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PREVENTION OF FREEZING AND OTHER COLD WEATHER PROBLEMS
AT WASTEWATER TREATMENT FACILITIES(U) COLD REGIONS
RESEARCH AND ENGINEERING LAB HANOVER NH

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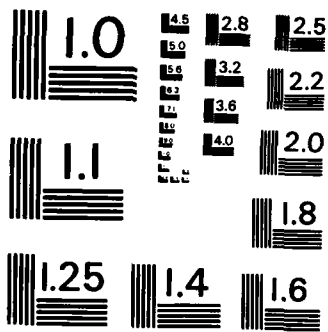
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July 1985



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**US Army Corps
of Engineers**

Cold Regions Research &
Engineering Laboratory

Prevention of freezing and other cold weather problems at wastewater treatment facilities

S.C. Reed, D.S. Pottle, W.B. Moeller, C.R. Ott,
R. Peirent and E.L. Niedringhaus

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20. Abstract (cont'd)

wastewater treatment system. A number of detailed case studies of problems and solutions at specific systems in northern New England are also included.

PREFACE

This report was prepared by Sherwood C. Reed, Environmental Engineer, Civil Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory; Donald S. Pottle, Professor, William B. Moeller, Professor, Charles R. Ott, Professor, and Robert Peirent, Graduate Student, of the Industrial Technology and Civil Engineering Departments of the University of Lowell, Massachusetts (under a grant from CRREL) and E. Landon Niedringhaus, Consulting Engineer, of WVP Corporation, Decatur, Illinois. A major portion of the technical data in this report were developed by D.S. Pottle and the other co-authors at the University of Lowell and are based on operational experiences at wastewater systems in northern New England.

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM Metric Practic Guide (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	by	To obtain
inches	25.4	millimetres
feet	0.3048	metres
square feet	0.09290304	square metres
gallons	0.003785412	cubic metres
gallons per minute	0.0000630902	cubic metres per second
gallons per day	0.00000004381264	cubic metres per second
horsepower	746.0	Watts
degrees Fahrenheit	$t_{\text{C}} = (T_{\text{F}} - 32)/1.8$	degrees Celsius

PREVENTION OF FREEZING AND OTHER COLD WEATHER
PROBLEMS AT WASTEWATER TREATMENT FACILITIES

S.C. Reed, D.S. Pottle, W.B. Moeller, C.R. Ott,
R. Peirent, and E.L. Niedringhaus

INTRODUCTION

Cold weather can have a significant and often severe effect on the operation and performance of wastewater treatment systems. Major problems include excessive snow loads and snow drifting, as well as ice formation and related freezing in system components. In addition, the physical, chemical and biological treatment responses are all temperature dependent and performance efficiency can suffer under low temperature conditions.

A large-scale survey by the U.S. Environmental Protection Agency (USEPA 1982) indicated that freezing and cold weather problems were a major cause of poor performance and often resulted in high operation and maintenance costs. In some cases it appears that the original system design did not adequately recognize the special winter requirements; the operators are then left to cope with the problems.

Freezing temperatures can occur at almost any location in the United States. These events are infrequent in the southern and some coastal portions of the country, not significantly threatening wastewater system performance. However, most of the country routinely experiences subfreezing conditions, and chronic problems at wastewater facilities are possible in the northern areas shown in Figure 1.

This report is intended for both design engineers and system operators. The information contained in the tables as well as the case study descriptions in Appendix A will be particularly useful for operators. We hope that the information provided may help designers avoid similar problems in future systems as well as assisting operators in coping with current deficiencies. The report is based in part on the personal experiences of the authors and information in the published literature. However, a significant portion of the report is based on contacts made during 1984

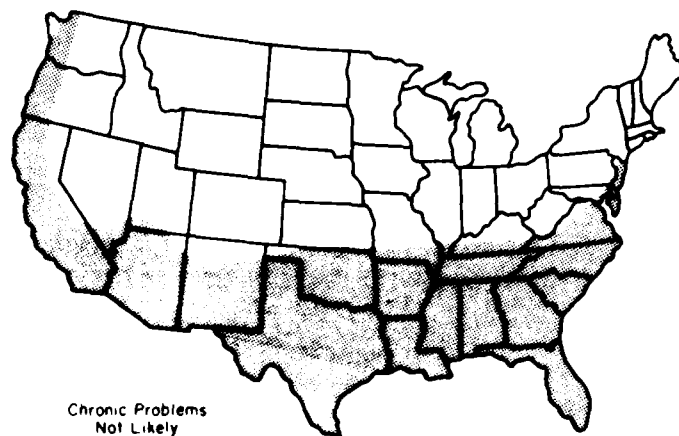


Figure 1. Locations in the U.S. with potential for cold weather problems.

with over 225 operating wastewater treatment facilities in northern New England (Maine, Massachusetts, New Hampshire and Vermont). We believed that this region, with numerous small- to moderate-sized treatment systems, would provide representative information that is applicable to the rest of the country. Data were obtained from about 43% of the systems investigated and about 74% of those had experienced significant operational problems because of freezing conditions.

GENERAL CONSIDERATIONS

The major concerns in this report are those problems related to system operation and performance. There are, however, other winter related problems such as snow loads, snow drifting, thermal efficiency of structures and components, etc., that significantly influence cost effectiveness of design and overall facility management. These are briefly discussed in a later section, and suggested references are listed in Appendix B if detailed assistance is required.

The potential for winter problems is not limited to a particular type of treatment process nor to any particular size of treatment plant. Data for this report were obtained from the following types of treatment processes:

- Primary treatment
- Conventional activated sludge
- Extended aeration
- Oxidation ditches
- Trickling filters

Table 1. Treatment process components (all processes do not necessarily have a component from each category).

Preliminary treatment	Clarifiers	Biological reactors	Sludge management	Disinfection
Pumping	Primary	Activated sludge	Digestion	Chlorination
Screens	Secondary	Extended aeration	Dewatering	
Grinders	Polishing ponds	Oxidation ditches	Disposal	
Grit chamber	Air flotation	Trickling filters		
Flow measurement	Thickeners	Rotary biological contactors		
Flow equalization		Aerated lagoons		
		Facultative lagoons		

- Rotating biological contactors (RBC)
- Aerated lagoons
- Facultative lagoons.

The majority of systems in the New England area were variations of the activated sludge process. This would indicate relatively recent construction and therefore suggests that problems are caused by design deficiencies rather than deterioration of the systems.

Most treatment processes have similar components ahead of, and following, the biological treatment unit as shown in Table 1. To avoid unnecessary repetition, this report describes problems and solutions at the component level rather than discussing each process sequence in detail. The reader can easily determine which components are of concern for a particular situation. The report also assumes that the reader has an understanding of wastewater treatment processes and terminology, so detailed information on process criteria and performance are not included.

The majority of winter operational problems can be grouped into four categories:

1. Ice formation and freezing in process components.
2. Viscosity changes in the wastewater and in lubricants in mechanical equipment.
3. Reaction rate changes in physical, chemical and biological processes.
4. Snow and ice accumulation on structures, control equipment, roads and walls.

Category 1 is the most frequent concern and it can result in temporary failure of a component and therefore disrupt the entire process. In many cases problems in all four categories will simultaneously occur.

PRELIMINARY TREATMENT

Preliminary treatment typically includes removal or grinding of trash and larger solids in the wastewater stream, the removal of coarse grit and raw wastewater pumping. It can also include holding basins or tanks for flow equalization. These are usually aerated and experience problems similar to those discussed in the aerated lagoon category. Table 2 summarizes the winter problems and the northern New England operators' solutions for preliminary treatment components.

Screens and grinders

Bar screens should be cleaned more frequently in cold weather since the rags and trash provide nuclei for ice formation, and once frozen to the screen their removal is more difficult. In the most severe climates, a weatherproof enclosure with the potential for stand-by heating is recommended.

Flow measurement

Calibrated flumes or weirs are typically used for flow measurement. Both the flume and the stilling well can be covered to retain heat. The stilling well is more likely to freeze and the use of a light bulb as a heat source is common. A layer of oil in the stilling well has also been used to prevent freezing, but if oil is used, the recorder must be recalibrated and the loss of oil to the channel during low flow must be prevented. Some facilities using ultrasonic methods for depth measurements have reported difficulties with frost buildup on the sensor head. A thin layer of petroleum jelly on the face of the detector has been used to correct the problem. Open wet wells that have bubble tubes for flow control may have condensate freezing in the air lines; this can be corrected with a heat tape wrapping.

Grit removal

Grit handling facilities are very difficult to keep operating during prolonged cold periods. Temporary wind screens erected each winter will reduce heat losses, but in severe climates complete enclosure of the unit

Table 2. Winter problems with preliminary treatment.

Problem	Solution
Ice buildup in headworks area	---
Icing of bar racks	<ol style="list-style-type: none"> 1. Cover inlet channel. 2. Flush with warm water. 3. Weatherstrip channels to reduce cold air entry into building. 4. Clean by hand.
Septage pumping lines freeze	<ol style="list-style-type: none"> 1. Use heat tape on lines and valves. 2. Use proper flushing after pumping truck. 3. Use manhole to directly dump into plant. 4. Do not handle septage in winter.
Septage freezing in truck	Pass engine exhaust through truck tank to prevent freezing.
Grit freezes in vacuum truck	
Collected grit freezes	<ol style="list-style-type: none"> 1. Store dumpsters in heated building before emptying. 2. Store truck inside. 3. Remove no grit in winter.
Icing of grit screen	Duct kerosene heater into chamber.
Grit machine freezes	Enclose unit.
Screened rags freeze	Remove regularly by hand.
Spiral lift pumps freeze	Run water on ice to reduce buildup.
Screw pumps freeze	Install timer to "bump" screw once per hour.
Valves and hoses freeze	<ol style="list-style-type: none"> 1. Drain lines. 2. Keep hoses on.
Automatic sampler freezes	<ol style="list-style-type: none"> 1. Place sampler inside building. 2. Do not use in severe cold. 3. Build insulated structure heated with light bulb. Insulate suction lines. Purge lines after sample taken. 4. Move sampler location to decrease exposure. Install suction lines to give a straight fall.

Table 2 (cont'd). Winter problems with preliminary treatment.

Problem	Solution
Flow measurement device freezes	<ol style="list-style-type: none"> 1. Use heat tape and glass fiber insulation on flow transmitter. 2. Insulate chamber and heat with one lightbulb. 3. Put heat tape on parshall flume linkage.
Float for flow measurement freezes	<ol style="list-style-type: none"> 1. Heat with light bulb and insulate. 2. Add antifreeze to float box.
Flow measurement tape freezes to measurement tube	Cover plastic with metal.
Grit removal bypass channel freezes	Temporarily switch flow to by-pass channel, 30 min./day.
Water freezing at comminutor	Build Plexiglas structure to keep influent warm.
Doors froze shut on screening enclosure because of condensation	Put heat tape around door enclosure.
Slippery stairs above screw pumps due to icing condensation	Plant policy requires all operators to keep one hand free at all times to use rails.

and the related conveyors may be necessary. At one location in New England, an Archimedes screw conveyor is used to lift grit out of the submerged hopper. Initially, the conveyor was exposed and froze completely every winter. It is now enclosed with insulated sheet metal and each morning a portable kerosene heater blows hot air into the unit for 3 to 5 hours before startup. The grit conveyors at several other locations discharge to exposed hopper containers. These freeze and cannot be emptied unless stored in a heated garage several days prior to dumping. The alternative would be to completely house and heat the entire conveyor discharge area.

