), and a methyl fuel (C_r = 2.58). Simple organic carbon compounds such as formaldehyde, acetic acid and glycol had lower C_r's than did dextrose or a fusel oil (measured as $C_5H_{11}OH$). An isopropanol waste also had a high observed C_r. The compounds with the lower C_r values are the ones that should be chosen as carbon sources in denitrification.

Another way of identifying the effectiveness of an industrial waste as a carbon source is by measuring the quantity of FCOD or FOC consumed per unit of NO_T-N removed (substrate consumption ratio). These ratios appear in Table 2 and results should be compared to the methanol average values of 5.41 kg FCOD consumed per kg NO_T-N removed and 1.17 kg FOC consumed per kg NO_T-N removed.

The distribution of substrate consumption ratios for methanol are plotted in Figure 4. As can be seen, normal distributions result for both FCOD and FOC consumption ratios, with the exception of three abnormally high FCOD consumption ratios. A plot of substrate consumption ratios for the industrial waste tested (Figure 5) indicates the data approximate log-normal distributions.

Wilson (1976a) suggests that when using industrial wastes as carbon sources, 3 to 6 kg FCOD per kg NO_3^--N removed is adequate without overdosing. Of the 30 wastes examined in this survey, only six wastes had more than 6.3 kg FCOD consumed per kg NO_T-N removed (Table 2). The range proposed by Wilson (1976a) is well supported by the results of batch testing in this project. However, the actual waste volume and concentration required for denitrification will depend on each individual waste carbon source.

Tan and Martin (1975) examined waste streams for use in denitrification, two of which were also examined in this study. They found ratios of FCOD consumed to NO_3^--N removed for brewery wort and cheese whey were 3.9 and 7.4, respectively. These values are comparable to the values found in this study (Table 2).

The FOC substrate consumption ratio results for methanol show a wide variation. In attempting to explain this variation, the ratio was correlated by linear regression with the initial FCOD concentration and the initial FOC:N ratio. There was a higher correlation to the initial FOC:N ratio ($r = 0.64$) than to the initial FCOD concentration ($r = 0.54$). Substrate consumption ratios, for both methanol and industrial wastes, as functions of initial FOC:N ratios are displayed in Figure 6. It appears that the quantity of organic carbon, in excess of that required for denitrification, may also have an effect on the substrate consumption ratio.

Waste volumes required for denitrification depend on the available carbon in each industrial effluent. The wastes should be metered into denitrifying reactors to maintain the required FOC:NO_T-N ratio. At a hypothetical FOC:NO_T-N ratio of 1.0, the required volumes are summarized in Table 5, accompanied by quantities available from each company. Waste volumes required were expressed in terms of treating 4540 m^3 (one million Imperial gallons) of fully nitrified sewage with an NO_3^--N concentration

