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Wastewater Treatment Through Atomizing Freeze-Crystallization

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ABSTRACT

The benefit of freeze-crystallization on the treatment of wastewater has long been known to the scientific community. This paper describes a new wastewater treatment process developed by Delta Engineering, called Snowfluent™. This process couples freeze-crystallization with specialized snowmaking technology.

Snowfluent™ is unique in that it is not used to simply concentrate the contaminants in a wastewater stream as with traditional freeze crystallization processes. Snowfluent™ can effectively treat the wastewater, both chemically and biologically, through rapid and complete freezing. Another unique aspect of this process is that it makes use of advanced snowmaking technology , also developed by Delta Engineering for effective treatment, without the high cost and practical difficulties of other freezing methods.

Snowfluent™ has been tested extensively by various agencies including the Ontario Ministry of the Environment and Energy since 1980. The quality of treatment has been found to exceed levels associated with even the most sophisticated tertiary level treatment plants, and at a very competitive cost. The technology is at the stage where a number of permanent Snowfluent™ plants are either planned or being constructed, both in Canada and the United States.

Key words: Wastewater treatment, tertiary levels, freeze crystallization, snowmaking.

INTRODUCTION

Growing costs of wastewater treatment coupled with increasingly stricter quality guidelines has resulted in the demand for innovative solutions to wastewater treatment. Traditional systems have been dominated by biological treatment systems and as such perform poorly in cold climates. In regions such as in Canada and the northern United States, this has always been a problem and has resulted in expensive inefficient systems. Snowfluent™ technology was developed specifically to work in cold climates.

PREVIOUS RELATED WORK

The use of freezing has long been known to be highly effective in concentrating the non-water fraction of wastewater. In 1961, researchers at the Robert A.Taft Sanitary Engineering Center (RTSEC) studied the effects of freezing on sea water. Their research, developed under the Advanced Waste Treatment Research (AWTR) Program, was based on the concept that when ice crystals form they are known to consist of virtually pure water, irrespective of any contaminants present. Preliminary findings of their study indicated sea water could be purified by freeze-crystallization in a multi-stage process. With the results of the first study, the AWTR Program commissioned a study to investigate the potential for use of freeze-crystallization in the renovation of municipal wastewater. A main concern was the impact of the organic contaminants on the freezing process. The results of the study showed 85% of the organic contaminants and 90% of the inorgainic contaminants could be removed by the freezing process (RTSEC, 1965).

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Muller and Sekoulov (1992), looked at the separation of wastewater by layering frozen sheets of wastewater with the use of a refrigeration-type unit known as a "Falling Film Reactor". Their study reports that due to the highly organized nature of an ice crystal, nearly every kind of solute and particle in water is removed by the advancing ice surface. They concluded that freeze crystallization is applicable as a main treatment stage for municipal wastewater.

This and other testing programs made use of active refrigeration processes to lower the temperature of wastewater, as well as elaborate mechanical methods to separate ice crystals. The studies all concluded that although freeze-crystallization provided excellent results, the energy costs were sufficiently elevated to preclude its use on any commercial scale, and that no obvious practical solution to handling large volumes of wastewater was apparent.

Other unrelated studies concerned with the application of freeze-crystallization, where the high energy costs could be justified, include:

- freeze concentration of fruit juices, and coffee
- production of "ice-beer"
- desalination of sea water
- sludge dewatering (Martel, 1993)
- in-flight recycling of aircraft wastewater to reduce take-off weights

The Snowfluent™ process differs from the more traditional understanding of freeze-crystallization in two major ways:

- produces total freeze-out of the wastewater
- makes use of advanced snowmaking technology for freezing

The effects of these two concepts are significant in that firstly, freeze-crystallization is not used as a concentration or a storage process, but as a treatment process, and secondly, advanced snowmaking technology reduces the cost of operation to a level making it economically viable.

THE SNOWFLUENT™ PROCESS

This section describes the Snowfluent™ process, and its use for wastewater treatment. Freeze-crystallization in this application is the combination of chemical and physical processes occuring with the use of advanced snowmaking technology.

Advanced Snowmaking Technology

The technique for making snow has been known since the 1930's, and developed extensively since the 1960's. Although it has seen some industrial applications, snowmaking has almost exclusively been applied to the ski industry. Ski resorts cover their trails with artificially made snow to assure early opening dates and consistent snow quality. Delta Engineering has developed snowmaking technology to a point where energy costs have been lowered, and fully automated plants are now being constructed. It is Delta Engineering's proprietary technology that makes Snowfluent™ so successful.

Snowmaking is in fact a misnomer as it involves the manufacture of ice globules, and not snow flakes. The methods used in snowmaking are varied but the basic technique remains the same. Water is atomized and projected into a cold atmosphere where the droplets are allowed to freeze as they fall to the ground.

