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Bioremediation of Aircraft Deicing Fluids (Glycol) at Airports

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16. Abstract

Bioremediation engineering is an outgrowth of two existing biochemical treatment technologies: biochemical engineering and wastewater engineering. Biochemical engineering applies biochemical processes in the production of many chemicals and food products from ethanol to antibiotic drugs and cheese. Wastewater engineering makes use of biochemical processes in the treatment of sewage. Bioremediation resembles wastewater engineering in that it treats water contaminated with hazardous chemicals. It is like biochemical engineering, however, in its degree of process control. Typically, it targets a specific chemical or group of chemicals rather than a general waste product such as domestic sewage.

This report describes the work done to determine the effectiveness of various aerobic bioremediation techniques for reducing the biochemical oxygen demand (BOD) of aircraft deicing fluid runoff. Primary emphasis has been placed on laboratory and field demonstrations of bioremediation systems using various combinations of inocula (bacteria), nutrient mixes, enzyme mixes, and ultrasonic stimulation.

Laboratory, field experiments, and a dual-tank bioreactor system were developed by Biotronics Technologies, Incorporated of Waukesha, Wisconsin.

Laboratory experiments with a variety of inocula and nutrients together with enzymes and ultrasound are demonstrated showing the importance of the appropriate bacteria and nutrient mix in bioaugmentation. The appropriate mix was shown to significantly influence biodegradation. Deicing solutions were routinely reduced to acceptable BOD levels for effluent discharge in 3 days or less.

In the field experiment, a special dual-tank bioreactor system was developed to demonstrate a pilot small-scale system. Experimental operation of this system confirmed that a 3-day or less remediation cycle was possible during the winter season. This is compared to the current cycle of 3 months starting when ambient temperatures are high enough (usually April) to promote activity.

The economics of this type of process depend on the initial chemical oxygen demand (COD)/BOD of the runoff, the operating temperature of the processor, and the maximum daily runoff.

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EXECUTIVE SUMMARY

Bioremediation engineering is an outgrowth of two existing biochemical treatment technologies: biochemical engineering and wastewater engineering. Biochemical engineering applies biochemical processes in the production of many chemicals and food products from ethanol to antibiotic drugs and cheese. Wastewater engineering makes use of biochemical processes in the treatment of sewage. Bioremediation resembles wastewater engineering in that it treats water contaminated with hazardous chemicals. It is like biochemical engineering, however, in its degree of process control. Typically, it targets a specific chemical or group of chemicals rather than a general waste product such as domestic sewage.

The principal concern regarding the environmental impacts of deicing activities relates to the amount of dissolved oxygen in water being consumed during the decomposition of deicing materials, principally glycol and urea, contained in runoff. Oxygen consumption occurs when bacteria decompose organic materials (including deicing chemicals) and use oxygen in the process. This phenomenon can deplete all dissolved oxygen from the water if the rate of decomposition is very high. The potential for oxygen consumption is expressed as biochemical oxygen demand (BOD) exerted over some standard period of time, typically 5 days (i.e., BOD5).

Ethylene glycol is toxic to aquatic and mammalian organisms; it is best contained and recycled or otherwise pretreated before disposal. For this reason it is being replaced, for now, by the less toxic propylene glycol for aircraft deicing. However, while ethylene glycol and propylene glycol are both biodegradable, propylene glycol degrades at a slower rate and has a greater biochemical oxygen demand. Thus, propylene glycol will remain in the environment longer than ethylene glycol and will consume more oxygen while it is being broken down. Therefore, it can still be harmful to the environment.

This report describes the work done to determine the effectiveness of various aerobic bioremediation techniques for reducing the biochemical oxygen demand (BOD) of aircraft deicing fluid runoff. Primary emphasis has been placed on laboratory and field demonstrations of bioremediation systems using various combinations of inocula (bacteria), nutrient mixes, enzyme mixes, and ultrasonic stimulation.

Laboratory experiments with a variety of inocula and nutrients together with enzymes and ultrasound were demonstrated showing the importance of the appropriate bacteria and nutrient mix in bioaugmentation. The appropriate mix was shown to significantly influence biodegradation. Deicing solutions from the Dane County Regional Airport, Wisconsin, were routinely reduced to acceptable BOD levels for effluent discharge in 3 days or less.

In the field experiment a special dual-tank bioreactor system was developed by Biotronics Technologies, Incorporated (BTI) of Waukesha, Wisconsin, to demonstrate a pilot small-scale system at the Dane County Regional Airport. This system included a preheater tank followed by a reactor tank. Experimental operation of this system at Dane County Regional Airport confirmed that a 3-day or less remediation cycle was possible during the winter season. This is compared to the current 3 month cycle at Dane County Regional Airport, starting when ambient temperatures are high enough (usually April) to promote activity.

Total heating costs per 150,000 gallons of runoff based on the 128th Air National Guard facility at the Dane County Regional Airport would be $3,337.50. Additional cost to discharge sludge to local Publicly Owned Treatment Works (POTW) vary depending on existing BOD capacity and ability to accept additional load. No cost data on sludge disposal was obtained for this report.