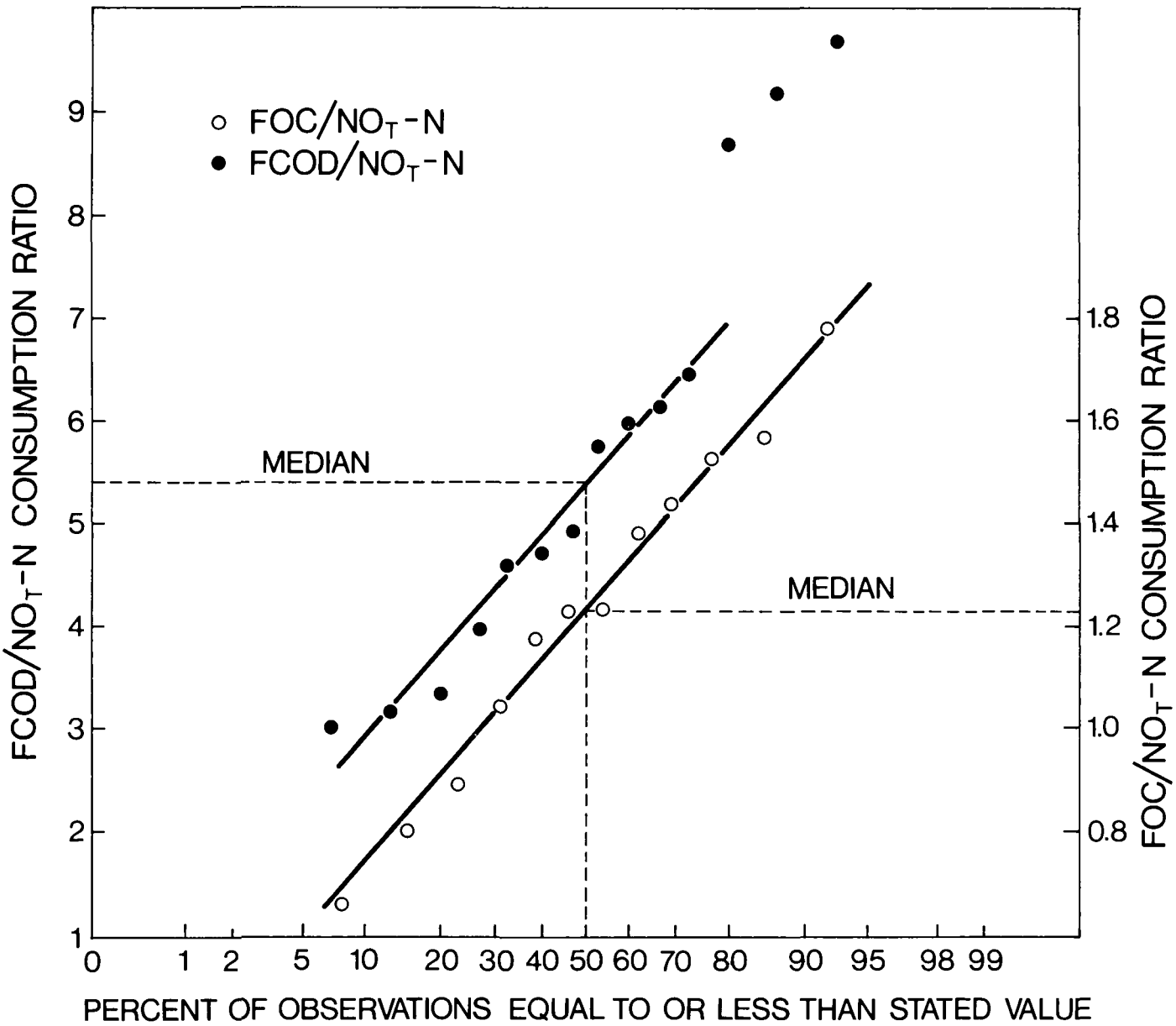

FIGURE 4. DISTRIBUTION OF SUBSTRATE CONSUMPTION RATIOS FOR METHANOL

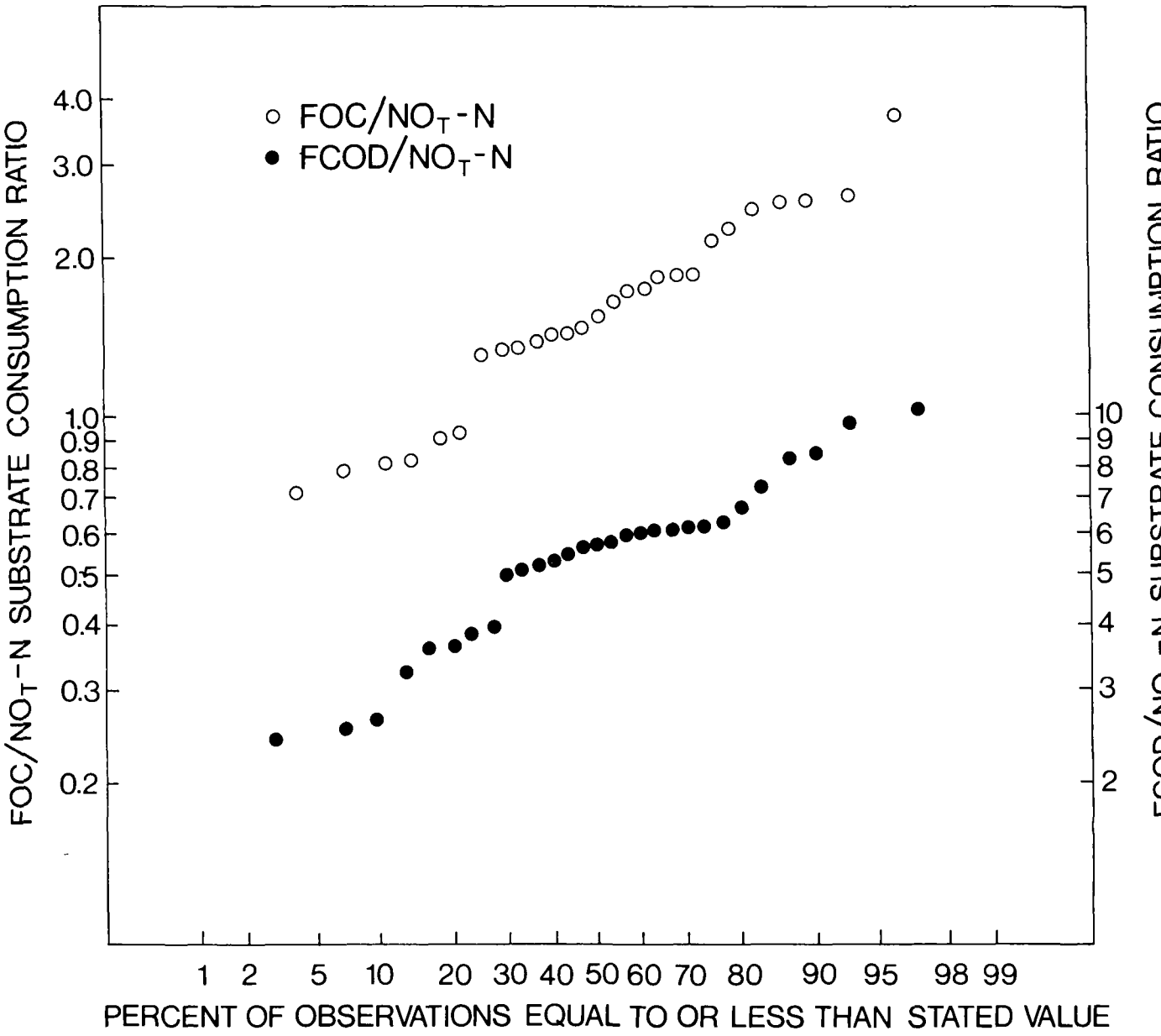

FIGURE 5. DISTRIBUTION OF SUBSTRATE CONSUMPTION RATIOS FOR INDUSTRIAL WASTES

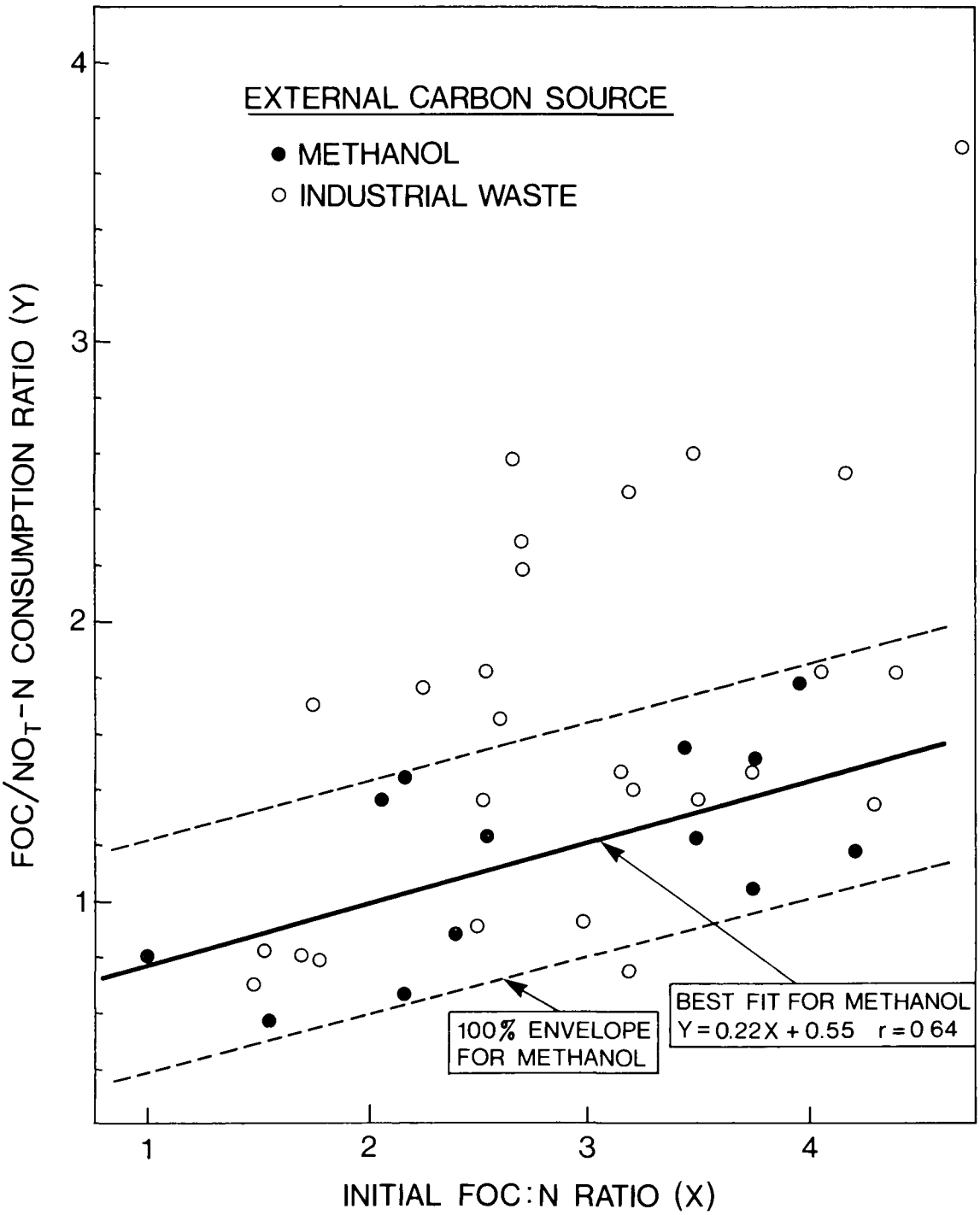

FIGURE 6. SUBSTRATE CONSUMPTION RATIO vs INITIAL FOC:N RATIO

TABLE 5. INDUSTRIAL WASTE VOLUMES REQUIRED FOR DENITRIFICATION*

Waste	Volume Required (m^3) for FOC:N = 1.0	Volume Available from Company
Food Processing Company 'A'		
- Tomato Sludge	3.78	Term: 2 months 45.4 - 54.6m^3 at 3 - 4 factories
- Pea Blancher	12.44	Term: 2 months 45.4 m^3/d at 2 factories
National Starch and Chemical Co.		
- "Colflo" Effluent	13.98	Continuous: 454 m^3/d
Ontario Paper Company		
- Methanol Heads	0.23	Continuous: 0.45 m^3/d
L.J. McGuinness and Co. Ltd.		
- Thin Stillage	10.58	Continuous: except July, Aug. - 240 m^3/d
- Light Distillate	0.23	Irregular: 45.4 m^3/a
- Fusel Oils	1.49	Irregular: 15.4 m^3/a
Labatt's Breweries		
- Spent Grains	11.08	Continuous: less than 22.7 m^3/d
Gos and Gris Cheese Factory		
- Whey	3.50	Continuous: 9 m^3/d
Rieder Distillery		
- Grape Slops	11.21	Continuous: except Aug., Sept., Oct. - 34 m^3/d
- Fusel Oils	0.30	Irregular: 0.7 m^3/month
Dow Chemical		Information not available for
- Acetic Acid Waste	4.99	publication
Organic Chemical Manufacturer 'A'		
- Methanol Still Bottoms	6.58	Term: 1/3 of year, 32.7 m^3/d
Jordan Wines		
- Sludge Centrate	3.95	Term: 681 m^3/season
- Pomace Extract	5.04	Term: 2951 m^3/season

* 4540 m^3 of wastewater with 20 $mg \cdot L^{-1}$ NO_3^--N.

Cont'd...../

TABLE 5 (CONT'D). INDUSTRIAL WASTE VOLUMES REQUIRED FOR DENITRIFICATION*

Waste	Volume Required (m^3) for FOC:N = 1.0	Volume Available from Company
Molson's Breweries		
- Trub	3.78	Estimate: 454 m^3/d cont.
- Last Runnings	4.32	
- Wort	1.89	
- Beer	2.67	Not generally available
Baxter Travenol Laboratories		
- Dextrose Solution	7.45	Continuous: less than 0.45 m^3/d
Millhaven Fibres Ltd.		
- Glycol Waste	19.32	Continuous: 5.9 m^3/d
Du Pont of Canada Ltd.		Currently used as fuel for steam
- High Boiling Organic Waste (saturated solution)	0.72	generator; approximately 227 000 m^3 over next 5 years
- Organic Acids Waste	4.77	Not available for use
Domtar Packaging Ltd.		
- Whitewater	13.57	Continuous: 136 m^3/d
- Black Liquor	2.02	Continuous: greater than 68 m^3/d
Norwich Pharmaceutical Co.		
- Isopropanol Waste	0.60	Estimated: continuous 2.3 m^3/d
Celanese Canada Ltd.		
- Light Ends	0.45	Continuous: 0.05 m^3/d
Canadian International Paper		
- Spent Sulphite Liquor	1.93	Continuous: 2079 m^3/d
Vulcan-Cincinnati		
- Methyl Fuel	0.45	Not commercially available
Commercial Methanol	0.30	Available as required

* 4540 m^3 of wastewater with 20 $mg \cdot L^{-1}$ NO_3^--N.

of 20 $mg \cdot L^{-1}$. In some cases (such as the glycol waste from Millhaven Fibres or the fusel oils and light distillates from the distilleries), the volumes of wastes required exceeded the availability.

Organizations such as the recently established Canadian Waste Materials Exchange, a joint Department of the Environment and Ontario Research Foundation venture, could facilitate the utilization of industrial wastes as external carbon sources for biological denitrification. For example, in the September 1978 issue of Canadian Waste Materials Exchange (1978), at least 15 industrial wastes suitable as external carbon sources for denitrification were listed as being available.

4 ECONOMIC CONSIDERATIONS

Where a denitrification treatment facility is adjacent to a waste carbon source, the concentration of the carbon is not a significant factor in its economic evaluation as a methanol alternative. Under such conditions hydraulic constraints would be the determining factor. However, when transportation is involved, industrial wastes used for denitrification must be as concentrated as possible to be economically attractive. In most cases, these effluents would be transported to a storage tank at the treatment plant site by tank truck or railway tank cars. Transportation rates were obtained from rail and bulk liquid trucking firms in Ontario and British Columbia. Because the type of liquid hauled is a determining price factor, both methanol and acetic acid waste from British Columbia (a potential carbon source) were used as examples. The cost of methanol was obtained from two industrial solvent distributors. Distance is also a factor in costing and several distances were evaluated. The results are summarized in Table 6.

In Ontario, the rates charged by trucking firms were almost identical; the only difference was that one firm levied a surcharge while the other gave limited free loading and unloading time.

Railway tank cars could be used if tracks up to the plant are available. Moreover, railway cars could be used as storage tanks, although a rental fee for the use of the tank car may be expected. A comparison of trucking and rail costs appears in Table 7 (assuming that rail facilities are available from the supplier of a carbon source to point-of-delivery).