CLARIFIERS

The basic purpose of clarifiers is to separate solids from the liquid wastewater stream. The various types listed in Table 1 are located in different points in the treatment process for a variety of functions.

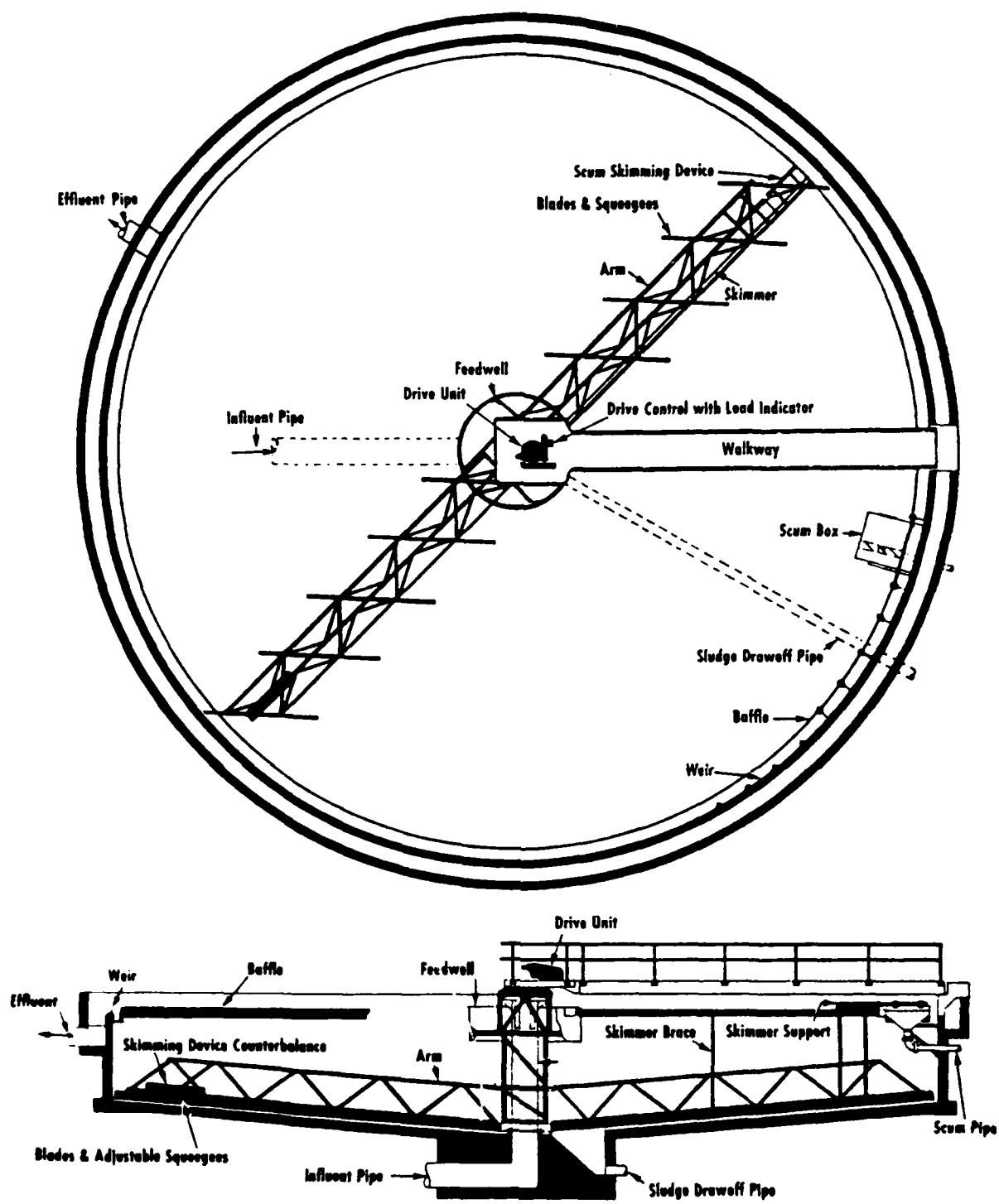


Figure 2. Typical circular clarifier.

Primary and secondary clarifiers can be further subdivided, depending on the tank configuration (circular or rectangular) and on the sludge removal mechanisms. In general, secondary clarifiers receive only solids from the biological reactor step and are somewhat easier to manage in the winter than primary clarifiers that receive raw solids and scum, grease and other floating material. Figure 2 is a typical circular clarifier that contains a rotating boom for sludge collection on the bottom and a scum collector at the water surface. The surface skimmer pushes the scum onto an inclined plate called the "beach" at the entrance of the scum box. Rectangular basins use chain-driven or traveling devices for the same purpose.

Experience has shown that clarifiers tend to have more severe operational problems during the cold winter months than any of the other system components listed in Table 1. The problems experienced with clarifiers in northern New England and operator solutions are listed in Table 3.

The most serious problem with both primary and secondary clarifiers is the freezing of surface scum and ice buildup on the beach plate as shown on Figure 3. This buildup may damage the skimming mechanism and the operator response at many locations is to remove the skimmer arm during the winter months. Some units have adjustable beach plates and these should be moved to minimize the exposed plate surface area in the winter. Figure 4 illustrates a flushing system in the scum trough developed at Hampton, New Hampshire, that washes out the remaining floating solids after each pass of the skimmer arm. The flush bar is tripped by the skimmer arm and allows treated effluent to enter the box and flush out any remaining floating solids. The amount of water allowed into the box is adjusted by adding or removing counterweights on the flush bar. The device works quite well, but freezing still occurs during prolonged periods of extremely low temperature. Frozen scum and ice are typically removed by hand or controlled by hot water sprays, heat tapes or lamps.

Ice formation on the main water surface in the tank can damage the structure of the skimming devices and the tank itself unless they are properly designed. In some cases where significant ice formation is expected, rock-filled plastic buckets have been suspended in the near surface liquid to prevent stress on the tank walls from ice expansion. Some designs, for secondary clarifiers, have specifically allowed ice formation on the tank (Benjes and Johnson 1984). This can be feasible when

Table 3. Winter problems with clarifiers.

Problem	Solution
Scum line freezes	<ol style="list-style-type: none"> 1. Flush out with hot water--use sewer bag to free blockages. 2. Install automatic flushing mechanism.
Scum trough freezes	<ol style="list-style-type: none"> 1. Cover exterior trough. 2. Break ice into pieces and remove by hand. 3. Install automatic flushing mechanism.
Scum freezes on beaching plate	<ol style="list-style-type: none"> 1. Flush off with hot water. 2. Discontinue scum removal in winter. 3. Shovel and hose down by hand. 4. If adjustable, decrease exposed plate area.
Ice on beaching plate hangs up collector arm and damages mechanism	<ol style="list-style-type: none"> 1. Remove skimmer during winter. 2. Remove ice by hand.
Scum freezes on outside ring of peripheral feed clarifier	---
Scum solidifies, won't flow	---
Scum freezes at center feed	Install a sprayer to keep scum moving toward skimmer.
Surface icing	<ol style="list-style-type: none"> 1. Remove secondary arms to prevent damage. 2. Keep clarifiers on 24 hours/day. 3. Remove thick ice with long-armed backhoe. 4. Shorten detention times.
Icing in idle units	Pump units routinely.
Icing in gear units	<ol style="list-style-type: none"> 1. Install heat tapes on drain line. 2. Drain water in bullgear after rain and when temperature rises.
Hoses and hydrants freeze	<ol style="list-style-type: none"> 1. Leave lines on. 2. Drain lines after use.
Traveling bridge controls ice up	Build enclosure over controls.
Icing of bus bar for bridges	Install heat guns.
Switches on monorakes freeze	Shut off units in snow and ice to prevent freezing.

Table 3 (cont'd). Winter problems with clarifiers.

Problem	Solution
Accumulation of snow on monorake rails stops wheels	Shut down rake during snowstorms.
Automatic sampler freezes	Build insulated boxes heated with a 100-W lightbulb.
Waste activated sludge lines freeze	1. Locate lines deeper. 2. Install proper drainage.

low scum concentrations are expected and appropriate structural measures taken.

Ice can be a severe problem for out-of-service clarifiers that may be partially full at the start of the winter. Attempting to fill or drain such tanks after ice has formed will damage the skimmer mechanisms. It is necessary in these cases to break up the ice prior to filling or draining.



Figure 3. Ice buildup on beach plate of clarifier.

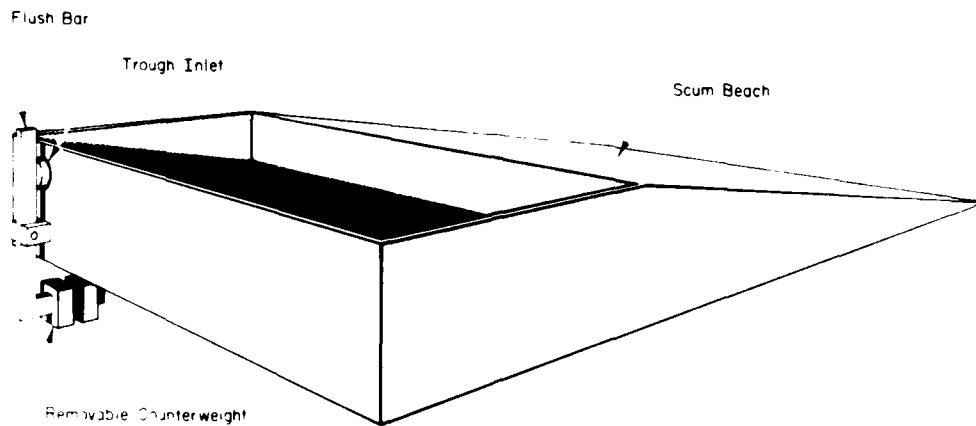


Figure 4. Self-cleaning scum trough at Hampton, New Hampshire, wastewater treatment plant.

The most common approach for stopping ice formation on the clarifier is to use covers. These range from removable panels for small rectangular tanks to prefabricated structures, air-inflated covers and plastic or metal domes on large circular units. Temporary panels include corrugated metal and insulated plywood. The major heat losses from exposed water surfaces are due to evaporation, convection and radiation, so in theory ice formation might be prevented with a thin sheet of plastic film. However, such a film would not support any snow load and the major reason for the rigid structural covers is to support the design snow load. The main disadvantage of covers is the high humidity and resulting condensation that creates a highly corrosive atmosphere inside. The use of noncorrosive structural elements and weatherproof electrical systems is essential.

The electrical drive systems on the clarifiers at Bennington, Vermont, experienced a unique winter problem (Szele 1984). When the air temperature dropped below 20°F, water vapor from the tank condensed and then froze on the electrical bus bars, which then short-circuited the system. Small hot-air blowers were installed to keep the copper bars clear of frost.