The economics of this type of process depend on the initial chemical oxygen demand (COD)/BOD of the runoff, the operating temperature of the processor, and the maximum daily runoff.

INTRODUCTION

Adherence to the Code of Federal Regulations (CFR) Title 14, Part 121 has increased the quantities of deicing fluids used by U.S. airlines and airports. U.S. glycol usage in 1990 was estimated at 11,500,000 gallons. Airport operators have reported that the volume of aircraft deicing fluid has increased threefold since 1992. This increased level of deicing activity has resulted in greater quantities of deicing fluid being carried into airport stormwater systems. In the past decade there has been a shift in the focus of environmental regulations for surface water discharges. The Clean Water Act prohibits the discharge of any pollutant to waters of the United States from a point source unless the discharge is authorized by a National Pollutant Discharge Elimination System (NPDES) permit. The NPDES permit specifies a treatment technology that should be used in order to manage these point sources. In the amended 1990 regulations, the term point source was expanded to include sources previously not considered. The Environmental Protection Agency (EPA) has broadly defined stormwater discharges associated with industrial activity to include airports. Regulations of airport stormwater discharges containing deicing fluids have also been, and currently are, a focus of numerous regulatory actions.

Experts in the field have indicated approximately 75–80 percent of the deicing fluid applied to an aircraft is deposited on the pavement around the deicing areas, either through overspray or drippage. The majority of this material makes its way into the stormwater system serving the apron. An additional 15-20 percent of the deicing fluid applied to an aircraft is lost to drippage and sloughing during taxiing and takeoff. This material is dispersed and deposited on the airfield, with some portion eventually reaching the airfield stormwater system.

The principal concern regarding the environmental impacts of deicing activities relates to the amount of dissolved oxygen in water being consumed during the decomposition of deicing materials, principally glycol and urea, contained in runoff. Oxygen consumption occurs when bacteria decompose organic materials (including deicing chemicals) and use oxygen in the process. This phenomenon can deplete all dissolved oxygen from the water if the rate of decomposition is very high. The potential for oxygen consumption is expressed as Biochemical Oxygen Demand (BOD) exerted over some standard period of time, typically 5 days (i.e., BOD5).

Ethylene glycol is toxic to aquatic and mammalian organisms; it is best contained and recycled or otherwise pretreated before disposal. For this reason it is being replaced, for now, by the less toxic propylene glycol for aircraft deicing. However, while ethylene glycol and propylene glycol are both biodegradable, propylene glycol degrades at a slower rate and has a greater biochemical oxygen demand. Thus, propylene glycol will remain in the environment longer than ethylene glycol and will consume more oxygen while it is being broken down. Therefore, it can still be harmful to the environment.

Bioremediation engineering is an outgrowth of two previous biochemical treatment technologies: biochemical engineering and wastewater engineering. Biochemical engineering applies biochemical processes in the production of many chemicals and food products from ethanol to antibiotic drugs and cheese. Wastewater engineering makes use of biochemical processes in the treatment of sewage. Bioremediation resembles wastewater engineering in that it treats water contaminated with hazardous chemicals. It is like biochemical engineering, however, in its degree of process control. Typically, it targets a specific chemical or group of chemicals rather than a general waste product such as domestic sewage. The technology is almost identical to that employed in industrial wastewater treatment where again the process is focused on a particular chemical contaminant or set of contaminants. It differs from industrial wastewater treatment in its emphasis on chemicals in groundwater and soil.

OBJECTIVES AND APPROACH

The overall object of the program was to determine the effectiveness of aerobic bioremediation to reduce the biochemical oxygen demand (BOD) of aircraft deicing fluid runoff to acceptable discharge levels. This program had three tasks:

1. Perform laboratory experiments to determine what form (combinations of inocula, nutrient mixes, enzyme mixes, and ultrasonic stimulation) of aerobic bioremediation was the most effective.

2. Demonstrate a pilot bioremediation system at an airport using the results of the laboratory test results.

3. Identify economic dependencies.

The first task used a building block approach to experimentally evaluate the following four forms of bioremediation:

1. Control Bioremediation
2. Nutrient-Enriched Bioremediation
3. Enzyme-Catalyzed Bioremediation
4. Ultrasonic Enzyme-Catalyzed Bioremediation

The first alternative used as the control in this effort was the approach currently used at the Dane County Regional Airport. The runoff is collected in a holding pond and is allowed to naturally biodegrade. This process normally takes a period of about 3 months, beginning in April when the temperature becomes warm enough for continuous microbe action.

The second alternative added a special mix of inoculated bacteria with a supporting mix of inorganic nutrients in various combinations to the runoff to expedite the bioremediation process.

The third alternative added an enzyme mix to the second alternative with the intention of further enhancement of bioremediation with the enzymes catalyzing the molecular breakdown of the target substrate. This alternative includes the same bacteria and nutrients of the previous alternative.

Finally, in the last alternative, ultrasonic stimulation was added to the bioremediation system by immersing a 500 kHz piezoelectric transducer, driven by an external power system, in the reactor. Ultrasonic energy expedites enzymatic action through vigorous mixing and cleaning of enzyme and substrate materials.