The transportation analysis primarily reveals that trucking is less expensive than transporting by rail, even when costs for a storage tank are included in truck costs. Expenses above the cost of a delivered tank include installation, piping, site development, engineering, and construction costs. In addition, unless a waste is highly concentrated in organic carbon, methanol is a better choice economically. From Table 8, it is observed that even if the acetic acid waste was obtained at no cost, the transportation cost would be much higher than the combined costs of methanol and its transportation to a treatment plant. If, however, the company producing the waste paid a nominal amount to have the waste removed (e.g., 10% of methanol cost, i.e., 1.8¢ per litre [see Table 8]), this

TABLE 6. COMPARISON OF RATES FOR TRANSPORTING CARBON SOURCES*

Mode of Transport	Distance Travelled	Material Transported	Rate
Tariffed Tank Tank A	110 km Toronto - St. Catharines	Methanol	1.37¢/kg first 22 700 kg 0.551¢/kg excess of 22 700 kg $23.00/h after 2 h loading or unloading
	280 km Toronto - Kingston	Methanol	2.05¢/kg first 22 700 kg 0.816¢/kg excess of 22 700 kg $23.00/h after 2 h loading or unloading
Tariffed Tank Tank B	110 km Toronto - St. Catharines	Methanol	1.37¢/kg first 22 700 kg 0.551¢/kg first 22 700 kg 7.05% surcharge
	320 km Toronto, 320 km radius	Methanol	2.45¢/kg first 22 700 kg 0.98¢/kg excess of 33 700 kg 7.05% surcharge
Railway Tank Car	130 km Toronto - Niagara Falls	Methanol	3.79¢/kg minimum $35.00
	320 km Vancouver - Penticton	Dilute acetic acid	7.34¢/kg minimum $35.00
Tank Truck C	416 km Vancouver - Penticton	-	$420/18 m^3 2.31¢/kg

* f.o.b. at site of liquid production unless otherwise noted - March, 1977.

TABLE 7. EVALUATION OF COSTS FOR TRANSPORTING CARBON SOURCE FROM ST. CATHARINES TO TORONTO

Assumptions: 1) 3.0 kg methanol (MeOH) required/kg NO_3^--N removed
2) 20 mg/L of NO_3^--N removed
3) Plant capacity = 45.46 x 10^3 m^3/d
4) Both truck and rail car capacity = 45.46 m^3 = 36 050 kg MeOH

Daily MeOH requirement = 3.0 kg MeOH/kg NO_3^--N x 20 mg NO_3^--N/L x 45.46 x 10^6 L
= 2728 kg MeOH/d
One load of MeOH lasts = 36 050 kg ÷ 2728 kg/d = 13 d
Number of loads per year = 365 d ÷ 13 d/load = 28
Methanol cost (March 1977) = 17.6¢/L bulk price

Truck (St. Catharines to Toronto)

Cost of first 22 700 kg	= 1.37¢/kg x 22 700 kg = $310.00
Cost of excess weight (13 300 kg)	= 0.551¢/kg x 13 300 kg = $73.25
Total cost of trucking charges	= $383.25 per load
Annual transportation cost	= $383.25 x 28 loads = $10 731
90.9 m^3 steel storage tank	= $27 000
*Installed cost + ancillary cost	= $77 800
Estimated life of tank	= 20 years
**Annual depreciation	= $3890
Total annual cost	= $14 620 = 0.09¢/$m^3$ of sewage treated

Rail (St. Catharines to Toronto)

Rail charges = 3.79¢/kg x 35 970 kg per load = $1364 per load
Annual cost = $38 192 = 0.23¢/$m^3$ of sewage treated

* Ancillary costs include piping, instrumentation, building and site development, power, engineering and construction, and contingencies (after Vilbrandt and Dryden, 1959).

** Straight line depreciation of installed + ancillary costs over 20 years.

TABLE 8. EVALUATION OF COSTS FOR TRANSPORTING CARBON SOURCE FROM VANCOUVER TO PENTICTON

Assumptions: 1) 3 kg methanol (MeOH) required/kg NO_3^--N removed
2) 4 kg FCOD required/kg NO_3^--N removed (acetic acid waste)
3) 20 mg/L NO_3^--N removed
4) plant capacity = 9080 m^3 (2 MIGD)
5) truck and rail tank car capacity = 45.5 m^3 (10 000 gal)
6) density of acetic acid (HAc) waste = density of water = 1 g/cm^3
7) cost of MeOH (March 1977) = 17.6¢/L ($0.80/gal)
8a) pay for HAc waste 10% of current MeOH price = 1.8¢/L ($0.08/gal)
8b) paid for removal of HAc waste at 1.8¢/L ($0.08/gal)

Daily MeOH requirement = 3 kg MeOH/kg NO_3^--N removed x 20 mg/L NO_3^--N x 10^{-6} kg/mg x 9.08 x 10^6 L/d = 544.8 kg = 687 L
Density of MeOH = 0.793 g/cm^3
One load of MeOH lasts = 45 500 ÷ 687 = 66 days
Number of loads of MeOH annually = 365 ÷ 66 = 6
Daily HAc requirement = 4 kg FCOD/kg NO_3^--N removed x 0.02 g/L NO_3^--N x 10^{-3} kg/g x 9.08 x 10^6 L/d = 726.4 kg FCOD
One load of HAc waste lasts = 0.050 kg FCOD/L x 45 500 L ÷ 726.4 kg FCOD/d = 3.1 days
Number of loads of HAc waste annually = 365 ÷ 3.1 = 118

Truck

Trucking cost MeOH = 2.315¢/kg ($1.05/cwt) x 35 970 kg/load = $832.70/load
Annual trucking cost = $832.70 x 6 loads/a = $4996
Annual MeOH cost = 22.2¢/kg x 35 790 kg/load x 6 loads/a = $47 910
Annual storage tank depreciation = $3900
Total cost for MeOH as carbon source = $56 800/a = 1.7¢/$m^3$ of sewage treated

Cont'd...../

TABLE 8 (CONT'D). EVALUATION OF COSTS FOR TRANSPORTING CARBON SOURCE FROM VANCOUVER PENTICTON

Truck cost HAc waste	= 2.315¢/kg x 45 360 kg/load = $1050/load
Annual trucking cost	= $1050/load x 118 loads/a = $123 900
Annual HAc waste cost	= 1.8¢/L x 45 460 L/load x 118 loads/a = $94 400
Annual storage tank depreciation	= $3900
Total cost for HAc waste as carbon source	= $222 200
Total cost (if paid 1.8¢/L for waste removal)	= $33 400/a = 1.07¢/$m^3$ of sewage treated
Rail	
Transport cost HAc waste	= $0.0734/kg ($3.33/cwt) x 45 360 kg/load = 3330/load
Annual rail costs	= $3330/load x 118 loads/a = $392 900
Annual HAc waste costs	= 1.8¢/L x 45 460 L/load x 118 loads/a = $94 400
Total cost for HAc waste as carbon source	= $487 300
Total cost (if paid 1.8¢/L for waste removal)	= $298 540
Methanol cost for rail transportarion not obtained	

could offset the truck transportation costs. In the example in Table 8, if the company paid 1.8¢ per litre for waste removal, the cash flow would be be $94 400. Thus, the net transportation cost would be $29 500 ($123 900 to $94 400).

Standardizing these costs shows that using methanol as the carbon source would cost approximately 1.7¢/m^3 sewage to be treated. Using a waste carbon source 260 miles distant and receiving a waste removal fee of 1.8¢ per litre reduces this cost to approximately 1.07¢/m^3.

Should industry decide to sell their wastes as carbon sources, the effluents must necessarily be high in organic carbon. Figure 7 was constructed using current costs for methanol and its transportation by tank truck to a 4546 x 10^3 m^3/d sewage treatment plant. Cost curves were also constructed for wastes selling at different prices. To be an economic alternative to methanol, both the COD concentration and the waste price must be taken into account. From Figure 7, a waste collected without charge would require a minimum filterable COD of 60 000 mg·L^{-1} to compete economically with methanol.

Transportation rates do not affect the operating costs of denitrification to any great extent over the range of 100 to 320 km examined. The FCOD concentration has a much greater bearing on DN costs than does the distance a liquid is hauled (Figure 8). Waste streams with FCOD concentrations greater than 190 000 mg·L^{-1}, when sold at a rate of 2.2¢ per litre, would compete favourably with methanol at a trucking distance of 110 km or less.