Factors affecting the production of artificially made snow are many and include:

- water droplet size
- ambient temperature
- relative humidity
- water temperature
- quantity and type of nucleating agents
- flight time of the droplets

The two basic methods used for making snow are known as "low pressure" and "high pressure" snowmaking.

Low pressure snowmaking relies on hydraulic atomization of the water through a number of specialized spray nozzles. The nozzles are located at the circumference of a large plenum complete with an internal, electrically driven fan. The fan produces a flow of air that carries the droplets into the atmosphere where the freezing process can begin. Other low pressure systems utilize the centrifugal effect of fan blades sprayed with water.

Experience has shown that low pressure snowmaking has been ineffective for wastewater treatment due to the relatively high percentage of unfrozen moisture in the snow.

High pressure snowmaking utilizes compressed air to atomize and project the water. Separate conduits bring compressed air and water to a specially modified nozzle that will atomize the water through high hydraulic pressure and expansion of the compressed air. Vectoring of the flow of expanding air projects the droplets into the cold atmosphere.

Snowfluent™ utilizes modified high pressure snowmaking technology with high efficiency nozzles, assuring total freezing of the wastewater droplets.

The main advantage of snowmaking is the efficiency in which it can remove the heat of crystallization from the water stream. The energy required to remove the heat from commercial quantities of water by traditional mechanical means, would be enormously expensive. Snowmaking utilizes the natural heat absorption capability of cold ambient air, in which case the energy consumed by the snowmaking plant is required only for the atomization, nucleation and projection of the water. The mechanical energy required is minor compared to the amount of heat transferred to the atmosphere.

HOW THE PROCESS WORKS

The following section describes the treatment capabilities of the Snowfluent™ process. It briefly explains the processes' effects on the chemical and biological components of the wastewater.

Influent Pre-treatment

Snowfluent™ is a direct treatment method, able to handle raw effluent as well as highly polished wastewater with the same resulting quality. The only pre-treatment required for the influent is a few hours of storage in order to allow the settling of larger solids. No dosing of the wastewater with coagulants such as alum or ferric chloride is required, resulting in reduction of operating costs and long term sludge build-up.

Chemical Action

A number of different inter-related reactions occur throughout all phases of the Snowfluent™ process. These phases have been divided into five steps for the purpose of clarity. Many of the chemcial reactions described here can be found in most post-secondary level chemistry textbooks.

Step 1: Atomization and Projection

At this point, the untreated wastewater is delivered at high pressure to the atomizing nozzles. The fine droplets are projected into the atmosphere where most of the CO_2 is stripped. The concentration of ammonia is reduced by about 5% to 8%, and almost all hydrogen sulfide (H_2S) is removed by stripping action. Also, up to 10% of the water will be lost due to the evaporative requirement of the heat transfer process, depending upon ambient conditions (Huber & Palmeteer, 1985). This action is relatively short lived as the droplets soon begin to freeze.

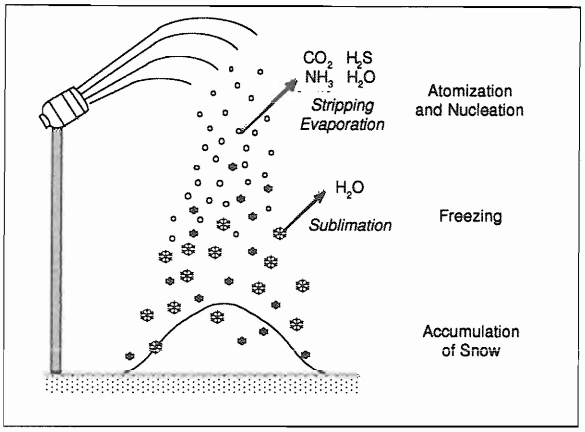


Figure 1. Atomization and Projection

Step 2: Freezing

As the water droplets travel through cold air, heat is extracted and the droplet temperature falls. Assuming sufficient nucleating agents are present, the droplets will begin the freeze at about 0°C. As each frozen droplet continues to fall, 20% to 30% of its mass can be lost through sublimation (Schmidt, 1972), depending on the size of the droplet, meteorological conditions and the time of flight. The freezing of the effluent has been shown (Huber & Palmeteer, 1985) to cause a number of reactions.