The general approach for completing the first task was to run side-by-side test comparisons with the same deicing fluids collected from Dane County Regional Airport in a laboratory environment. In this way, the efficacy of each of the experimental factors from the nutrient mix to ultrasound could be evaluated. This first task was completed using batch reactor experiments performed in a laboratory setting.

For the second task, a pilot bioremediation system was demonstrated at Dane County Regional Airport. Since it was not practical to build three pilot systems for each of the factor combinations, the pilot demonstration was treated as a second stage objective with only the best of the four processing alternatives from the laboratory results being implemented in the demonstration system.

For the third task, the economic dependencies were identified and costs were calculated for a full-scale airport facility.

BATCH REACTOR EXPERIMENTS

As previously noted, in addition to the control, the batch reactor experimentation tested three different reactor configurations:

1. Bioaugmentation
    - special bacterial inoculum
    - enriched inorganic nutrient mix

2. Bioaugmentation + Enzymes—enzyme mix added

3. Bioaugmentation + Enzymes + Ultrasound—ultrasonic stimulation added

The initial inoculum was comprised of three bacterial species:

1. Pasteurella multocida
2. Acinetobacter anitratus
3. Pseudemonas stutzeri

The nutrient mix employed is tabulated in table 1. The concentrations of each inorganic element are listed in table 2. Each batch run was loaded with this nutrient mix which was not further replenished throughout the experimental sequence.

The experimental bioreactor is shown in figure 1. The air pump was used to create an aerobic condition for all of the experiments. A stirrer was used in early experiments but was found to be unnecessary later on. The ultrasonic transducer with its associated power supply and temperature controller was used only during the ultrasonic experiments.

TABLE 1. BIOAUGMENTATION OPTIMAL NUTRIENT CONTROL FOR REMEDIATION

ATCC EG-NaCl Medium #7.0		Salt Solution	
K_2HPO_4	7.5 g	$ZNSO_4.7H_2O$	4.4 g
$(NH_4)SO_4$	0.8 g	$MNSO_4.H_2O$	3.0 g
KH_2PO_4	1.0 g	$CaCL_2.2H_2O$	6.0 g
$MgSO_4.7H_20$	0.1 g	$CuC_{12}.2H_2O$	0.2 g
$FeSO_4.7H_2O$	10 m	$(NH_4)Mo_7O_{24}$	1.82 g
NaCl	8.5 g	Distilled Water	1.0 L
Salt Solution	1.0 mL		
Distilled Water	1.0 L		

TABLE 2. INORGANIC NUTRIENTS AND QUANTITIES

P	1.56 g/L	Cu	0.000095 g/L
S	0.22 g/L	Mn	0.0011 g/L
K	3.65 g/L	N	0.17 g/L
Mg	0.02 g/L	Cl	5.674 g/L
Na	3.34 g/L	Mo	0.001 g/L
Ca	0.0022 g/L	Zn	0.0018 g/L
Fe	0.0037 g/L		

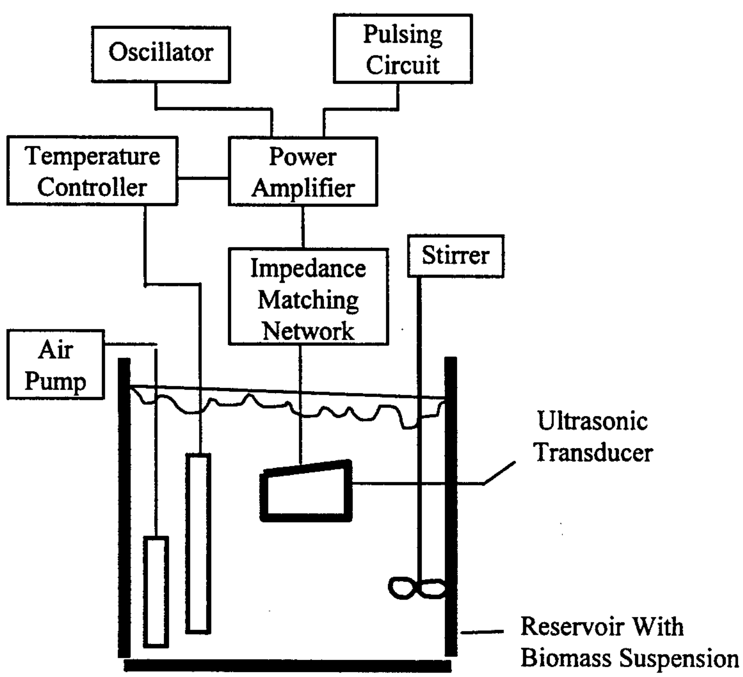

FIGURE 1. EXPERIMENTAL ULTRASONIC BIOREACTOR

The primary control variable used for these experiments was chemical oxygen demand (COD). COD is frequently the second variable of choice after biochemical oxygen demand (BOD) as a measure of wastewater strength or quality because COD results are available in about 2 hours; BOD measurements have a 5-day time lag. The ratio of COD to BOD varies with the wastewater being processed. It also varies with the level of COD. For typical untreated domestic wastewater, the ratio varies from 1.25 to 2.5. For industrial wastewater, such as the glycol mix, it tends to be higher since microbes in the 5-day BOD test do not oxidize some chemicals oxidized by the chemical oxidizing agent. A ratio of approximately 3.8 was found from simultaneous measurements of COD and BOD during the laboratory testing phase of the sample glycol mixes.