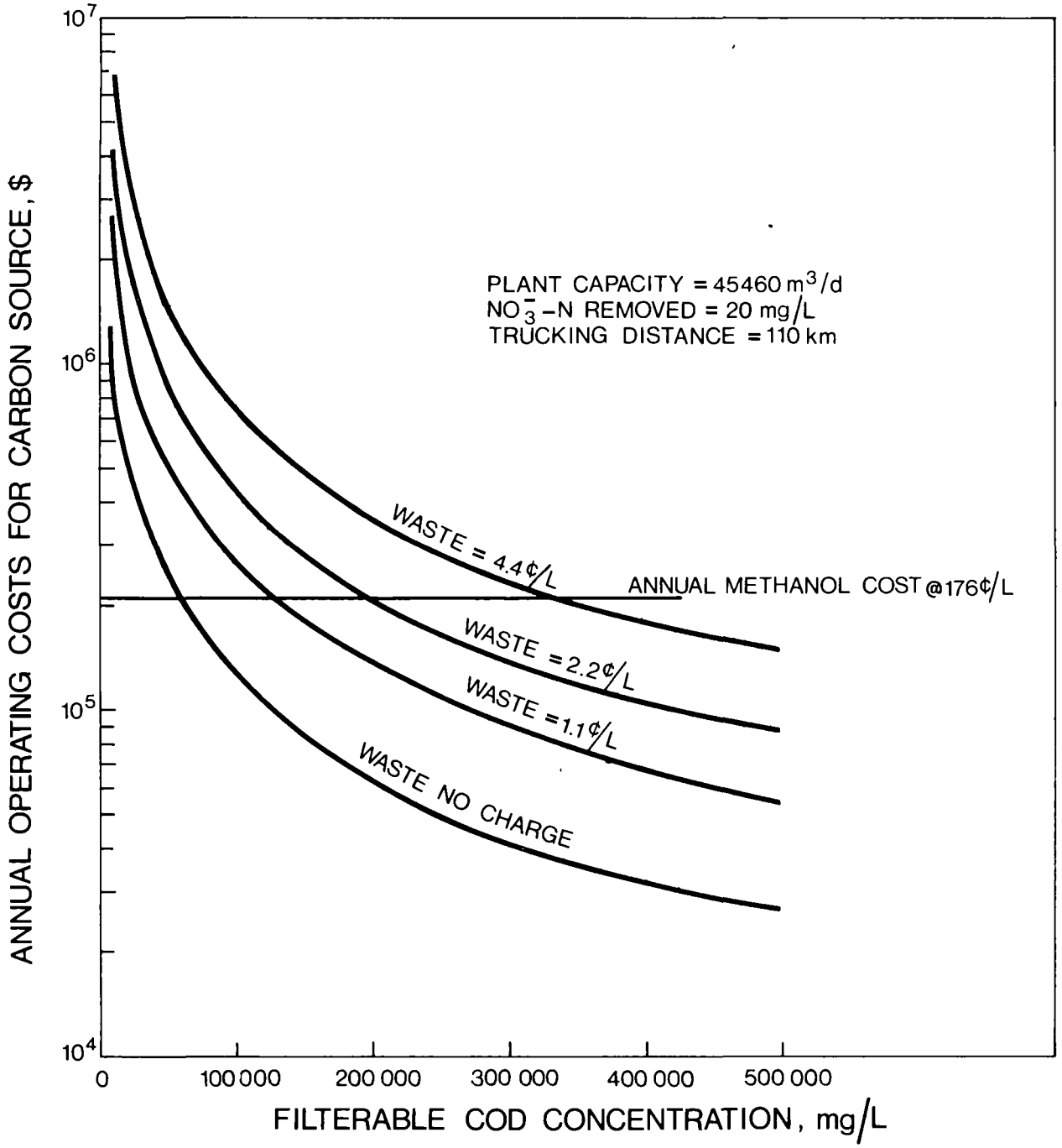

FIGURE 7. ANNUAL OPERATING COSTS OF WASTE CARBON SOURCES FOR VARYING WASTE PRICES

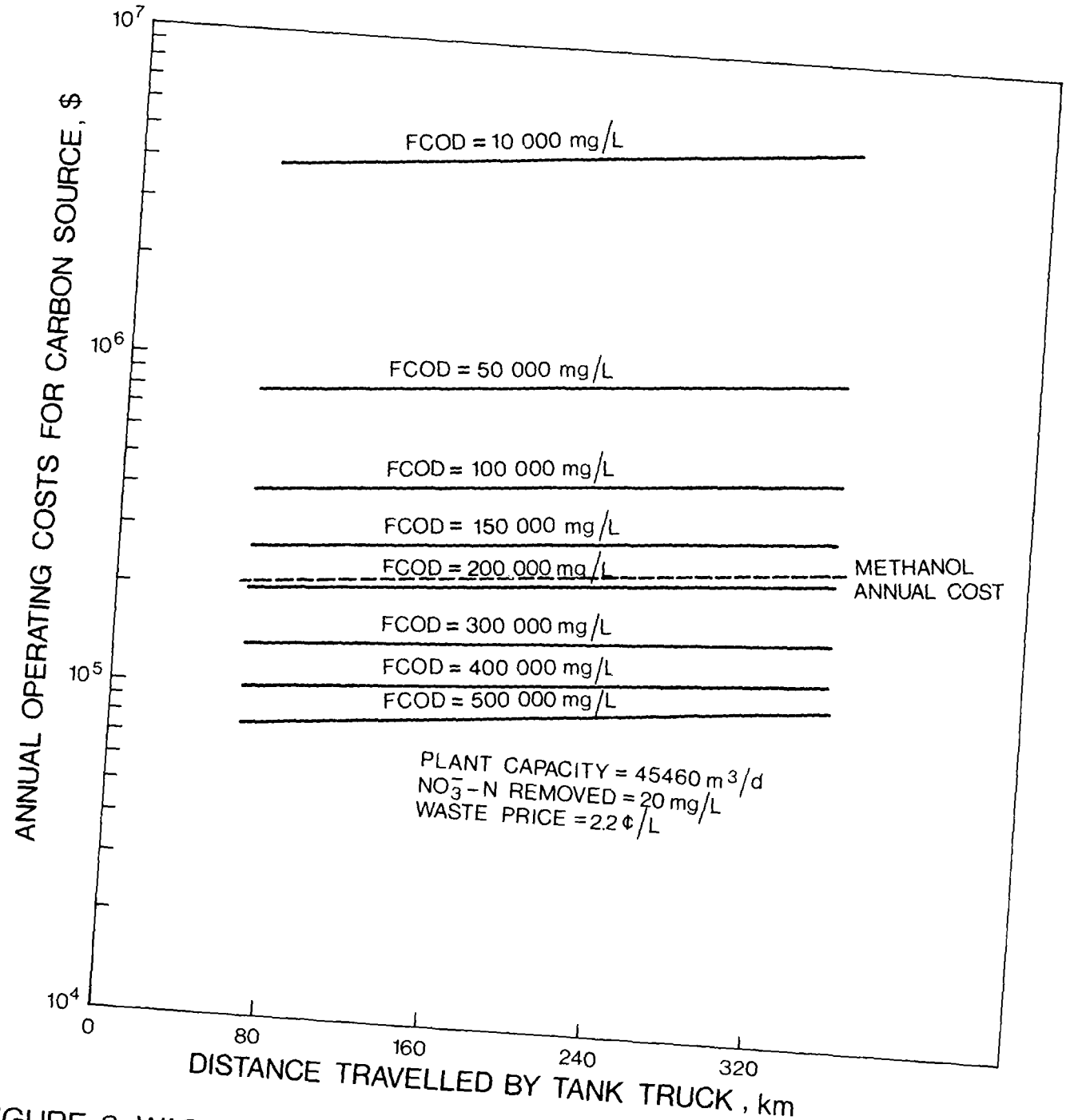

FIGURE 8. WASTE CARBON ANNUAL OPERATING COSTS FOR VARYING FCOD CONCENTRATIONS

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- Mrs. Dianne Crabtree for final typing of the report.
- All industries and industrial representatives who provided waste samples and permitted publication of the results.

APPENDIX I

LIST OF INDUSTRIES SURVEYED

APPENDIX I

Companies Contacted and Waste Streams Sampled

1. A & K Petro-Chem Industries, Downsview, Ontario.
   - wholesale distribution only; no production.
2. Abitibi Paper Company, Smooth Rock Falls, Ontario Mill, Ontario.
   - evaporator condensate.
3. Baxter Travenol Laboratories of Canada Ltd., Alliston, Ontario.
   - waste dextrose solution.
4. Canadian International Paper Company, Hawkesbury, Ontario Mill, Ontario.
   - spent sulphite liquor.
5. Celanese Canada Ltd., Cornwall, Ontario.
   - light ends (waste process distillate);
   - finishing tower effluent (raffinate).
6. Consolidated Alcohols Ltd., Toronto, Ontario.
   - out of production at time of survey.
7. Corby's Distillery Company, Corbyville, Ontario.
   - temporarily shut down for inventory adjustment.
8. Dominion Cisco Industries Ltd., Weston, Ontario.
   - wholesale distribution only; no production.
9. Dominion Foundry and Steel Company Ltd., Hamilton, Ontario.
   - rolling oil.
10. Domtar Packaging Ltd., Trenton, Ontario.
    - black liquor;
    - process white water.
11. Dow Chemical of Canada Ltd., Ladner, British Columbia.
    - acetic acid waste.
12. Dow Chemical of Canada Ltd., Sarnia, Ontario.
    - glycol bottoms.
13. Du Pont of Canada Ltd., Maitland Works, Maitland, Ontario.
    - high boiling organic waste;
    - organic acids denitrification waste.
14. Food Processing Company 'A'
    - caustic tomato sludge;
    - pea blanchwater.

15. Food Processing Company 'B'.

- tomato caustic peel water;
- bean blanchwater;
- corn washwater;
- pumpkin washwater.

16. Food Processing Company 'C'.

- wastes considered too weak to sample.

17. Gos and Gris Cheese Factory, Hannon, Ontario.

- whey.

18. Gulf Oil Canada Ltd., Montreal, Quebec.

- wastes considered too weak to sample.

19. Harrison's and Crossfield (Canada) Ltd., Toronto, Ontario.

- wholesale distribution only; no production.

20. Hart Chemical Company Ltd., Guelph, Ontario.

- waste considered too weak to sample.

21. Humpty Dumpty Potato Chip Company, Etobicoke, Ontario.

- sliced potato washwater.

22. Industrial Chemicals and Solvents Ltd., Toronto, Ontario.

- waste considered too weak to sample.

23. Jordan Wines, St. Catharines, Ontario.

- centrifuge sludge centrate;
- pomace extract.

24. Labatt's Ontario Breweries Ltd., Toronto, Ontario.

- spent grains extract.

25. M & T Products (Canada) Ltd., Hamilton, Ontario.

- waste considered too weak to sample.

26. L.J. McGuinness and Company Ltd., Toronto, Ontario.

- thin stillage;
- light distillate;
- fusel oils.

27. Millhaven Fibres Ltd., Kingston, Ontario.

- glycol waste.

28. Molson's Brewery (Ontario) Ltd., Barrie, Ontario.

- wort;
- beer;
- last runnings;
- trub;
- yeast.

29. National Starch and Chemical Company (Canada) Ltd., Collingwood, Ontario.

    - starch "Colflo" effluent.

30. Norwich Pharmaceutical Company, Cambridge, Ontario.

    - isopropanol waste.

31. Ontario Paper Company Ltd., St. Catharines, Ontario.

    - methanol heads;
    - evaporator condensate.

32. Organic Chemical Manufacturer 'A'.

    - methanol still bottoms.

33. Rieder Distillery Ltd., Grimsby, Ontario.

    - grape distillery slops;
    - fusel oils.

34. Seagram's Distillers Ltd., Waterloo, Ontario.

    - wastes considered too weak to sample because of their own treatment system.

35. Union Carbide Ltd., Montreal, Quebec.

    - waste considered too weak to sample.

36. Uniroyal (Canada) Ltd., Elmira, Ontario.

    - methanol still bottoms.