Many equipment manufacturers specify both warm and cold weather oils for the clarifier gear boxes and recommend a seasonal change; however, 20 to 30 gal. of oil may be required for each unit so the costs and labor requirements for seasonal changes will be high. A number of systems in New England have switched successfully to the use of the synthetic, multiviscosity, year-round lubricating oils (after the original equipment warranty

period was complete). At the Amherst, Massachusetts, plant, this lubricant is analyzed semi-annually for metals and water to determine excessive equipment wear or the presence of moisture. The lubricant has not been changed for 3 years.

In addition to the physical and mechanical problems described above, the designer must consider viscosity effects on clarifier performance since the operator will have minimal possibility for adjustments after construction. The settling of solid particles in primary clarifiers is governed by Stoke's law. As the liquid gets colder, the time required for solids separation increases. The equation below can be used to determine the adjustment factor when water temperatures less than 68°F are expected.

$$M = 3.07 e^{-0.0165T} \quad (1)$$

where M is a multiplier to be applied to the 68°F design detention time, and T is expected water temperature (°F).

For example, if 38°F water is expected in a clarifier normally designed for a 2-hour detention time at 68°F, the adjusted detention time would be:

$$\begin{aligned} M &= 3.07 e^{-(0.0165)(38)} \\ &= 1.64. \end{aligned}$$

Adjusted detention time is $(2)(1.64) = 3.3$ hours.

It may be desirable to provide multiple clarifier units in order to provide the required "adjusted detention time," with the extra units on-line in the winter and out of service in the warm months. If multiple units are not provided, the operator can make no adjustments. The opposite problem can occur at newly constructed systems where the actual flow is significantly less than the ultimate design rate. In these cases, it may be necessary to take some clarifiers out of service in the winter to avoid freezing problems from excessively long detention times.

Secondary clarifiers and thickeners typically receive higher concentrations of flocculent solids and settling is not controlled by Stoke's law (Reed and Murphy 1969). Unit designs for entering suspended solids concentrations higher than 6000 mg/L do not require a special temperature adjustment (Reed and Murphy 1969). Units expecting 2000 mg/L of solids or less should have their design based on eq 1. See the Cold Climate Utilities

Delivery Design Manual (USEPA 1979) for criteria for conditions between these two limits.

Unit design for very low temperature wastewater is not typically required. In the general case, the raw wastewater will be relatively warm (more than 50°F). The designer and the operator should both recognize this resource and do whatever necessary to take advantage of it. Simple wind screens, and covers where possible, will contribute significantly to heat retention and reduce winter operating problems in clarifiers.

BIOLOGICAL REACTORS

The listing of biological treatment components in Table 1 is not complete and is only intended as a representative grouping of concepts in common use at small- to moderate-sized facilities. The many variations of the activated sludge process, for example, would require a separate table for a complete listing. Extended aeration is a variation of activated sludge, and oxidation ditches are a further subgrouping of extended aeration. However, each may have a special configuration for the treatment components and that in turn results in unique cold weather problems. Trickling filters and Rotating Biological Contactors (RBC) are similar in that they depend on biological growth attached to a surface that is in contact with both the wastewater stream and the atmosphere for the necessary oxygen supply. In essence, lagoons model the reactions and responses of natural ponds and water bodies. The facultative lagoon has essentially no mechanical energy inputs and provides treatment during a relatively long detention time via natural processes. Aerated lagoons trade mechanical energy for time and utilize aeration for oxygen supply and mixing. As the aeration intensity increases the detention time decreases, until a "complete mix" level is reached, at which point the process is back in the activated sludge mode.

Activated sludge

In theory, all biological reaction rates depend on temperature, and design criteria for most of the basic treatment processes can be found in the Cold Climate Utilities Delivery Design Manual (USEPA 1979). In practice, low air temperatures have little effect on the performance of conventional and high rate (aeration time less than 4 hours) activated sludge systems with submerged aeration devices, because the wastewater is

relatively warm and the detention time is short in the aeration basin. Extended aeration systems, with aeration time of 10 hours or longer, can experience a significant reduction in mixed liquor temperature because of the longer exposure time. In these cases, it is necessary to increase the Mean Cell Residence Time (MCRT) or lower the Food-to-Microorganism (F/M) ratio to maintain a specified removal efficiency at the lower temperature. In essence, this results in maintaining a higher Mixed Liquor Suspended Solids (MLSS) concentration in the aeration tank during the low temperature period. At an extended aeration plant near Burlington, Vermont, the operator found it necessary to reduce the F/M ratio by about 6% for every 2°F change in mixed liquor temperature (if flow and detention time remained constant) to maintain the optimum removal efficiencies obtained at 68°F (Estus 1978).

Most of the winter operational problems with the activated sludge components are mechanical problems ascribable to ice buildup. Table 4 summarizes the problems and the operators' solutions at plants in northern New England. Facilities using submerged distribution of diffused air have a significant advantage over mechanical aeration devices during cold weather. There tends to be less surface turbulence and spray from diffused air systems, with no direct impact on the aeration equipment at all. In contrast, the spray and resulting ice buildup has resulted in performance problems and sometimes in failure of mechanical aerators and their structural supports. A problem that must be avoided with diffused air systems is blockage of the intake screens for the air compressors with snow, ice or frozen rain.

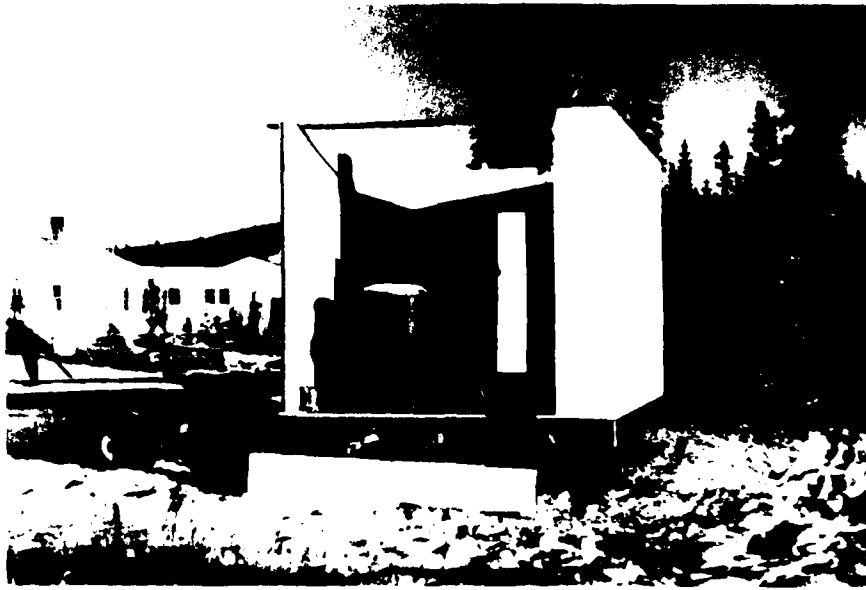
Mechanical aerators can be operated at low speed or cycled with time switches or both, and still maintain acceptable mixing and oxygen levels while reducing temperature losses and spray. Some mechanical aerators can develop severe icing between the aerator and the shroud. A successful approach has been to briefly shut off the aerator. Heat conduction from the warm liquid helps to soften the ice and the aerator is then operated for about 1/2 hour at high speed during the warmest part of the day.

Above-grade aeration tanks should be avoided during design whenever possible since they have the maximum exposure to severe winter conditions. Where system hydraulics require an above-grade unit, the tank walls should be insulated and a cover used.

Table 4. Winter problems with activated sludge.

Problem	Solution
Ice buildup on surface aerator	<ol style="list-style-type: none"> 1. Remove by hand. 2. Run on high speed for 15 minutes. 3. Turn off for 1/2 hour, allow mixed liquor to warm aerator, turn on high speed. 4. Steam ice off. 5. Bump aerator on and off.
Ice buildup on support tower bridging to aerator	Run water from hose on ice to prevent buildup.
Impellor icing causing pounding on fixed shroud	Remove shroud, ice will still build up, but aerator will not be damaged.
Ice buildup on supporting columns causing rotating shroud to pound on columns	Shorten detention times, run aerators on timers.
Cooling of mixed liquor	<ol style="list-style-type: none"> 1. Install timers on aerators. 2. Use diffused air instead of surface aeration. 3. Remove some aerator blades.
Icing in idle tank damaging structure	<ol style="list-style-type: none"> 1. Fill tank 1 ft above baffle. Install small sump pump to keep surface free of ice. 2. Exercise units regularly during sunny days. Care must be taken not to damage units.
Ice buildup on splash guard, electrical conduit and walkways	<ol style="list-style-type: none"> 1. Use good snow and ice removal procedures, salt. 2. Plant policy requires operators to keep one hand free to hold railing.
Decreased removal efficiencies	Increase MCRT, decrease F/M.

Persistent ice formation over the entire liquid surface must be avoided. The ice eliminates the possibility for surface aeration and also entraps some of the biological solids needed for treatment, and the system will not perform well. Such ice formation is unlikely for activated sludge systems with a short detention time but is possible for the extended aeration variations. Wind screens and temporary winter tank covers have been successful in these cases.



a. Being enclosed.



b. Completed enclosure.

Figure 5. Packaged treatment unit in Alaska.

Extended aeration

In these systems the aeration period is extended beyond that normally used in conventional activated sludge. The major purpose is to reduce the total mass of sludge that ultimately must be disposed of and to simplify the operation. Systems range from large, open basins with mechanical aerators to small (less than 1000 gal./day), prefabricated "packaged" plants in a variety of configurations. The major disadvantage of extended aeration in the cold regions is the longer exposure and increased risk of low temperature problems. Solutions have ranged from complete encapsulation as shown in Figure 5 for a package plant in Alaska, to burial or wind screens and covers in the northern contiguous U.S.

Low temperature operation requires adjustment in the F/M ratio as described in the previous section. Under low temperature conditions, the sludge mass (MLSS) will tend to increase naturally because of lower endogenous oxidation rates, so that the operator can usually make the necessary adjustments by wasting sludge less frequently than required in warm weather. Extended aeration units have been successfully operated with mixed liquor temperatures as low as 33°F (Reed and Murphy 1969) while still achieving high Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) removal efficiencies. Routine operation at these very low temperatures is not recommended since there may be severe icing problems in final exposed clarifiers. However, at the other extreme, enclosing and heating the entire system to 60-70°F is not necessary for process efficiency and should only be considered for operator comfort and convenience. If covers or enclosures are used, free circulation of air is still necessary, so condensation and icing in vent stacks must be considered as well as ice and snow blockage of air intake screens. Figure 6 illustrates a simple insulated vent stack successfully used on an above-ground, covered extended aeration plant operated for several winters in New Hampshire. A stand-by heat tape might also be needed in more extreme climates.

