ACRP

FACT SHEETS

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Deicer Treatment Technologies

TRANSPORTATION RESEARCH BOARD
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FACT SHEETS

Deicer Treatment Technologies #101–111

ACRP Report 99

Guidance for Treatment of Airport Stormwater Containing Deicers

AIRPORT COOPERATIVE RESEARCH PROGRAM 2013

On-Site
Biological Treatment
Aerobic

FACT SHEET 101

Activated Sludge

1. Description

Process Description

Activated sludge is the most common technology used in municipal wastewater treatment plants and has been applied successfully at airports to treat deicer-affected stormwater. The process uses aerobic bacteria to convert the deicer compounds into more bacteria, carbon dioxide, and water. To support the conversion process, the bacteria also require oxygen and nutrients. Within the broad category of activated sludge, there are numerous technology variations and adaptations, but all activated sludge systems incorporate the basic elements described in the following.

The activated sludge process is made up of two primary components: an aerated basin and a biological solids removal unit, typically a clarifier. Deicer-affected influent is pumped into a large aeration basin that contains suspended bacteria (biomass). For nutrient-deficient influent such as deicing-affected stormwater, nutrients are fed to the basin to stimulate biological growth. Oxygen is added one of two ways: by mechanical surface aerators or by compressors blowing air into the bottom of the basin. Treated effluent leaving the aeration basin flows through a clarifier, which removes the bacterial solids.

Although activated sludge is used in many municipal and industrial wastewater treatment plants, the following unique characteristics of deicer-affected stormwater result in the need to adapt traditional activated sludge design to the treatment of deicer-affected stormwater:

- Highly variable influent flow rate and COD concentration.
- Generally high COD influent concentrations and mass loads.
- Potential for low water temperatures.
- Inadequate nutrients (normally present in municipal wastewater).

Municipal activated sludge plants typically use flow rate as the primary basis-of-design parameter because the COD concentrations and flow rates of sanitary wastewater are relatively consistent. The COD concentration of airport stormwater may be 5 to 200 times greater than the COD concentration of sanitary wastewater. Flow rates from collected deicer-affected stormwater can vary similarly.

While a traditional activated sludge system with large aeration basins has some capability to absorb variation in flows and COD mass loading, the operation of an activated sludge system is optimized if storage and equalization are upstream of treatment or if mass loading rates into treatment are controlled to minimize variation. Equalization and load control promote a less variable and healthier bacterial population, which aids in the consistency of effluent quality and reduces the chance that system upsets will affect compliance.

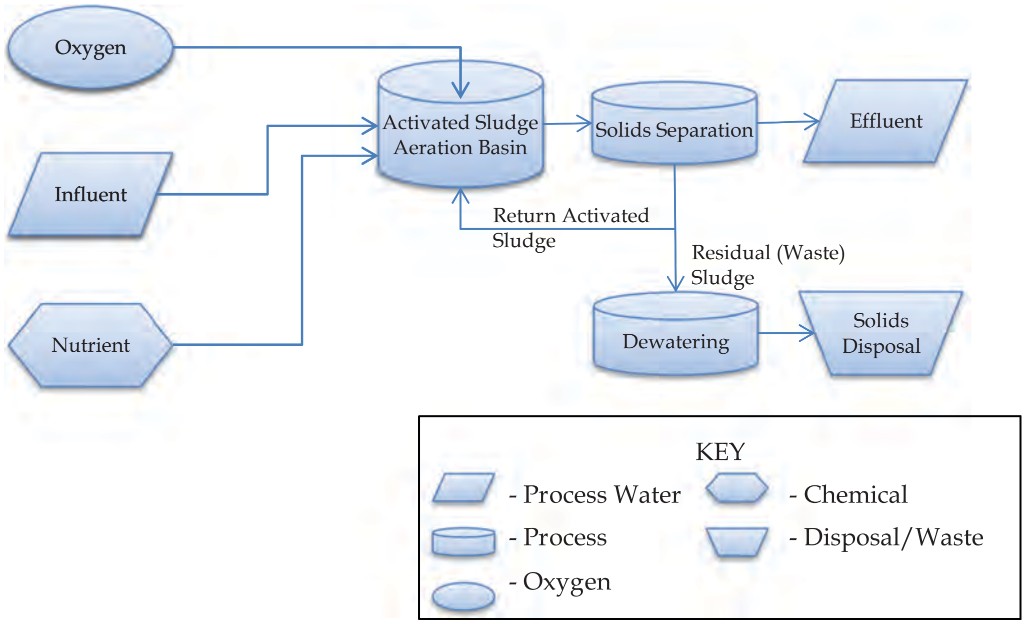


Figure 1. Activated sludge process flow chart.

Most municipal activated sludge plants benefit from warm influent wastewater (domestic sewage) that provides a positive environment for the bacteria. Airport stormwater containing deicer is typically much colder. Since bacteria grow slower in colder temperatures, the sizing of aeration basins and aeration capacity needs to account for the level of bacterial activity at cold temperatures.

Deicer-affected stormwater is virtually devoid of the nutrients (nitrogen, phosphorus, and minerals) that are needed to support the growth and sustenance of a large bacterial population. Nutrients similar to fertilizer (nitrogen, phosphorus, and other compounds) must therefore be added to the influent entering activated sludge aeration basins to stimulate the new bacterial growth. The nutrient addition rates must be paced with the COD mass loading rates (typically expressed as lbs or kg COD/day). Adding enough nutrients to allow bacterial growth without producing nutrient concentration in the treated effluent that exceeds permit limits is one of the principal challenges of operating an activated sludge system to treat deicer. Frequent monitoring of effluent nutrient concentrations and frequent addition of nutrients are required.

Cold weather, inadequate nutrients, long bacterial ages, or other factors that upset the bacteria in the aeration basin may cause the growth of types of bacteria that do not settle well and are therefore not removed sufficiently in the clarifier. When this occurs, biomass (i.e., treatment capacity) is lost from the system, and the effluent will contain a high concentration of suspended solids.

In the aeration basin, bacteria must be well mixed and supplied with sufficient oxygen. The mixing and oxygen are often supplied by the same source: either mechanical mixers or diffused air pipe networks at the bottom of the basin. There is some thought that heated air from blowers has a slight impact in raising the water temperature in the aeration basin. However, evaporative cooling in the bubbles rising in the water diminishes this impact.

Because the activated sludge process converts the deicer compounds primarily to new bacteria cells, the treatment system generates excess bacteria (sludge) as a waste product. The sludge collected from the clarifier has a very high fraction of water (99% water versus 1% solids is typical). To reduce the volume and weight of the sludge being disposed of, a dewatering process is an important support system for activated sludge systems that do not discharge solids to the sanitary sewer. A general rule of thumb is that the volume of sludge produced in an activated sludge system is approximately 10 times more than in an anaerobic treatment system. The high volume of sludge to process from an activated sludge system is one of the principal disadvantages of this technology.

The activated sludge process needs a bacterial population in the aeration basin for treatment to begin. Therefore, during the start-up of the system in its first season of operation, the process must be seeded with an appropriate bacterial population. At the end of the deicing season, if the deicer, oxygen, or nutrient supplies are shut off, the bacterial population will begin to die off. The die-off will reduce the amount of biomass, which reduces the treatment capacity. In addition, during periods in which deicer is not added, deicer-consuming bacteria will be consumed by other bacteria, decreasing the overall population through die-off. The decay of the bacteria will release nitrogen and phosphorus back into the effluent, and provisions may be needed to control the ammonia and orthophosphate concentrations in the effluent during this period.

At the start of each successive deicing season, the biological population needs to be re-established. This can be accomplished by reseeding with an outside source from another wastewater treatment plant or by regrowth of the population using the remaining bacteria in the basin. It the reseed source is a municipal sludge, it may take some time for the bacterial population to acclimate to the treatment of deicer constituents. Operators of deicer activated sludge systems have experimented with various ways to increase the population of viable bacteria that remains at the end of the summer season, including continued aeration, continued nutrient addition, and addition of an outside source of carbon such as

Figure 2. Activated sludge aeration basin.

off-spec deicer. While this continued operation in summer can eliminate the need for reseeding with an outside bacterial source, it can be costly.

Advantages

1. Well-understood process with readily available operator pool.
2. Biogrowth is rapid, such that treatment capacity increases quickly after start-up, relative to other treatment technologies.
3. Able to achieve very low effluent concentrations, in the range of less than 30-mg/L COD.

Disadvantages

1. High operating costs (utility costs for aeration, high nutrient demand, high volume of sludge for disposal).
2. Must reseed each season or keep bacteria alive by operating over the summer, potentially with an added carbon source like off-spec deicer.
3. Increased ammonia and phosphorus concentrations in effluent at end of treatment season.
4. Managing the various unit processes (influent feed variation, nutrient addition, return sludge, aeration, wasted sludge) can be complex.

Required Support Systems

1. Aeration system
   a. The aeration system provides oxygen for the aerobic bacteria and for mixing. Aeration system sizing dictates the mass loading rate of the system.
   b. The equipment can be either surface mixers or blowers and an air-piping network.
2. Nutrient feed system
   a. Provides nutrients, mixing and storage tanks, and metering system typically paced to COD loading.
   b. Nutrient solution must be prepared on-site by airport staff or sourced from a third-party provider. (Nutrient feed may be solutions of various orthophosphate compounds and ammonium salts or urea.)
   c. The equipment typically includes mixing/storage tanks and metering pumps.
3. Sludge handling system
   a. Reduces sludge volume and costs for disposal; typically clarifier sludge concentrations of 0.5% to 1% are increased to 8% to 20% solids concentration, reducing the volume by a factor of 6 to 10.
   b. Equipment may include digesters, centrifuges, belt presses, and filter presses.
4. Analytical and control system
   a. Routine measurement of influent flows and concentrations for COD and nutrients are required to determine system loading, nutrient, and aeration requirements.
   b. Equipment may include online monitors or analytical test kits.
   c. Use of supervisory control and data acquisition (SCADA) system with programmable logic controllers is recommended for more stable operation.

Current Applications of Activated Sludge Technology

Installed Systems:	Cincinnati–Northern Kentucky Airport (CVG) – Extended Aeration
	Nashville International Airport (BNA) – Extended Aeration
	Frankfurt International Airport (FRA) – Sequencing Batch Reactor (SBR)

Variant Technologies

Extended aeration activated sludge is a variation of the standard activated sludge process. It uses a larger aeration basin to provide extended hydraulic and solids retention times. This provides somewhat more protection against the variation in influent flows and mass loads common with deicing applications. In this technology, achieving uniform COD loading, nutrient loading, aeration, and mixing can be a challenge.

SBRs incorporate the aeration basin and clarification step into one tank. SBRs use a fill-and-draw methodology where treatment occurs in steps. Influent is added as a batch and then shut off during the aeration step. In the subsequent step, the aeration is shut off and the biomass settles. The treated water is then drawn off the top, and the process is restarted. Multiple tanks are used so that influent can be routed continuously to treatment. One potential issue that could arise with SBR systems relates to the difficulty in optimizing the solids settling phase since solids removal does not occur in a distinct unit process. For example, polymer cannot be used to aid in settling. If non-settling bacteria develop in the aeration tank due to a process upset in an SBR system, the effluent quality will be difficult to control.

Membrane bioreactors (MBRs) are also a variant of the activated sludge process. At the discharge end of the aeration basin, membranes are used to filter the effluent and keep the bacteria in the basin. There are no clarifiers in the MBR system, and the bacteria can be maintained at a higher concentration. This results in a smaller footprint for the basin. However, membrane installation, maintenance, and replacement costs may make this technology economically infeasible for airports. MBRs are especially affected by cold temperatures as the high-viscosity water slows down the flow rates through the membranes, resulting in the need for more membranes and a higher system cost. This cold weather consideration makes the use of MBRs a challenge for treating deicer-affected stormwater.

2. Data for Technology Selection Process

The information in this section can be used in conjunction with the methodologies presented in Chapter 4 and Chapter 5 of the guidebook to facilitate the assessment and selection of deicer treatment technologies.

Potential Applications

The activated sludge process is typically applied where COD influent concentrations are less than 10,000 mg/L. The activated sludge process is capable of achieving COD concentrations of less than 30 mg/L. Typically, however, the maximum COD concentration in deicer treatment systems is not a limiting factor. Activated sludge systems for deicer treatment are more likely to become limited by COD mass loading limits (lbs or kg/day) associated with insufficient biomass, insufficient nutrients, insufficient mixing, and insufficient aeration. Low temperatures cause lower treatment rates per unit of bacteria mass, and as such, at low temperatures there may be insufficient biomass to treat the desired COD load. There are few inherent limitations on flow rate through an activated sludge system, provided that the aeration basins are large enough to meet hydraulic detention time needs.

This combination of characteristics makes activated sludge best suited to treat more dilute, high-volume flows, such as runoff from larger airfield deicer application areas.

The data provided in this section are based on the most typical composition of the activated sludge technology, which includes a nutrient feed system, an activated sludge aeration basin, an aeration system, and a solids separation system for removal of biological solids from the effluent. Effluent concentration data represent the optimal potential performance based on collected field data (when available). Other variations of the activated sludge system may provide different results. In addition, the characteristics of individual influent stormwater streams and operational decisions may affect the performance on a site-by-site basis.

Criteria Useful in Screening Analysis of Potential Treatment Technologies

See Table 1 for activated sludge process selection criteria.

Table 1. Activated sludge process selection criteria.

Technology Parameter	Value or Rating	Description
Most applicable influent streams	Dilute Streams	Most applicable to streams with COD concentrations of less than 10,000 mg/L, although systems should be sized based on COD mass loading rate (lbs or kg/day), not COD concentration.
Minimum COD concentration	None	Not limited by low COD concentrations.
Typical area (footprint)	<1 acre	Majority of footprint is open aeration basin and clarifier.
Typical building/ equipment height	<20 ft	Building will house sludge handling equipment, which can make the building slightly taller than 10 ft.
Open water surface	Open water	Open water aeration basins and clarifier.
Reliance on other entities	No reliance	With proper application and sizing, the technology is capable of meeting effluent limits for BOD, COD, PG, and EG found in most NPDES permits. Therefore, reliance on other entities for compliance is minimal.
Maximum capital funding	See Figure 3	
Maximum annual O&M funding	See Figure 4	

Criteria Useful in Comparative Analysis of Other Treatment Technologies

See Table 2 for activated sludge effluent concentration information and Table 3 for activated sludge selection criteria.

Technology-Specific Application Considerations

1. Typical and minimum stormwater temperature
   Cold stormwater temperatures will reduce the mass of COD removed per unit mass of bacteria. The most critical condition occurs when the water

Table 2. Activated sludge example effluent concentrations.

Parameter	Concentration or Value	Description
COD	10–30 mg/L	Based on post-clarifier operating data.
NH_3-N	Not available	Fed as a nutrient but controlled to 1–5 mg/L.
Ortho-P	Not available	Fed as a nutrient but controlled to <1 mg/L.
Flow	Varies	Flow rate varies with application.
pH	Varies, but near 7.0	Near 7.0 for optimum rate.
DO	Varies based on design	Typically about 4 mg/L.
TSS	Varies, < 30 mg/L with clarifier	Solids are primarily biological and are assumed to be removed in clarifiers or discharged to the sanitary sewer.
TDS	Same as influent	Some salts may be temporarily taken up by biomass.
Temperature	Ambient	If influent is warm, will cool to ambient air temperature.

Table 3. Activated sludge selection criteria.

Effects of presence of fuels	Free-product fuel spills will inhibit bacterial growth. Dissolved fuel components may be partially treated.
Effects of presence of metals	Inhibition of aerobic bacteria occurs at high concentrations, but this is not an issue in typical airport runoff.
Susceptibility to fouling and clogging	Grit removal and screening are recommended before aeration basin to avoid solids buildup in basin.
Site contamination	Consideration must be given to existing site contamination because aeration tanks are generally excavated.
Utility requirements	Requires electrical, water utility, and communications connections.
Effects of groundwater conditions	Groundwater within approximately 10 ft of the surface may affect system design if basins or clarifiers are partially buried.
Treatment plant operation needs	Treatment plant operation requires understanding of multiple unit processes and requires engaged operation by one to two experienced, well-trained wastewater treatment operators.
Time required for design and construction	Design and construction typically require 12 to 18 months.
Accessibility	Accessibility required for delivery of nutrient chemicals and sludge removal.

temperature is less than 41°F. The most effective means for compensating for cold temperatures is providing for a large enough total mass of bacteria to withstand the decreased efficiency of individual bacteria in the cold.