Typically, the BOD level must be below 50 mg/L before wastewater can be discharged to stormwater drainage. Based on a 3.8 ratio, a COD value of 190 mg/L would represent the equivalent of a BOD of 50 mg/L. Other variables such as dissolved oxygen and optical density were also measured throughout the laboratory tests.

The laboratory tests were conducted before the deicing season at Dane County Regional Airport; information obtained from the airport engineer indicated that a 2.25/0.25 propylene/ethylene mix would approximately simulate the deicing solution used by the various airlines operating at that airport. Therefore, the first set of tests used a synthetic solution of 2.25% propylene glycol and 0.25% ethylene glycol with the specified inoculum. The initial COD levels were in the 4,300 mg/L to 4,600 mg/L range to simulate conditions expected at the Dane County Regional Airport. Test results are shown in figure 2.

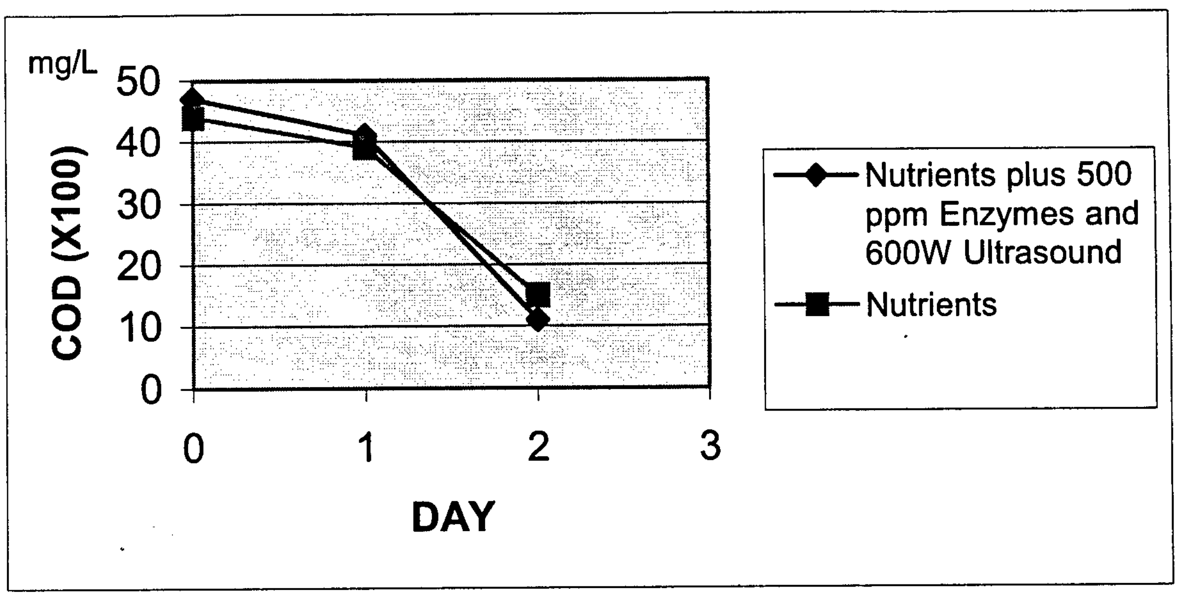

FIGURE 2. ENHANCED BIOREMEDIATION—2.25% PROPYLENE GLYCOL AND 0.25% ETHYLENE GLYCOL (BTI INOCULUM)

Although not shown in figure 2, the COD leveled off at approximately 1200 COD (315 BOD) after 2 days. The leveling off indicates that the bioremediation of the glycols was completed.

The 1200 COD represents the residual biomass, which remains after the target substrate (chemicals) have finished biodegrading. This material is also referred to as sludge in an activated sludge process. Since microbes are tiny chemical factories, this residual biomass will exhibit a COD value. It cannot decline further unless the microbes feed on themselves. The COD/BOD level of the effluent is essentially zero and could be discharged directly into the sewer system or storm drains. The remaining solid effluent, the residual biomass (sludge), cannot be released and has to be disposed of by alternative means.

The amount of residual biomass or sludge generated from this type of bioremediation technique ranges from 5% to 10%, typically 7% of beginning volume. Because of its COD/BOD level, it could not be discharged with the target substrate and would have to be disposed of with alternate means. Disposal of the residual biomass should only be necessary at the end of the deicing season or if too much sludge were produced during the current season because the residual biomass (20% recommended) from one batch process would provide the grown microbes necessary for subsequent batches.

Laboratory tests showed that the addition of enzymes and a combination of enzymes and ultrasound did not significantly reduce biodegradation time in any of the subsequent tests.

Actual deicing solutions with initial levels of 3,600 (1% solution) and 13,500 (10% solution) COD from the Denver International Airport were used in the next series of experiments. The results of the 3,600 COD run are displayed in figure 3. Again, the solutions were reduced to the base (biomass COD) in 2 days.