37. University of Guelph, Guelph, Ontario.

    - formaldehyde waste.

38. Vulcan-Cincinnati Ltd., Cincinnati, Ohio, U.S.A.

    - methyl fuel.

39. Winery 'A'.

    - no soluble streams available.

40. Winery 'B'.

    - no streams considered worth sampling.

41. Winery 'C'.

    - concentrated lees.

APPENDIX II

SUMMARY OF WASTE CHARACTERIZATION

TABLE II-1. WASTE CHARACTERIZATION RESULTS

Company	Waste	BOD_5 ($mg \cdot L^{-1}$)		COD ($mg \cdot L^{-1}$)		FOC ($mg \cdot L^{-1}$)	TKN ($mg \cdot L^{-1}$)		NH_3-N ($mg \cdot L^{-1}$)	NO_2^--N ($mg \cdot L^{-1}$)	pH	Total Solids ($mg \cdot L^{-1}$)
		Filt.	Unfilt.	Filt.	Unfilt.		Filt.	Unfilt.				
Food Processing Company 'A'	Tomato Sludge	17 200	20 000	42 800	59 700	24 000	100	105	44	0	12.0	60 500
	Pea Blanchwater	8 930	13 800	18 000	25 000	7 300	628	772	159	0	6.2	61 100
National Starch and Chemical Co. (Canada) Ltd.	"Colflo" Effluent	10 000	10 900	15 300	17 300	6 500	37.0	46.5	15	0	5.8	19 500
Ontario Paper Co.	Methanol Heads	802 000	805 000	1 380 000	1 450 000	400 000	0	0	0.15	0	1.0	804
	Evaporator Condensate	660	590	1 700	1 760	330	6.0	320	5.1	0	5.9	335
Food Processing Company 'B'	Tomato Caustic Peel	1 960	2 230	4 440	5 240	-	124	-	8.3	0	11.8	8 000
	Corn Washwater	1 500	2 190	3 020	4 640	-	30.1	-	0.9	0	3.5	3 340
	Bean Blanchwater	2 400	2 400	2 500	3 600	1 600	148	162	6.7	0	6.3	3 570
	Pumpkin Washwater	1 600	1 700	2 700	3 500	1 260	34.8	49.9	4.6	0.4	5.1	2 800
L.J. McGuinness and Co. Ltd.	Thin Stillage	12 000	18 000	24 000	38 000	8 600	353	483	5.4	0	4.0	21 600
	Light Distillate	-	-	-	1 600 000	390 000	-	30.0	0.7	0	3.8	50
	Fusel Oils	-	-	260 000	-	61 000	0	-	0.7	0	4.6	4 400
Labatt's Ontario Breweries	Spent Grains Extract	11 000	11 000	23 000	23 000	8 200	308	362	14.8	0	3.8	19 700
Gos & Gris Cheese Factory	Sweet Whey	31 000	45 000	69 000	73 000	26 000	1 390	1 400	13.1	0	6.4	55 600
Humpty Dumpty Potato Chip Co.	Potato Slicing Wash-water	1 400	1 700	1 600	2 700	870	357	445	145	0	6.8	3 450
Rieder Distillery Ltd.	Distillery Slops	13 000	19 000	25 000	48 000	8 100	180	615	10.6	0	3.5	25 600
	Fusel Oils	-	-	-	1 400 000	310 000	-	210	<5	0	1.6	3 800
Molson's Brewery (Ontario) Ltd.	Trub	35 000	37 000	70 000	74 000	24 000	495	535	48	0	5.3	67 000
	Last Runnings	27 000	32 000	59 000	60 000	21 000	640	640	17	0	5.6	-
	Ale	63 000	65 000	124 000	130 000	34 000	640	640	2.1	0	3.7	40 400
	Wort	61 000	68 000	135 000	143 000	48 000	1 040	1 070	60	0	5.1	123 000
	Yeast	120 000	140 000	230 000	300 000	61 000	73 600	73 600	58	0	6.1	99 200
Dow Chemical of Canada Ltd.	Acetic Acid Wastes	24 000	25 000	50 000	56 000	18 200	0	80	0.8	0	2.3	900

Cont'd...../

TABLE II-1 (CONT'D). WASTE CHARACTERIZATION RESULTS

Company	Waste	BOD_5 ($mg \cdot L^{-1}$)		COD ($mg \cdot L^{-1}$)		FOC ($mg \cdot L^{-1}$)	TKN ($mg \cdot L^{-1}$)		NH_3-N ($mg \cdot L^{-1}$)	NO_2^--N ($mg \cdot L^{-1}$)	pH	Total Solids ($mg \cdot L^{-1}$)
		Filt.	Unfilt.	Filt.	Unfilt.		Filt.	Unfilt.				
Organic Chemical Manufacturer 'A'	Methanol Still Bottoms	29 000	31 000	50 000	51 000	13 800	40	120	0	-	10.3	41 500*
Jordan Wines	Sludge Centrate	34 000	36 000	62 000	63 000	23 000	1 110	1 160	48	0	3.1	60 700
	Pomace Extract	19 000	25 000	46 000	50 000	18 000	255	330	44	0	3.3	45 400
Baxter Travenol Laboratories of Canada	Dextrose Solution	4 500	-	32 000	-	12 200	0	-	0	0	4.3	31 700*
Millhaven Fibres Ltd.	Glycol Waste	4 500	9 900	11 000	22 000	4 700	20	44	3.2	0	7.8	541
Du Pont of Canada Ltd.	High Boiling Organic Waste-0.3% aq. sol'n.	2 500	2 500	5 600	5 700	1 800	2.0	16.1	0.1	0	3.4	1 440
	-sat. aq. sol'n.	-	-	-	400 000	-	-	18.0	-	-	-	-
	Organic Acids Waste	30 000	30 000	58 000	59 000	19 000	23	27	1.6	0	2.2	870
Winery 'C'	Lees-collected Aug.'76	50 200	56 500	92 600	274 000	23 800	359	4 300	17	36	3.7	194 000
	-collected Dec.'76	79 000	133 000	130 000	225 000	43 000	1 050	8 460	29	-	3.7	143 000
Norwich Pharmaceutical Company	Isopropanol Waste	210 000	260 000	620 000	680 000	150 000	>16 700	>16 700	16 700	610	8.3	154 000
Domtar Packaging Ltd.	Whitewater	8 000	9 400	27 000	29 000	6 700	178	180	0.1	1.1	5.8	23 800
	Black Liquor	-	62 000	-	150 000	45 000	-	546	-	-	9.3	145 000
University of Guelph	Formaldehyde Waste	51 000	53 000	78 000	78 000	28 000	174	236	0	0	5.2	2 500
Abitibi Paper Co.	Evaporator Condensate	190	260	430	910	270	0	0	0	0.9	10.1	1 060
Celanese Canada Ltd.	Light Ends (Tray 25)	680 000	680 000	1 200 000	1 200 000	200 000	50	65	1.7	0	3.6	69
	Flushing Tower Effluent	730	880	1 500	1 500	460	52	54	2.3	0	4.1	196
Canadian International Paper Company	Spent Sulphite Liquor	33 000	38 000	190 000	190 000	47 000	4 025	4 200	3 520	0	1.6	140 000
Vulcan-Cincinnati Ltd.	Methyl Fuel	-	350 000	-	1 400 000	200 000	-	48.0	-	-	6.1	110

* Measured as dissolved solids.

APPENDIX III

DATA FROM BATCH DENITRIFICATION RATE STUDIES

TABLE III-1. BATCH DENITRIFICATION RATE STUDIES

RUN #1													
Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
Food Processing Company 'A'	Pea Blanchwater	0	97	280	<0.2	22.0	<0.1	<0.1	55		7.1	18	0.4
		0.5		220	<0.2	15.5	<0.1	<0.1					
		1.0		340*	<0.2	37.0*	<0.1	<0.1	120**	25			
		1.5		280	<0.2	27.0	<0.1	<0.1					
		2.0		260	<0.2	27.0	<0.1	<0.1					
		2.5		230	<0.2	21.0	<0.1	<0.1					
		3.0		200	<0.2	14.0	<0.1	<0.1			7.6	19	0.5
		4.0		140	<0.2	2.5	<0.1	<0.1	80	5			
		5.0		160	<0.2	0.5	<0.1	<0.1					
National Starch and Chemical Co. (Canada) Ltd.	"Colflo" Effluent	0	109	270	<0.2	21.0	<0.1	<0.1	50		7.1	18	0.5
		0.5		220	<0.2	9.5	<0.1	<0.1					
		1.0		250*	<0.2	30.0*	<0.1	<0.1	100**	15			
		1.5		240	<0.2	27.0	<0.1	<0.1					
		2.0		200	<0.2	19.0	<0.1	<0.1					
		2.5		180	<0.2	13.5	<0.1	<0.1					
		3.0		180	<0.2	8.5	<0.1	<0.1			8.0		
		4.0		160	<0.2	1.0	<0.1	<0.1			7.2	18	0.4
		5.0		160	<0.2	0.5	<0.1	<0.1	75	10			

* Respiked reactor.
** Estimated.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #1 AND #2													
Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
	Methanol Control Run 1	0	140	330	<0.2	34.5	<0.1	<0.1	84		7.1	17	0.5
		0.5		170	<0.2	31.0	<0.1	<0.1	110**	5			
		1.0		430*	<0.2	60.5*	<0.1	<0.1					
		1.5		390	<0.2	56.5	<0.1	<0.1					
		2.0		400	<0.2	54.5	<0.1	<0.1					
		2.5		380	<0.2	51.5	<0.1	<0.1					
		3.0		380	<0.2	47.5	<0.1	<0.1					
		4.0		350	<0.2	40.5	<0.1	<0.1			7.7	17	0.5
		5.0		340	<0.2	33.5	<0.1	<0.1	79	10			
Food Processing Plant 'A'	Tomato Sludge Run 2	0	122	260	<0.2	47.0	1.1	6.8	81	74	7.8		
		0.5		240	<0.2	41.5	1.1	6.5					
		1.0		240	<0.2	34.5	1.1	6.7					
		1.5		210	<0.2	29.0	1.0	6.6			7.9	18	0.4
		2.0		200	<0.2	22.0	1.0	6.3					
		2.5		180	<0.2	15.5	1.6	6.7					
		3.5		190	<0.2	3.5	1.1	6.0					
		4.5	49	140	<0.2	0.5	1.3	6.8	44	62	7.6	18	0.5
		5.5		180	<0.2	0	1.9	8.6					