2. Range of COD concentrations
   The treatment system operates most efficiently when it receives a more constant load (lbs per day) of COD. COD concentration is not a significant design and operation factor if influent flow rates are lowered to compensate for high concentrations and influent flow rates are raised to compensate for low COD concentrations. (This achieves a constant COD mass loading.)
3. Flow rate
   Peak design flow rates through an activated sludge system typically need to be limited to values that do not result in hydraulic retention times of less than 2 to 3 days. At less than 3 days, washout of the bacteria from the aerated basin to the effluent can occur, resulting in reductions in treatment capacity.
4. Solids management
   The amount of sludge produced and the desired disposal solids percentage will dictate the sludge handling method.
5. Over-summering of the sludge
   Since the majority of the biomass will not survive through the summer, the method for restarting the treatment must be considered. Methods that have been successfully used are reseeding in the fall or feeding deicer, or another carbon source, to the system prior to the start of the deicing season.

Costs

The order-of-magnitude cost curves shown in Figure 3 and Figure 4 are based on the probable construction costs and operation and maintenance costs for typical treatment facilities in June 2012. The capital cost curves reflect the unit processes that are most typically needed to execute the core technological functions. Individual airports may incur additional costs, beyond those determined from these curves, for support system items (e.g., a building to house the system) based on site-specific needs and owner preference.

The intent of these graphs is to provide order-of-magnitude costs for comparison purposes during the treatment technology screening process. These costs are considered ANSI Class 5 cost estimates. For final selection of technologies and design, costs should be developed for the site-specific conditions.

A 20% uncertainty contingency has been added to capital costs to reflect the detail accuracy of the estimate. Typically, the expected accuracy within the industry of an estimate at the conceptual stage of a project ranges from between –20/–50% to +30/+100% of the final cost of the project. Since site-specific conditions have not been considered, the actual site-specific costs may be outside of this range.

The chart shown in Figure 3 can be used to understand order-of-magnitude costs for the core unit processes for activated sludge technology applications. The core unit processes and systems incorporated into the Figure 3 costs include:

- Land acquisition,
- Aeration basin and aeration equipment,
- Nutrient feed system,

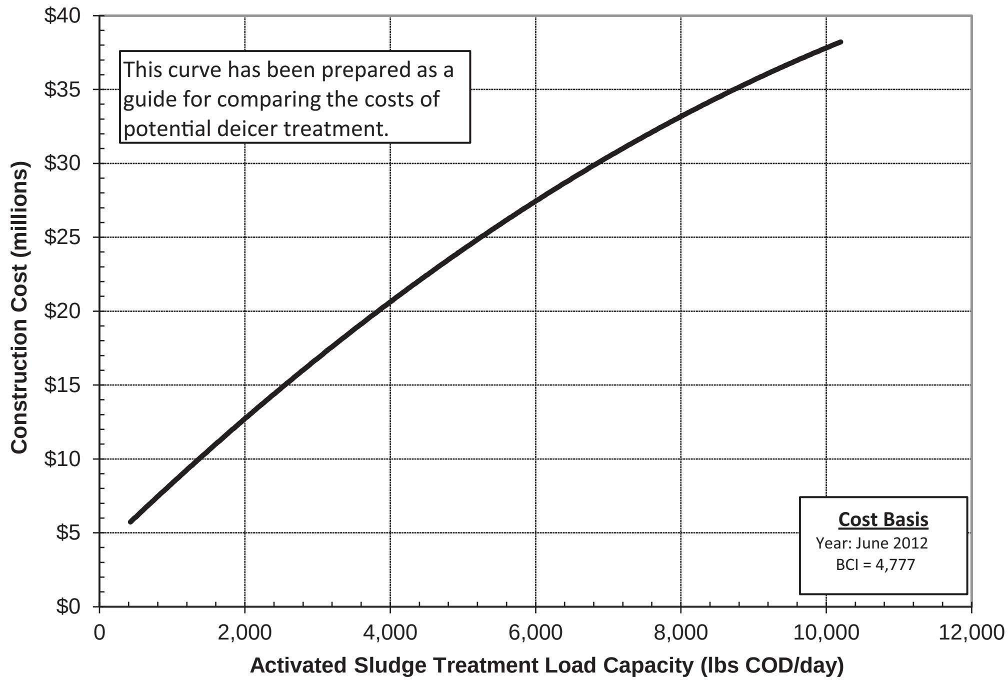


Figure 3. Capital cost curve.

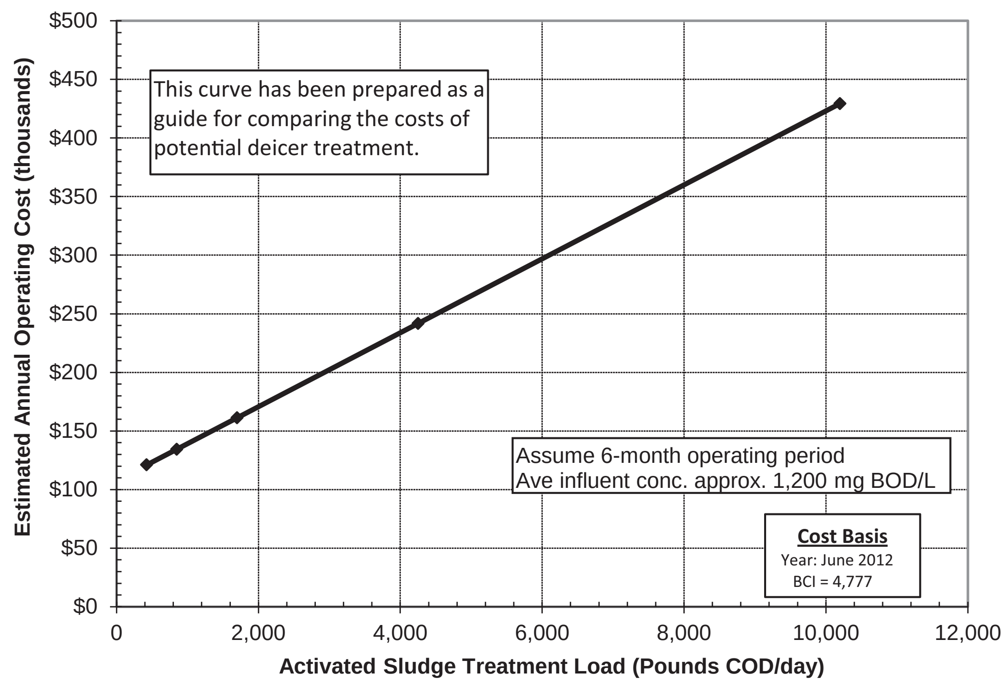


Figure 4. O&M cost curve.

- Clarifier and return sludge system,
- Sludge thickening,
- Electrical and control systems, and
- Operator building.

Potential additional activated sludge support systems excluded from the Figure 3 costs include:

- Storage/equalization,
- Influent pumping system, and
- Sludge dewatering and storage.

Figure 4 provides a means of understanding the order-of-magnitude annual operating costs for an activated sludge deicer treatment system. The major operating cost items incorporated into the Figure 4 costs include:

- Labor (two operators),
- Sludge disposal,
- Utilities (power, communications), and
- Nutrients.

The utility costs for mixing and oxygen supply are one of the largest operational costs of the system.

FACT SHEET 102

Aerated Gravel Beds

1. Description

Process Description

The aerated gravel bed is a hybrid system that combines key facets of engineered wetlands and aerated lagoons. The system is biological in nature and relies on aerobic bacteria to degrade glycols and other deicing compounds. From a wastewater treatment perspective, the system is a lightly loaded, aerobic, submerged, attached-growth system. For nutrient-deficient influent such as deicing-affected stormwater, nutrients are fed to stimulate biological growth. The main components of the system are shown in Figure 1.

In an aerated gravel bed system, influent flow is pumped through a distribution tubing network at the top of the bed. The water travels downward through the gravel bed and is collected by perforated drain lines at the bottom of the bed. The collection lines are connected to an effluent hydraulic control structure that controls the elevation of the water in the bed. The water level is maintained to keep the process water just under the surface of the aerated gravel bed, thereby submerging the gravel but preventing the occurrence of exposed water on the surface. Aeration lines cover the bed floor and supply air bubbles to the gravel, which maintains aerobic conditions for the bacteria. The treatment bed is lined with an impermeable liner, similar to those used for aerated lagoons. The final grade is matched with the ground elevation and covered with mulch and grass.

COD loading to the system is limited by a mass flux of organics (lbs COD/ft^2/day) to the system's surface area. This means that the treatment capacity is directly proportional to the footprint. Additionally, process flows are controlled in inverse proportion to influent concentration in order to maintain a relatively constant mass loading rate. (Large volumes can be treated when pollutant concentrations are low; however, only low volumes can be treated with high concentrations.) The aerobic bacteria responsible for treatment accumulate over the deicing season and are aerobically digested in situ during the off-season.

Compressed air blowers typically provide aeration of the gravel. The aeration provides the required oxygen. Compressed air blowers do not significantly heat the water. Although the compressed air is warm, evaporative cooling that occurs in the bubbles actually negates heating by the warm air.

The treatment process uses a bacterial population for treatment. At the end of the deicer season, when the supplies of deicer, oxygen, and nutrients are shut off, the bacterial population will begin to die off. The die-off will reduce the amount of biomass, which reduces the treatment capacity. Some biomass will typically be available at the beginning of the next deicer season, and an approximately 1-week start-up period is typically required to regain the treatment capacity.

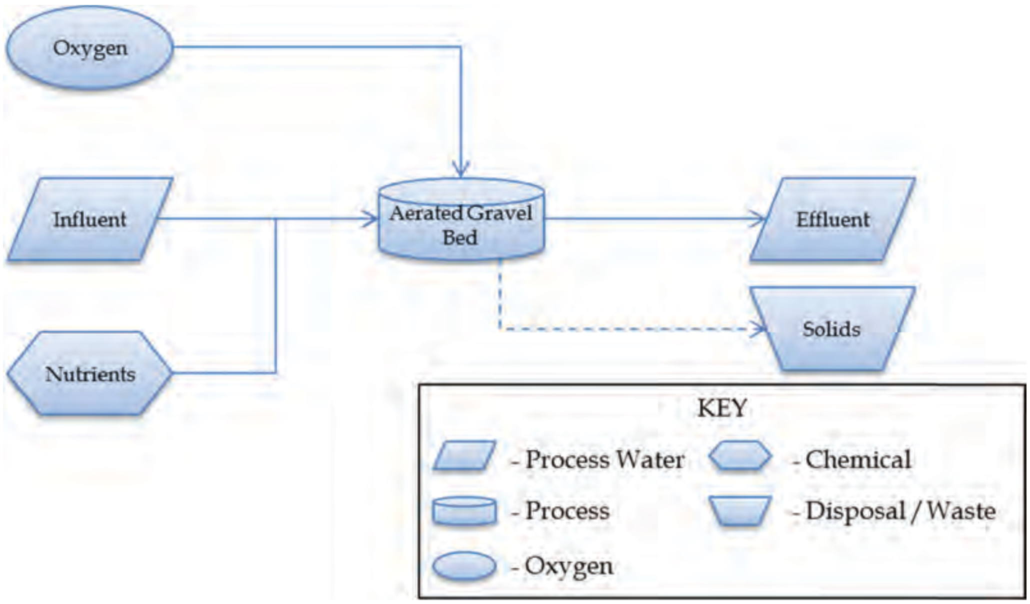


Figure 1. Aerated gravel bed process flow chart.

A photo of the aerated gravel bed system at the Buffalo Niagara International Airport (BUF) during its installation is shown in Figure 2.

Advantages

1. Relatively straightforward operation, including automatic operation of pumps and manual operation of blowers.
2. Aerated, attached-growth bacteria are suitable for achieving biological treatment during periods with cold temperatures.

Figure 2. Aerated gravel bed at Buffalo Niagara International Airport (Courtesy Mark Liner).

3. Ability to achieve low propylene glycol effluent concentrations and effluent concentrations in the 40-mg/L to 90-mg/L COD range.
4. Consistent and predictable performance over a wide range of influent concentrations if loading into the treatment system is controlled.
5. Underground construction allows installation on unused airside land.

Disadvantages

1. Potentially large land area required.
2. Influent concentrations of greater than 9,000-mg/L COD result in relatively low water volumes treated.
3. Overloading of system may result in biological plugging of gravel beds.
4. Challenge in matching nutrient feed to nutrient needs.
5. Nutrient deficiency will result in system upset.
6. Cost of system is linear with size; minimal economies of scale.
7. Approximately 1 week of start-up to regrow bacteria required each year.

Required Support Systems

1. Aeration system
   a. The aeration system provides air uniformly over the floor of the beds. Aeration system sizing dictates the treatment rate (in lbs per day) of the system.
   b. The equipment typically includes blowers and an air piping network.
2. Influent dosing system
   a. The influent dosing system distributes influent flow uniformly over one side of the aerated gravel bed. Daily volumes pumped to the beds must be adjusted according to influent concentrations.
   b. The equipment includes pumps and a piping distribution network.
3. Nutrient feed system
   a. Nutrient solution must be paced into influent relative to the load of organics (COD) to account for nutrient deficiency. Online analytical equipment is required to determine the exact concentrations of organics in the influent.
   b. Nutrient solution must be prepared on-site by airport staff or sourced from a third-party provider. Nutrient feed may be solutions of various orthophosphate compounds and ammonium salts or urea.
   c. The equipment typically includes mixing/storage tanks and metering pumps.
4. Analytical system
   a. Routine measurement of influent flows and concentrations is required to determine system loading, nutrient and aeration requirements.
   b. Equipment may include online monitors or analytical test kits.

Current Applications of Aerated Gravel Bed Technology

Installed Systems:	Buffalo Niagara International Airport (BUF)
	Heathrow International Airport (LHR)
	Edmonton International Airport (YEG)
	Long Island MacArthur Airport (ISP)

Variant Technologies

The reciprocating subsurface treatment system process is a variation of the aerated gravel bed. Rather than blowing air into the bottom of the gravel bed, bacteria is supplied oxygen by exposure of the gravel bed to air. Reciprocating subsurface systems are designed with cell pairs, and water is pumped in a batch mode, back and forth from one cell in the pair to the other. At any given point in the reciprocation cycle, the biofilm on the gravel of the empty cell is temporarily exposed to air, and the biofilm on the full cell is exposed to water. The advantages to this system over the supplied-air gravel bed are the lack of air piping buried in the soil and lower operating power costs. The primary disadvantage is the limit on treatment capacity under certain conditions when sufficient oxygen from the atmosphere cannot be drawn into the lower levels of the gravel bed.

A reciprocating wetland system was operational at the Wilmington Airpark (ILN) from 2000 through 2010 and is described in Appendix D.

2. Data for Technology Selection Process

The information in this section can be used in conjunction with the methodologies presented in Chapter 4 of the guidebook to facilitate the assessment and selection of deicer treatment technologies.

Potential Applications

Aerated gravel beds are best suited for systems that typically have concentrations of less than 10,000-mg/L COD. The system can provide a more stable operation than suspended growth systems like activated sludge and aerated lagoons, but requires more land area.

The data provided in this section are based on the most typical composition of the aerated gravel bed technology, which includes influent feed with controlled COD loading, a nutrient feed system, an influent dosing system, multiple aerated gravel bed cells operating in parallel, an aeration system, and no separate clarification system for solids removal. Effluent concentration data represent the optimal potential performance based on collected field data (when available). Other variations of the aerated gravel bed system may provide different results. In addition, the characteristics of individual influent stormwater streams and operational decisions may affect the performance on a site-by-site basis.

Criteria Useful in Screening Analysis of Potential Treatment Technologies

See Table 1 for aerated gravel bed process screening criteria.

Criteria Useful in Comparative Analysis to Other Treatment Technologies

See Table 2 for example gravel bed effluent concentrations and Table 3 for aerated gravel bed selection criteria.

Table 1. Aerated gravel bed process screening criteria.