First, since significant quantities of CO_2 have come out of the solution and stripped away (Muller & Sekoulov, 1992), a decrease in concentration of hydrogen ions will result, due to an imbalance in the carbonic acid equilibrium.

$$HCO^-_3 + H^+ <=> CO_2 + H_2O \quad [1]$$

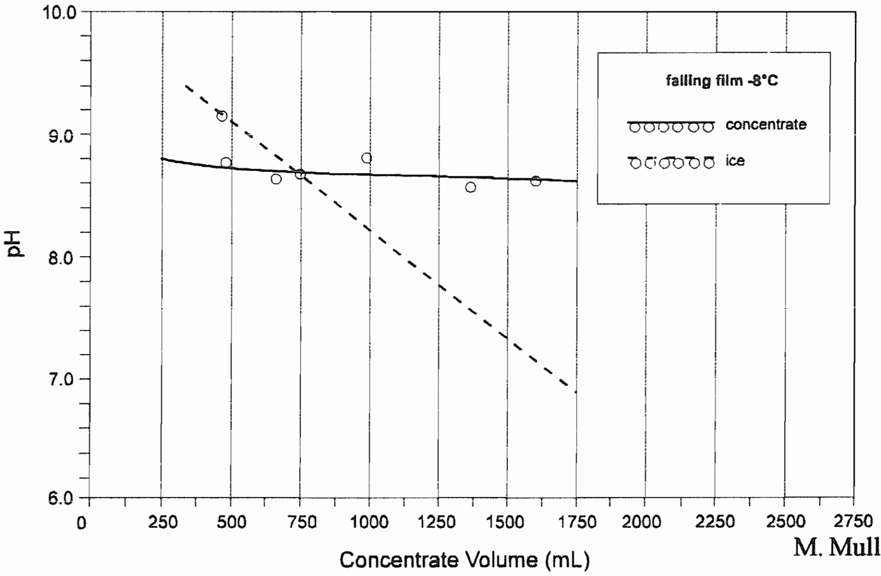
The decreasing levels of CO_2 and H^+ ions are reflected by a significant jump in the pH level of 1.5 to 2.5 points. The higher pH will in turn accommodate the conversion of NH_4^+ ions to ammonia (NH_3) gas as described by [2] (EPA, 1993).

$$NH_4^+ <=> NH_3 + H^+ \quad [2]$$

The ammonia gas however, cannot readily volatilize because of its entrapment within the ice globule, but will slowly volatilize as the snow ages (Huber & Palmateer, 1985).

The freezing of the wastewater droplets also causes other dissolved contaminants to precipitate, such as chlorides and sulfates etc.. This is due to the increasing concentration of the dissolved salts in the liquid fraction as ice formation progresses, and the reduction of temperature. These compounds can also be trapped within the globules of ice, but will not re-dissolve without the addition of sufficient heat and water.

By the same mechanism, dissolved phosphorus is also forced out of solution. Although the more active ammonium ion to form highly soluble ammonium phosphate, the reduced availability of ammonium require other cations. In the presence of sufficient alkalinity, which experience has shown to be 150 - 175 mg/L, insoluble compounds such as calcium and magnesium phosphates are produced. This reaction is a key element of the process, as the conversion of phosphorus into an insoluble form will prevent it from re-dissolving into the melted snow. It should be understood however, that this action is not instantaneous but occurs gradually as the snowpack ages and ammonium is converted to free ammonia which volatilizes.



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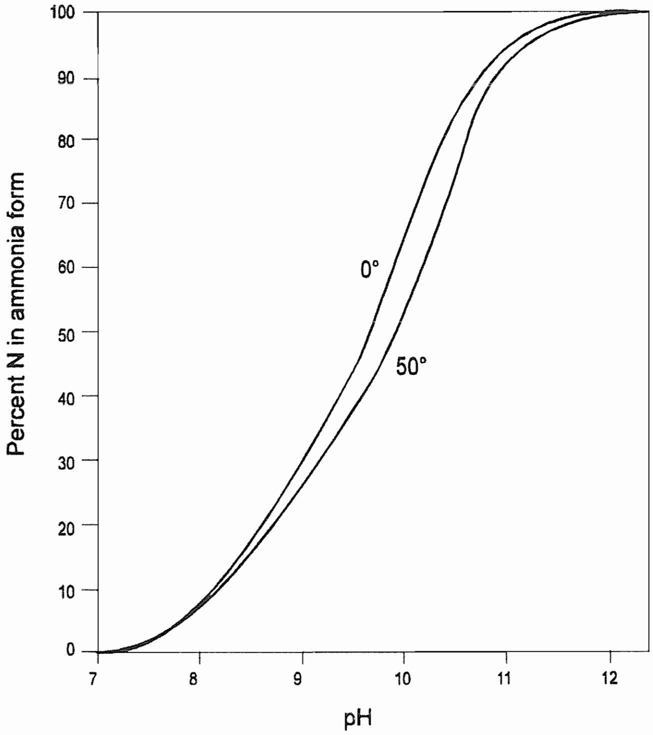
This is known as the Workman-Reynold Effect (Gross, 1965). During freezing processes, a charge separation occurs, because ice prefers the incorporation of anions.

Figure 2 - Effect of the freeze concentration on the pH



Water and Wastewater Treatment, Schroder, Edward D.