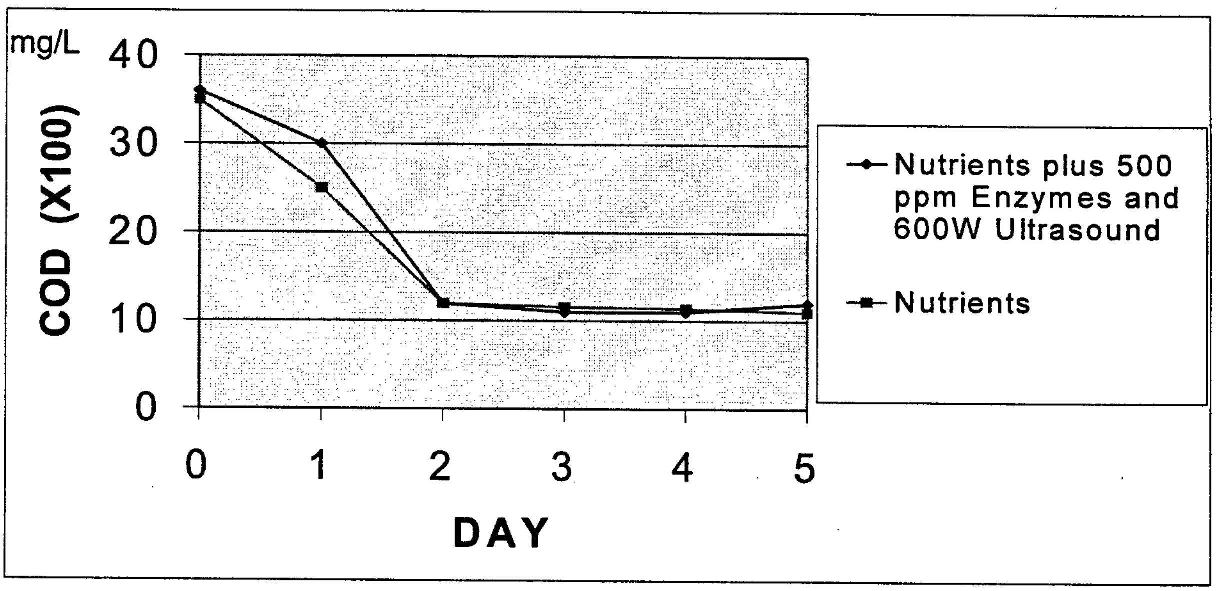

FIGURE 3. ENHANCED BIOREMEDIATION—1% DENVER DEICING SOLUTION (BTI INOCULUM)

The 13,500 COD example shown in figure 4 required about 4 days time to reach the base level. Once again, in all of the experiments, neither the enzymes nor ultrasound significantly reduced biodegradation time.

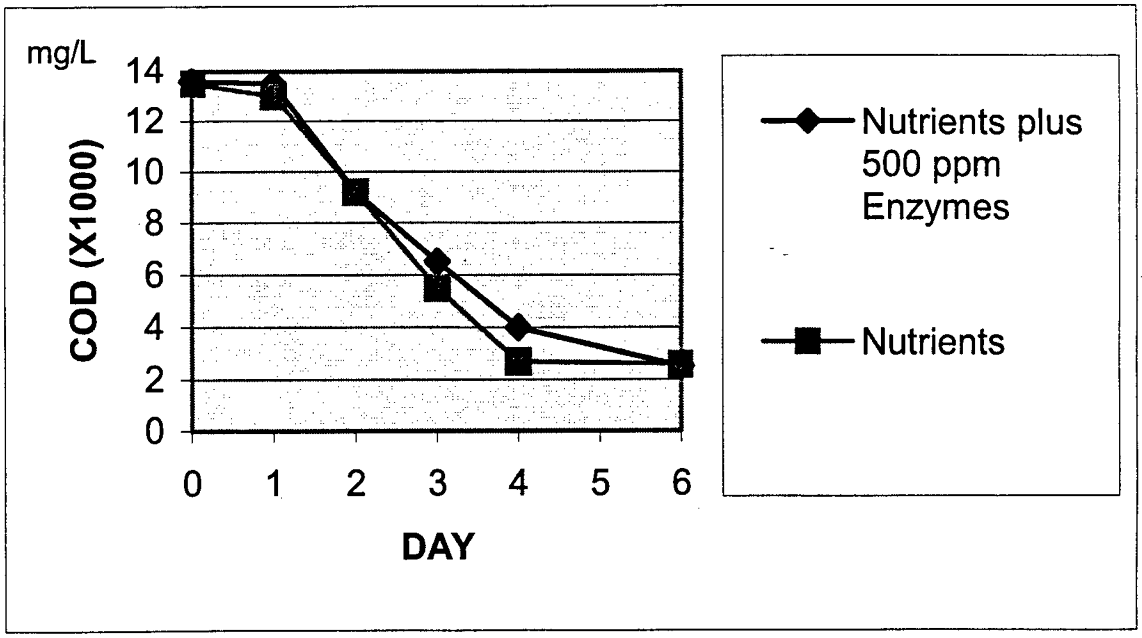

FIGURE 4. ENHANCED BIOREMEDIATION—10% DENVER DEICING SOLUTION (BTI INOCULUM)