Technology Parameter	Value or Rating	Description
Most applicable influent streams	Dilute streams	Most applicable to streams with COD concentrations of less than 10,000 mg/L, although systems should be sized based on COD mass loading rate (lbs or kg/day), not COD concentration.
Minimum COD concentration	None	Not limited by low COD concentration.
Typical area (footprint)	>1 acre	Majority of footprint is gravel beds.
Typical building/ equipment height	<20 ft	Building will typically house nutrient system and monitoring instruments.
Open water surface	No open water	Water level is maintained at below top of gravel.
Reliance on other entities	No reliance	With proper application and sizing, the technology is capable of meeting effluent limits for BOD, COD, PG, and EG from most NPDES permits. Therefore, reliance on other entities for compliance is minimal.
Maximum capital funding	See Figure 3	
Maximum annual O&M funding	See Figure 4	

Technology-Specific Application Considerations

1. Control of influent flow rates and mass loads
   Regular monitoring and measurement of influent flows and concentrations are required. The organic mass load capacity of the system (lbs COD/day) is fixed, and care must be taken to operate the system within its given capacity.

Table 2. Aerated gravel bed example effluent concentrations.

Parameter	Concentration or Value	Description
COD	50–100 mg/L	Based on 2010–2011 season average soluble BOD measured in the effluent from the Buffalo aerated gravel bed.
NH_3-N	Not available	Fed as a nutrient but controlled to 1–5 mg/L.
Ortho-P	Not available	Fed as a nutrient but controlled to <1 mg/L.
Flow	Varies	Flow intentionally varied to adjust to variable COD concentrations such that constant mass load is maintained.
pH	Varies, but near 7.0	Near 7.0 for optimum rate.
DO	Varies based on design	Typically about 4 mg/L.
TSS	Varies	Solids are primarily biological and created in gravel beds. Solids amounts are less than other aerated systems.
TDS	Same as influent	Some salts may be temporarily taken up by biological film on gravel beds.
Temperature	Ambient	Slight temperature increase through system from oxidation of organics by the bacteria.

Table 3. Aerated gravel bed selection criteria.

Effects of presence of fuels	Free-product fuel spills will inhibit bacterial growth. Dissolved fuels components will be partially treated.
Effects of presence of metals	Inhibition of aerobic bacteria occurs at high metal concentrations, but this is not typically an issue in airport runoff.
Susceptibility to fouling and clogging	Grit removal and screening (for Styrofoam peanuts, wrappers, etc.) is necessary prior to influent feed pumps.
Site contamination	Consideration must be given to existing site contamination because of excavation of gravel beds.
Utility requirements	Requires electrical utility connection. Water connection is recommended.
Effects of groundwater conditions	Groundwater within 6 ft of the surface will affect system design.
Treatment plant operation needs	Treatment plant operation is typically performed by airport personnel or by contract personnel.
Time required for design and construction	Design and construction typically require 12 to 18 months.
Accessibility	Accessibility required for delivery of nutrient chemicals.

2. Nutrient addition
   Proper nutrient augmentation is critical for this process. Both influent and effluent monitoring will permit operational staff to fine-tune nutrient addition.
3. Routine cleaning
   Influent feed lines, drain lines, and air lines must be cleaned annually during the off-season. An acid solution is used for cleaning the air lines.
4. Availability of cost-effective bed aggregate (gravel)
   The primary cost component of the system is the gravel material, and a local supply of clean, well-graded gravel material is critical to the process.

Costs

The order-of-magnitude cost curves shown in Figure 3 and Figure 4 are based on the probable construction costs and operation and maintenance costs for typical treatment facilities in June 2012. The capital cost curves reflect the unit processes that are most typically needed to execute the core technological functions. Individual airports may incur additional costs, beyond those determined from these curves, for support system items (e.g., a building to house the system) based on site-specific needs and owner preference.

The intent of these graphs is to provide order-of-magnitude costs for comparison purposes during the treatment technology screening process. These costs are considered ANSI Class 5 cost estimates. For final selection of technologies and design, costs should be developed for the site-specific conditions.

A 20% uncertainty contingency has been added to capital costs to reflect the detail accuracy of the estimate. Typically, the expected accuracy within the industry of an estimate at the conceptual stage of a project ranges from between –20/–50% to +30/+100% of the final cost of the project. Since site-specific

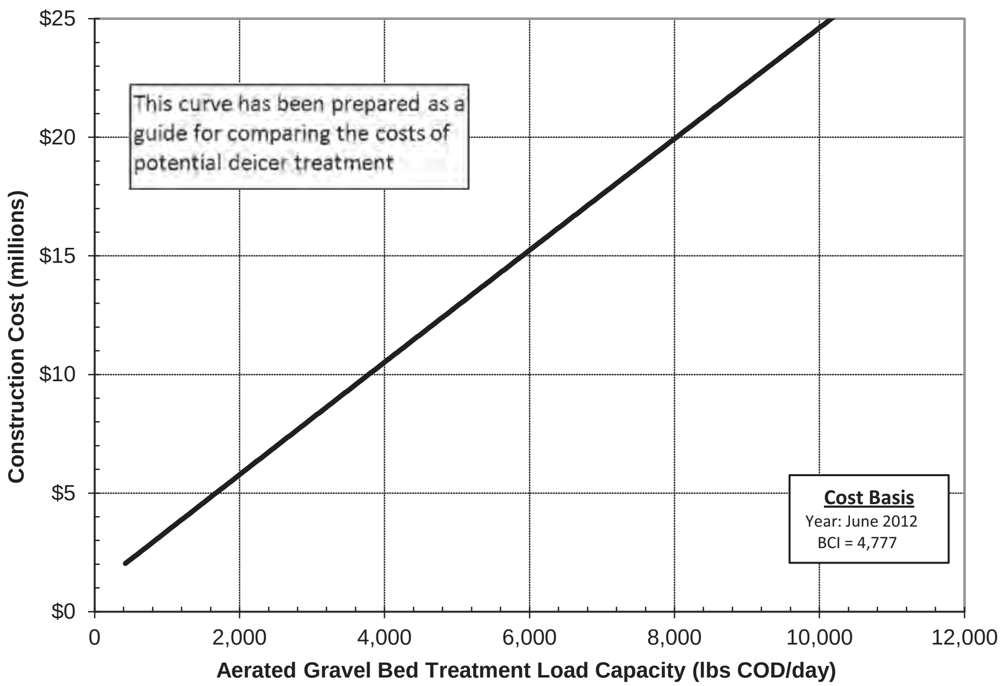


Figure 3. Capital cost curve.

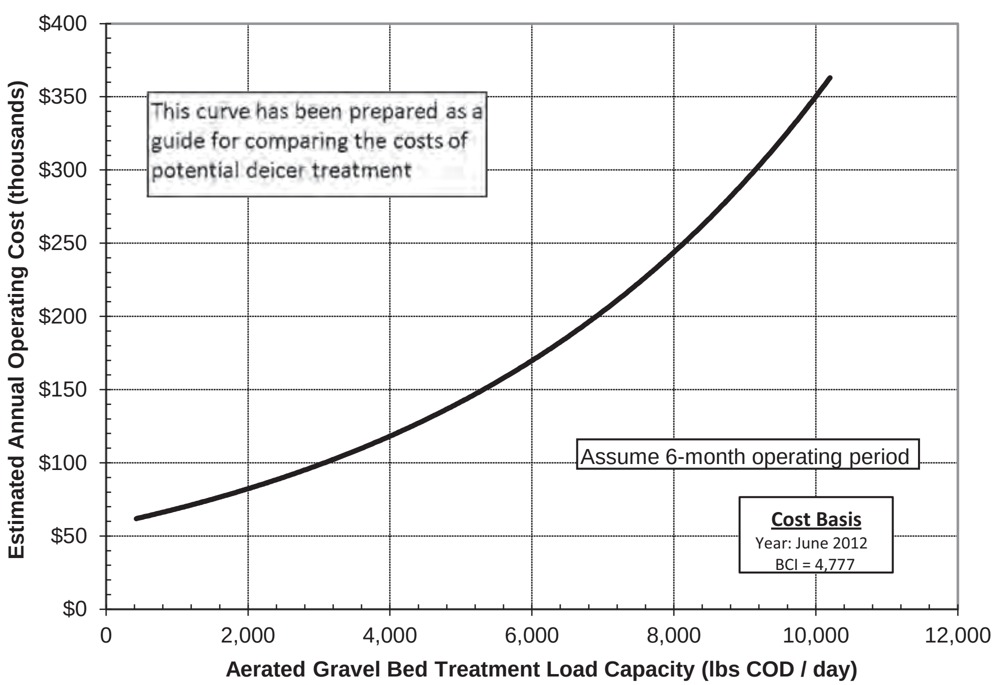


Figure 4. O&M cost curve.

conditions have not been considered, the actual site-specific costs may be outside of this range.

The chart in Figure 3 can be used to understand order-of-magnitude costs for the core unit processes for aerated gravel bed technology applications. The core unit processes and systems incorporated into the Figure 3 costs include:

- Land acquisition,
- Lined subsurface gravel bed cells,
- Aeration system,
- Influent flow distribution system in cells,
- Effluent discharge system,
- Nutrient feed system,
- Electrical and control system, and
- Operator building.

Potential additional aerated gravel bed support systems excluded from the Figure 3 costs include:

- Storage/equalization,
- Solids removal, and
- Solids storage and dewatering.

Figure 4 provides a means of understanding the order-of-magnitude annual operating costs for an aerated gravel bed deicer treatment system. The major operating cost items incorporated into the Figure 4 costs are:

- Labor (two operators),
- Utilities (power, communications), and
- Nutrients.

The utility costs for oxygen supply are one of the largest operational costs of the system.

FACT SHEET 103

Aerated Lagoons

1. Description

Process Description

Aerated lagoons are earthen basins that employ aeration systems to deliver oxygen to the lagoon water for use by microorganisms in the biodegradation of wastewater. The aeration equipment can be either mechanical (floating splash or aspirator-type units that mix the lagoon liquid with atmospheric air) or diffused (submerged diffusers with an air compressor to blow air into the liquid). The aeration provides both air and mixing to maintain bacteria, biological solids, and the organic compounds from the influent in suspension in the lagoon. The aerobic, suspended bacteria are responsible for the removal of organic contaminants (i.e., glycol), and design of the process requires the creation of a stable environment suitable for their growth. Water levels in the lagoon are kept at a consistent elevation by a hydraulic control structure (i.e., weir) at the outlet.

A number of aerated lagoon configurations exist. Low-energy partial-mix lagoons are relatively large and aerated to meet oxygen demands. Bacterial solids generated during treatment are left to settle to the lagoon floor in an area without aeration mixing. Other complete-mix lagoons provide substantially more mixing energy to create conditions in which solids are uniform across the entire basin. This type of lagoon process is usually followed by a settling cell that functions as a solids-separation step in the process. The settling cell is sized to accommodate the sedimentation, storage, and digestion of influent solids generated in the process.

The performance of aerated lagoon systems for treating deicing runoff has been mixed. The suspended aerobic bacteria responsible for treatment readily degrade glycols under favorable conditions. In most cases, the lack of performance is likely due to insufficient nutrients, insufficient hydraulic residence time, and failure to adapt to decreased biological activity during cold temperatures. Oxygen requirements for deicing treatment systems can be high, and equipment suppliers should be consulted with respect to the proper sizing of aeration equipment. The major difference between aerated lagoons and activated sludge technology is that aerated lagoons do not incorporate return of active biomass to the lagoon reactor, thereby limiting the biomass and the corresponding loading capability of an aerated lagoon. While this makes aerated lagoons inherently less efficient per unit of volume than activated sludge systems, they typically are easier to operate. Despite the relative ease of operation, aerated lagoons do require controls and operator attention. The perceived minimal attention needed for aerated lagoons to function and corresponding inadequate operator attention in some cases is a contributing factor to their variable success in treating deicer. Aerated lagoons can function effectively, but the operators must understand their capabilities and limiting conditions.

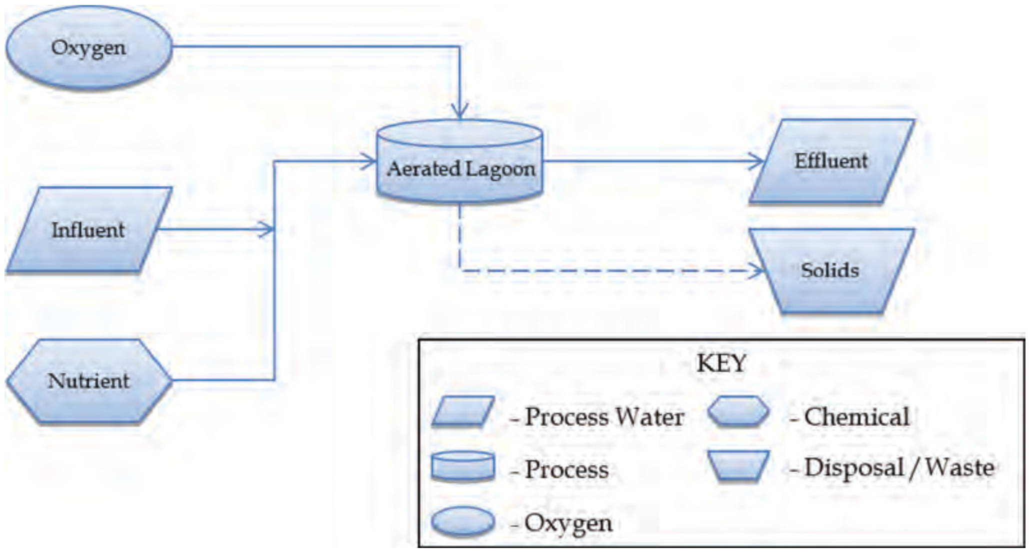


Figure 1. Aerated gravel bed process flow chart.

Some airports do not use aerated lagoons for continuous treatment, but provide enough storage capacity for all collected runoff to be stored until the warm weather season is encountered. In warmer temperatures, aeration and nutrient feed are started to initiate treatment.

Advantages

1. Relatively straightforward operation with automatic operation of aeration equipment.
2. Simple construction with simple mechanical equipment.
3. Large water volume provides dilution (equalization) of influent.
4. Lower cost than other biological treatment systems.

Figure 2. Aerated lagoons with aspirator aerators (left) *and submerged diffusers* (right)*. (Photos courtesy of Mark Liner)*

Disadvantages

1. Potentially large volumes and land area required.
2. Challenge in matching nutrient feed to nutrient needs.
3. Nutrient deficiency will result in suboptimal performance.
4. Measures must be taken to prevent water surface being a bird attractant.
5. Suspended bacteria can be washed out during peak flow events, causing upsets.
6. Bacterial activity slows in cold temperatures, and other measures must be employed to maintain treatment levels.
7. Additional treatment processes may be required to achieve low effluent levels.
8. Difficulty overcoming perception that aerated lagoons require little or no controls, monitoring, or operator attention.

Required Support Systems

1. Aeration system
   a. The aeration system must be suitable for application and deliver the required amount of oxygen and mixing.
   b. The equipment can be either surface mixers or blowers and an air piping network.
2. Nutrient feed system
   a. Nutrient solution must be paced into influent relative to the load of organics to account for nutrient deficiency. Analytical equipment may be required to determine exact concentrations of organics (COD, glycol, etc.) in the influent.
   b. Nutrient solution must be prepared on-site by airport staff or sourced from a third-party provider. (Nutrient feed may be solutions of various ortho-phosphate compounds and ammonium salts or urea.)
   c. The equipment typically includes mixing/storage tanks and metering pumps.
3. Analytical system
   a. Routine measurement of influent flows and concentrations is required to determine system loading, nutrient, and aeration requirements.
   b. Equipment may include online monitors or analytical test kits.
4. Flow control system
   a. The aeration lagoon technology, if operated on a continuous basis during the winter, should have a flow control system that allows management of influent BOD loads to help maintain steady biomass concentrations.

Current Applications of Aerated Lagoon Technology

Installed Systems:	Nashville International Airport (BNA)
	Duluth Airport (DLH)
	London Gatwick (LGW)
	London Heathrow (LHR)
	Chicago Rockford International Airport (RFD)

Variant Systems

Algal treatment is a variant of the aerated lagoon (see Chapter 3 of the guidebook for description). Algal treatment relies on some mechanical aeration, but also oxygen supplied by the algae.

Data for Technology Selection Process

Potential Applications

Aerated lagoons are best suited for systems that typically have concentrations of less than 0.5% (8,000 mg/L) COD, large land areas, favorable discharge standards, and the ability to hold water during the coldest conditions.