Figure 3 - Percentage of ammonia form as a function of pH and temperature

Step 3: Aging of Snowpack:

As the snowpack is formed, the frozen particles have entrapped within them a number of different constituents. These ice particles will slowly begin to undergo a metamorphosis resulting from physical contact with each other (Gray & Male, 1981). When two or more ice particles come into contact, a portion of each will melt and re-freeze, thus fusing into a larger particle. This ultimately produces what is commonly known as "corn" or "sugar" snow. The effect of this metamorphosis on frozen wastewater is that it allows the entrapped solids and gases to be released into the space between particles. The solids have then been observed to slowly gravitate to the bottom of the snowpack, while gases migrate upward to be eventually released to the atmosphere. (Huber & Palmateer, 1985).

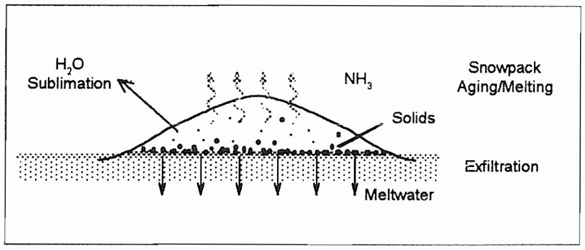


Figure 4: Aging of Snowpack

Crystal metamorphosis is an on-going process, as are the chemical processes. With the continued aging of the snowpack, the pH of the snow remains high and the conversion processes continue until virtually all ammonium ions have been converted to free ammonia and volatilized. Without ammonium, phosphorus is rendered insoluble, given adequate alkalinity. Test data has shown (Huber & Palmateer, 1985) that sufficient ammonia in the snowpack decreases as the pack ages. Field observations indicate that the quantity of solid residue increases as the pack ages.

Step 4: Melting of Snowpack

As the ambient temperatures increase, the outer layer of the snowpack will begin to melt. The aging process of the snow continues, and liquid water is gradually released to make its way to the bottom of the snowpack. The rate at which the water is released is relatively slow due to the fact that a large amount of heat is required to melt the snow, and that snow also acts as a good thermal insulator (Gray & Male, 1981). In addition, the bulk of the snowpack retains a good percentage of free water within it.

Long before the melting begins, nitrogen will have been removed through conversion and volatilization of free ammonia and the phosphorus will be in an insoluble phosphate form. In addition to the phosphorus, other precipitated compounds such as chlorides and sulfates, move toward the bottom of the snowpack. These compounds will not re-dissolve without sufficient heat.

The meltwater will subsequently be discharged under controlled conditions following either of two separate options, as determined by the local situation. In one option, the water is allowed to infiltrate the soils beneath the snowpack; whereas in the second, it is collected in a contained impermeable area and subsequently discharged into a body of water, or used for irrigation purposes.

Step 5a: Exfiltration Option

If it has been determined by hydrogeological analysis that the soils below the snow deposit have adequate permeability and absorption capacity, the meltwater can be allowed to infiltrate the soils. The insulating properties of the snowpack will have prevented deep frost penetration in the ground beneath it, thus allowing the soils in the deposit area to accept the meltwater early in the warm season, with no surface runoff.

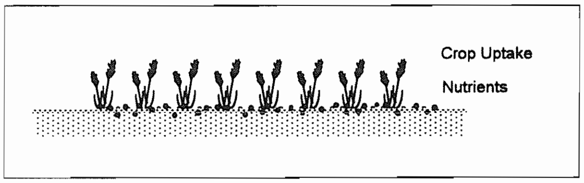


Figure 5: Exfiltration Option

As the meltwater passes into the soils, some of the precipitated contaminants will be in the form of a nutrient residue trapped at the surface of the grass matrix. These nutrients are available to vegetation such as forage crops, which can later be harvested. Crop harvest accommodates the process, as it removes most of the nutrients from the area. Table 2.1 (EPA, 1981) lists a number of selected crops and their associated nutrient uptake rates. Crops are selected for their hardiness, nutrient consumption rates, and their early growth rates.

It has been observed that uptake of the deposited nutrients begins very early, as some crops will begin to grow beneath the snowpack. Since the temperature at the surface of the ground is only slightly above freezing, the plant life will have the opportunity to take up precipitated, normally soluble compounds such as chlorides and sulfates, before they can re-dissolve into the meltwater or rainwater. Any phosphorus still in soluble form will be drawn into the upper strata of the soils, but as the concentrations are so low, it can be easily removed by absorption and precipitation reactions in the soil.

The exfiltration option is ideal in applications where no direct discharge of wastewater effluent into a receiving body of water is desired, or where a viable receiving body of water is unavailable.

Step 5b: Collection and Decanting

If it has been determined that the soils at the snow deposit site are unsuitable for absorption of meltwater, the collection option may be used. In this option, the deposit area is designed to contain the meltwater. Precipitated contaminants are allowed to settle to the bottom of the containment area, and meltwater can then be discharged from the surface via decantation. After several years, the accumulated residue can be collected by standard means, and used as a crop fertilizer, etc.. Meltwater has a pH of 8 to 9 and can serve to partially offset the detrimental effects of acid rain or snow on the receiving waters.