Oxidation ditches

This concept uses open channels and a rotating brush or similar device to provide mixing and oxygen transfer as well as to maintain flow of the liquid around the channels. Typical temperate zone construction involves simple earthwork excavation, with sloping side walls for the channels and the center islands. A design that was developed in Alaska specifically for

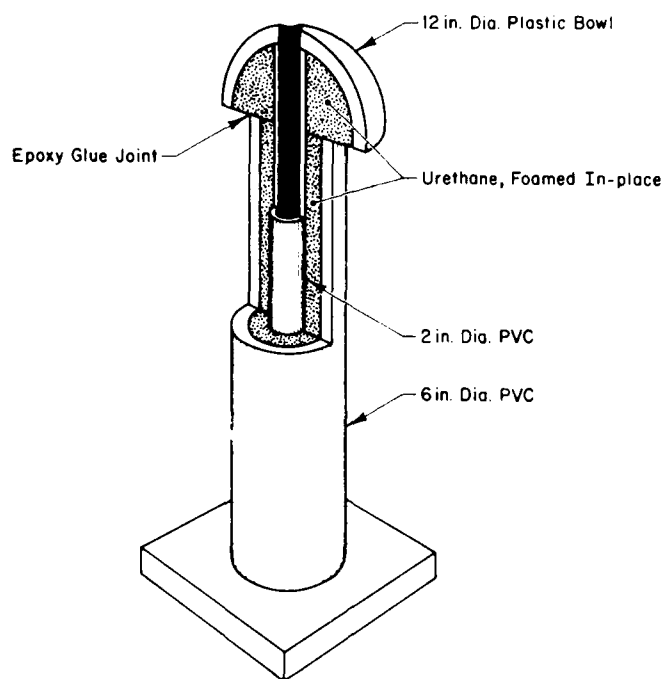
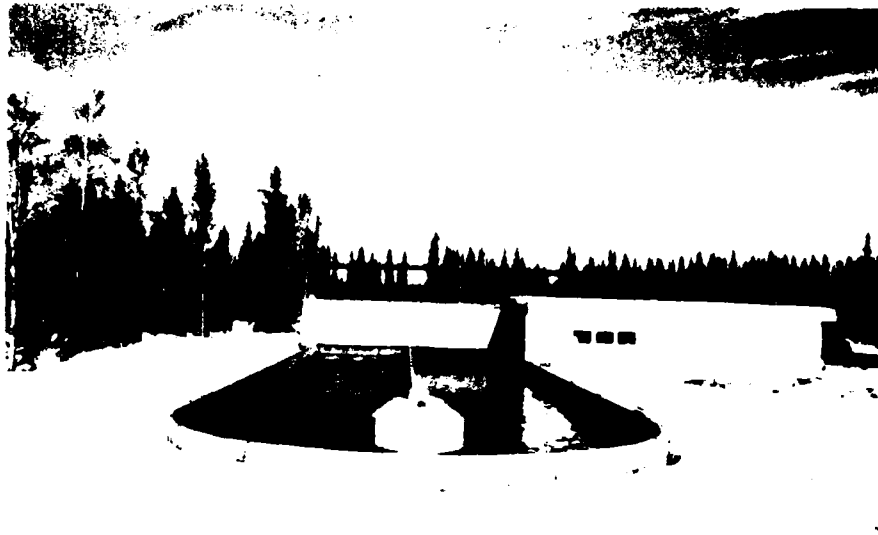


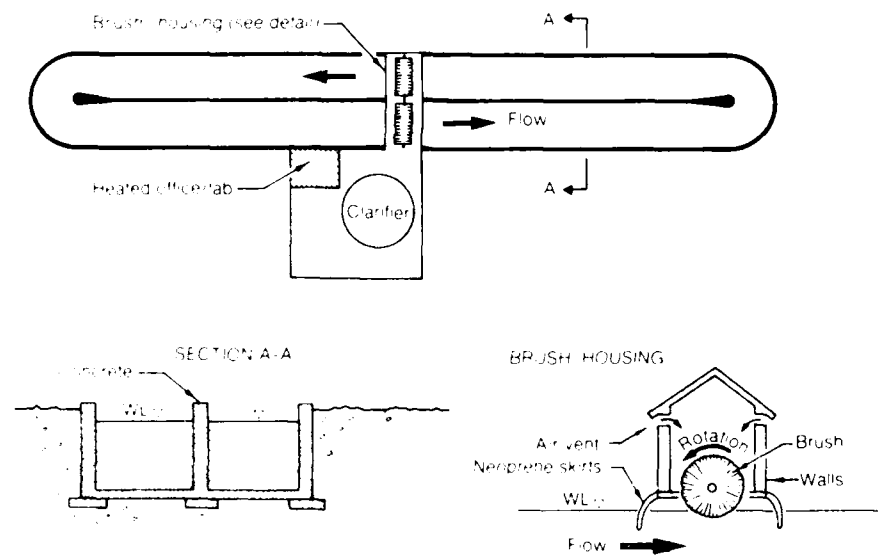
Figure 6. Toblasson insulated vent stack.

low temperature operation is shown in Figure 7. The vertical ditch walls and center island result in minimal exposed water surface and therefore maximum heat retention. Temporary winter covers were planned, but never used. The warm raw wastewater (65°F) entering this unit was sufficient to prevent a persistent ice cover with ambient air temperatures down to -55°F.

There were, however, icing problems at this, and at a number of other, oxidation ditch systems in the vicinity of the rotating brushes. The accumulating ice can form a shroud around the brush and reduce oxygen transfer. Pieces of ice that break off float into the rotating brush, and then damage or break the rotor blades. It may be possible to straighten a bent blade once, but it will typically fail the second time. Heat lamps, screens and weirs have all been used with varying success to prevent ice damage to the rotors. A successful approach is shown in Figure 7b. The rotors were enclosed in a simple unheated structure with air vents under the roof eaves to allow circulation. Neoprene skirts that extended several inches into the water were installed at both faces of the structure. These flexible skirts permanently eliminated icing problems at this Alaskan installation while the vented enclosure maintained the necessary oxygen transfer conditions.



a. Oxidation ditch in Alaska.



b. Design features.

Figure 7. Cold climate oxidation ditch.

Other special features of this Alaskan system are worthy of note and consideration for application elsewhere. As shown on Figure 7b, the secondary clarifier was enclosed with an unheated building for thermal protection. A small portion of that structure was blocked off and used as an office and laboratory, which was the only portion of the facility that was heated. The humidity inside the clarifier building was always very high and the resulting condensation on the cold walls and ceiling resulted in very wet conditions and ice throughout the winter. However, these conditions were anticipated during design and appropriate materials selected. All electrical controls were either installed inside the heated space or weatherproof units placed on the heated common walls. Condensation on cold outer walls in extreme climates will rapidly freeze and the resulting ice buildup will render any controls or switches in those locations inoperable.

Trickling filters

Trickling filters are more sensitive to low temperature stresses than are conventional activated sludge systems, both biologically and physically. As a result, it is common practice to cover the filter bed with some type of dome or inflated cover in the northern areas shown in Figure 1. The new high rate systems using plastic media in above ground towers are at greater risk than the older, low-rate rock media units that were typically partially buried.

Figure 8 illustrates a trickling filter tower with uncovered plastic media in northeastern Pennsylvania. The tower walls are coated metal, similar to farm silo construction. The spray from the outer nozzles freezes on these walls and builds up to a point where rotation of the boom is stopped. Under windy conditions ice will also form on much of the media surface.

This particular facility includes two primary clarifiers (in parallel), Archimedes screw pumps to lift wastewater to the top of the trickling filter towers, a recirculation pit and two parallel secondary clarifiers as the major elements in the hydraulic flow path. An aerated equalization basin was also included since chemical treatment for phosphorus removal was part of the overall process. There was severe icing when the aerated equalization basin and all clarifiers were in service (Reed 1983). This was primarily caused by the long detention times and exposure, since the

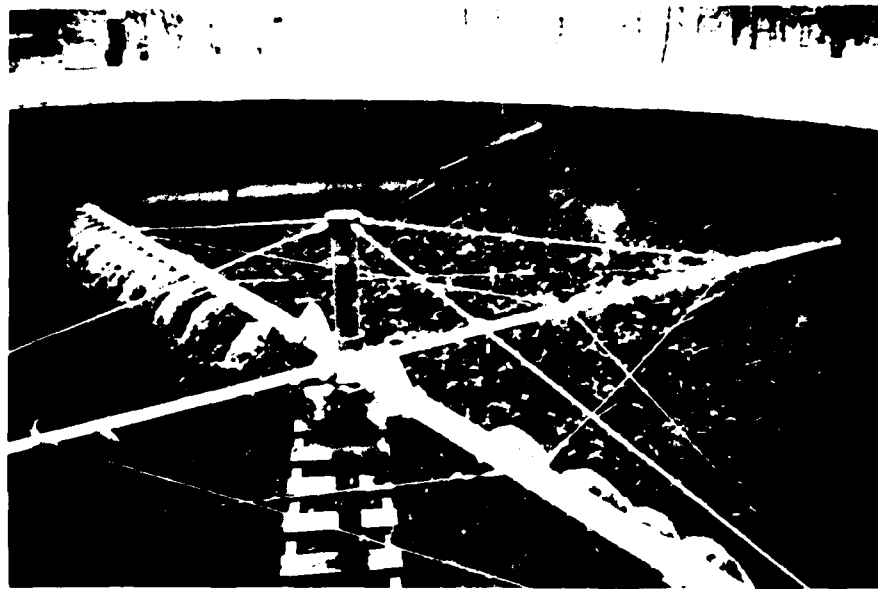


Figure 8. Trickling filter unit with plastic media.

initial system flow was about 40% of the design rate.

During the 1983-84 winter, the equalization basin was bypassed and only one of each clarifier pairs operated. Temperatures were measured at selected locations and a thermal analysis of the system conducted (Reed et al. 1984b). Table 5 summarizes the average daily temperatures at critical points in the system on four typical days.

Table 5. Winter temperature conditions in a trickling filter system.

Location	Average temperatures for selected days (°F)			
Air	33	26	19	10
Raw sewage	58	56	55	56
Primary influent	54	53	52	53
Primary effluent	54	52	52	53
Liquid in pump pit	46	45	39	40
Trickling filter surface	43	39	35	34
Trickling filter media (1 ft deep)	45	43	38	37
Trickling filter media (2 ft deep)	46	43	39	38
Trickling filter effluent	45	43	38	37
Secondary clarifier influent	45	43	38	37
Secondary clarifier effluent	45	42	37	36

A number of interesting conclusions can be drawn from these data and the complete thermal analysis (Reed et al. 1984b). Ice never formed on the clarifiers, but there was perimeter icing and the trickling filter boom stopped on the occasions when the air temperature dropped below 18° F. Calculated heat losses from the clarifiers and the Archimedes pump system were negligible. Conduction and convection losses through the container walls for the trickling filter are considered minor (about 12% of total loss from tower). The major heat losses from the system are caused by convection, radiation and evaporation losses at the exposed top surface of the trickling filter tower.

The data show that the water applied to the trickling filter loses most of its heat during flow through the top 2 ft of the filter bed, with minor losses thereafter. Calculations show that, for the operational conditions prevailing during the study period, temperatures within the filter bed would be too low to sustain significant nitrification when the ambient air temperature dropped below 30°F. Freezing conditions would prevail on the general filter surface with air temperatures of 9°F and freezing temperatures would penetrate at least 1 ft into the media with ambient air temperatures below 0°F. Based on this analysis, it has been decided that this tower must be covered to ensure successful operation of the system. The cover will eliminate icing and ensure successful BOD removal but it is not yet clear if maintenance of acceptable nitrification temperatures will be possible, even with the cover, since continuous air circulation through the tower is still essential.