* Respiked reactor.
** Estimated.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #2													
Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
Ontario Paper Co. Ltd.	Methanol Heads	0	170	290	<0.2	59.5	1.9	4.8	92	81	7.4		
		0.5		300	<0.2	62.5	1.9	4.3					
		1.0		280	<0.2	57.0	1.9	5.3			7.4	18	0.4
		1.5		250	<0.2	50.0	1.9	5.3					
		2.0		250	<0.2	47.0	1.8	4.7					
		2.5		240	<0.2	42.0	1.7	4.7					
		3.5		230	<0.2	32.0	2.0	5.6			7.6	18	0.4
		4.5	73	210	<0.2	20.5	2.1	6.5	60	86			
		5.5		180	<0.2	13.5	3.7	7.4					
	Methanol Control	0	274	470	<0.2	62.5	0.9	4.7	150	81	7.4		
		0.5		480	<0.2	66.0	1.6	4.0					
		1.0		500	<0.2	62.0	1.5	4.0					
		1.5		520	<0.2	58.0	1.5	4.6			7.5	17	0.5
		2.0		460	<0.2	52.5	1.4	5.8					
		2.5		420	<0.2	48.0	1.1	4.9					
		3.5		430	<0.2	38.5	1.7	5.0			7.8	17	0.2
		4.5	201	450	<0.2	28.4	0.9	5.4	120	78			
		5.5		320	<0.2	22.0	1.3	6.4					

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #3													
Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
Gos & Gris Cheese Factory	Whey	0	189	500	1.6	52.0	4.0	15.6	130	95			
		0.5		323	3.4	43.0	4.0	13.8					
		1.0		302	5.0	42.4	6.0	13.2			7.7	20	0.9
		1.5		270	7.0	31.8	6.0	12.2					
		2.0		238	9.0	22.0	6.0	11.0					
		2.5		226	10.6	14.6	4.0	10.0			7.8		
		3.5		185	10.0	0	4.0	7.5					
		4.5		121	0	0	4.0	7.2			8.0	20	
		5.5	61	125	0	0	4.0	6.7	81	82	7.1		0.2
Jordan Wines	Pomace Extract	0	164	339	1.8	49.5	6.0	14.2	170	84			
		0.5		286	4.6	45.2	6.0	12.0			7.5	20	0.6
		1.0		246	6.8	34.8	2.0	9.6					
		1.5		198	8.8	22.4	4.0	8.6					
		2.0		157	10.4	13.8	4.0	7.3					
		2.5		145	10.8	6.4	2.0	5.6			7.6		
		3.5		109	1.8	0.2	2.0	5.4					
		4.5		113	0	0	2.0	4.9			7.8	20	0.2
		5.5	116	109	0	0	2.0	4.8	39	96	7.1		

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #3 and #4													
Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
Organic Chemical Manufacturer 'A'	Methanol Control Run 3	0	207	339	0.6	55.0	4.0	8.0	70	80			
		0.5		327	1.0	49.0	4.0	7.6			7.7	20	0.5
		1.0		331	1.4	48.4	2.0	7.4					
		1.5		319	1.8	48.6	2.0	7.0					
		2.0		323	2.2	43.8	2.0	7.0					
		2.5		387	2.6	38.2	2.0	6.7			7.8		
		3.5		359	3.4	27.6	4.0	6.5					
		4.5		294	4.0	18.0	4.0	6.5			8.0	20	0.1
		5.5	155	274	3.6	5.2	2.0	5.9	76	71			
	Methanol Still Bottoms - Run 4	-0.2†							27				
		0	148	246	1.4	49.5	2.0	6.4	74	83	6.9		
		0.5		246	1.0	46.0	0	4.4			7.4	20	0.4
		0.1		242	1.0	45.0	0	4.9					
		1.5		214	0.8	36.8	4.0	4.9					
		2.0		173	1.0	30.8	2.0	3.9					
		2.5		161	1.2	22.6	2.0	3.8	63				
		3.5		108	1.6	7.8	2.0	3.7			7.8	20	0.3
		4.5		88	0	0	2.0	3.1					
		5.5	15	88	0	0	0	3.1	38	80	7.2		

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #4

Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
Dow Chemical of Canada Ltd.	Acetic Acid Waste	-0.2†							29				
		0	131	211	2.6	48.4	4.0	7.7	85		6.9		
		0.5		179	4.4	41.4	4.0	7.0		74			
		1.0		147	5.8	35.8	4.0	7.0			7.2	20	0.4
		1.5		120	7.4	29.0	4.0	7.0					
		2.0		92	8.6	22.8	2.0	6.9	22				
		2.5		68	9.8	16.8	2.0	6.9			7.5	20	0.3
		3.5		72	9.5	11.5	0	6.9					
		4.5		72	8.5	8.0	0	6.2					
		5.5	14	64	5.0	5.0	0	6.2	20		7.1		
	Methanol Control	-0.2†							40				
		0	201	315	3.0	45.5	0	6.9	74		6.9		
		0.5		291	4.0	37.5	0	6.5		66			
		1.0		271	4.5	30.0	0	5.0					
		1.5		241	4.5	21.5	0	4.1			7.4	19	0.4
		2.0		213	4.5	15.0	0	3.3					
		2.5		197	4.0	7.5	0	3.0	53				
		3.5		173	0	0	0	2.9			7.7	20	0.3
		4.5		157	0	0	0	2.7					
		5.5	91	157	0	0	0	2.7	40	65	7.2		

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #5													
Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
Molson's Brewery (Ontario) Ltd.	Trub	-0.2†							87				
		0	249	540	0.5	55.0	15.0	24.6	260	136	7.0		0.3
		0.5		480	0.5	49.0	15.0	22.7					
		1.0		400	0.5	43.5	15.0	21.2					
		1.5		400	0.5	38.0	15.0	20.7			7.3	20	0.2
		2.0		410	0.5	33.5	15.0	19.2					
		2.5		360	0.5	28.0	15.0	18.8	93				
		3.5		300	0.5	17.5	15.0	16.5			7.5	20	0.3
		4.5		420	0.5	9.0	15.0	16.4					
		5.5	118	150	0.5	1.0	15.0	14.7	66	134	7.6		
L.J. McGuinness and Co. Ltd.	Light Distillate	-0.2†							88				
		0	766	1500	0.5	54.5	20.0	39.7	540	137	7.0		0.4
		0.5		2000	0.5	50.5	20.0	36.6					
		1.0		1900	0.5	44.5	20.0	34.4					
		1.5		1900	0.5	37.0	20.0	32.4			7.4	20	0.4
		2.0		1940	0.5	31.0	20.0	30.3					
		2.5		1850	0.5	24.0	20.0	28.9	498				
		3.5		1870	0.5	12.0	20.0	23.6			7.7	20	0.4
		4.5		1610	0.5	2.0	20.0	19.8					
		5.5	1160	1500	0.5	2.0	20.0	19.8	460	91	7.7		

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #5 AND #6

Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
	Methanol Control Run 5	-0.2†							76				
		0	282	600	0.5	60.5	20.0	20.7	230	105	7.0		0.6
		0.5		570	0.5	57.5	20.0	20.7					
		1.0		570	0	55.0	20.0	20.6					
		1.5		560	0	51.0	20.0	21.1			7.2	20	0.4
		2.0		550	0	48.5	20.0	20.7					
		2.5		530	0	44.5	20.0	20.3	101				
		3.5		420	0.5	36.0	20.0	19.5			7.5	20	0.7
		4.5		340	0	27.0	20.0	19.5					
		5.5	204	410	0.5	21.5	20.0	19.4	67	114	7.6		
Baxter Travenol Labs. of Canada Ltd.	Dextrose Solution Run 6	-0.2†							48				
		0	180	460	2.0	56.5	2.5	11.3	150	81	7.4	20	0.2
		0.5		370	3.8	55.5	2.5	9.9					
		1.0		480	5.3	47.8	2.5	8.6					
		1.5		390	6.3	41.3	<0.1	8.3					
		2.0		340	7.3	38.0	<0.1	8.5					
		2.5		300	8.0	29.3	<0.1	8.3	82		7.6	20	0.2
		3.5		270	10.8	21.8	<0.1	7.3					
		4.5		220	13.0	15.0	<0.1	6.3					
		5.5	38	180	15.0	9.3	<0.1	5.6			7.3		
		6.5		150	16.5	3.8	<0.1	5.0	52	70			

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #6

Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
L.J. McGuinness and and Co. Ltd.	Fusel Oil	-0.2†							47		7.5	20	0.1
		0	410	680	1.8	60.0	2.5	14.0	190				
		0.5		670	2.8	53.5	2.5	13.2		90			
		1.0		630	3.5	45.5	0	12.1					
		1.5		600	4.8	40.0	0	10.5					
		2.0		560	5.3	32.8	0	10.1			7.8	20	0.2
		2.5		460	5.0	22.3	0	7.9	140				
		3.5		390	3.5	3.8	0	4.1					
		4.5		360	0.3	0.1	0	3.4					
		5.5	210	340	0	0	0	2.9	100	86	7.4		
	Methanol Control	-0.2†							71		7.4	20	0.1
		0	430	780	0.8	66.0	2.5	4.0	170				
		0.5		730	0.8	57.5	2.5	3.8		78			
		1.0		680	0.5	53.8	0	3.0					
		1.5		900	0.5	49.3	0	2.9					
		2.0		670	0.5	45.0	0	3.1			7.6	20	0.3
		2.5		630	0.3	39.5	0	3.0	140				
		3.5		560	0.3	27.5	0	3.1					
		4.5		480	0.3	17.8	0	3.4					
		5.5	190	390	0.3	6.0	0	2.8	96	60	7.4		