Disinfection

Bacteria such as coliforms, fecal streptocci, clostridium pertringens, have an ability to survive, and in some cases be preserved, by gradual freezing of wastewater. The result is that freezing in itself is not suitable for disinfection of the wastewater. In the case of Snowfluent™ however, the wastewater is atomized into small droplets, which are made to freeze rapidly. Bacteria are good nucleating agents and will induce the conversion of water into ice crystals. The net result is that ice will begin th form within the bacteria and cause the cell walls to rupture. This will either kill the bacteria immediately, or damage them so badly that they will not survive long. The very few organisms that survive will be eliminated by exposure to solar UV radiation.

Test data shows that Snowfluent™ will disinfect wastewater more effectively than other more traditional methods such as chlorination, without producing any toxic residues (Huber & Palmateer, 1985). Bacterial and pathogenic aerosols are at levels similar to those of traditional secondary level

CROP TYPE	UPTAKE RATES (kg ha-yr)		
	NITROGEN	PHOSPHORUS	POTASSIUM
ALFALFA*	225 - 540	22 - 35	175 - 225
BROMEGRASS	130 - 225	40 - 55	245
COASTAL BERMUDAGRASS	400 - 675	35 - 45	225
KENTUCKY BLUEGRASS	200 - 270	45	200
QUACKGRASS	235 - 280	30 - 45	275
REED CANARYGRASS	335 - 450	40 - 45	315
RYEGRASS	200 - 280	60 - 85	270 - 325
SWEET CLOVER*	175	20	100
TALL FESCUE	150 - 325	30	300
ORCHARDGRASS	250 - 350	20 - 50	225 - 315
BARLEY	125	15	20
CORN	175 - 200	20 - 30	110
COTTON	75 - 110	15	40
GRAIN SORGHUM	135	15	70
POTATOES	230	20	245 - 325
SOYBEANS*	250	10 - 20	30 - 55
WHEAT	160	15	20 - 45

* Legumes will also take nitrogen from the atmosphere

Reproduced from "Land Treatment of Municipal Wastewater" United States Environmental Protection Agency, 1981

Table 1: Nutrient Uptake Rates for Selected Crops

wastewater treatment plants during processing. In addition, Huber & Palmateer (1985) have found no measureable impact due to the inhalation of aerosolized micro-organisms near secondary sewage works.

An independent study (Sanin et al., 1994) has shown that rapid freezing is very effective in eliminating viruses and parasites such as cryptosporidium parvum.

Odours

The typical odours present around lagoons and spray irrigation systems are not typical of the Snowfluent™ process since volatilization of NH_3, H_2S, etc. are at concentrations sufficiently low to be undetectable. As Snowfluent™ is a winter treatment process, the wastewater storage lagoons will be empty by spring. Odorous gases such as H_2S, and NH_3 do not collect beneath a covering layer of ice, and therefore do not cause odour problems during breakup.

TESTING

The following test programs were carried out to either specifically study the Snowfluent™ process, or were part of a more general investigation during treatment operations.

Collingwood, Ontario, 1980-85

The first extensive testing (Huber and Palmateer ,1985) of the Snowfluent™ process was carried out by the Ontario Ministry of the Environment and Energy M.O.E.E., (Southwest Region) and Delta Engineering over two seasons in 1980 to 1982. The purpose of the study was to determine if the manufacture of snow from lagoon wastewater was a suitable treatment option.

During the first year of study, 35 different snowmaking runs were conducted, each of which tested 16 separate chemical and a minimum of four microbiological parameters. Bacterial aerosol sampling was also undertaken during 32 different runs.

In the second year of testing, more emphasis was placed on the bacteriological aspects than on the chemical component of the study. Twenty runs of bacterial aerosol sampling were conducted, along with 28 runs of standard bacteriological tests and nineteen runs of chemical analyses.

In each year of study, the lagoon wastewater used for the testing had constituent concentration levels not unlike those associated with raw sewage. Nevertheless, the study concluded that maximum concentration of various contaminants measured in the *surface* runoff adjacent to the melting snow, was extremely low (see Table 1).

The study also concluded that pollution indicator bacteria were at or below detection limits in the site run-off and that concentrations of pathogenic bacteria and coliphage were undetectable in the aerosol.

Bruce Industrial Park, Tiverton, Ontario, 1990

In 1990, emergency requirements for sewage treatment were presented which offered an opportunity for additional testing of the Snowfluent™ process.