Since the biological reactions in trickling filters are more sensitive to temperature changes than conventional activated sludge, some adjustment in design criteria for winter conditions is necessary. Eckenfelder has developed an approach that accounts for both temperature and media characteristics (Benefield and Randall 1980). The equation allows the designer to vary either the depth or the cross-sectional area of the filter bed, or both, to adjust for temperature. The unit size should be based on winter conditions. The basic equation is:

$$\frac{S_e}{S_o} = e^{-\frac{D}{(Q)^n} K_{20} \theta^{(T-20)}} \quad (2)$$

where S_e = BOD of system effluent after secondary clarification
 S_o = BOD of primary effluent (not including recirculation)
 D = depth of filter (ft)
 Q = q/A , design hydraulic loading (gal./min \cdot ft²)

q = design flow of primary effluent (not including recirculation)
(gal./min)

A = surface area of filter bed (ft²)

n = exponent characteristic for filter media:
rock, $n = 0.7$
plastic, $n = 0.5$

K_{20} = treatability factor at 20°C (min⁻¹). Also dependent on filter media:
rock, $K_{20} = 0.04$
plastic, $K_{20} = 0.06$

θ = temperature constant (1.035)

T = liquid temperature in filter bed (°C).

This equation is valid for single stage units with no recirculation. Benefield and Randall (1980) give the procedure with recirculation, and also for specific values of n and K_{20} for particular filter media. Both of these factors can also vary with wastewater type, so a treatability study is recommended for a large scale project. The example below illustrates the use of equation 2.

Assume: $S_o = 300$ mg/L
 $S_e = 30$ mg/L
Design flow = 800,000 gal./day
Plastic media, 16 ft deep
 $\theta = 1.035$
 $n = 0.5$
 $K_{20} = 0.06$.

Find the required surface area at 10°C by first solving for the exponential portion of eq 2:

$$\begin{aligned} (D)(K_{10}) &= (16 \text{ ft})(k_{20})^{\theta(T-20)} \\ &= (16)(0.06)(1.035)^{(10-20)} \\ &= 0.6806 \end{aligned}$$

Substitute into eq 2,

$$\frac{S_e}{S_o} = e^{-\frac{(0.6806)}{Q^n}}$$

Solve for Q^n :

$$Q^{0.5} = \frac{0.6806}{2.3026} = 0.2956$$

$$Q = 0.087 \text{ gal./min}\cdot\text{ft}^2.$$

$$\text{Actual flow, } q = \frac{(800,000 \text{ gal./day})}{(24 \text{ hr/day})(60 \text{ min/hr})} = 556 \text{ gal./min.}$$

$$\text{Surface Area, } A = \frac{q}{Q} = \frac{556}{0.087} = 6391 \text{ ft}^2.$$

Two 64-ft-diameter filters could be used.

Based on the temperature dependence of eq 2, the approximate relationship between filter surface area and temperature can be defined with the following equation:

$$A_T = A_{68^\circ} [13.48 e^{-0.0382(T)}] \quad (3)$$

where A_T = required area at temperature T (ft^2)

A_{68° = required area at 68°F

(T) = expected design temperature ($^\circ\text{F}$)

The multiplier with temperature in $^\circ\text{C}$ is

$$A_T = A_{20} [3.96 e^{-0.0688(T)}] \quad (4)$$

Equation 2 or some other design approach can be used to determine the required surface area at 20°C , then eq 4 can be used to estimate the adjustment for the design temperature. Equation 4 is related to the temperature influences on biological reaction rates in the trickling filter. It indicates a stronger dependence on temperature than expressed in eq 1, presented earlier, which is based only on physical effects due to temperature and viscosity changes.

Rotating biological contactors

RBCs like trickling filters depend on biological growths attached to the media surfaces, but in this case the media are large circular disks that are partially submerged and rotate. It is always necessary to enclose

the unit, not only to prevent freezing but to avoid dessication of the growth during dry weather and washout during intense rainfall. Since the units are enclosed there are no reported physical or mechanical problems related to cold weather operations. The rate of biological activity in the RBC will be retarded with low temperature wastewater in the unit. Benefield and Randall (1980) and the manufacturer's literature for a particular device should be consulted for details.

Aerated lagoons

Aerated lagoons with mechanical surface aerators, either floating or structurally supported, experience the same type of icing problems as do clarifiers (Table 3). Lagoons with submerged diffused aeration have fewer icing problems in the basin but they require special care for design and operation of blowers and related air intakes. In many systems, the designer did not consider snow and ice and located the blower intakes near the ground level in a convenient wall of the building. It has been necessary for operators to relocate the intakes to avoid blockage from drifting snow or ice accumulation from freezing rain. Selection of the proper lubricant for the blower is essential for winter operations. The air temperature differential through the blower can easily exceed 100°F with intake of very cold air.

Lagoons of all types should be maintained at maximum possible operating depth during the winter. This will compensate for any ice formation and ensure that the maximum possible treatment volume is available. Low water levels may also allow surface ice to entrap the air piping and baffles. Any subsequent change in water level will damage them and may result in total failure of the encapsulated devices.

Most of the systems with submerged aeration tubing require periodic acid cleaning with HCl gas. When the gas assembly is outside, low temperature conditions will reduce the gas production rates. Exposed propane gas tanks have a similar problem; at extremely low temperatures the propane will remain in the liquid state inside the tank.

Surface ice can form on lagoons with submerged diffused aeration but it will not form a continuous and permanent cover over the entire water surface, even under extreme conditions. Figure 9 illustrates a small aerated lagoon in Alaska. The ambient air temperature was -50°F during the period when the photograph in Figure 9b was made. There were always areas of open water adjacent to the aeration lines.



a. In warm months.



b. In winter (-50°F).

Figure 9. Diffused air lagoon.

Facultative lagoons

Facultative lagoons with no mechanical energy inputs will develop a continuous ice cover on the water surface in the cold regions, and this can often persist for the entire winter. The ice prevents surface reaeration and much of the lagoon may turn anaerobic; this in turn can result in greater release of sulfides, ammonia and other compounds from the bottom sludge so that the overall water quality deteriorates. Such a lagoon, capable of producing a high quality effluent in 20 to 40 days in warm weather, may function as little more than a primary clarifier in the winter. As a result, lagoon design in most of the north-central U.S. and in Canada requires detention times in excess of 100 days or complete storage with no discharge permitted during the winter. The land area required for such a system would typically eliminate it from consideration for much of the northeastern U.S.

Since there are no mechanical components in the typical facultative lagoon, cold weather and icing do not result in operation problems in the lagoon itself. However, special care may be necessary to avoid ice problems at or near the outfall if winter discharge is permitted. The long detention time will reduce liquid temperatures close to the freezing point

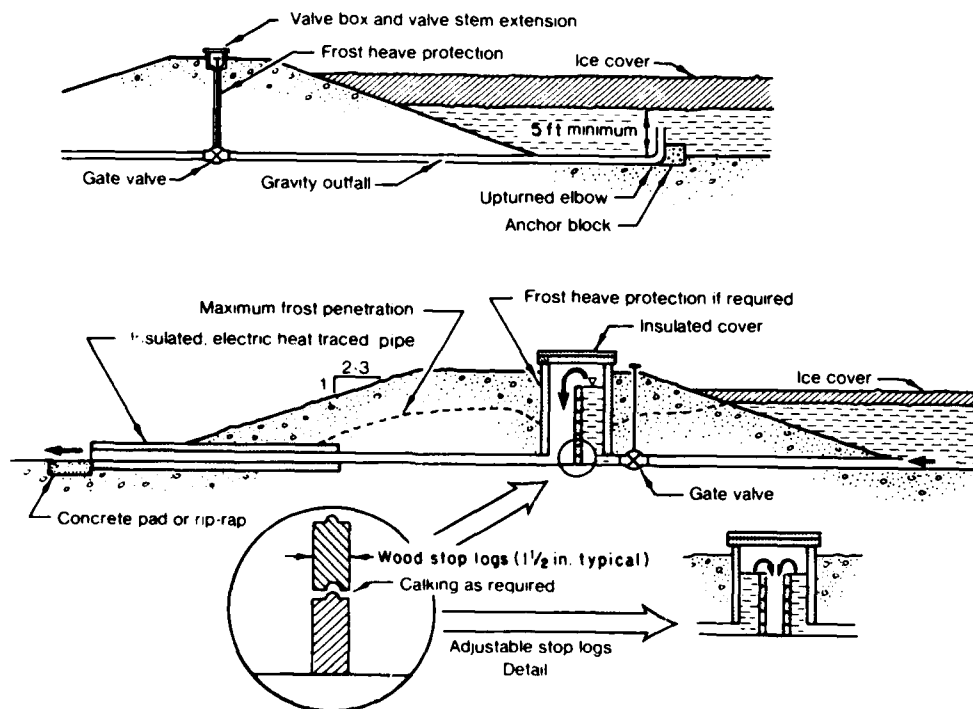


Figure 10. Design features, cold regions lagoons.

and ice can quickly form at an exposed outfall. Figure 10 illustrates design features typically used with outfalls in Alaska to avoid freezing problems. Submerged outfalls in adjacent rivers and streams must be designed to avoid damage from ice in those water bodies. The Cold Climate Utilities Delivery Design Manual (USEPA 1979) provides additional discussion on the design of these outfalls. Figure 10 also illustrates a stop-log weir design that can be used to control water levels in any type of lagoon system.

SLUDGE MANAGEMENT

Winter conditions can have an adverse effect on all aspects of sludge management including digestion, dewatering and disposal. Table 6 lists the sludge problems encountered in typical northern New England systems.

Anaerobic digestion requires heat to sustain the necessary temperatures. Typically, digester tanks are enclosed and insulated or partially buried to retain heat. Figure 11 shows an anaerobic digester in New Hampshire with a wind screen that the operator installed for additional thermal protection.

The major cold weather problem with sludge management occurs at those facilities that depend on open drying beds. Sludge applied to such beds in the winter will freeze and the bed will then not function as originally designed. The standard approach has been to cover such beds to extend the drying season or to store all sludge in the winter and only use the drying beds in the summer. In some cases the drying rate is still too slow even under a covered bed because of a particular sludge's characteristics. In these cases, the use of polymers or the conversion of the units to wedge wire or vacuum assisted systems has been successful (Reed et al., in press). It is also possible to change the design and operational approach and use the cold weather and freezing temperatures in a beneficial way for sludge dewatering.

Freezing and then thawing a sludge will convert a material with a jelly-like consistency to a granular material that drains readily. The process will work with any type of sludge, but it is particularly effective with chemical and biochemical sludges containing alum that are very slow to drain naturally. Energy costs for artificial freezing and thawing are

Table 6. Winter problems with sludge management.

Problem	Solution
Unable to use sludge drying beds in winter, beds freeze	---
Not able to apply sludge to land in winter	Stockpile sludge in winter months.
Aerobic sludge digester freezes if blower is shut off to allow thickening by decanting	Cover tank.
Sludge freezes in tank	Run mechanical agitator overnight.
Ice forming on digesters	---
Icing in gravity thickener	---
Sludge hold tank freezes	Take off-line during winter.
Sludge freezes on truck	Use truck body heated with exhaust gases.
Sludge lines freeze, valves freeze	<ol style="list-style-type: none"> 1. Drain lines correctly. 2. Dismantle and thaw valve. 3. Put heat tape on lines. 4. Increase return rates.
Holding tanks too small to last winter	Use spare clarifier of oxidation ditch.
Extensive heat loss from anaerobic digester	---
Operating temperature could not be reached in new compost pile	<ol style="list-style-type: none"> 1. Cover pile and insulate. 2. Mix sludge and wood chips with hot compost. 3. Blow hot exhaust from working pile into new pile.

prohibitive so the concept must depend on natural freezing to be cost-effective. As shown in Figure 12, that area can include most of the northern half of the U.S.