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #7

Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
	Methanol Control #1	-0.2†							49				
		0	120	460	0.3	76.0	2.5	4.7	76		7.6		
		0.5		270	0.8	76.0	2.5	5.7		24			
		1.0		430	0.3	67.0	2.5	4.6					
		1.5		460	0.3	67.0	2.5	4.4			7.7	20	0.2
		2.0		430	0.3	67.0	2.5	4.8					
		2.5		430	0.3	67.0	2.5	4.9	68				
		3.5		460	0.3	63.3	2.5	5.1					
		4.5		140	0.3	57.0	2.5	4.5			7.2	20	0.3
		5.5	160	300	0.3	51.5	2.5	3.9	56	48			
Labatt's Ontario Breweries Ltd.	Spent Grains	-0.2†							160				
		0	510	970	3.0	88.0	0.5	14.9	280	141	7.0		
		0.5		880	6.5	59.0	0.5	12.7					
		1.0		820	11.5	49.5	0.5	10.1			7.2	20	0.2
		1.5		710	13.5	31.0	0	7.9					
		2.0		660	16.5	20.5	0	6.0					
		2.5		630	19.0	11.0	0	5.3	130				
		3.5		520	12.5	0	0	4.5					
		4.5		440	0.3	0	0	3.8			7.7	20	0.1
		5.5	210	460	0	0	0	2.5	95	179			

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #7 (Cont'd)													
Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
Molson's Brewery (Ontario) Ltd.	Wort	-0.2†							270				
		0	640	1400	3.5	95.5	0.5	18.5	410		7.0		
		0.5		1300	6.0	76.5	0.5	16.6		169			
		1.0		1200	9.0	56.5	0.5	15.3			7.3	21	0.3
		1.5		1100	9.5	35.0	0	14.9					
		2.0		1100	11.5	27.0	0	12.2					
		2.5		990	14.5	18.0	0	13.9	320				
		3.5		930	17.5	0.5	0	10.6					
		4.5		790	2.0	0.5	0	5.5			7.7	21	0.2
		5.5	490	830	0	0.3	0	5.3	290	160			
	Methanol Control #2	-0.2†							260				
		0	680	1200	1.5	102	0.5	4.9	390		7.0		
		0.5		1200	1.0	78.0	0	4.2		129			
		1.0		1200	1.0	66.5	0	4.2			7.4	20	0.3
		1.5		1200	1.5	56.0	0	4.4					
		2.0		1100	1.0	99.5	0	4.6					
		2.5		1100	1.0	45.5	0	4.8	330				
		3.5		1100	1.5	34.0	0	3.4					
		4.5		980	0.8	25.5	0	4.4					
		5.5	600	940	1.0	16.8	0	4.1	300	117	7.7	20	0.4

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #8													
Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
Rieder Distillery Ltd.	Fusel Oil	-0.2†		760	0.8	0.5	7.5	9.4	170		7.4		
		0	670	1300	5.8	116	15.0	21.3	370				
		0.5		1280	8.0	99.0	15.0	23.2		171			
		1.0		1300	7.0	92.5	15.0	22.2					
		1.5		1230	4.0	68.5	12.5	22.0			7.6	21	0.1
		2.0		1240	2.5	52.5	12.5	22.0					
		2.5		1190	2.0	41.0	10.0	20.6	320				
		3.5		1090	1.8	37.8	12.5	20.3			7.6		
		4.5		1110	1.8	34.5	15.0	19.0				20	0.1
		5.5	600	1070	2.0	16.0	15.0	17.5	290	152			
	Methanol Control	-0.2†		700	0	17.0	5.0	6.8	180		7.4		
		0	510	1100	2.0	127	10.5	12.1	280				
		0.5		1160	0.2	114	10.5	11.1		128			
		1.0		1170	0	93.5	5.0	7.6					
		1.5		1020	0	79.5	5.0	8.2			7.4	20	0.1
		2.0		1110	0	77.5	5.0	8.1					
		2.5		1090	0	85.5	7.5	8.5	260				
		3.5		1050	0.5	83.0	7.5	8.8			7.4		
		4.5		1020	0.5	73.5	7.5	11.0				20	0.1
		5.5	480	970	0	57.8	5.0	8.5	240	126			
		6.5		950	0	46.8	5.0	9.0			7.5		

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #9													
Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
Domtar Packaging Ltd.	Whitewater	-0.2†		570	0	0.5	0	5.4	140		7.7		
		0		940	1.0	64.5	0	9.5	240				
		0.5		900	2.5	59.0	0	9.5		113			
		1.0	410	840	4.0	50.5	0	9.7					
		1.5		810	5.0	44.5	0	9.6			7.2	21	0.1
		2.0		750	6.5	36.5	0	9.5					
		2.5		750	7.5	27.0	0	9.1	200				
		3.5		690	9.5	10.5	0	9.9					
		4.5		630	12.5	0.5	0	10.3			7.8	21	0.1
		5.5	240	590	4.5	0	0	9.8	150	115			
Norwich Pharmaceutical Company	Isopropanol Waste	-0.2†		480	0	0.5	0	8.1	100		7.9		
		0		1080	0.5	70.5	0	40.5	310				
		0.5		1080	0.5	64.5	0	36.7		109			
		1.0	410	1050	0.5	62.0	0	36.7					
		1.5		1040	0.5	59.0	0	36.4			7.4	20	0.1
		2.0		960	0.5	54.5	0	45.6					
		2.5		950	0.5	51.0	0	45.3	260				
		3.5		910	0.5	42.5	0	37.2					
		4.5		870	1.0	32.0	0	45.5			7.6	20	0.1
		5.5	280	920	1.0	26.0	0	33.3	230	116			

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #9 (Cont'd)

Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
	Methanol Control	-0.2†		780	0	8.5	0	6.8	180		7.6		
		0		1510	0	78.5	0	4.8	310				
		0.5		1490	0	77.5	0	3.2		83			
		1.0	540	1510	0	74.0	0	1.3					
		1.5		1430	0.5	71.0	0	1.3			7.1	21	0.2
		2.0		1430	0.5	69.5	0	1.6					
		2.5		1380	0.5	67.0	0	1.4	280				
		3.5		1380	0.5	62.0	0	1.4					
		4.5		1380	0.5	56.0	0	1.2			7.4	20	0.1
		5.5	480	1260	0.5	50.0	0	1.3	260	90			
		6.5		1260	0.5	43.5	0	5.3					
Domtar Packaging Ltd.	Black Liquor	-0.2†		380	0.5	13.0	0	1.6	85		7.9		
		0		630	1.0	76.0	0	6.9	170				
		0.5		600	2.0	73.0	0	7.0		139			
		1.0	280	580	2.5	67.5	0	7.2					
		1.5		530	3.0	62.0	0	6.8			7.2	18	0.1
		2.0		490	3.5	53.5	0	6.3					
		2.5		490	4.0	50.5	0	6.6	130				
		3.5		450	4.0	43.5	0	6.6					
		4.5		410	3.0	38.0	0	6.9			7.7	18	0.1
		5.5	140	380	3.0	32.5	0	7.2	97	138			

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #9 (Cont'd)

Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
Millhaven Fibres Ltd.	Glycol Waste	-0.2†		403	0	2.0	0	3.8	94		7.8		
		0		840	0.5	68.0	0	7.5	200				
		0.5		770	0.5	61.5	0	6.7		120			
		1.0	290	790	0.5	59.0	0	6.3					
		1.5		760	0.5	56.0	0	6.6			7.1	18.5	0.1
		2.0		730	1.0	54.5	0	5.8					
		2.5		710	1.0	49.0	0	5.3	180				
		3.5		750	0.5	37.5	0	6.2					
		4.5		630	0.5	25.0	0	6.4			7.4	19	0.1
		5.5	220	580	0.5	24.5	0	6.1	160	111			
Rieder Distillery Ltd.	Distillery Slops	-0.2†		450	0	1.5	0	3.7	92		7.8		
		0		760	1.5	65.5	0	10.3	210	112			
		0.5		760	2.5	59.5	0	10.0					
		1.0	400	670	5.0	50.0	0	7.8					
		1.5		700	5.0	42.5	0	8.8			7.1	20	0.1
		2.0		640	5.0	34.5	0	7.0					
		2.5		620	6.0	29.0	0	6.0	160				
		3.5		530	5.5	15.0	0	5.6					
		4.5		480	4.0	5.0	0	5.0			7.6	20	0.1
		5.5	210	440	3.0	0	0	4.6	120	105			

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #10													
Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
	Methanol Control #1	-0.2†		730	0	0	1.4	10.4	170		7.8		
		0	560	1300	0.5	79.5	1.3	10.5	280				
		0.5		1260	1.0	78.0	0.9	10.6		106			
		1.0		1200	1.5	73.5	0.5	8.3			7.1	21	0.1
		1.5		1160	1.0	62.5	0.4	8.2					
		2.0		1130	1.0	58.5	0.5	8.6					
		2.5		1100	0.5	49.0	0.2	8.3	250				
		3.5		1060	0.5	34.5	0.3	8.7					
		4.5		1000	0.5	24.0	0.3	8.9					
		5.5	370	900	1.0	13.5	0.3	8.9	200	97	7.6	21	0.1
Molson's Brewery (Ontario) Ltd.	Ale	-0.2†		800	0	0.5	1.3	17.2	190		8.0		
		0	550	1150	1.5	74.5	1.2	29.7	310				
		0.5		980	5.5	69.0	1.3	29.2		101			
		1.0		1000	11.5	65.0	1.0	28.1			7.0	21	0.1
		1.5		960	15.5	48.0	0.5	25.9					
		2.0		920	17.5	31.0	0.1	24.2					
		2.5		880	22.5	22.0	0.1	21.5	230				
		3.5		790	25.5	0	0.3	19.6					
		4.5		630	9.0	0	0.1	7.6					
		5.5	290	630	0	0.1	0.2	6.4	190	99	7.6	20	0.1

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #10 (Cont'd)

Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
	Methanol Control #2	-0.2†		900	0	0	1.1	3.5	200		7.9		
		0	690	1490	0.5	75.0	1.0	3.5	320				
		0.5		1390	0.5	65.0	0.6	3.1		99			
		1.0		1460	0.5	63.0	0.3	2.9			7.1	20	0.1
		1.5		1310	0	55.5	0.3	1.9					
		2.0		1300	0	51.0	0.3	2.3					
		2.5		1280	0	46.0	0.3	2.5	270				
		3.5		1230	0.5	35.5	0.3	3.1					
		4.5		1150	0.5	25.0	0.3	3.1					
		5.5	590	970	0.5	15.5	0.4	3.4	250	95	7.5	20	0.1
Du Pont of Canada Ltd.	High Boiling Organic Waste (Saturated Solution)	-0.2†		420	0	12.5	0.4	4.5	91		7.8		
		0	300	800	0	83.0	0	14.8					
		0.5		750	0	82.5	0.3	15.0		99			
		1.0		700	0	79.0	0.2	15.4			7.0	19	0.1
		1.5		690	0	66.0	0.3	15.4					
		2.0		670	0	61.0	0.4	14.2					
		2.5		640	0	56.0	0.4	13.6	190				
		3.5		580	0	44.5	0.3	13.6					
		4.5		530	0.5	34.5	0.3	12.9					
		5.5	150	460	0.5	26.0	0.4	12.0	150	97	7.3	19	0.1

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #10 (Cont'd)

Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
	Methanol Control #3	-0.2†		600	0	0.5	0.6	3.5	130		7.8		
		0	400	1190	0.5	75.0	0.4	4.4	260				
		0.5		1190	0	70.5	0.2	4.2		91			
		1.0		1180	0	64.0	0.2	3.9			7.1	19	0.1
		1.5		1040	0	60.0	0.3	4.1					
		2.0		1080	0	56.5	0.3	4.5					
		2.5		1020	0	51.5	0.2	4.7	230				
		3.5		960	0	41.0	0.3	4.9					
		4.5		850	0	30.5	0.2	3.3					
		5.5	280	690	0	24.0	0.2	2.7	180	85	7.5	20	0.1
University of Guelph	Formaldehyde Waste	-0.2†		620	0	0.5	0.8	2.0	150		7.9		
		0	540	1050	0	74.5	0	3.5	270				
		0.5		1040	0	71.5	0	3.7		93			
		1.0		1040	0	69.5	0	4.2			7.1	20	0.1
		1.5		910	0	66.5	0.1	5.5					
		2.0		1000	0	65.0	0.1	5.8					
		2.5		940	0	60.0	0.1	5.5	250				
		3.5		960	0	59.0	0.1	6.8					
		4.5		940	0	54.5	0.2	7.5					
		5.5	400	900	0	54.5	0.2	8.2		63	7.5	20	0.1
		6.5		870	0	45.5	0.2	9.2	230				

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #11

Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
Canadian International Paper Company	Spent Sulphite Liquor	-0.2†		360	1.1	24.0	0.3	2.4	80		7.5		
		0	290	870	1.5	119	8.5	24.1	210	49			
		0.5		950	0	101	8.4	25.2					
		1.0		900	0	98.5	8.0	24.8					
		1.5		910	0	95.0	7.5	23.9			7.0	19	0.1
		2.0		810	0	89.0	6.8	24.6					
		2.5		730	0	85.0	6.0	22.4	190				
		3.5		810	0	75.5	4.7	23.0					
		4.5		710	0	67.5	3.0	21.6			7.5	19.5	0
		5.5	130	620	0	57.0	2.4	19.9	160	46			
		6.5		660	0	50.3	1.9	19.8					
	Methanol Control	-0.2†		410	2.0	14.0	0.1	2.1	91		7.6		
		0	550	950	0	87.5	0.1	1.9	180	43			
		0.5		980	0	83.5	0.2	2.2					
		1.0		920	0	79.0	0.3	2.4					
		1.5		920	0	77.5	0.3	2.2			7.3	19.5	0
		2.0		880	0	72.5	0.3	2.4					
		2.5		870	0	70.5	0.3	2.4	170				
		3.5		840	0	62.5	0.3	2.5					
		4.5		860	0	57.3	0.2	2.5			7.6	20	0
		5.5	390	740	0	51.3	0.3	2.4	130	98			
		6.5		700	0	45.3	0.3	2.6					

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #11 (Cont'd)													
Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
Celanese Canada Ltd.	Light Ends (Tray 25)	-0.2†		450	0	0.1	0.3	2.6	101		7.6		
		0	650	1270	0	80.5	0	1.7	280	30			
		0.5		1260	0	75.5	0	2.3					
		1.0		1290	0	71.5	0	2.3					
		1.5		1200	0	68.0	0	2.6			7.3	21	0.2
		2.0		1180	0	62.5	0	2.7					
		2.5		1180	0	57.8	0.1	2.5	220				
		3.5		1120	0	51.5	0.1	2.6					
		4.5		1110	0	44.8	0.2	2.8			7.7	21.5	0
		5.5	550	1040	0	36.5	0.2	2.7	220	36			
		6.5		990	0	28.3	0.1	2.3					
Du Pont of Canada Ltd.	Organic Acids Waste	-0.2†		440	0.1	0.1	0.4	2.0	96		7.5		
		0	500	780	0	80.5	0	6.3	210	90			
		0.5		770	0	77.0	0	5.7					
		1.0		760	0	71.5	0.1	2.3					
		1.5		730	4.5	62.5	0.2	6.3			6.6	21	0.2
		2.0		670	7.3	52.8	0.1	6.3			7.0		
		2.5		640	10.3	46.5	0.1	6.0	170				
		3.5		600	16.8	30.8	0.5	5.5					
		4.5		570	23.8	18.0	0.1	6.6			8.0	21.5	0
		5.5	320	500	26.0	0	0	5.6	120	44			
		6.5		450	24.3	0	0.1	7.0					

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #11 (Cont'd)												
Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
Vulcan-Cincinnati Ltd.	Methyl Fuel	-0.2†		410	0	0.1	0.2	2.6	96		7.6		
		0	880	1530	0	78.5	0.2	5.3	320	41			
		0.5		1510	0	75.0	0.1	5.4					
		1.0		1500	0	70.5	0.1	5.2					
		1.5		1460	0	66.0	0.1	5.2			7.3	21	0
		2.0		1400	0	60.3	0.2	5.1					
		2.5		1390	0	56.3	0.2	5.0	300				
		3.5		1330	0	49.5	0.3	4.5					
		4.5		1330	0	43.3	0.3	4.3			7.7	21	0
		5.5	690	1260	0	34.8	0.3	3.9	240	36			
		6.5		1190	0	25.0	0.1	4.0					

† In this and following runs, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #12													
Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
Jordan Wines	Sludge Centrate	-0.2†		200	6.0	0.5	0	2.2	59		7.0		
		0	170	620	3.0	74.0	0	10.5	220	86			
		0.5		580	4.5	69.5	0	9.4					
		1.0		540	5.5	57.0	0	8.9					
		1.5		460	6.5	48.5	0	8.3			7.1	20.5	0.1
		2.0		340	7.5	40.5	0	8.0					
		2.5		380	8.5	31.5	0	8.0	110				
		3.5		340	10.5	18.5	0	7.9			7.3	20.5	0.1
		4.5		220	14.0	9.5	0	7.0					
		5.5	61	200	18.0	1.5	0	6.2	69	70	7.4	21	0.1
L.J. McGuinness and and Co. Ltd.	Thin Stillage	-0.2†		220	0	0	0.9	2.5	55		7.0		
		0	260	520	0.5	66.5	0.7	11.7	180	96			
		0.5		440	2.0	52.5	1.0	11.3					
		1.0		380	3.0	44.0	0.9	10.2					
		1.5		320	4.5	35.5	0.7	8.4			7.1	21	0.1
		2.0		280	6.0	24.5	0.6	7.8					
		2.5		250	7.0	15.5	0.6	7.4	83				
		3.5		180	9.5	0.5	0.7	6.0			7.4	20.5	0.1
		4.5		160	3.5	0	0.8	3.8					
		5.5	66	160	0	0	0.7	3.4	59	97	7.6	21	0.1

† In this run, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.

Cont'd...../

TABLE III-1 (CONT'D). BATCH DENITRIFICATION RATE STUDIES

RUN #12 (Cont'd)													
Company	Waste	Reaction Time (h)	Filtered Samples ($mg \cdot L^{-1}$)							Unfiltered TKN ($mg \cdot L^{-1}$)	Reactor Conditions		
			BOD_5	COD	NO_2^--N	NO_3^--N	NH_3-N	TKN	FOC		pH	T°C	DO ($mg \cdot L^{-1}$)
	Methanol Control	-0.2†		280	0	0	1.4	3.0	69		7.0		
		0	370	660	0.5	82.5	1.5	3.4	180	82			
		0.5		640	0.5	81.0	1.2	3.2					
		1.0		620	0.5	68.0	0.9	3.2					
		1.5		680	0.5	60.5	1.0	2.6			7.2	21	0.1
		2.0		600	0.5	58.5	1.0	2.5					
		2.5		580	0.5	52.0	1.1	2.4	150				
		3.5		540	1.0	44.0	1.0	2.5			7.5	21	0.1
		4.5		480	1.5	35.0	1.0	2.9					
		5.5	260	440	3.0	24.5	1.0	2.9	100	70	7.7	21	0.1
Molson's Brewery (Ontario) Ltd.	Last Runnings	-0.2†		240	0	0	1.2	1.8	55		7.0		
		0	350	680	0.5	83.0	0.9	15.5	210	97			
		0.5		620	1.5	66.0	0.9	13.7					
		1.0		540	2.5	55.5	0.4	12.2					
		1.5		500	3.5	46.5	0	11.5			7.2	20	0.1
		2.0		400	4.5	39.0	0	10.5					
		2.5		360	5.5	29.0	0	10.3	110				
		3.5		280	7.5	14.5	0	8.6			7.5	20.5	0.1
		4.5		220	9.5	3.5	0	6.7					
		5.5	69	180	8.5	0	0	4.8	73	85	7.6	20.5	0.1

† In this run, the time -0.2 indicates a control sample collected for FOC determination before the waste carbon source was added.