A situation arose at an industrial park adjacent to the Bruce Nuclear Generating Station in Tiverton, Ontario, where the wastewater treatment plant was overloaded. The industrial park's wastewater lagoons were designed for a maximum BOD_5 loading of 400 mg/l, but the addition of the wastewater load from an ethanol plant brought the BOD_5 level to over 1,000 mg/l at peak times, and total phosphorous up to 40 mg/l. Because of the increased effluent loading, the lagoons were full, and the alternatives were to either shut down the industrial park, or discharge the wastewater into Lake Huron, or treat it using the

Table 1 Contaminant Concentrations

PARAMETER	MAXIMUM CONCENTRATION mg l
TOTAL PHOSPHORUS	0.08
SOLUBLE PHOSPHORUS	< 0.05
BOD_5	2
AMMONIA	< 0.1
NITRATES	< 0.01

Snowfluent™ process.

The Snowfluent™ option was chosen, a temporary plant was installed, and in excess of 60,000 m³ of wastewater was processed. A Certificate of Approval was granted by M.O.E.E. for the temporary plant along with very stringent requirements for levels of treatment.

Additional testing performed by M.O.E.E. during this operation, served to confirm the findings of the Collingwood tests. On a control basis of testing of surface waters, it was found that no detectable difference was measured between waters entering and leaving the site.

Carrabassett Valley Sanitary District, Maine, 1994

The Carrabassett Valley Sanitary District (CVSD) is the first client to contract Delta Engineering for the design and construction of a permanent Snowfluent™ wastewater treatment plant. Although construction of the plant was to take place during the fall of 1994, a temporary plant was installed to process approximately 19,000 m³ of partially treated wastewater during late February and early March, 1994. Testing was performed by an independent laboratory, for the CVSD and the Maine Department of Environmental Protection.

The proposed Snowfluent™ plant is to replace an existing spray irrigation plant. The test data in Table 2 (Delta Engineering, 1989) shows the difference between Snowfluent™ meltwater at the surface, and surface water from the spray irrigation system (average values).

INCO Mine Tailings, Sudbury, Ontario, 1989

Testing was also performed in 1989 in association with Energy, Mines and Resources Canada (EMR / CANMET) during a study of the effects of Snowfluent™ on acid mine tailings. This program investigated the ability of Snowfluent™ to separate contaminants from the liquid mine tailings, and study its ability to reduce the acidity of the effluent. The results of the testing program (Delta Engineering, 1989) were very positive and showed the ability of Snowfluent™ to separate metals in a highly acidic solution. The concentration of iron (Fe) in the wastewater was reduced from 314 mg/l to less than 15 mg/l, and the pH was increased from an average of 3.05 to over 4.33. Examination of the solid residue was not within the scope of this study.

PERFORMANCE

The treatment performance of the Snowfluent™ process is very significant. Table 3 and Figure 6 (Huber et al, 1985) show the average performance of Snowfluent™ in comparison to raw sewage influent as well as effluent from wastewater treatment lagoon. The parameters associated with the Snowfluent™ process are divided into those obtained from the meltwater on the surface of the ground at the snow deposit site, and those obtained after exfiltration through a ground wedge.

Table 2 Summary of Test Data from CVSD Pilot Program

PARAMETER	UNITS	SPRAY IRRIGATION	SNOWFLUENT(1)
ALKALINITY	mg/l	210	49
N as NH_3	mg/l	6.45	< 0.5*
BOD_5	mg/l	51	ND
CHLORIDES	mg/l	47	< 10*
CONDUCTANCE	µmho	664	143
NO_3	mg/l	<0.5	< 0.5*
NO_2	mg/l	<0.05	< 0.05*
TKN	mg/l	6.4	< 1.0*
Psol	mg/l	4.7	0.2
Ptot	mg/l	5.1	0.21
E-Coli	#	31000	0