Sludge can be dewatered by freezing regardless of the initial sludge concentration or degree of stabilization but the cost-effectiveness of the operation can be influenced by both factors. A very dilute sludge (less than 1% solids) will increase costs by requiring more space for the freezing beds; thickened sludge in the range 2 to 7% solids is recommended. The use of stabilization for wastewater sludges is recommended to avoid odor



Figure 11. Anaerobic digester with wind screen.

complaints during final drying and regulatory constraints on final disposal options.

The design of a freeze-dewatering system must be based on worst case conditions to ensure success at all times. If sludge freezing is to be a reliable part of the treatment system every year, the design must be based on the warmest winter during the period of concern (usually 20 years) and on a layer thickness that will freeze within a reasonable time if there are freeze-thaw cycles during the winter. It is essential for the layer to freeze completely if the benefits are to be realized. In many locations, a

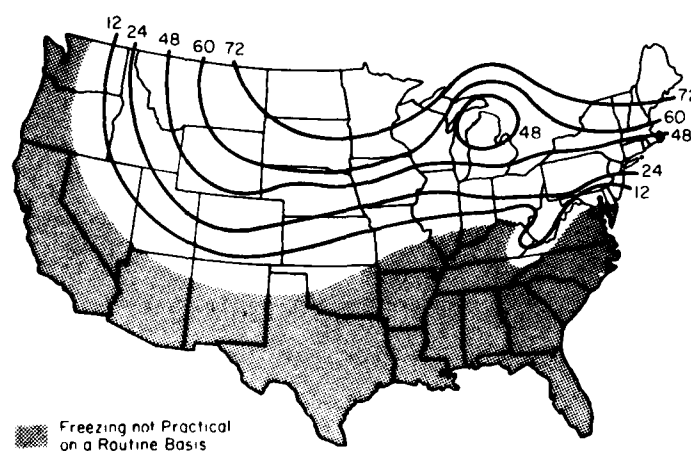


Figure 12. Potential total depth of sludge that could be frozen if applied in 3-in. layers.

large single layer may never freeze completely to the bottom and only the upper portion will go through alternating freezing and thawing cycles.

Recent research at CRREL (Reed et al. 1984a) indicates that a 3-in.-thick layer of sludge is practical for most locations in moderately cold climates. A thicker layer is feasible in colder climates; Duluth, Minnesota, for example, successfully freezes water treatment sludges in 9-in. layers (Schleppenback 1983). We recommend that a 3-in. layer be used for feasibility assessment and preliminary design. A larger increment may then be justified by a detailed evaluation during final design.

The freezing or thawing of a sludge layer can be described with the following equation:

$$X = m \sqrt{\Delta T \cdot t} \quad (5)$$

where

X = depth of freezing or thawing (in.)

m = proportionality coefficient ($[\text{°F} \cdot \text{days}]^{-1/2}$)

$\Delta T \cdot t$ = freezing or thawing index ($\text{°F} \cdot \text{days}$).

The proportionality coefficient m is related to the thermal conductivity, the density and the latent heat of fusion for the material being frozen or thawed. It was experimentally determined at CRREL and a value of 0.6 is suggested for sludges (0-7% solids). The freezing or thawing index is an environmental characteristic for a particular location and can be determined from weather records or can often be found directly in other published documents. The ΔT in eq 5 is the difference between the average air temperature during the period of concern (t) and 32°F. For example:

Average air temperature, November 8,9,10 = 28°F

t = 3 days

Freezing index for the period = $(32^\circ - T)(t)$
= $(32 - 28)(3) = 12^\circ\text{F} \cdot \text{days}$.

Since a layer thickness of 3 in. has been suggested and the coefficient m defined, it is possible to rearrange eq 5 and solve for the time required to freeze the layer:

$$t = \frac{\left(\frac{X}{m}\right)^2}{\Sigma \Delta T} \quad (6)$$

with $X = 3$ in. (layer thickness) and $m = 0.6$, eq 6 becomes

$$t = \frac{25}{\Sigma \Delta T} \quad (7)$$

where $\Sigma \Delta T$ is the sum of the average daily temperature differences between temperature T and 32°F for the time period t .

For design, this equation is used with local weather records for the period of concern to determine how many 3-in. layers can be frozen during each winter. The year with the smallest number of layers is then the control year for design. The approach might assume, for example, that the first 3-in. increment is applied to the bed on 1 November. Equation 7 is then used to determine the number of days required for freezing the layer under the average daily temperature conditions indicated in the records. Either the intensity of the temperature or duration must be sufficient to freeze the layer of concern in a continuous period. The calculations are repeated for the entire winter season for each year of concern with due account taken for all thaw periods and a one day allowance each time for a new application and cooling. The next layer is not applied until the previous layer has frozen completely. Thawing of previously frozen layers during a warm period is not a major concern since these solids still retain their desirable characteristics. Mixing of a new deposit of sludge with thawed solids from a previously frozen layer will extend the time required for freezing the combined layer (solve eq 6 for the combined thickness). If there is an extended thaw period, the thawed sludge cake should be removed.

The design procedure described above can be easily programmed for rapid calculations with a small computer or desk-top calculator. An even more rapid approach for feasibility assessment and preliminary design has been developed at USACRREL (Reed et al. 1984a). Equations 5 and 7 are based on the freezing index. The depth of frost penetration into the soil for a particular location is related to the same factor and published values can be found in the literature (Whiting 1975). Equation 7 above was used to calculate the design depth of sludge that could be frozen in 3-in. layers at selected locations in the "design" year. Those values were then compared to the maximum depth of frost penetration for the same locations. Equation 8 below describes the relationship:

$$EX = 1.76 (F_p) - 38 \quad (8)$$

where: ΣX = total depth of sludge that could be frozen in 3 in. layers, during the "design" year (in.)

F_p = maximum depth of frost penetration (in.).

Whiting (1975) gives frost penetration values, as do other sources. For convenience, typical calculations have been performed and the total depth of sludge (in 3 in. layers) that could be frozen are plotted on Figure 12. Equation 8 and Figure 12 are only valid for preliminary calculations. Detailed weather records and eq 6 should be used for final design.

The frozen sludge drains very rapidly upon thawing, with a solids concentration about 25% as soon as the material is completely thawed. In 1984 field trials in New Hampshire, a 10.2-in. deposit of frozen wastewater sludge (applied in three layers) thawed completely in 14 days during late March and early April. Solids concentration on the 14th day was 35% and reached 54% by the 25th day. On the 27th day 2-in. of rain fell but drained immediately from the uncovered bed. The solids concentration was 40% about 12 hours after the rain stopped, indicating the sludge particles retained their desirable characteristics. The time required for thawing frozen material can be estimated with eq 6 and the weather data for spring and summer conditions.

The basic facilities would be similar in construction and costs to conventional, open, underdrained sand beds. A roof over the bed is not essential in areas where winter precipitation is essentially all snow. If a snow layer is less than 2-3 in. thick, snow removal is not necessary. The newly applied sludge will melt the snow and the meltwater would be a relatively minor contribution to the total mass to be frozen. The combination that should be avoided is a new sludge application under a deep snow layer since the snow will act as insulation, so the snow should be removed in this case. New freezing beds should be deeper than the typical sand drying bed to accommodate the design depth of frozen material. Existing drying beds can be used for this purpose also, up to the limits of the freeboard provided, and operators in suitable locations are encouraged to try the concept.

If freezing is the only method used for dewatering, then sludge storage will be necessary during warm periods. A more cost-effective alternative will be to combine winter freezing with polymer-assisted summer

dewatering on the same beds. That combination would eliminate the need for large scale sludge storage and reduce the number of, or changes the size of, the freezing beds required. In a typical case, winter application in layers might start in November and continue until 2 ft or more of frozen material had accumulated. This should thaw and drain by early May. Polymer assisted dewatering on the same beds can then continue through the warm months. A detailed cost analysis during final design would be necessary to select the most cost-effective combination.

The final disposal of sludge from most small- to moderate-sized systems is either to the land or to landfill. Land spreading and soil incorporation of sludges is not possible with frozen soils nor practical with snow covered fields. The typical approach has been to stockpile the sludge during the winter months. In locations with extreme climates, landfill trenches are often excavated prior to the onset of winter and cover soils stockpiled. This allows continuous use of the trenches all winter but freezing of the cover soil stockpile can be a problem.

DISINFECTION

Chlorination is the most widely used form of disinfection in wastewater treatment. Gas chlorination systems may require the cylinders to be stored in a heated enclosure or the use of an evaporator to allow sufficient chlorine withdrawal at low temperatures for proper disinfection. The U.S. Environmental Protection Agency recommends the chlorine storage area be maintained above 50°F to prevent liquefaction of chlorine gas in the header. They also recommend the temperature be maintained below 158°F to prevent cylinder rupture. Hypochlorite tablets dissolve more slowly at low temperatures, making it difficult to obtain the proper dosage with this method. Ozone should provide effective disinfection at reduced temperatures although this chemical is not widely used. Ultraviolet disinfection is growing in popularity and may prove to be an ideal method for low temperature applications. Reduced temperatures do have a slight effect on the ultraviolet radiation level, but the use of a few additional lamps can offset this reduction. Table 7 summarizes the winter problems with disinfection operations in New England.

Table 7. Winter disinfection problems (many northern plants do not necessarily have a component from each category).

Problem	Solution
Feed lines freeze	Enclose all storage and pumping facilities in a heated building.
Hypochlorite solution crystallizes in pumps and pipes	---
Surface contact chamber freezes	Cover and insulate tanks.

CIVIL ENGINEERING CONCERNS

In addition to the cold weather impacts on wastewater processes and components, there are general civil engineering concerns related to site maintenance, snow loads on roofs, and accumulated snow and ice restricting safe access to the facilities.

Roofs on wastewater treatment components include conventional structures with built-up roofs, geodesic domes and air-supported covers. Most types have failed because of excessive snow loads.

A geodesic dome covering an off-line clarifier in New England collapsed, with the apparent cause being excess snow load. The operators of this system note that snow accumulation is less on the domes covering the operating clarifiers. Apparently, heat losses from the water in the system is enough to keep the dome clear of snow and accumulated ice. A similar approach is required for air-supported structures that are not designed for snow loads; warm air must be circulated at the roof crown. Typically, a double layer of fabric is used at the crown and warm air circulated between the layers.

Snow and ice accumulation on roads and walkways can make access to system components difficult, and often hazardous. Effective snow removal and the use of chemicals and sand are necessary. Heat lamps have been used to keep critical building entrances ice free. If access to system components is not easy and safe at all times, it is very likely that routine operation and maintenance activities will be neglected.

The potential for snow drifting should be a special concern for all system designers. Quite often the process design and component layout has only considered hydraulics and process requirements, with little thought

for the physical setting in the winter. The results have often been snow-clogged air intakes and inaccessible valves and other control or monitoring elements. The operator may not be able to make changes once the system is constructed, so it is critical for the designer to anticipate these problems.