The data provided in this section are based on the most typical composition of the aerated lagoon technology, which includes an aeration system, nutrient feed system, and no additional clarification system for solids removal. Effluent concentration data represent the optimal potential performance based on collected field data (when available). Other variations of the aerated lagoon system may provide different results. In addition, the characteristics of individual influent stormwater streams and operational decisions may affect the performance on a site-by-site basis.

Criteria Useful to Screening Analysis of Potential Treatment Technologies

See Table 1 for aerated lagoon process selection information.

Criteria Useful in Comparing to Other Treatment Technologies

See Table 2 for aerated lagoon effluent concentration information and Table 3 for aerated lagoon selection criteria.

Table 1. Aerated lagoon process selection criteria.

Technology Parameter	Value or Rating	Description
Most applicable influent streams	Dilute streams	Most applicable to streams with COD concentrations of less than 8,000-mg/L COD, although systems should be sized based on COD mass loading rates (lbs or kg COD/day), not COD concentrations.
Minimum COD concentration	None	Not limited by low COD concentrations.
Typical area (footprint)	>1 acre	Majority of footprint is the water surface of the lagoon.
Typical building/ equipment height	<20 ft	Building will typically house nutrient system and monitoring instruments.
Open water surface	Open water	Open water aeration basins and clarifier.
Reliance on other entities	No reliance	Treatment does not rely on recycling, glycol market, or POTW acceptance.
Maximum capital funding	See Figure 3	
Maximum annual O&M funding	See Figure 4	

Table 2. Aerated lagoon example effluent concentrations.

Parameter	Concentration or Value	Description
COD	30–100 mg/L	Theoretical concentration based on effluent from an aerated lagoon without an additional clarifier.
NH_3-N	Not available	Feed as a nutrient but controlled to 1–5 mg/L.
Ortho-P	Not available	Feed as a nutrient but controlled to <1 mg/L.
Flow	Varies	Flow rate varies with application.
pH	Varies, but near 7.0	Near 7.0 for optimum rate.
DO	Varies based on design	Typically about 4 mg/L.
TSS	Varies	Difficulty in settling of biological solids may be experienced in cold weather.
TDS	Same as influent	Some salts may be temporarily taken up by biomass.
Temperature	Ambient	If influent is warm, will cool to ambient air temperature.

Technology-Specific Application Considerations

1. Control of Influent Flows and Loadings
   Regular monitoring and measurement of influent flows and concentrations is required. The loading capacity of the system is fixed with respect to the oxygen provided by the aeration equipment. The influent flow rates must be controlled so as not to exceed the minimum hydraulic residence time (typically 2 or 3 days).
2. Nutrient Addition System
   Proper nutrient augmentation is critical for this process. Both influent and effluent monitoring will permit operational staff to fine-tune nutrient addition.

Table 3. Aerated lagoon selection criteria.

Effects of presence of fuels	Free-product fuel spills will inhibit bacterial growth. Dissolved fuel components will be partially treated.
Effects of presence of metals	Inhibition of anaerobic bacteria occurs at high concentrations.
Susceptibility to fouling and clogging	Grit removal and screening are recommended prior to influent feed pumps.
Site contamination	Consideration must be given to existing site contamination because of excavation of lagoon.
Utility requirements	Requires electrical utility connection for aerators and pumps. Water connection is recommended.
Effects of groundwater conditions	Groundwater within 10 ft to 12 ft of the surface will affect system design.
Treatment plant operation needs	Treatment plant operation is typically performed by airport personnel or by contract personnel.
Time required for design and construction	Design and construction typically require 6 to 12 months.
Accessibility	Accessibility required for delivery of nutrient chemicals and for annual lagoon cleaning.

3. Solids Management
   Accumulation of bacterial solids must be monitored. A practical means of desludging the lagoons must be included in the lagoon design. Desludging can be a rough process, and the lagoon's liner system must be designed with this taken into consideration.

Costs

The order-of-magnitude cost curves shown in the graphs in Figure 3 and Figure 4 are based on the probable construction costs and operation and maintenance costs for typical treatment facilities in June 2012. The capital cost curves reflect the unit processes that are most typically needed to execute the core technological functions. Individual airports may incur additional costs, beyond those determined from these curves, for support system items (e.g., a building to house the system) based on site-specific needs and owner preference.

The intent of these graphs is to provide order-of-magnitude costs for comparison purposes during the treatment technology screening process. These costs are considered ANSI Class 5 cost estimates. For final selection of technologies and design, costs should be developed for the site-specific conditions.

A 20% uncertainty contingency has been added to capital costs to reflect the detail accuracy of the estimate. Typically, the expected accuracy within the industry of an estimate at the conceptual stage of a project ranges from between –20/–50% to +30/+100% of the final cost of the project. Since site-specific conditions have not been considered, the actual site-specific costs may be outside of this range.

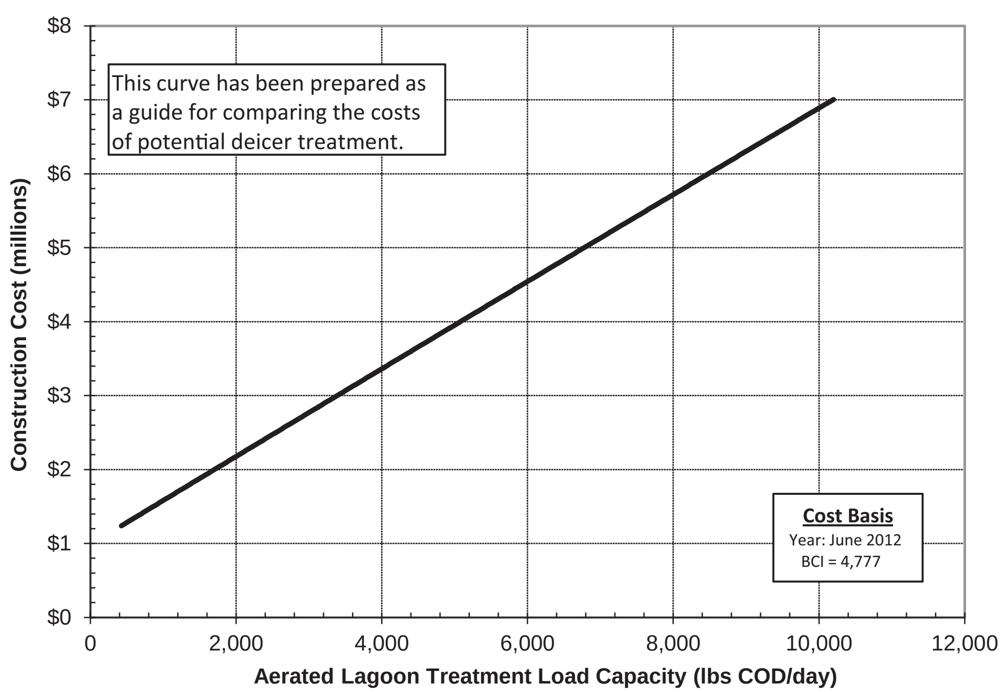


Figure 3. Capital cost curve.

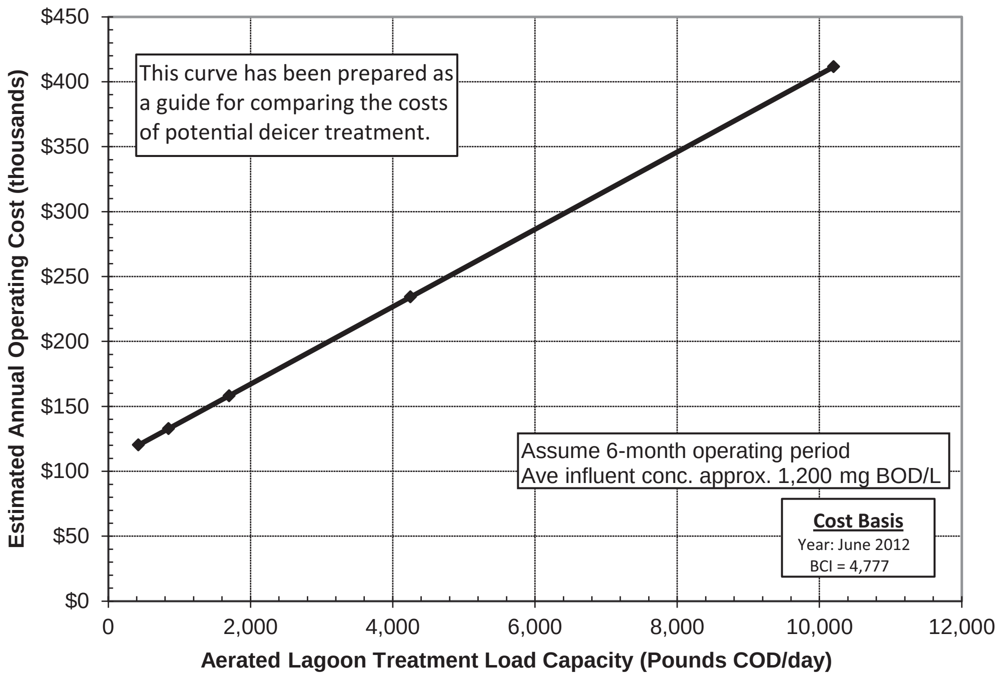


Figure 4. O&M cost curve.

The chart shown in Figure 3 can be used to understand order-of-magnitude costs for the core unit processes for aerated lagoon technology applications. The core unit processes and systems incorporated into the Figure 3 costs include:

- Land acquisition;
- Aerated, lined lagoon, and surface aeration equipment;
- Influent pumping system;
- Nutrient feed system;
- Electrical and control systems; and
- Operator building.

Potential additional aerated lagoon support systems excluded from the Figure 3 costs include:

- Storage/equalization, and
- Sludge storage and dewatering.

Figure 4 provides a means of understanding the order-of-magnitude annual operating costs for an aerated lagoon deicer treatment system. The major operating cost items incorporated into the Figure 4 costs include:

- Labor (two operators),
- Sludge disposal,
- Utilities (power, communications), and
- Nutrients.

The utility costs for mixing and oxygen supply are one of the largest operational costs of the system.

FACT SHEET 104

Anaerobic Fluidized Bed Reactors

1. Description

Process Description

The anaerobic fluidized bed reactor (AFBR) technology uses an anaerobic biological process that is well suited to treat runoff with high COD concentrations and provides a usable by-product in the form of methane. The process uses anaerobic bacteria—bacteria that do not use oxygen—to convert the deicer compounds into methane and other by-products. Since deicing-affected stormwater is typically nutrient deficient, addition of nutrients is required to maintain the biological process. Anaerobic bacteria typically used in this process grow best at a temperature of approximately 85°F to 90°F; therefore, the water must be heated to achieve the correct conditions for treatment. In the AFBR process, the methane by-product is captured and used to heat the water to the required temperature.

The AFBR process is usually housed in a vertical tank. Anaerobic bacteria grow on a media of activated carbon, sand, or other material. This media bed is fluidized by forcing water into the bottom of the tank. This fluidization allows the entire surface of the media to be covered with bacteria. The tank is heated and nutrients are fed to stimulate biological growth. Water flows out of the top and, typically, through a second tank, which removes the media and returns it to the treatment tank. The fluidization loop flow rates are 5 to 20 times more than the influent flow rate to maximize treatment rates and minimize reactor size and cost.

Anaerobic bacteria are used in the AFBR treatment process. The anaerobic bacteria used in the AFBR process have the following characteristics:

- Produce methane,
- Require heat, and
- Are slow growing.

Anaerobic bacteria do not require oxygen, eliminating the utility costs for oxygen supply required with aerobic biological treatment systems. Anaerobic bacteria have an optimum temperature range of approximately 85°F to 90°F. Treatment is significantly reduced below approximately 80°F. Anaerobic bacteria produce methane as the primary gaseous by-product of treatment. The methane can be used as a fuel source to provide heat for the process and potentially for other heating or power generation needs. The methane captured from the anaerobic reactions in the bioreactor is typically burned in a boiler to heat water, which is passed through a heat exchanger to raise the temperature of the water in the reactor. A flare may be installed to burn off excess methane for safety reasons.

Anaerobic bacteria are slow-growing bacteria. Although anaerobic bacteria require several weeks to grow and reach capacity at the beginning of each deicing season, they provide some advantages. The slow growth means there is less

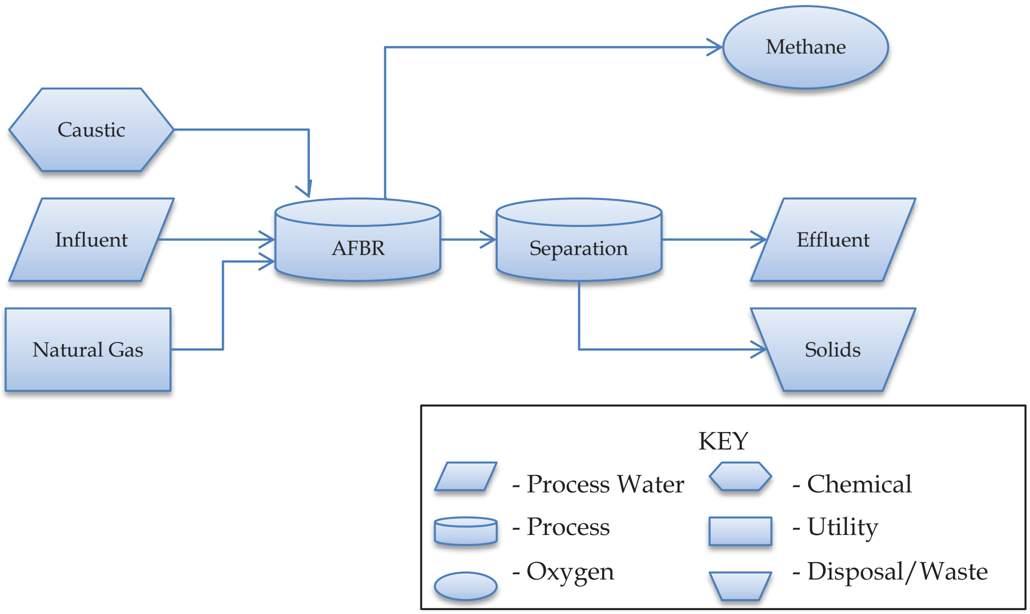


Figure 1. AFBR process flow chart.

excess biomass produced once the treatment capacity is reached. This leads to less wasting of the biomass and less disposal cost. In addition, the biomass will die off more slowly over the summer, when treatment is not occurring. For the Akron–Canton Airport AFBR system, for example, between 25% and 35% of the biomass survives to the next season, and no outside seeding is required to begin treatment for the next year.

The influent flow rate for the AFBR is typically controlled to provide a constant COD load to the treatment process. Flow rates are designed to vary based on the typical COD concentration expected for the influent. (To maintain the load target, high concentrations require low flow rates, and low concentrations require high flow rates.) Flow rates can vary from a few gallons per minute for very high-concentration flows to between 50 to 200 gallons per minute, depending on the treatment system capacity.

Airport deicing-affected stormwater typically does not have the nutrients to support a large biological population. Nutrients similar to fertilizer (nitrogen, phosphorus, and other compounds) must be added to stimulate the new bacterial growth.

If the AFBR effluent is discharged directly to a surface water, a solids removal process will generally be required. Although solid concentrations are generally low, TSS may increase above discharge limits during wasting of excess biomass. Anaerobic bacteria are nearly the same density as water and, because they may still be producing methane gas, they have a tendency to float. Therefore, dissolved air floatation (DAF) processes are often used to remove the solids. Airports with treatment processes that discharge to sanitary sewers may opt to discharge solids to the local wastewater treatment plant, with approval of the local sanitary district. Discharge of high levels of TSS may result in surcharges

Figure 2. AFBR equipment at Akron–Canton Airport.

paid to the POTW, although this may be a reasonable trade-off for not having to handle and dispose of solids at the AFBR.

The influent water is passed through a heat exchanger with effluent water to exchange heat leaving the process to the influent entering the process. This saves on the external heat demand required to heat the influent to the design temperature. A natural gas boiler with a hot water process loop is typically used to maintain the temperature of the treatment system. Methane available to maintain the temperature is the limiting factor for self-sustaining heating of the system. Depending on the efficiency of the heat exchangers, the heat lost by the reactors, and other heat demands of the boiler system, the lowest deicer concentration that is capable of self-sustained heating, with no need to use natural gas to supplement the process-generated methane, is between 2,700-mg/L and 4,100-mg/L COD.