A third series of batch reactor experiments were conducted from deicing solutions collected from the Dane County Regional Airport using various inocula and nutrient mix combinations. The inocula and nutrient mixes were varied to determine whether the bioremediation times could be reduced further. Two different inocula and two different nutrient mixes (manufactured by Biotronics and Advanced Biotech) were used in four combinations as follows:

1. Biotronics (B) Inoculum and Advanced Biotech (AB) Nutrient Mix (B/AB)
2. AB Inoculum and B Nutrient Mix (AB/B)
3. AB Inoculum and AB Nutrient Mix (AB/AB)
4. B Inoculum and B Nutrient Mix (B/B)

In addition to Biotronics, Advanced Biotech, Inc., a California company, has extensive experience with bioaugmentation (inocula and nutrients) of bioremediation processes, and their nutrient mix has been improved over a period of many years so that it could potentially make a significant contribution to bioremediation improvement.

The results of two test sequences are shown in table 3. In both test sequences, the B/AB combination of the original Biotronics inoculum and the Advanced Biotech nutrient mix was clearly the most effective. This test sequence successfully demonstrates that both inoculum and nutrient mix can have a decisive effect on the rate of bioremediation.

TABLE 3. BATCH REACTORS WITH DANE COUNTY REGIONAL AIRPORT DEICING SOLUTION (COD VALUES mg/L—OPERATING TEMPERATURE 30°C (86°F))

Test Sequence 1				
DATE	B/AB	AB/B	AB/AB	B/B
1/14/97	5000	5000	5400	4600
1/15/97	5000	5000	4500	3300
1/16/97	2700	2300	1330	1380
1/17/97	1600	2600	1100	1500
1/20/97	666	1635	1005	1405
Test Sequence 2				
1/21/97	4350	4800	4400	4500
1/22/97	2700	2000	3000	22300
1/23/97	2700	2000	2600	2400
1/24/97	1600	2000	1230	1570
1/27/97	670	1900	1230	1500

The series of experiments portrayed in figures 3 and 4 show a drastic reduction in bioremediation time compared to natural biodegradation, which took 3 months at the Dane County Regional Airport. The 2-day bioremediation sequence demonstration in the batch reactor represents a significant improvement over unassisted natural biodegradation. The third series of experiments showed that changes in the nutrient mix can also further reduce treatment time and substantially lower the level of the COD/BOD in the residual biomass.

DUAL-TANK REACTOR SYSTEM

The experiments described in the previous section established the feasibility of rapid bioremediation of deicing runoff fluids and the importance of both the bacterial inoculum and nutrient enrichment. The next task was to demonstrate the operation of a complete system, at pilot-scale level. A small-scale pilot system (restricted by the available space at the test site) was developed and tested to demonstrate the efficacy and practicality of on-site bioremediation of deicing runoff fluids.

This pilot system was designated the Dual-Tank Bioremediation System. A block diagram of the system is shown in figure 5. It consists of a preheating tank (5-gallon capacity, heated to 18-27°C (65-80°F)) to preheat the runoff fluid prior to remediation and a processing (bioremediation) tank (5-gallon capacity heated to 27.8°C (82°F)) for COD/BOD degradation of the runoff fluid. Pumps are shown in the diagram although the first pump may be unnecessary in a gravity-fed system. The second pump will be needed, however, to control flow between the two tanks. A total organic carbon (TOC) analyzer at the output of the system provides a measure of quality control to insure that BOD, COD, and TOC requirements of the effluent are met. A microcomputer-based controller manages the system based on temperature, level, and TOC signals from process instrumentation.

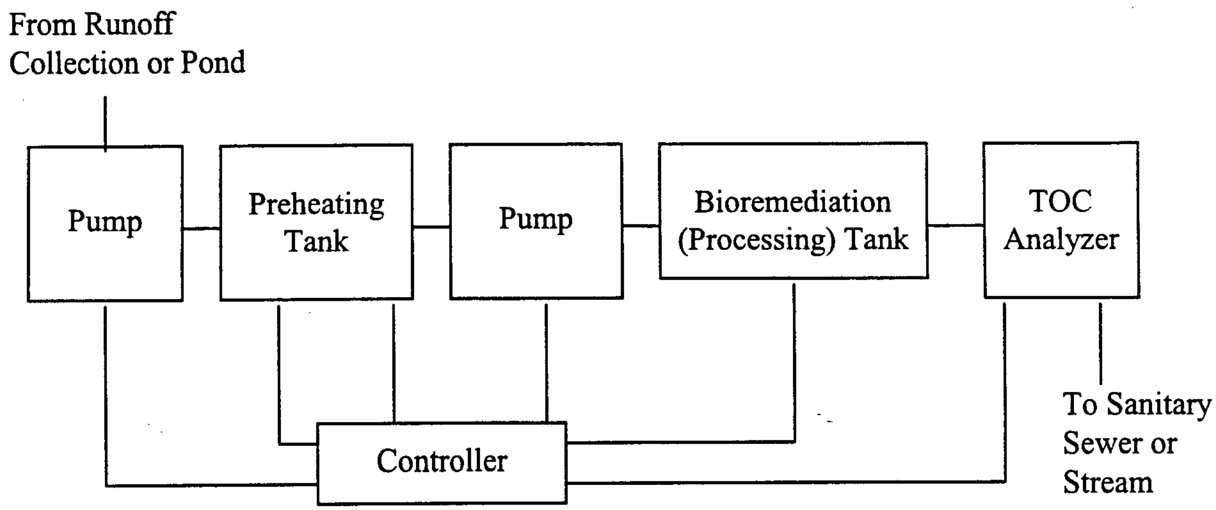

FIGURE 5. DUAL-TANK BIOREMEDIATION SYSTEM

TEST OPERATION AND RESULTS.