The following guidance is quoted from TM 5-852-9/AFM 88-19, Chap. 9, Arctic and Subarctic Construction - Buildings (Departments of the Army and Air Force 1971). Snow drifting around groups of structures is difficult to predict but the following general guidelines are offered to minimize problems:

1. Use trees, shrubs, snowfences or even structures to precipitate snow before it reaches the site proper. Where storms may occur from any direction, provide protection from other quadrants.
2. Place major roads parallel to the wind.
3. Do not locate roads directly upwind or downwind of large obstructions. Where possible maintain a 100-ft clearance upwind and 200 ft downwind.
4. Locate parking lots alongside roads to act as buffer zones. Do not place parking lots among buildings. Expect additional snow accumulation around parked vehicles, and provide ample room for snow storage on the downwind end of a lot away from roads.
5. Parking aprons should be placed alongside, not upwind or downwind of, hangars and garages.
6. Orient surface structures with their longest dimension parallel to the wind. Doors placed on the downwind end of the structure will be subjected to suction forces during drift formation and will be rapidly blocked with drifted snow. Those on the upwind face are difficult to seal. Doors are best located along the sides, toward the upwind end.
7. Orient large garage doors nearly parallel to the wind even if this results in a building orientation perpendicular to the wind. Adjust this orientation slightly to assure that the doors are not in the lee of the upwind corner of the building.
8. Place structures in rows perpendicular to the wind with enough space between to permit effective snow removal. If a second row is necessary, place those structures directly downwind of those in the first row.
9. Locate priority buildings toward the downwind end of the facility where they are afforded protection by less important upwind structures.

10. Provide snow dumping areas to eliminate large piles of snow and windrows in the site area. Piles and windrows act as obstructions and increase future snow removal requirements.

Appendix B contains a list of references that we recommend as source material for those needing additional design information on the civil engineering problems of thermal aspects of building design and construction, snow loads, and snow and ice removal. Most of these references can be found in University and similar technical libraries.

CONCLUSIONS

Cold weather problems can seriously affect operation and performance of wastewater treatment facilities. Most of these problems can be eliminated or at least reduced to a tolerable level with the procedures described in this report. It is critical that operators be well trained and fully understand the processes involved to allow rational adjustments and modifications for low temperature conditions. It is equally important for designers of cold regions systems to anticipate and eliminate potential winter problems. Early in every design, the engineer should pause and consider what site conditions may be like in February with high winds and snow.

Clarifiers, particularly the scum removal mechanisms, are the most frequent source of winter problems. The preliminary treatment components rank next, with the final, mechanical grit removal stage the most difficult activity to maintain in cold weather. It is possible to solve the problems by housing and heating the complete unit in both cases. More innovative approaches may be forthcoming if equipment manufacturers and design engineers recognize the general nature of these problems and focus more attention on this aspect of system design.

Operators of existing facilities do not in many cases have much flexibility for adjustment and must somehow cope with the problems in some other way. The information provided in Tables 2 through 6 and in Appendix A will indicate how operators elsewhere managed these problems. Operators with facilities in appropriate locations (Fig. 12) are encouraged to try the sludge freezing method discussed in this report. It can provide a low cost method for sludge dewatering and will allow year-round use of sand drying beds.

LITERATURE CITED

- Benefield, L.D. and C.W. Randall (1980) Biological Process Design for Wastewater Treatment. Englewood Cliffs, N.J.: Prentice-Hall.
- Benjes, H.J. and C.G. Johnson (1984) Small town conquers wastewater tribulations. Public Works, October.
- Departments of the Army and Air Force (1971) Arctic and Subarctic Construction: Buildings. TM 5-852-9/AFM, 88-19, Chap. 9.
- Estus, W.N. (1978) The process control index. Journal of the New England Water Pollution Control Association, 12(1):99-104.
- Reed, S.C. (1983) Preliminary report - freezing and nitrogen removal at Tobyhanna Army Depot sewage treatment plant. Report to Baltimore District, U.S. Army Corps of Engineers. U.S. Army Cold Regions Research and Engineering Laboratory.
- Reed, S.C. and R.S. Murphy (1969) Low temperature activated sludge settling. Journal of the American Society of Civil Engineers, Sanitary Engineering Division, 95:747-767.
- Reed, S.C., J. Bouzoun and W.S. Medding (1984a) A rational method for sludge dewatering via freezing. Proceedings, 7th Symposium on Wastewater Treatment, November, Montreal, Quebec. Ottawa, Ontario: Environment Canada.
- Reed, S.C., B. Mair and R. Bates (1984b) Investigations at Tobyhanna Army Depot sewage treatment plant. U.S. Army Cold Regions Research and Engineering Laboratory, Internal Report 850.
- Reed, S.C., J.E. Smith, J. Resta and R.S. Sletten (in press) Disposal of alum and other metallic hydroxide sludges. U.S. Army Cold Regions Research and Engineering Laboratory, Special Report.
- Schleppenback, F.X. (1983) Water filtration at Duluth, Minnesota. EPA 600/2-84-083. Cincinnati, Ohio: U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory.
- Szele, G.W. (1984) Winter water and wastewater operations. Public Works, August.
- USEPA (1979) Cold climate utilities delivery design manual. EPA 18-79-027. Cincinnati, Ohio: U.S. Environmental Protection Agency, Center for Environmental Research Information.
- USEPA (1982) Handbook - identification and correction of typical design deficiencies at municipal wastewater treatment facilities. EPA-625/6-82-007. Cincinnati, Ohio: U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory.
- Whiting, D.M. (1975) Use of climatic data in design of soil treatment systems. EPA 660/2-75-018. Corvallis, Oregon: U.S. Environmental Protection Agency, Corvallis Environmental Research Laboratory.

APPENDIX A: CASE STUDIES

The case studies that follow describe specific cold weather problems at selected wastewater treatment systems in northern New England. The major problems and solutions are included in the basic text of this report but these case studies provide additional background and detail. This material was assembled and prepared by D.S. Pottle and the other University of Lowell co-authors in addition to their other contributions to this report.

Amherst, Massachusetts

This conventional activated sludge plant became operational in 1979 and has experienced a number of cold weather problems, many of which have been solved; the operators have also learned to work around some of them.

Originally, this plant used both cold and warm weather oils in the gear boxes on all the clarifiers and the aeration tanks. The original equipment manufacturer's recommendation was to change this oil seasonally. After the warranty period expired, the operators switched to multiviscosity oil in their units and have not changed oil for the past 3 years. Semi-annually, the oil is analyzed for metals and water to see if there is excessive wear on equipment or moisture in the oil. A large savings in labor has been realized by not having to change oil seasonally, since these units take up to 30 gal. of oil each and it takes much time to drain these gear boxes.

At the headworks, an Archimedes screw is used to lift the grit out of a submerged hopper into a grit canister. In winter the screw, which is located outdoors, freezes solid. The solution was to enclose the screw housing with insulation and sheet metal. Each morning heat from a portable kerosene heater is ducted into the screw chamber for thawing. The heater blows hot air into this covered unit for 3-5 hours before it is started.

The University of Massachusetts is located in Amherst and the majority of flow into the plant comes from it. This creates great variations in flow, especially during winter intersession and vacation periods. Fluctuating flows result in the operators having to take tanks out of service or put additional units on-line. This is a major problem and can have serious consequences during cold weather. Ice buildup is normally unavoidable and dangerous in idle clarifiers, and this is compounded by having to switch units on- or off-line. The Amherst facility is unique in

that it has a central wet well that is lower than all of the tanks to which all clarifiers and aeration tanks drain. During each operating shift this well is pumped out.

Scum freezes in the clarifier beaching plates, which are not adjustable, requiring plant personnel to flush the beaching plate and scum line with hot water to thaw frozen material. A sewer bag is sometimes inflated and the resulting hydraulic pressure is used to flush out blockages in the scum line.

In the aeration tanks, ice develops on the aerator shrouds. These dual-speed aerators are run at high speed for 1 hour during the day, which melts off the ice. If the shrouds can be adjusted, they should be lowered to keep spray in contact with the shroud. Exercising idle units in the winter may cause more problems than good; two aerator oil pump shafts broke while they were being exercised during extremely cold conditions.

This plant completely drains all froth control piping and closes all yard hydrants. These units drain well and freezing is prevented.

Bethel, Maine

This extended aeration plant, completed in June 1972, relies on a somewhat antiquated collection system that has parts dating to the 1890's. This system allows severe infiltration of storm runoff and groundwater.

The operators have put much effort into developing homemade solutions to a variety of problems. And many cold weather problems have been reduced by these modifications. Originally, all parts of the plant were open and exposed to the air. The rectangular clarifiers froze up every winter, causing destruction of the sludge scrapers, shafts and attached equipment. The last two winters, the clarifiers have been kept ice free by covering them with panels constructed of 2-in. styrofoam insulation board, 5/8-in. exterior plywood and roofing paper. The panels are placed on 2- x 4-in. studs and supported by pressure-treated beams spanning the clarifiers and chlorine contact chambers.

A shed was built to house the speed reducers, compressors and rake drive. The sludge return lines, which project 6 ft or so from this shed, occasionally freeze up. Perhaps if the lines were shorter, they would be less likely to freeze up.

The floating aerators freeze in place during cold periods. The chief operator believes covering the aerators is the only solution to this

problem. The second aeration tank is used as a sludge digester. However, with only one 7-1/2 hp floating aerator, it is only partially mixed and freezes over in cold weather.

Fort Kent, Maine

This extended aeration plant employs an oxidation ditch with rotor aerators combined with two secondary clarifiers for wastewater treatment.

Despite its northern location, with temperatures dropping to -40°F in wintertime, the plant does not experience any major cold weather problems. Ice does form on the surface of the ditch but it does not interfere with treatment, although the ice once built up to 4 in. thick during 21 successive days of subfreezing weather. A heat lamp is used to keep the rotor aerator free of ice. However, the paddles on the rotor were occasionally damaged by chunks of ice that broke loose and were struck by them. The problem was solved by installing a large screen in the ditch before the rotor to keep floating ice away from the paddles.

The secondary clarifiers are covered by corrugated steel panels during the winter. The panels rest on cross-members over the clarifiers. These panels are laid horizontally and have no difficulty in withstanding the winter snow loads. In fact, snow, acting as insulation, is desirable on top of the panels. Sampling is done through a small removable panel. During the winter, the second 1-million-gal. clarifier is used as a sludge storage lagoon. Sludge is stored here until it can be removed by truck on warm days.

Franklin, New Hampshire

A feature of this plant that makes it resistant to cold weather problems is its diffused aeration system. Plant operators estimate that the temperature of the mixed liquor never falls below 9°C (48°F). The mixed liquor is warmed in part by the diffused air (which in some plants can be as high as 140°F). Diffused aeration systems reduce the rate of heat loss by reducing the total amount of mixed liquor exposed to the surrounding air. Mechanical aerators splash the mixed liquor through the air, causing rapid cooling. Many operators will run mechanical aerators as little as possible, thereby reducing the cooling of the liquor.

Hampton, New Hampshire

Cold weather problems have been encountered with the operation of the

aeration tanks and the secondary clarifiers at this conventional activated sludge plant.