The treatment process needs a bacterial population to begin. Therefore, the process must be seeded with an appropriate biological population at the first season's start-up. The biological seed is typically obtained from another anaerobic system that treats wastewater high in sugar or alcohol content. Digester sludge from a municipal wastewater treatment plant may also be used; however, a longer start-up time, typically 2 to 3 months to get full treatment capacity, should be expected in the first operating season because the bacterial population for the digester sludge differs from what is optimal for deicer treatment.

Advantages

1. Oxygen is not required, reducing operating costs.
2. System is isolated/protected from weather conditions.
3. Biogrowth is slow, so approximately 10 times less sludge must be disposed of than from an aerobic treatment process.
4. Methane gas produced can be used to heat the influent water; if excess gas is produced, it can provide additional energy for other uses (such as building heat).

Disadvantages

1. Slow-growth bacteria do not allow rapid increases in treatment capacity in the start-up period or during large variations in loading during the deicing season.
2. May require auxiliary heating system for periods when methane production is inadequate to provide sufficient heating for deicing-affected stormwater.
3. A building is required to house most, if not all, of the treatment process.
4. The water flow must be enclosed to prevent oxygen from entering the process.
5. Although effluent COD concentration of 40-mg/L to 100-mg/L COD can be obtained, the potential treated effluent COD concentrations are typically not as low as with an aerobic treatment system.

Required Support Systems

1. Chemical feed system
   a. Provides mixing, storage tanks, and metering system for nutrient feed to biological reactor. Nutrient is typically paced to the COD treatment capacity. Analytical equipment may be required to determine concentrations of organics (COD, glycol, etc.) in the influent.
   b. Nutrient solution must be prepared on-site by airport staff or sourced from a third-party provider. (Nutrient feed may be solutions of various orthophosphate compounds and ammonium salts or urea.)
   c. The equipment typically includes mixing/storage tanks and metering pumps.
2. Sludge handling system
   a. Sludge handling equipment may be required to meet discharge requirements to surface waters. The equipment typically includes DAF and mechanical dewatering equipment.
3. Biogas handling
   a. Anaerobic treatment produces biogas containing methane. Biogas equipment is typically installed to remove water vapor prior to the flare and boiler.

Current Applications of AFBR Technology

Installed Systems:	Albany Airport (ALB)
	Akron–Canton Airport (CAK)
	Portland International Airport (PDX)
	T. F. Green Airport (PVD)

Variant Technologies

The up-flow anaerobic sludge bed (UASB) is a variant of the AFBR process. Being anaerobic in nature, this process has the same advantages as the AFBR (methane produced for possible reuse, low sludge production, ability to treat high COD concentrations), but the UASB does not use a carbon media on which to grow the sludge bed. UASBs instead rely on growing anaerobic bacteria in granules that are the correct size to fluidize. Breakdown of the granules during process shutdown or upsets make control challenging, and as such, a UASB may not provide the same stability for deicer treatment as an AFBR.

The anaerobic membrane bioreactor (AnMBR) is another variant of the AFBR process. Rather than in a fluidized bed, anaerobic bacteria are contained in a tank, and the effluent is forced through a membrane. The process footprint is smaller, but operation and maintenance costs are increased because of the system pressure and periodic membrane replacement. To date, no systems of this type have been used to treat deicer.

2. Selection Criteria

Potential Applications

The AFBR process is best suited to high-COD–concentration water that can be processed at relatively low flow rates, such as deicing pad runoff or collected stormwater from systems that segregate runoff into high-concentration fractions using online monitoring and diversion systems. The process is also capable of achieving relatively low effluent concentrations, although for situations where discharge limits are less than 40-mg/L COD, an aerobic polishing process may be required to supplement the AFBR. Methane is produced as a by-product and may be economical for other use if the COD concentration is high and there is a sufficient quantity of COD.

The data provided in this section are based on the most typical composition of the AFBR technology, which includes influent feed with controlled COD loading, fluidized bed reactors operating in parallel, a solids separation system, a chemical feed system, a biogas collection system, and a dissolved air flotation system for removal of biological solids from the effluent. Effluent concentration data represent the optimal potential performance based on collected field data (when available). Other variations of the AFBR system may provide different results. In addition, the characteristics of individual influent stormwater streams and operational decisions may affect the performance on a site-by-site basis.

Criteria Useful to Screening Analysis of Potential Treatment Technologies

See Table 1 for AFBR process selection criteria.

Criteria Useful to Comparative Analysis to Other Treatment Technologies

See Table 2 for AFBR effluent concentration information and Table 3 for AFBR selection criteria.

Technology-Specific Application Considerations

1. Range of COD Loadings
   The treatment system operates most efficiently when it receives a constant COD load (pounds per day). The treatment system can handle wide variation in concentration by adjusting the flow rate to provide the constant load. Therefore, very high COD concentrations can be processed if the flow rate

Table 1. Anaerobic fluidized bed reactor process selection criteria.

Technology Parameter	Value or Rating	Description
Most applicable influent streams	Concentrate streams	Most applicable to deicer-affected runoff with concentrations consistently above 2,700-mg/L COD. Well suited to deicing pad runoff, GRV-collected runoff, and runoff from apron areas that has been segregated into low- and high-concentration fractions.
Minimum COD concentration	Approximately 2,700-mg/L COD	Treatment is effective below this concentration, but as COD concentrations decrease below this threshold, methane production becomes less than methane demand, and natural gas is needed to supplement methane for meeting fuel requirements.
Typical area (footprint)	<1 acre	Majority of footprint is process tanks.
Typical building/ equipment height	>20 ft	Reactors are over 35 ft in height.
Open water surface	No open water	All treatment occurs in enclosed tanks.
Reliance on other entities	No reliance	Treatment does not rely on glycol market or POTW acceptance.
Maximum capital funding	See Figure 3	
Maximum annual O&M funding	See Figure 4	

Table 2. Anaerobic fluidized bed reactor example effluent concentrations.

Parameter	Concentration or Value	Description
COD	155 mg/L (pre-solids removal) 40 mg/L (post-solids removal)	Based on 2009-2010 average soluble COD in the effluent from the Akron–Canton reactor.
PG	<1 mg/L	PG is completely degraded.
NH_3-N	NA	Feed as a nutrient but controlled to 5–10 mg/L.
Phosphorous	NA	Feed as a nutrient but controlled to 1–5 mg/L.
Flow	Varies	Flow rates are changed in response to COD concentrations to maintain a steady COD loading rate.
pH	Varies, but near 7.0	Near 7.0 for optimum rate.
DO	Near 0 mg/L	Re-aeration may be required for direct discharge.
TSS	Varies	TSS primarily from biological solids created in reactor.
TDS	Same as influent	Some salts may be temporarily taken up by biomass.
Temperature	Approx. 55–60°F	Discharge temperature is controlled by heat exchanger and dependent on influent temperature.

Table 3. Anaerobic fluidized bed reactor selection criteria.

Effects of presence of fuels	Free-product fuel spills will inhibit bacterial growth. Dissolved fuel components will be partially treated.
Effects of presence of metals	Inhibition of anaerobic bacteria occurs at high concentrations, although metal concentrations in airport runoff are not typically high enough to have an effect.
Susceptibility to fouling and clogging	Grit removal and screening are required before process feed.
Site contamination	Minimal consideration can be given to existing site contamination because process only requires minor excavation.
Utility requirements	Requires electrical, natural gas, and water utility connections.
Effects of groundwater conditions	Groundwater within approximately 10 ft of the surface may be a factor in construction, depending on system design.
Treatment plant operation needs	Treatment plant operation is typically performed by experienced wastewater treatment operators.
Time required for design and construction	Design and construction typically require 18 to 24 months.
Accessibility	Accessibility required for delivery of nutrient chemicals and sludge removal.

is low enough to meet mass loading criteria. COD concentrations as high as 80,000 mg/L have been treated in active AFBR deicer treatment systems. However, there may be physical limitations on the range of flows that can be delivered based on the physical limitations of the pumps.

2. Biogas Usage
   High-methane biogas (70% to 80%) can be available as a by-product of treatment. The break-even point for heating the influent water occurs at approximately 2,700-mg/L COD. The higher the deicer concentration, the more methane is available for other uses.

Costs

The order-of-magnitude cost curves shown in the graphs in Figure 3 and Figure 4 are based on the probable construction costs and operation and maintenance costs for typical treatment facilities in June 2012. The capital cost curves reflect the unit processes that are most typically needed to execute the core technological functions. Individual airports may incur additional costs, beyond those determined from these curves, for support system items (e.g., a building to house the system) based on site-specific needs and owner preference.

The intent of these graphs is to provide order-of-magnitude costs for comparison purposes during the treatment technology screening process. These costs are considered ANSI Class 5 cost estimates. For final selection of technologies and design, costs should be developed for the site-specific conditions.

A 20% uncertainty contingency has been added to capital costs to reflect the detail accuracy of the estimate. Typically, the expected accuracy within the industry of an estimate at the conceptual stage of a project ranges from between −20/−50% to +30/+100% of the final cost of the project. Since site-specific conditions have not been considered, the actual site-specific costs may be outside of this range.

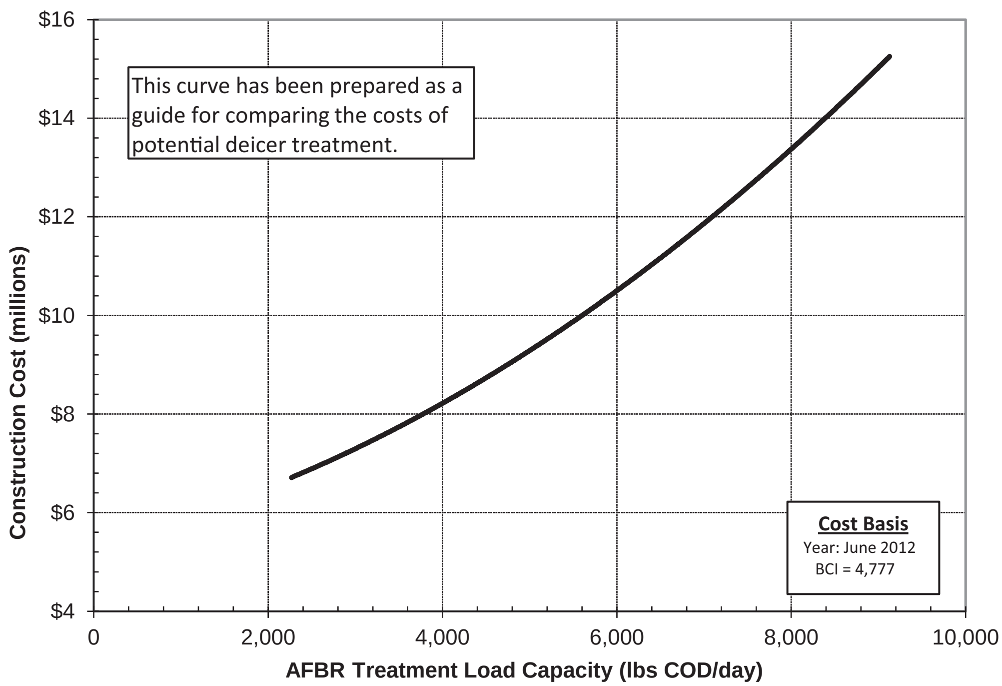


Figure 3. Capital cost curve.

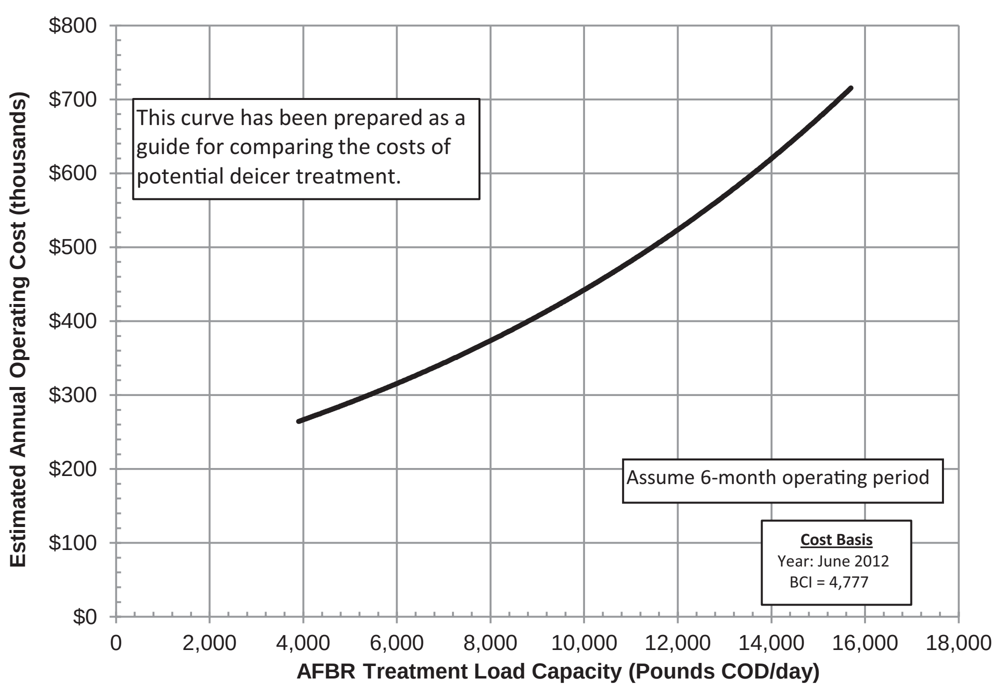


Figure 4. O&M cost curve.

The chart shown in Figure 3 can be used to understand order-of-magnitude costs for the core unit processes for anaerobic fluidized bed reactor technology applications. The core unit processes and systems incorporated into the Figure 3 costs include:

- Land acquisition,
- Influent pumping system,
- Recirculation pumping system,
- Anaerobic reactors (2),
- Solids separation system,
- Nutrient feed system,
- pH control,
- Hot water loop/temperature control,
- Biogas capture,
- Sludge collection,
- Treatment building, and
- Electrical and control systems.

Potential additional anaerobic fluidized bed reactor support systems excluded from the Figure 3 costs include:

- Storage/equalization, and
- Sludge storage and dewatering.

Figure 4 provides a means of understanding the order-of-magnitude annual operating costs for an anaerobic fluidized bed reactor deicer treatment system. The major operating cost items incorporated into the Figure 4 costs include:

- Labor (2 operators),
- Sludge disposal,
- Utilities (power, communications, natural gas), and
- Nutrients.

The operating costs in Figure 4 assume that from the period between the end of seasonal start-up and season shutdown, there are no costs for natural gas to heat the influent stormwater because all fuel is supplied by methane captured in the treatment off-gas. The costs do not reflect additional cost savings that might be achieved through use of any captured methane that is not needed to heat the system influent water to the desired operating temperature.

FACT SHEET 105

Distillation

1. Description

Process Description

Distillation is a physical treatment process where deicing-affected stormwater is subjected to heat or pressure variations that cause evaporation. The distillation process separates the water from the organics in the deicing-affected stormwater based on the different boiling points between these components. The water is brought to a boil, separates from the organics, and turns into a vapor. When the vapor cools, it condenses. The separated water stream is collected and discharged, while the concentrated organics from the deicing-affected stormwater are captured for reuse.

In the case of treatment of deicer-affected stormwater using distillation, the main focus is to separate and reclaim either propylene glycol or ethylene glycol, which is the primary component of aircraft deicing fluid. The concentrated product produced by distillation-based recycling systems has a higher concentration and, in turn, a higher value than the glycol solutions produced by thermal vapor recompression, mechanical vapor recompression, and other evaporation-based systems. This is due to the ability of distillation systems to produce a glycol product with concentrations as high as 99.5%

Distillation is energy-intensive, so it is generally not cost-effective to distill and recycle waste glycol solutions at low concentrations due to the energy requirements to evaporate large volumes of water. Depending on configuration, glycol concentrations ranging from 30% to 60% are most commonly treated with distillation-based systems. As a result, distillation systems are normally used as a complementary technology to further concentrate glycols produced from MVR and other evaporator technologies. Most distillation systems designed for glycol applications use vacuum distillation to reduce pressure since the boiling point of the glycol/water mixture is lower at a lower external pressure. This results in the system using less energy to separate the glycol and water components.