The dual-tank reactor system was operated as a sequencing batch reactor (SBR) in which 1 gallon (20%) of each remediation run was saved as a starter for the next batch sequence. Dissolved Oxygen (DO) was measured and included in table 4. After a 4-day seed sequence for initial microbial buildup, the system was tested with the results which are shown in table 4.

TABLE 4. SEQUENCING BATCH REACTOR VALUES

Date	Chemical Oxygen Demand (COD) mg/L	Dissolved Oxygen (DO) mg/L	Biochemical Oxygen Demand (BOD) mg/L
2/3/97	5600		1570
2/4/97 a.m.	3450	0.6	
p.m.	2700	0.2	
2/5/97 p.m.	1600	0.5	
2/6/97 p.m.	1100	5.0	280

The results support a 3-day bioremediation cycle for deicing runoff solutions at Dane County Regional Airport. The residual BOD of 280 represents primarily the residual biomass sludge, which could be used as the starter for a subsequent batch process. The BOD of the liquid effluent from the reactor was well below the required 50 BOD level.

TEMPERATURE EFFECTS ON BIOREMEDIATION.

Although a temperature of 30°C (86°F) was used as the standard in this feasibility study, microbial growth will still take place at other temperatures as shown in table 5.

TABLE 5. TEMPERATURE EFFECTS ON MICROBIAL GROWTH RATE

Temperature °F	Temperature °C	Microbial Growth Rate
50-60	10-15.6	x
60-70	15.6-21.1	2x
70-80	21.1-26.6	4x
80-90	26.6-32.2	8x
90-100	32.2-37.7	16x

Given x as a reference microbial growth rate in the temperature range of 10-15.6°C (50-60°F), microbial growth rate doubles with every 5.5°C (10°F) increase in temperature. At 30°C (86°F), the system is in the 26.6-32.2°C (80-90°F) range with a growth rate factor of 8x, as compared to 10°C (50°F). Therefore, a tradeoff between growth rate and heating costs exists and is discussed later in this section.

It is important to distinguish between microbial growth rate and biochemical reaction rate. The effect of temperature on biochemical reaction rate is well established in the professional literature (Metcalf and Eddy, Wastewater Engineering, McGraw-Hill, 1991) as shown in the following formula

$$r_T = r_{20}A^{(T-20)}$$

where

r_T = reaction rate at T°C
r_{20} = reaction rate at 20°C (68°F)
A = temperature-activity coefficient = 1.04 (for batch bioremediation)
T = temperature, °C

Using this relationship, the reaction rates at 30°C (86°F), 40°C (104°F), and 45°C (113°F) as a function of the reaction rate at 20°C (68°F) are:

$r_{30} = 1.48\ r_{20}$
$r_{40} = 2.19\ r_{20}$
$r_{45} = 2.66\ r_{20}$

The increase in reaction rates is less than the increase in microbial growth rates but still significant in scope. The highest practical reaction temperature in biochemical reactions involving proteins is about 45°C (113°F). Operation at such a temperature would increase the reaction rate by about 80% over the rate at 30°C (86°F) and, with the lower cost of preheating, this is an option worth considering. The lowest practical operating temperature is about 10°C (50°F), below which microbial growth rates drop off significantly. Because of the low costs of preheating, it is not necessary to be restricted to the lower reaction rates.

pH LEVELS AND SLUDGE DISPOSAL.

The pH levels in all tests remained relatively constant in the 7.0-8.5 range without any attempt outside of the system control. This level proved ideal for bioremediation during the experimental study and is not expected to be any problem in future developments with the dual-tank reactor system.

Sludge disposal is a problem of much greater concern. Sludge disposal represents one of the major problems and is a major cost in an activated sludge system. Typically, sludge is separated in a clarifier tank and then either recirculated back into the aerobic process or transferred for anaerobic digestion in a separate reactor.

SYSTEM SCALE-UP CONSIDERATIONS.

The two most influential factors of a full-scale system are its size and cost. How much runoff is produced, what are the COD/BOD levels of the runoff, and how fast must the runoff be processed would determine the size of the system. The initial installation and operating costs would be dependent on the system size. Based on the COD/BOD levels encountered at Dane County Regional Airport, the bioremediation process, at 30°C (86°F), would take 3 days. The capacity of a full-scale system would therefore need to support three times the maximum daily runoff to avoid overflow.