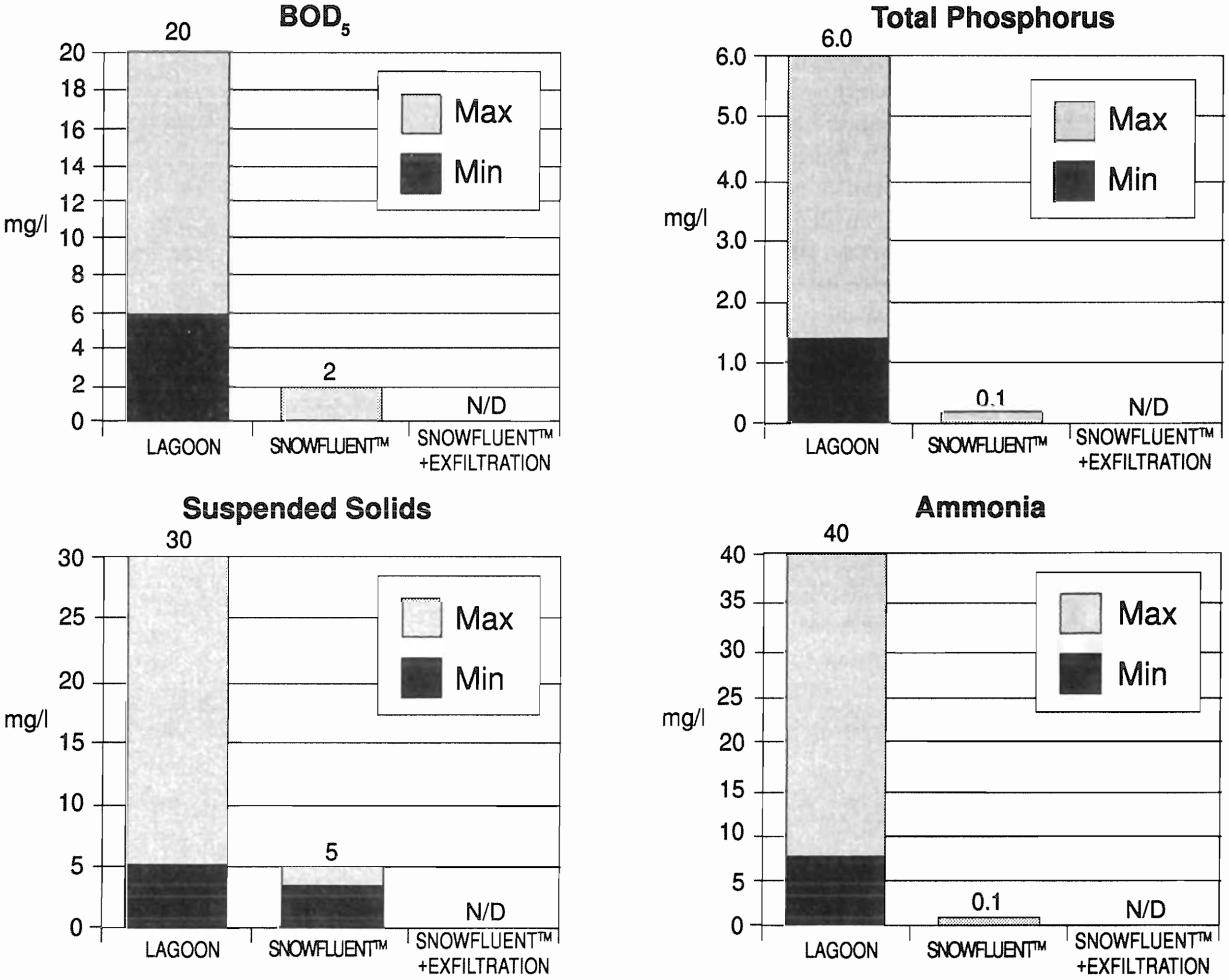
ND = Non Detectable * = at or below detection limits

Table 3 Performance of Snowfluent™ Process

PARAMETER	UNIT	INFLUENT LOW	INFLUENT HIGH	LAGOON LOW	LAGOON HIGH	SNOWFLUENT LOW	SNOWFLUENT HIGH	SNOWFLUENT + EXFILTRATION
BOD_5	mg/l	120	250	6	20+	0	2	N/D
Suspended Solids	mg/l	200	315	5	30	3	5	N/D
pH		6.8	7.2	6.7	7.2	8	9	7-8
Ammonia	mg/l	7.5	40	7.5	40	0.1	0.1	N/D
Total Kjeldahl Nitrogen	mg/l	10	50	10	50	0.2	0.2	N/D
Nitrites	mg/l	0.5	1	0.5	1	0.01	0.01	< 0.01
Nitrates	mg/l	1	2	1	2	0.1	0.1	< 0.1
Total Phosphorus	mg/l	5	15	1.5	6	0.01	0.1	N/D
Fecal Coliform	MPN	10^6-10^8	10^6-10^8	10^6-10^8	10^6-10^8	< 4	< 4	N/D
Pathogens in Aerosols	MPN	N/A	N/A	N/A	N/A	N/D	N/D	N/A
Coliphage in Aerosols	MPN	N/A	N/A	N/A	N/A	N/D	N/D	N/A

NOTE: N/D = Non Detectable; N/A = Not Applicable; MPN = Most Probable Number

Figure 6: Selected Parameters of Snowfluent™ Process



PLANT DESIGN

Collection methods for a Snowfluent™ plant are the same as with traditional methods where wastewater is collected from individual sites and transferred to a central location where solids, debris and grit are removed. Storage of wastewater during summer months is generally done by use of a sewage lagoon, which will vary in size depending upon whether or not a summer treatment process like Intermittent Filtration or Spray Irrigation is being employed. One key difference in a lagoon used with Snowfluent™ is it is used only as storage and not treatment. This means the lagoons could be deeper reducing the amount of surface area required. Chemical floccing is not required for phosphorous removal with Snowfluent™ as it is removed in a later stage of the process.