Components of a typical distillation system are:

- Column(s) or towers;
- Heat exchangers of various sizes and styles;
- Heat transfer medium re-boiler (use of steam or heat medium fluid);
- Natural gas–, oil-, or electricity-based heat source and heating system;
- Vacuum vessels (water and glycol);
- Chiller/condenser;
- Numerous pumps and motors;
- Instrumentation: pressure, temperature, and flow transmitters and gauges;
- Programmable logic controller or equivalent controls;
- Vacuum pump(s); and
- Air compressor(s).

Distillation for the purpose of treating deicer-affected stormwater is typically run continuously, as opposed to using batch processing. Depending on distillation manufacturer and design criteria, single-stage, two-stage, or three-stage systems are typically used for glycol applications. The columns/towers used for each stage can be composed of trays or packings to enhance the contact between vapor and liquid. With distillation being an energy-intensive separation method, the influent is usually preheated through heat exchangers (economizers) before entering the vacuum distillation towers. Heat exchangers can be horizontal or vertical and are typically of the shell-and-tube type. A re-boiler is used to provide the heat to the bottom of the distillation column(s). It boils the liquid from the bottom of the distillation column to generate vapors, which return to the column to drive the physical separation. The water vapors exit from the top of the columns, and the heaviest products (the glycol and other organics) exit from the bottom of the column and are often called the “bottoms.” Distillation towers use reflux to achieve a more complete separation of products. “Reflux” refers to the portion of the condensed overhead liquid product from the column that is returned to the upper part of the tower. Inside the distillation towers, the reflux liquid that flows downward provides cooling and condensation of the vapors moving upward, thereby increasing the efficiency of the towers. Vapors produced from the distillation towers are condensed in a chiller or condenser.

Design variables include temperature, distillation column height, desired flow rates, and reflux ratio. Depending on distillation configuration, normally three output streams are produced.

1. The effluent product is a concentrated glycol-containing stream (>99% concentration) that can be sold as industrial glycol or possibly be refined to be used as the glycol component in ADF.
2. The effluent distillate stream from distillation units contains glycol and other organics measured as COD that must be discharged to a POTW or treated on-site in a biological process for further treatment.
3. The bottoms, or the residual waste produced from the system, are the last stream that contains the additives and contaminants that are removed from the spent deicing fluid waste. This material is normally trucked off-site for disposal.

Large distillation systems can be expensive to build on-site at an airport. A large volume of glycol needs to be reclaimed so that the glycol product can be sold to offset capital and operating expenses. There are only a few airports that spray and recover enough ADF to justify the installation of a large on-site distillation system. Historically, as an alternative to on-site distillation, spent ADF has been concentrated to a 30% to 60% glycol level on-site at an airport by other recycling technologies, such as mechanical vapor recompression, with the resulting fluid transported to a centralized distillation plant that serves a number of airports.

Distillation technology has advanced, and systems have now been developed so that smaller modular distillation systems can be installed at airports to make this process more cost-effective. In addition, the airport that hosts the modular sys-

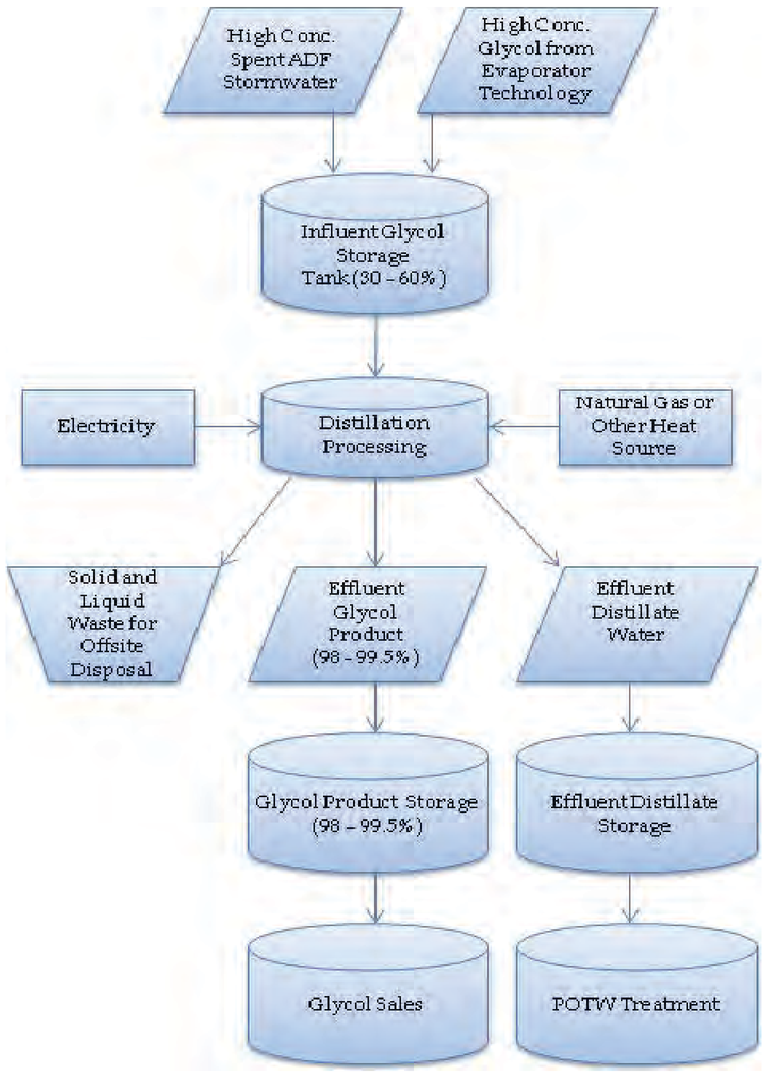


Figure 1. Distillation technology flowchart.

tem can serve as a centralized distillation outlet for other airports in the region if it is appropriately permitted to do so.

Advantages

1. The higher the glycol content produced, the greater the value of the product for resale. Distillation systems have the capability to produce up to 99.5% propylene glycol (PG) concentration. The glycol reclaimed can be sold, and the revenues generated can be used to offset operating expenses.
2. Distillation can be used in conjunction with other complementary technologies such as mechanical vapor recompression or other evaporator systems to improve the efficiency of recycling.
3. Due to recent advances in distillation technology, the quality of the glycol produced is acceptable for reuse as a feedstock for on-site production of ADF at airports. This can provide substantial savings in logistics costs.

Figure 2. Distillation columns at Portland International Jetport.

Disadvantages

1. A drawback of distillation is that it creates contaminated wash-down water and bottoms waste from the columns that cannot be discharged and must be treated further.
2. The distillate or condensate water stream that distillation produces contains COD concentrations that are usually above acceptable levels to discharge to stormwater, which requires airports to discharge these residual streams to POTWs for further treatment or treat the streams with an on-site biological treatment process.
3. Distillation columns can be very tall. Height can be an issue at airports.
4. Large distillation systems can be expensive to build. A large volume of glycol needs to be reclaimed so that the glycol product can be sold to offset capital and operating expenses. There are few airports that spray and recover enough ADF to justify installation of an on-site distillation system.
5. Distillation is energy-intensive; therefore, it is generally not cost-effective to distill and recycle waste glycol solutions at low concentrations.

Required Support Systems

1. Storage tanks
   a. Provide storage of the effluent streams until discharged or removed from the airport.
2. Other recycling technologies (typically)
   a. Distillation is normally used as a complementary technology to further concentrate glycols produced from MVR and other evaporator technologies.

3. Filtration systems
    a. Adding filtration, such as use of activated carbon, to the distillation process can decrease the amount of solids and particulate matter that normally would have accumulated in the heat exchangers. Without filtration, the system would be subject to frequent shutdowns and tedious maintenance to clean the exchangers.
4. Bottoms waste
    a. An off-site facility is usually required to dispose of the bottoms waste.

Current Applications of Distillation Technology

Installed Systems:	Denver International Airport (DEN)
	Salt Lake City International Airport (SLC)
	Portland International Jetport (PWM)

2. Selection Criteria

The information in this section can be used in conjunction with the methodologies presented in Chapter 4 and Chapter 5 of the guidebook to facilitate the assessment and selection of deicer treatment technologies.

Potential Applications

The distillation process is best suited to high-concentration water. The process can produce PG or EG that is sufficiently pure to be resold. There are several contaminated waste streams that cannot be recycled and must be discharged to a sanitary sewer or treated on-site with a biological treatment system (i.e., contaminated wash-down water and bottoms waste).

The data provided in this section are based on the most typical composition of distillation technology, which includes a filtration system and a distillation processing unit. It is assumed that an MVR or equivalent treatment system is used to provide influent with a COD concentration of at least 300,000 mg/L as influent to the distillation system. While a distillation system typically discharges distillate to a POTW or other treatment technology to reduce COD concentration, this step is considered external to the core distillation process, and data presented in the following do not reflect the effect of the additional distillate treatment step. Effluent concentration data represent the optimal potential performance based on collected field data (when available). Other variations of the distillation system may provide different results. In addition, the characteristics of individual influent stormwater streams and operational decisions may affect the performance on a site-by-site basis.

Criteria Useful to Screening Analysis of Potential Treatment Technologies

See Table 1 for distillation process selection criteria.

Table 1. Distillation process selection criteria.

Technology Parameter	Value or Rating	Description
Most applicable influent streams	Highly concentrated streams	Because of the cost of evaporation in dilute streams, application of distillation is limited to streams with COD concentrations of at least 300,000 mg/L (30%).
Minimum COD concentration	Approx. 300,000-mg/L COD	Treatment can be performed below this concentration; however, energy demands rise in relation to products recovered.
Typical area (footprint)	<1 acre	Includes building, associated structures, equipment, parking, access, and required storage tanks.
Typical building/ equipment height	>20 ft	Equipment can be installed in a building height ranging from 20 ft to 30 ft, depending on type of distillation system and height of columns.
Open water surface	No open water	All treatment occurs in enclosed tanks.
Reliance on other entities	Reliance	Effluent water produced must be sent to a POTW or further treated for discharge to stormwater. Reclaimed glycol is usually shipped off-site by a third-party vendor for sales. A small amount of bottoms waste is generated by maintenance activities and must be disposed of off-site.
Maximum capital funding	See Figure 3	
Maximum annual O&M funding	See Figure 4	

Criteria Useful in Comparative Analysis to Other Treatment Technologies

See Table 2 for distillation effluent concentration information and Table 3 for distillation selection criteria.

Technology-Specific Application Considerations

1. High-grade components should be incorporated into system design.
   There can be incompatibility issues between the feed/effluent mixture and the tube material composition in heat exchangers, which can lead to early tube failures.
2. Amount of ADF used at the airport and the amount of glycol that can be reclaimed
   The larger the volume of glycol that can be recycled, the more cost-effective the distillation treatment system becomes.
3. Average concentration of spent ADF
   Distillation systems are not typically installed unless other complementary technologies are used on-site to provide ideal glycol concentrations in the range of 30% to 60%.
4. Effluent discharge
   A POTW outlet or other treatment equipment (such as membranes) is required to discharge the effluent water produced by the distillation system if discharge permits are stringent.

Table 2. Distillation example effluent concentrations.

Parameter	Concentration or Value	Description
COD	Varies between 5,000 and 25,000 mg/L	Represents the COD concentration in the distillate. Concentrations vary based on the type of system and site-specific conditions that influence overall design specifications.
PG/EG	Varies between 5,000 and 25,000 mg/L	Based on the type of system and site-specific conditions that influence overall design specifications.
NH_3-N	None expected	No nutrients required.
Phosphorous	None expected	No nutrients required.
Flow	Varies	Depends on overall capacity of system being used.
pH	Varies between 5 and 8	Typically between 6 and 7 to meet POTW or other discharge permit requirements.
DO	Ambient	Process has no direct effect on dissolved oxygen.
TSS	Varies	Solids are removed as bottoms and do not appear in the effluent distillate stream.
TDS	Varies	Solids are removed as bottoms and do not appear in the effluent distillate stream.
Temperature	Varies	Heat exchangers are typically used to cool the water effluent and heat the incoming influent.

Note: Concentrations listed are for distillate (wash water)—the salable PG or EG stream is approximately 99%.

Costs

The order-of-magnitude cost curves shown in the graphs in Figure 3 and Figure 4 are based on the probable construction costs and operation and maintenance costs for typical treatment facilities in June 2012. The capital cost curves reflect the unit processes that are most typically needed to execute the core technological functions. Individual airports may incur additional costs, beyond those determined from these curves, for support system items (e.g., a building to house the system) based on site-specific needs and owner preference.

Table 3. Distillation selection criteria.

Effects of presence of fuels	Free-product fuel spills will contaminate PG stream and should be removed.
Effects of presence of metals	Metals will concentrate in wastewater stream.
Susceptibility to fouling and clogging	Grit removal and screening are required before process feed.
Site contamination	Minimal consideration can be given to existing site contamination because process only requires minor excavation.
Utility requirements	Requires electrical, natural gas, and water utility connections.
Effects of groundwater conditions	Minimal consideration can be given to groundwater because all equipment is typically installed above-grade.
Treatment plant operation needs	Treatment plant operation is typically performed by experienced process operators.
Time required for design and construction	Design and construction typically require 18 to 24 months.
Accessibility	Accessibility required for removal of PG stream by tanker trucks.

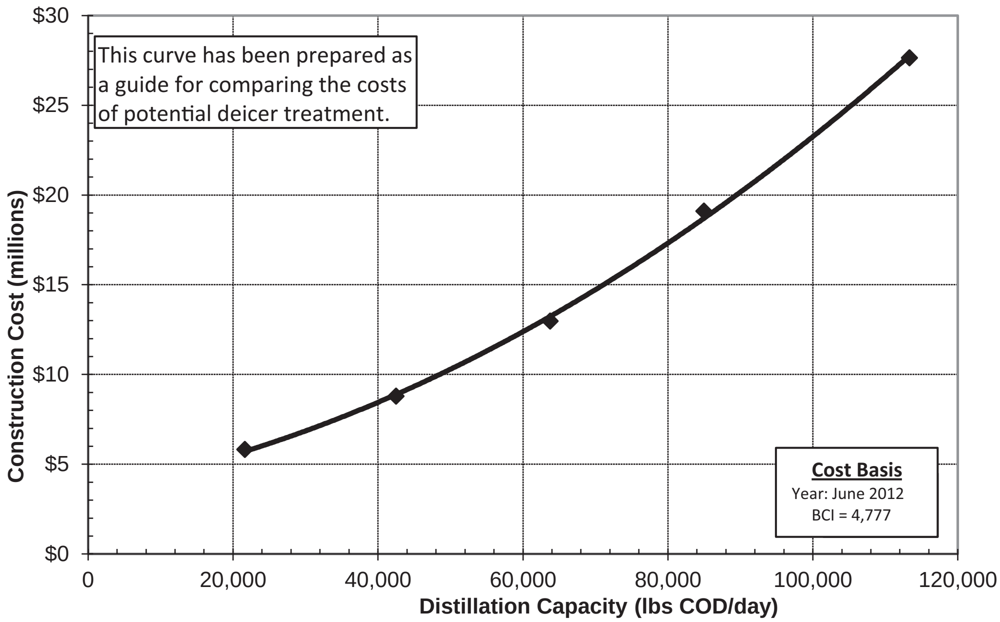


Figure 3. Capital cost curve.