To further examine the feasibility of a full-scale dual-tank bioreactor system, the scale-up and preheating costs were evaluated on a small airport facility, the 128th Air Refueling Group (ARG), Wisconsin Air National Guard located at Dane County Regional Airport. Although the 128th ARG deicing system uses only two deicing pads, its requirements can be extrapolated to larger multipad systems. The 128th ARG estimated that a peak day could produce 50,000 gallons of runoff (Baltimore Washington International Airport estimated 35,000 gallons per day).

The preheating tank shown in figure 5 would require a capacity of 150,000 gallons to provide for 3 days of storage while the bioremediation tank is processing a previous solution. The heater capacity should be sized to preheat the tank to the specified temperature level over a maximum period of 24 hours to allow for an adequate safety margin in system operation. An alternate approach would be based on the TOC level as furnished by the on-line analyzer depicted in figure 5. Heater output could be adjusted to complete the heating cycle concurrent with the completion of the bioremediation cycle. This form of optimal preheating would avoid needless accelerated preheating and subsequent heat maintenance costs resulting from untimely heating of the influent volume. The bioremediation processing tank would also require a capacity of 150,000 gallons to provide for 3 days of treatment time.

The dual-tank system would then require two 150,000 gallon tanks and associated control and accessory equipment. A tank of this capacity would probably have the dimensioning of 50′x50′x8′. Building space would approximate about 7,000 square feet for the entire system, assuming an above ground installation. Below ground tanks, because of inevitable leakage problems, are generally not environmentally acceptable in many states.

PREHEATING ECONOMICS.

The economics of preheating runoff during cold weather operations must be considered as well. Heating costs can be attributed to two components:

1. Preheating costs—to raise the temperature from the ambient temperature to the operating temperature.

2. Process heating cost—to maintain the operating temperature of the process throughout the bioremediation cycle.

Based on the COD/BOD levels encountered by the 128th ARG installation, the bioremediation process for 50,000 gallons would take 3 days at an operating temperature of 30°C (86°F). Operating temperatures of 10°C (50°F) more or less would have an impact on the microbial growth rate which would impact the processing time which, in turn, would impact on the storage requirements.

In the following example, an ambient temperature of 0°C (32°F) is assumed.

Preheating costs:

Specific heat = 2.75 watt-hour/gal-°C

Amount of effluent = 150,000 gallons

Operating Temperature = 30°C (86°F)

Preheat energy = E = 150,000x2.75x30
= 12,375 kWh

At an inflated electrical energy rate of $0.10/kWh

Preheating cost per process = $1237.50.

Process heating costs:

The laboratory experiments required approximately 3.34 kWh for 24 gallons. This translates to 0.14 kWh/gal per day during the bioremediation process.

Scaling up this energy usage for 150,000 gallon a day (50,000 gal x 3 days) for the 128th ARG

Processing energy requirements = P
P = 0.14 x 150,000
= 21,000 kWh

Process heating costs @ $0.10/kWh = $2,100.

The total heating costs per 150,000 gallons processed would be $3,337.50.

Total effluent at beginning of process	150,000 gal
Total liquid effluent discharged to water system	-139,500 gal
Typical sludge from process (7%)	10,500 gal
Sludge retained as seed for next process (20%)	- 2,100 gal
Remaining sludge to be disposed	8,400 gal

Sludge disposal costs:

Cost to discharge sludge to local Publicly Owned Treatment Works (POTW) vary depending on existing BOD capacity and ability to accept additional load. Cost data were not obtained for this report.

Differences in the ambient temperature would result in total energy costs of $7.64 per degree (F) of change as indicated in table 6.

TABLE 6. AMBIENT TEMPERATURE CHANGE EFFECTS ON TOTAL ENERGY COSTS

Ambient Temperature	Processing Temperature	Total Energy Cost
4.5°C (40°F)	30°C (86°F)	$2,451.39
0°C (32°F)	30°C (86°F)	$2,512.50
-3.9°C (25°F)	30°C (86°F)	$2,565.97
-6.7°C (20°F)	30°C (86°F)	$2,604.17

CONCLUSIONS

Based on the results of the study, the following conclusions can be drawn:

1. Rapid (~ 3-day) bioremediation of glycol fluids is possible in batch reactor processes employing selected inocula and optimal nutrient mixes when heated to 30°C (86°F).

2. Bioremediation of glycol-based fluids using batch-based processing at airports can be effective. Dane County Regional Airport runoff fluids are normally contained in a holding pond and biodegraded in approximately 3 months. The dual-tank process reduced the bioremediation time to 2-3 days.

3. The economics of this process is dependent on:

    - the initial COD/BOD of the runoff—which influences the processing time and storage capacity requirements

- initial temperature of runoff
- the operating temperature of the processor—which influences the processing time and storage capacity requirements
- flow rates
- the maximum daily runoff—which influences the storage capacity requirements.

4. Aerobic bioremediation generates sludge. Sludge disposal represents one of the major problems and costs in an activated sludge system.

These conclusions assume that the runoff of deicing fluids can be collected and stored. This can be done by constructing deicing pads or by collecting the fluid in an independent drainage system isolated from the normal stormwater drainage system. If however, a collection system does not exist, it could be the most costly part of the process.