A system is sized largely according to weather modelling carried out for each individual site. Fifty to one hundred years of data is used to determine the number of available snowmaking hours in a given time period. The wastewater annual load is entered into a computer along with the weather data and the system size is generated. It is also possible to vary system paramaters to whatever settings are desired and the model will indicate how many hours are available to those parameters. The tower layout is determined by a wind analysis which indicates that the percentage frequency the wind is coming from a particular direction. Key elements of a Snowfluent™ plant include: a pumping system, compressed air system, towers, nozzles, and control system. Finally, the site itself may be engineered if required to adequately handle meltwater. This is determined by geotechnical and hydrogeological analyses.

COSTS

The capital costs for a 100% Snowfluent™ plant can range from 50% to 75% of comparably-sized secondary treatment systems and 25% to 40% of comparably-sized tertiary treatment systems. Combined systems: fully integrated Snowfluent™ and intermittent filtration systems, will range from 35% to 55% of comparably sized secondary treatment systems, and 20% to 30% of comparably-sized tertiary treatment systems.

SUMMARY

Snowfluent™ provides very effective wastewater treatment at a very competitive cost. It has the following advantages:

- very high level of treatment quality
- batch process; does not depend on continuous wastewater flow
- can tolerate high fluctuation of loading without deleterious effect
- level of treatment quality not affected by temperature variations
- functions in cold climates, where other processes either fail or are less effective
- suitable for zero direct discharge options
- no requirement for floccing to remove suspended solids
- effective elimination of bacteria without requirement for addition of chemical disinfectants - no toxic residues
- higher pH of meltwater may serve to offset effects of acid rain and snow
- low cost of operation
- snow deposit land can be used for revenue generating agricultural purposes

Disadvantages associated with the Snowfluent™ process include:

- active process; consumes energy
- functions only in cold climates
- requires land for storage of snow

The Snowfluent™ process is a natural process made very cost-effective through the use of Delta's advanced snowmaking technology. It is a very forgiving technology which uses standard equipment, and provides very high quality treatment. Used in combination with a process such as intermittent filtration, the above-noted disadvantages can be minimized or eliminated completely.

REFERENCES

1. Delta Engineering (1989) "Psychromechanical Process for Mine Tailings Wastewater." Final Report for Canada Center for Mineral and Energy Technology (CANMET), Energy, Mines, and Resources, DSS File No.: 06SQ.23440-8-9204.

2. Delta Engineering (1994) "Carrabassett Valley Sanitaty District—Snowfluent Project." Report on Temporary Snowfluent Plant Period: Mar 17 to May 31, 1994.

3. Handbook of Snow (Gray, D.M., Male, D.H., Ed.) (1981) "Handbook of Snow—Principles, Processes, Management and Use." Division of Hydrology, University of Saskatchewan, Saskatoon, Canada.

4. Huber, D., Palmateer, G. (1985) "Snowfluent." Ontario Ministry of the Environment and Energy Southwest Region report, A Joint Experimental Project Between Southwest Region of the Ministry of the Environment and Group Delta in the Storage and Renovation of Sewage Effluent by Conversion to Snow.

5. Martel, C.J., U.S. Army Cold Regions Research and Engineering Laboratory (1993) "Fundatnentals of Sludge Dewatering in Freezing Beds." Wat. Sci. Tech., Vol 28, No. 1, pp. 29–35

6. Marsden, Kurt, P.E., Woodard and Curran (1994) "Carrabassett Valley Sanitary Distnct—Facilities Plan for Long Term Wastewater Management."

7. Müller, M., Sekoulov, I. (1992) "Wastewater Reuse By Freeze Concentration with a Falling Film Reactor." Wat. Sci. Tech., Vol 26, No. 7-8, pp. 1475–1482

8. Robert A. Taft Sanitary Engineering Center (1965) "The Advanced Waste Treatment Research Program." United States Department of Health, Education, and Welfare Summary Report Part 4, Jan 1962 to Jun 1964, pp. 52–64.

9. Sanin, F.D. et al. (1994) "Pathogen Reduction in Freeze/Thaw Sludge Conditioning." Water Research, Vol 26, No. 11, Nov 1994.

10. Schmidt, R.A., Jr. (1972) "Sublimation of Wind-Transported Snow—A Model." United States Department of Agriculture: Forest Service research paper RM-90, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

11. Schroeder, Edward D. (ca 1975) "Water and Wastewater Treatment."

12. Tabler, Ronald D. (1973) 41st Annual Western Snow Conference, "Evaporation Losses of Windblown Snow and the Potential for Recovery."

13. United States Environmental Protection Agency (1981) "Land Treatment of Municipal Wastewater." # EPA Process Design Manual # EPA 625/1-81-013, chapt. 1, 4.

14. United States Environmental Protection Agency (1993) "Nitrogen Control." EPA Manual #625/R-93/010.