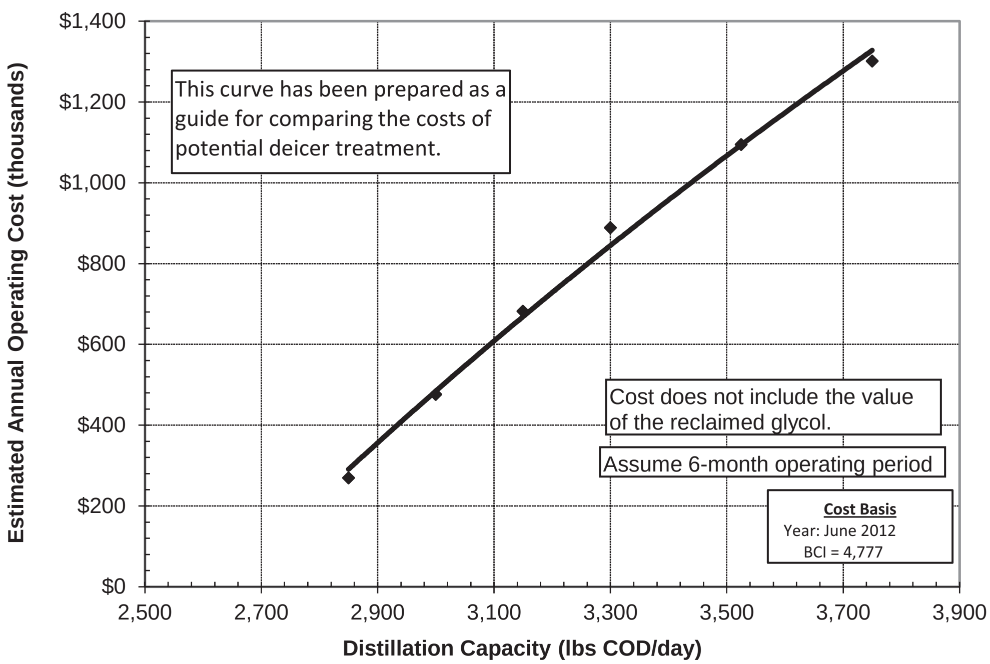


Figure 4. O&M cost curve.

The intent of these graphs is to provide order-of-magnitude costs for comparison purposes during the treatment technology screening process. These costs are considered ANSI Class 5 cost estimates. For final selection of technologies and design, costs should be developed for the site-specific conditions.

A 20% uncertainty contingency has been added to capital costs to reflect the detail accuracy of the estimate. Typically, the expected accuracy within the industry of an estimate at the conceptual stage of a project ranges from between −20/−50% to +30/+100% of the final cost of the project. Since site-specific conditions have not been considered, the actual site-specific costs may be outside of this range.

The chart shown in Figure 3 can be used to understand order-of-magnitude costs for the core unit processes for distillation technology applications. The core unit processes and systems incorporated into the Figure 3 costs include:

- Land acquisition,
- Pre-treatment system,
- Distillation column,
- Electrical and control system, and
- Operator building.

Potential additional distillation support systems excluded from the Figure 3 costs include:

- Solids handling and disposal, and
- Distillate waste treatment/disposal.

Figure 4 provides a means of understanding the order-of-magnitude annual operating costs for a distillation deicer treatment system. The major operating cost items incorporated into the Figure 4 costs include:

- Labor (two operators),
- Solids disposal,
- Utilities (power, natural gas, communications), and
- Distillate discharge to sanitary sewer or treatment.

FACT SHEET 106

Mechanical Vapor Recompression

1. Description

Process Description

Mechanical vapor recompression (MVR) is a type of evaporation technology that can be used to remove glycols from stormwater. It is a physical process where deicing-affected stormwater is heated, the water is evaporated, and the fluid is subsequently separated into a stream of distilled water and a stream of fluid with concentrated glycol. This technology is typically used to reclaim concentrated glycol, the primary component of ADF. MVR systems are typically designed to handle influent concentrations of glycol of 1% to 30%.The glycol product that is produced has value and can be further refined or sold.

An MVR system can be designed to process water-ethylene or water-propylene glycol-spent ADF mixtures of up to 30% glycol concentration. The water is separated from the ADF stream based on the difference in boiling points between water and the type of glycol. MVR systems can be installed on-site at an airport or be part of an off-site centralized recycling facility. Manufacturers of this equipment offer MVR units that can be assembled and configured on steel skid units prior to delivery so that the units do not have to be constructed on-site. The system is scalable since units can be added or removed to increase or decrease processing capacity.

Most MVR units are designed to be operated with programmable logic controllers (PLC) for ease of operation. At many airports, MVR systems run for 24 hours a day and 7 days a week, assuming there is a sufficient volume of fluid to process. Throughput flow rates vary according to the glycol concentration that is being fed through the system and are dependent on the quality of the feed. Spent ADF is usually contaminated with small amounts of mechanical impurities such as airfield contaminants, rust, sand, grit, and salt. The feed is typically stored in tanks prior to being treated and pumped through a filtration system before being sent to an MVR unit. Depending on the type of MVR system, the separation of water and glycol can occur in a primary heat exchanger or evaporator tank.

The principal components of an MVR system are a heat exchanger, an evaporation tank, a cyclone, and a mechanically driven compressor or blower. Typically, the influent deicer-affected stormwater is preheated in a heat exchanger. The influent is evaporated in the evaporation tank. Following evaporation, the glycol/steam mixture enters a cyclone, where the steam separates from the recovered glycol product. The steam generated during this process is compressed and used as a heat source for the evaporation tank and heat exchanger. This minimizes energy requirements to supply constant heat to the system.

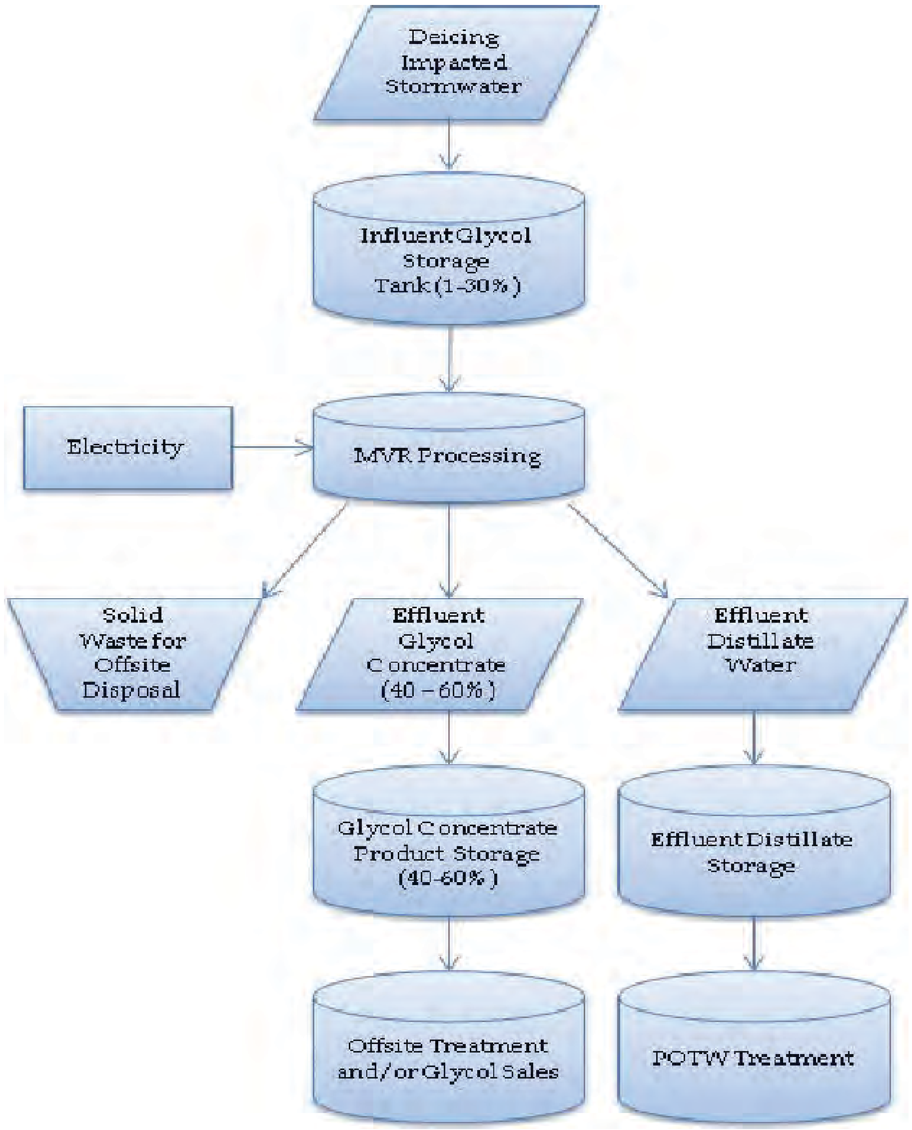


Figure 1. MVR flowchart.

The distillate effluent produced from the MVR system contains low levels of COD and is typically discharged to a POTW. The recovered glycol product stream is segregated into a separate storage tank. Typical concentrate products produced from MVR systems contain between 40% and 60% glycol.

Advantages

1. MVR technologies are most applicable to airports that generate spent ADF concentrations of 1% and higher.
2. MVR systems can be designed to be modular, which means they can be installed in a relatively small footprint, and additional units can be added if increased capacity is required.

Figure 2. MVR unit at Denver International Airport.

3. MVR units with PLC systems can be adjusted while in operation to deal with varying influent concentrations caused by variability in precipitation-related deicing events.
4. MVR units can be used in conjunction with other complementary technologies, such as membrane treatment systems and distillation, to improve the efficiency of recycling.
5. The glycol reclaimed can be sold, and the revenues generated can be used to offset operating expenses.

Disadvantages

1. The distillate (dilute) stream from MVR systems requires further processing, either through discharge to a POTW or through biological treatment on-site.
2. MVR units installed on-site are more economical the greater the volume of ADF sprayed at the airport and, more importantly, the greater the glycol that can be captured at the airport for recycling.
3. MVR heat exchangers require more maintenance and cleaning when dealing with spent ADF with higher concentrations of thickened fluids (i.e., Type IV fluids).
4. Flow rates through individual units are relatively low compared to biological treatment systems, and as such, processing high flow rates (i.e., large runoff volumes) with MVR systems may not be cost-effective compared to other treatment technologies.

5. Additional processing of the MVR concentrate stream is usually required to maximize cost-effectiveness of the recycling operation. Additional processing (i.e., further concentration of the glycol) can occur either through on-site distillation or off-site transport to a regional distillation facility.
6. A market for the concentrated glycol from the MVR must be found.

Required Support Systems

1. Storage tanks
   a. Provide storage of the effluent (distillate) streams until discharged or removed from the airport.
2. Filtration systems
   a. Filtration prior to MVR treatment reduces the frequency of downtime associated with maintenance to clean heat exchanger systems.
3. Other recycling technology
   a. Most glycol reclaimed from MVR systems is further refined through a distillation system to achieve higher glycol concentrations (i.e., 99%) to increase the value of the glycol product to be sold.
   b. Scrubber or membrane systems can be added to MVR systems to further treat the distillate effluent if discharging to stormwater.

Current Applications of MVR Technology

Installed Systems:	Washington Dulles International Airport (IAD)
	Portland International Jetport (PWM)
	Bradley International Airport (BDL)
	Denver International Airport (DEN)
	Halifax International Airport (YHZ)
	Toronto Pearson International Airport (YYZ)
	St. John’s International Airport (YYT)
	Cincinnati International Airport (CVG)
	Minneapolis International Airport (MSP)
	Cleveland Hopkins International Airport (CLE)
	Pittsburgh International Airport (PIT)
	Salt Lake City International Airport (SLC)

2. Selection Criteria

The information in this section can be used in conjunction with the methodologies presented in Chapter 4 and Chapter 5 of the guidebook to facilitate the assessment and selection of deicer treatment technologies.

Potential Applications

MVR systems are applicable to situations where recycling of glycols is desired. The technology is limited, for economic reasons, to processing concentrations of greater than 1% glycol. A contaminated waste stream (e.g., one contaminated with PG) must be treated or discharged to a sanitary sewer. Economics may limit application to situations where relatively low runoff volume will be processed, such as runoff from deicing pads and GRVs.

The data provided in this section are based on the most typical composition of MVR technology, which includes a filtration system, one or more MVR units, a scrubber, and an additional treatment system. A MVR treatment system typically discharges distillate to a POTW or another treatment technology to reduce COD concentration. This additional treatment system is considered external to the core MVR process, and data presented in the following do not reflect the effect of this additional treatment step. Effluent concentration data discussed in the following represent the optimal potential performance based on collected field data (when available). Other variations of the MVR system may provide different results. In addition, the characteristics of individual influent stormwater streams and operational decisions may affect the performance on a site-by-site basis.

Criteria Useful to Screening Analysis of Potential Treatment Technologies

See Table 1 for MVR process selection criteria.

Table 1. Mechanical vapor recompression process selection criteria.

Technology Parameter	Value or Rating	Description
Most applicable influent stream	Concentrate streams	Best suited for increasing the glycol concentration of the relatively low-volume, high-concentration runoff streams from deicing pads and GRVs.
Minimum COD concentration	Approx. 10,000-mg/L COD (1% PG)	Treatment can be performed below this concentration; however, energy demands rise in relation to products recovered.
Typical area (footprint)	<1 acre	Includes building, associated structures, equipment, parking, access, and required storage tanks.
Typical building/ equipment height	May be >20 ft	Equipment can be installed in a building with height ranging from 16 ft to 22 ft, depending on MVR manufacturer.
Open water surface	No open water	All treatment occurs in enclosed tanks.
Reliance on other entities	Reliance	Effluent water produced is usually sent to a POTW or further treated for discharge to stormwater. Reclaimed glycol is usually shipped off-site by a third-party vendor for sales. A small amount of nonhazardous solid waste is generated by maintenance activities. Operation of MVRs is often contracted out by airport.
Maximum capital funding	See Figure 3	
Maximum annual O&M funding	See Figure 4	

Table 2. MVR example effluent concentrations in distillate streams.

Parameter	Concentration or Value	Description
COD	50 mg/L–1,000 mg/L	Based on site-specific conditions and whether EG- or PG-based ADF is processed.
NH_3-N	None	No nutrients added.
Phosphorous	None	No nutrients added.
Flow	Varies	Depends on influent glycol concentration and type/manufacturer of MVR.
pH	Varies between 4 and 8	Typically between 6 and 7 to meet POTW or other discharge permit requirements.
DO	No effects	No effects on dissolved oxygen unless distillate is stored for long periods.
TSS	Varies	Solids in the influent are concentrated in the glycol effluent stream that is produced or removed from the heat exchangers and filtration systems.
TDS	Varies	Solids in the influent are concentrated in the glycol effluent stream that is produced or removed from the heat exchangers and filtration systems.
Temperature	Varies	Heat exchangers are typically used to cool the water effluent and heat the influent.

Note: concentrations listed are for the distillate wastewater stream—the salable PG stream is approximately 40% to 60% PG or EG.

Criteria Useful in Comparative Analysis to Other Treatment Technologies

See Table 2 for MVR effluent concentration information and Table 3 for MVR selection criteria.

Technology-Specific Application Considerations

1. Consider the amount of ADF used at the airport and, more importantly, the amount of glycol that can be reclaimed

Table 3. MVR selection criteria.

Effects of presence of fuels	Free-product fuel spills will contaminate PG stream.
Effects of presence of metals	Metals will concentrate in wastewater stream.
Susceptibility to fouling and clogging	Grit removal and screening are required before process feed.
Site contamination	Minimal consideration can be given to existing site contamination because process only requires minor excavation.
Utility requirements	Requires electrical, natural gas, and water utility connections.
Effects of groundwater conditions	Minimal consideration can be given to groundwater because all equipment is typically installed above-grade.
Treatment plant operation needs	Treatment plant operation is typically performed by experienced process operators.
Time required for design and construction	Design and construction of facility typically requires 18 to 24 months.
Accessibility	Accessibility required for removal of glycol stream by tanker trucks.

The larger volume of glycol that can be recycled, the more cost-effective MVR treatment systems become.

2. Consider the average concentration of spent ADF to be processed
   MVR systems are not typically installed unless the glycol concentration in the spent ADF is at least 1%. These systems run more efficiently when glycol concentrations are ideally between 8% and 15%. Lower concentrations are also typically associated with larger volumes of deicer-affected stormwater to process. Larger volumes increase the number of MVR units required and the cost of the process.
3. Effluent discharge
   A POTW outlet or other on-site treatment processes are required to treat the effluent water produced by MVR systems.

Costs

The order-of-magnitude cost curves shown in Figure 3 and Figure 4 are based on the probable construction costs and operation and maintenance costs for typical treatment facilities in June 2012. The capital cost curves reflect the unit processes that are most typically needed to execute the core technological functions. Individual airports may incur additional costs, beyond those determined from these curves, for support system items (e.g., a building to house the system) based on site-specific needs and owner preference.

The intent of these graphs is to provide order-of-magnitude costs for comparison purposes during the treatment technology screening process. These costs are considered ANSI Class 5 cost estimates. For final selection of technologies and design, costs should be developed for the site-specific conditions.