During the winter months, there is some icing on the splash plates in the aeration tanks. The mechanical aerators at the plant can only be operated at a single speed, but sometimes tripping the aerator on and off will free the ice. If this is not successful, the ice must be removed by hand. If the speed of the aerators could be varied, the ice might be freed by running the aerator on the highest speed for a short time.

This plant had two cold weather problems in the secondary clarifiers. Greasy foam from the large number of restaurants on the beachfront has been a constant problem in the clarifiers. During the winter, the foam would build up and freeze on the scum beach. If the ice buildup was excessive, the skimmer arm would hang up on the beach. Foam would also build up in the scum trough and the scum lines. In the winter, the trough and lines would become blocked and freeze. So far, the only solution to the ice buildup on the beach is to remove the ice by hand. Sometimes the skimmer must be removed so that it won't be damaged, but the operators do not like to do this because of the continuing foam problems. Freezing and blocking of the scum trough and lines have been solved by flushing the trough once every revolution of the collector arm. The plant staff has constructed a device that is tripped by the collector arm, and flushes wastewater into the trough from a hole on the side of the trough. The amount of water flowing into the trough is adjusted by use of counterweights on the trip bar (Fig. 4).

Henniker, New Hampshire

This facility is an extended aeration plant with surface aerators and adjustable weirs. During cold weather it was difficult to control the Dissolved Oxygen (DO) and the high DO resulted in reducing the alkalinity and pH. Originally, there were no timers on the aerators, as the manufacturer stated that placing the aerators on timers might damage the bearings in the gear boxes. For the past 4 years, however, the aerators have been placed on timers and the weir is placed in the middle position to ensure adequate mixing. In addition, during cold weather one-third of the aerator blades are removed. This is the maximum recommended by the manufacturer. The net result is that during the winter months DO is more closely controlled and the reduced alkalinity and pH problem is now lessened. Because

of less aeration, the temperature of the mixed liquor does not drop as low as it had previously. There has been no apparent damage to the bearings to date.

Another problem had been ice bridging between the support tower and the surface aerator, which would cause enough drag resistance to shut down the drive motor. Initially, this was solved by running a hose with cold water on the blade support and this prevented the solid ice mass from forming completely. High winter flows have since cured this problem and the running of water onto this unit is no longer necessary.

Manchester, New Hampshire

This conventional activated sludge facility became operational in 1978 and has experienced several cold weather problems.

The septage handling facility at this plant typically receives 25 to 30 truckloads per day. During the winter, ice builds up after dumping and hosing down of the area. Although this problem is a nuisance and can cause safety related problems, it does not seem to disrupt the treatment process in any way. This is not a problem during warm periods.

In the winter, water would condense and freeze inside the gear boxes of both the primary and secondary clarifiers. To correct this problem, heat tapes were installed on the drain lines of the gear boxes. The lines are purged each shift to remove any water that may have collected.

Another problem encountered with both clarifiers is scum freezing on the beaches and in the scum trough. When the buildup becomes excessive, the beaches are shoveled out and flushed by hand. Flushing hoses are used frequently to clean the scum beaches, distribution box and aeration tank shrouds and impellers. These hoses tend to freeze up, so they must be left on a bit to stop freezing.

There is some icing on the impellers and shrouds in the aeration tanks. The ice often bridges the gap between the support pillars and impeller shroud. A partial solution to this problem has been to run the surface aerators on high speed for 15 minutes. The vibrations caused by the drive and the force of the thrown water are often enough to clear the ice. If this technique is not successful, the ice must be removed by hand with ice chisels. The combined storm and sanitary system in Manchester results in wastewater temperatures of 45°F (7°C) in February and March, with short-term temperatures as low as 41°F (5°C) during melting events.

These low wastewater temperatures compound the icing problems.

During the winter, about half of the aeration tanks are routinely empty. If the tanks are not cared for, ice builds up on the bottom, which can cause failure of the cables supporting the anti-vortex baffle boards. The problem is solved by keeping the tanks filled above the level of the baffles. A small sump pump is lowered 1 ft below the surface to keep the water moving and prevent complete freezing of the surface.

The grated covers of the channels between the primary and secondary units become frost covered in cold weather. The walkways are then slippery and hazardous; however, sunshine on clear days is able to remove the frost.

Montague, Massachusetts

This new activated sludge facility has the entire headworks indoors and therefore has no winter problems with these units. Cold weather problems were encountered with the scum collection pit for the primary clarifiers. This is an open concrete sump and the floating grease and scum would freeze. Plywood covers were fabricated for this sump, alleviating the freezing problem.

In the secondary clarifier, a scum area would form and freeze in the center feed area. This was solved by mounting a spray nozzle directed to wash the scum toward the tank periphery where it was constantly skimmed.

At this plant, the operators normally changed gear oil in the drives on the primary clarifiers, aeration tanks and secondary clarifiers seasonally. This is a time-consuming job as some of the gear boxes drain slowly and contain up to 20 gal. of oil. After the equipment warranty period was up synthetic oils were used. These are multiviscosity, year-round lubricants and have not been changed for over 1 year, saving much labor. The operators anticipate a financial benefit, depending on how long oils are used before changing.

This facility has enclosed low lift screw pumps. To prevent freezing, those pumps are alternated hourly during the winter months.

South Portland, Maine

This is a conventional activated sludge facility that uses composting to process almost half of its sludge.

The screw-type grit conveyors in use at this plant are heated by a blower to reduce icing. However, the outlet end of the screw does not get heated and ice builds up, often freezing the conveyor. Although styrofoam

has been placed at the open end of the conveyor to help insulate it, some icing still occurs. The delivery end is totally exposed to the weather, but because of its location, it does not seem possible to cover this end. The grit hoppers are located outside and therefore freeze. They cannot be emptied when frozen, so they must be stored in a heated garage for 3 days to thaw out before they can be dumped.

The original design of the grit chamber was such that air could flow through the chamber causing freezeup at the water line. The operator has modified the chamber by putting in a sill and rubber curtain at the outlet trough. The sill maintains water levels while the curtain cuts off air flow.

A plant water line in the grit house froze on cold days even though it was insulated. The line has now been boxed in with more insulation that extends 2 ft below grade. The boat-type flow measuring float regularly ices up in cold weather. It is necessary to remove the ice every day, either by breaking it off or by melting it with hot water. The composite sampler freezes even though the sample jar motor and drive unit are inside a glass house perched above the inlet trough. The endless chain goes down through a 12 in. tube that ends above the water surface. The chain freezes at the exposed end of the tube. This problem has been solved by ducting heat into the tube to melt the ice.

The single-speed surface aerators at this plant do not have splash shrouds. In cold weather, ice builds up on the impeller blades and surrounding walkways. The aerators are never shut off in winter because the operators feel that the rapid growth of ice from the platform to the impeller would lock up the impeller. The sludge return lines in the aeration tanks occasionally freeze at a 90° bend. The effluent well lines regularly freeze because they are used infrequently. In-tank return lines are used instead to feed the units.

The entire sludge composting operation freezes in the winter, since it lacks any heating system. The composting is currently used only during the summer months, but it will be redesigned in the future to make year-round use possible. The inside of the totally enclosed facility becomes frost coated, and all water lines must be drained in the winter to prevent freezing. The new chip silo freezes so that no chips can be removed. The bucket elevator that carries chips to the silo freezes on the bottom so that the buckets cannot clear the bottom sprocket. The conveyor systems,

which are supposed to feed used chips, sludge and new chips to the pug mill, freeze up. The old chips freeze after being taken from the fresh compost.

Wastewater is degrittied at four pump stations ahead of the plant intake. Grit at these pump stations is conveyed to a dumpster stored in a small shed. One wall of the shed is constructed of open concrete blocks, and this open grillwork allowed the grit to freeze solid in the dumpsters. Plywood has been attached to the inside of the wall to cut down the flow of cold air. The door of the wetwell is kept open to provide some heat in the shed; however, moisture from the wetwell now causes a condensation problem in the sheds.

Winchester, New Hampshire

The oxidation ditch at this plant is open and therefore susceptible to icing during the winter. However, the entire surface of the ditch has never frozen over. A timber plank is placed partially submerged across the ditch to stop pieces of ice from traveling into the rotor and damaging the rotor paddles. Ice also builds up on the rotor shroud and interferes with the operation of the rotors. The paddles strike the ice chunks and are bent or broken. They can be straightened only once; at the second attempt they break off. Three to four of the 29 rows of paddles must regularly be replaced each year.

An attempt to reduce oxygen transfer during the wintertime has helped to also reduce the icing problem. Twelve rows of paddles were removed, which made deeper submersion of the rotor possible. Ice buildup on the shroud was less of a problem with the rotor in this position. This plant has two ditches with rotors but usually only has one unit in operation at a time. The units are alternated so that each rotor can be serviced and each ditch cleaned regularly.

The secondary clarifiers are covered, eliminating most cold weather problems. Ice has formed infrequently on the surface of the clarifiers, but their operation was not disrupted. The peripheral feed scum pits located outside the dome freeze regularly. For some unknown reason, mixed liquor temperatures were higher than usual in 1983. Temperatures normally drop to 32°F but this winter they did not fall below 39°F. Influent temperatures and all treatment processes have remained the same, which does not explain the temperature change.

Freezing of the sludge holding tanks has been the most disruptive cold weather problem. Disposal of sludge is difficult during the winter. The sludge beds are unheated, causing the sludge to freeze, so that the beds cannot be emptied until springtime. If there is a break in the sludge lines it aggravates an already difficult situation. Draining of all the sludge lines after use has prevented most freezeups.

This plant has had problems with droplets freezing in the sample tube or internal chambers of its automatic sampler. A small lightbulb was installed inside the sampler to solve this problem.

APPENDIX B: BIBLIOGRAPHY FOR CIVIL ENGINEERING PROBLEMS

Thermal aspects of building design and construction

ASHRAE (1981) ASHRAE Guide and Data Book. New York: American Society of Heating, Refrigeration and Air Conditioning Engineers.

ASHRAE (1982) ASHRAE Handbook of Fundamentals. New York: American Society of Heating, Refrigeration and Air Conditioning Engineers.

Hutcheon, N.B. and G.O.P. Handegord (1983) Building Science for a Cold Climate. New York: John Wiley and Sons. 440 p.

Snow loads on roofs and other structures

ANSI (1982) Minimum Design Loads of Buildings and Other Structures. New York: American National Standards Institute Inc. 100 p.

Baker, M.C. (1980) Roofs - Design, Application and Maintenance. McGill College, Montreal, Quebec: Multiscience Publications Ltd. 362 p.

Tobiasson, W. (1980) Roofs in cold regions. U.S. Army Cold Regions Research and Engineering Laboratory, Miscellaneous Paper 1408.

Snow and ice removal

Gray, D.M. and D.H. Male (1981) Handbook of Snow: Principles Processes, Management and Use. New York: Pergamon Press.

Minsk, L.D. (1974) Minimizing deicing chemical use. In Synthesis of Highway Practice 24, National Cooperative Highway Research Program. Washington, D.C.: Transportation Research Board.

PWS (current Year) Public Works Annual Manual. Section B-7. Snow and Ice Control. Public Works Corporation, 200 S. Broad St., Ridgewood, New Jersey 07451.

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