A 20% uncertainty contingency has been added to capital costs to reflect the detail accuracy of the estimate. Typically, the expected accuracy within the industry of an estimate at the conceptual stage of a project ranges from –20/–50% to +30/+100% of the final cost of the project. Since site-specific conditions have not been considered, the actual site-specific cost may be outside of this range.

The chart shown in Figure 3 can be used to understand order-of-magnitude costs for the core unit processes for MVR technology applications. The core unit processes and systems incorporated into the Figure 3 costs include:

- Land acquisition,
- Pretreatment system,
- Vapor-recompression units,
- Electrical and control systems, and
- Treatment building.

Potential additional MVR support systems excluded from the Figure 3 costs include:

- Storage/equalization,
- Influent pumping system,
- Solids handling and disposal, and
- Distillate waste treatment.

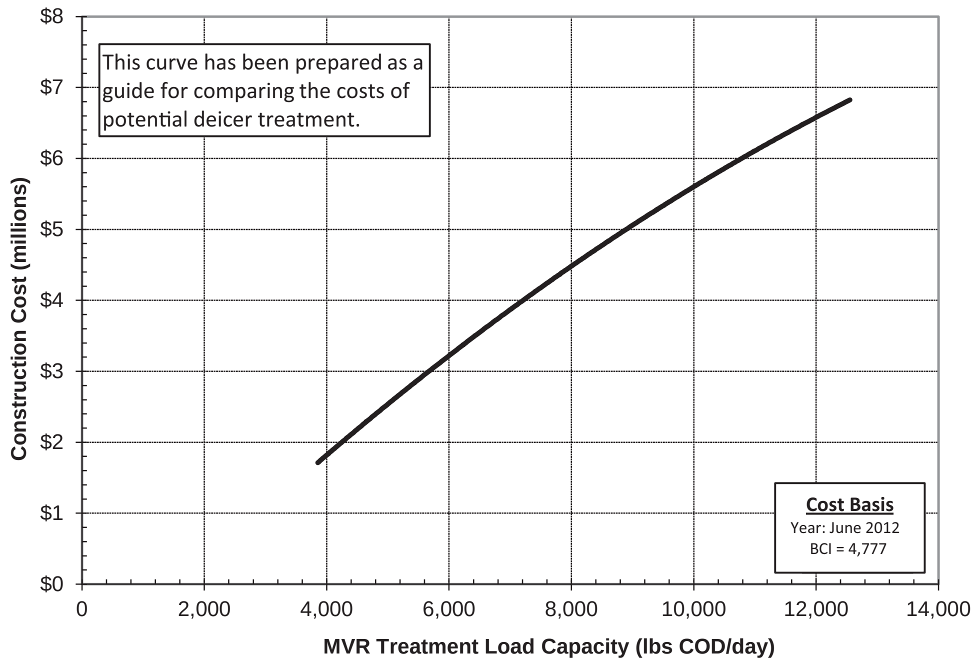


Figure 3. Capital cost curve.

Figure 4 provides a means of understanding the order-of-magnitude annual operating costs for an MVR deicer treatment system. The major operating cost items incorporated into the Figure 4 costs include:

- Labor (two operators),
- Solids disposal,
- Utilities (power, natural gas, communications), and
- Distillate discharge to sanitary sewer.

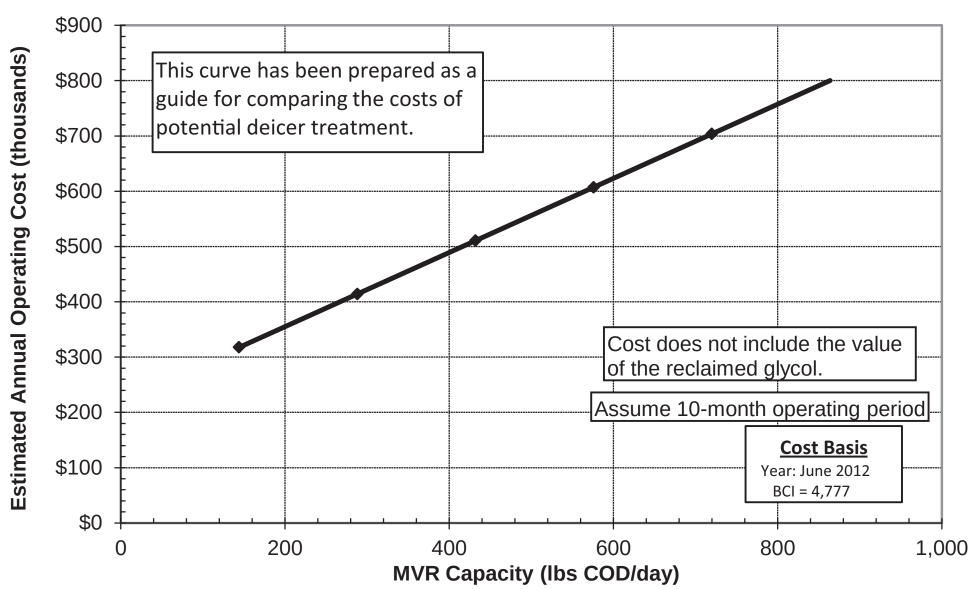


Figure 4. O&M cost curve.

FACT SHEET 107

Moving Bed Biofilm Reactors

1. Description

Process Description

The moving bed biofilm reactor (MBBR) is a hybrid biological treatment system that operates similarly to an activated sludge process, but with the biomass fixed on a medium rather than suspended directly in the water. The benefit of the process is the ability to obtain high populations of biomass in a relatively small volume. As with other aeration technologies, aeration is required for treatment.

The MBBR process uses aerobic bacteria to degrade glycols and other deicing compounds. Influent is pumped into a large, open aeration tank. Oxygen is typically fed to the basin using compressed air blowers. Nutrients are fed to stimulate biological growth. Screens are installed at the discharge point to keep the media in the aeration tank. Because some bacteria do detach from the media, a clarifier is included to remove the biological solids that are in the discharge from the aeration basin. The main components of the system are shown in Figure 1.

MBBR technology is relatively new, although the biological concept is similar to the aerated gravel bed (AGB), which also operates with bacteria fixed to media. It has similarities to the activated sludge technology in that it is an aerated process in which the bacteria (on the media) are suspended. There are several functional differences in the technologies:

1. In the MBBR, the media/bacteria are suspended in the aeration basin, while in the AGB the media are fixed in place. In activated sludge, the bacteria float freely, without media.
2. The moving bed promotes self-cleaning of the media. AGBs have static/fixed media that are not routinely cleaned by surface-to-surface bumping. This means that mixing energy is critical to the MBBR process.
3. The MBBRs have much higher loading rates (i.e., pounds BOD per square foot area) because of the greater surface area for bacterial growth, and they do not rely on recycling of sludge back to the aeration basin like the activated sludge process.
4. Compared to activated sludge, less sludge is created in an MBBR per pound of organic material produced. Because the amount of sludge solids is so low, there is typically little wasting of sludge during the deicing season. (Some wasting may be necessary after the deicing season.)

Aeration in an MBBR is typically provided by compressed air blowers rather that surface aerators. Surface aerators would destroy the media. The aeration provides the required oxygen and keeps the media in suspension.

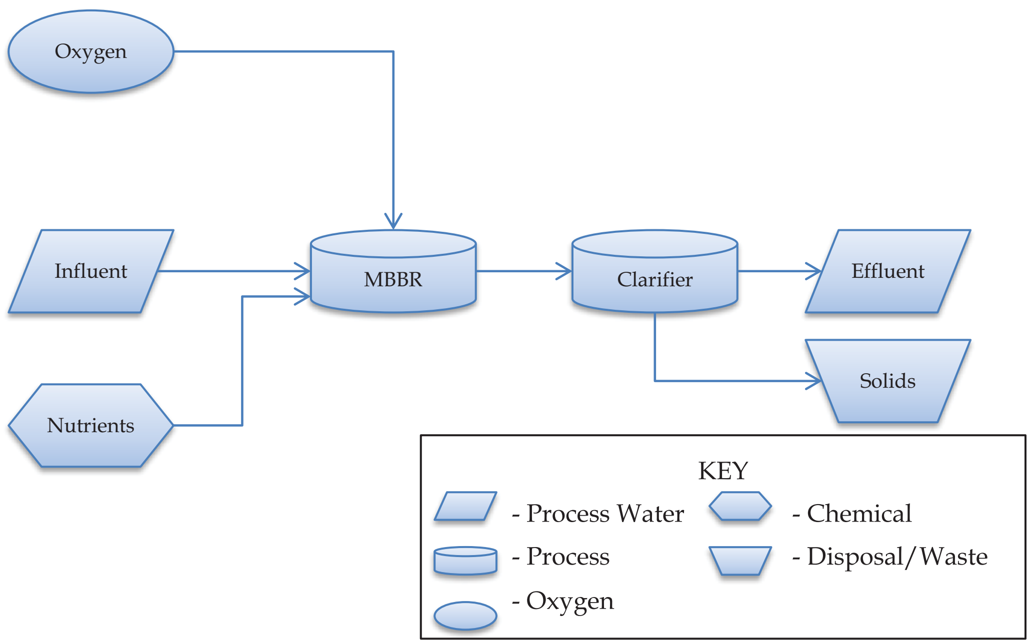


Figure 1. MBBR process flowchart.

The media are supplied by a variety of different vendors. The aeration tank is typically filled between 30% and 70% with media. Each vendor will have a sizing criteria based in its media surface-area-to-volume ratio. This ratio ranges from 100 to 200 square feet per cubic feet. Since biofilm grows on the surface of the media, the treatment sizing is based on an aerial loading rate for BOD per square foot. Once the area is determined, the volume of media is calculated from the manufacturer's surface-area-to-volume ratio. The aeration tank is then sized by the ratio of the fill percentage.

The treatment process uses a bacterial population for treatment. At the end of the deicer season, when the deicer, oxygen, and nutrients are shut off, the bacterial population will begin to die off. The die-off will reduce the amount of biomass, which reduces the treatment capacity. This technology has been tested at an airport; however, the amount of biomass that is typically available at the beginning of the next season is uncertain. Some start-up period would be required to regain the treatment capacity.

Advantages

1. Aerated, attached-growth bacteria are better suited for achieving biological treatment during periods of cold temperatures.
2. Has the ability to achieve low propylene glycol and concentrations of less than 15-mg BOD/L for a three-stage system.
3. Has consistent and predictable performance over a wide range of influent concentrations if loading into the treatment system is controlled.
4. Has a smaller footprint compared to activated sludge and aerated gravel beds.

Disadvantages

1. More mixing energy is required than activated sludge.
2. Because of the need for diffused air for mixing, is not easily adaptable to existing lagoons with irregular shapes.
3. During the period when water warms up, there may be biofilm sloughing and increased sludge generation.
4. The amount of biofilm that will over-summer is unknown, and the system may have to be reseeded each year.
5. The addition of engineered media results in an additional capital cost compared to activated sludge.
6. Some media may break down or be lost, and some must be replaced over time. Typically, 5% of total volume must be replaced.

Required Support Systems

1. Aeration system
   a. The aeration system provides oxygen for the aerobic bacteria and for mixing. Aeration system sizing dictates the treatment rate (in pounds COD per day) of the system. However, the mixing requirement may also be the limiting factor for the blower system.
   b. The equipment includes blowers and an air-piping network.
2. Nutrient feed system
   a. Provides nutrients, mixing, storage tanks, and metering system typically paced to treatment capacity.
   b. The equipment typically includes mixing/storage tanks and metering pumps.
3. Sludge handling system
   a. Reduces sludge volume. Typically clarifier sludge concentrations of 0.5% to 1% are increased to 8% to 20% solids concentration, reducing the volume by a factor of 6 to 10.
   b. Equipment may include digesters, centrifuges, belt presses, and filter presses.
4. Analytical system
   a. Routine measurement of influent flows and concentrations are required to determine system loading, nutrient, and aeration requirements.
   b. Equipment may include online monitors or analytical test kits.

Current Applications of Moving Bed Biofilm Reactor Technology

Applied at:	Oslo Gardermoen Airport (OSL)
Planned for:	Pittsburgh International Airport (PIT)

Variant Technologies

An aerobic fluidized bed reactor is a variation of the MBBR process. The media bed is typically housed in a vertical tank, and the bed is fluidized by a flow loop. Pure oxygen is fed into the bottom of the tank. The effluent is then treated in a clarifier to remove the free-floating biofilm.

An aerobic fluidized bed reactor is currently in operation as the polishing treatment at the Albany Airport. It has been in operation since 2001.

2. Data for Technology Selection Process

The information in this section can be used in conjunction with the methodologies presented in Chapter 4 and Chapter 5 of the guidebook to facilitate the assessment and selection of deicer treatment technologies.

Potential Applications

The MBBR process is best suited to low-concentration, high-volume flows where available land is an issue. The process also has better solids settling control than the typical activated sludge process. The process is capable of achieving very low effluent concentrations.

The data provided in this section are based on the most typical composition of the MBBR technology, which includes pretreatment, a nutrient feed system, an aeration system, an MBBR treatment cell, and a solids separation system for removal of biological solids from the effluent. Effluent concentration data represent the optimal potential performance based on collected field data (when available). Other variations of the MBBR system may provide different results. In addition, the characteristics of individual influent stormwater streams and operational decisions may affect the performance on a site-by-site basis.

Criteria Useful to Screening Analysis of Potential Treatment Technologies

See Table 1 for MBBR process selection criteria.

Criteria Useful in Comparative Analysis to Other Treatment Technologies

See Table 2 for MBBR effluent concentration information and Table 3 for MBBR selection criteria.

Table 1. Moving bed biofilm reactor process selection criteria.

Technology Parameter	Value or Rating	Description
Most applicable influent streams	Dilute	Well suited for lower COD concentration, high flow rate runoff from airfield areas or large aircraft deicing apron areas.
Minimum COD concentration	None	
Typical area (footprint)	<1 acre	Majority of footprint is open aeration tank with media.
Typical building/ equipment height	<20 ft	Building will typically house nutrient system and sludge handling equipment, which can make the building slightly taller than 10 ft.
Open water surface	Open water	Open water aeration basins and clarifier.
Reliance on other entities	No reliance	Treatment does not rely on recycling, glycol market, or POTW acceptance.
Maximum capital funding	See Figure 3	
Maximum annual O&M funding	See Figure 4	

Table 2. Moving bed biofilm reactor example effluent concentrations.

Parameter	Concentration or Value	Description
COD	Not available from existing deicer treatment systems	Effluent concentration of full-scale system should be similar to activated sludge effluent: 10 mg/L–20 mg/L.
NH_3-N	Not available	Feed as a nutrient but controlled to 1 mg/L–5 mg/L.
Phosphorous	Not available	Feed as a nutrient but controlled to <1 mg/L.
Flow	Varies	Flow rate varies with application.
pH	Varies, but near 7.0	Near 7.0 for optimum rate.
DO	Varies based on design	Typically about 4 mg/L.
TSS	Varies	Solids are primarily biological and created in aerated beds. Solids concentration depends on clarification technology.
TDS	Same as influent	Some salts may be temporarily taken up by biomass.
Temperature	Ambient	If influent is warm, will cool to ambient air temperature.

Technology-Specific Application Considerations

1. Sizing of aeration basin is dependent on which medium is proposed.
   Vendor supplying the media will typically assist with sizing of aeration basin. The vendor may also have other proprietary equipment, such as the screens to maintain the media in the basin and the air diffusers.
2. Typical and minimum stormwater temperature.
   This information is used by the treatment system designer to adjust the size of the treatment system.
3. Range of BOD concentrations.
   The treatment system operates most efficiently when it receives a constant load (pounds per day) of deicer. The treatment system can handle some

Table 3. Moving bed biofilm reactor selection criteria.

Effects of presence of fuels	Free-product fuel spills will inhibit bacterial growth. Dissolved fuel components will be partially treated.
Effects of presence of metals	Inhibition of aerobic bacteria occurs at high metals concentrations, but this is not typically a concern for airfield runoff.
Susceptibility to fouling and clogging	Grit removal and screening are recommended before aeration basin.
Site contamination	Consideration must be given to existing site contamination because aeration tanks are generally excavated.
Utility requirements	Requires electrical and water utility connection.
Effects of groundwater conditions	Groundwater within approximately 10 ft of the surface will affect system design.
Treatment plant operation needs	Treatment plant operation is typically performed by experienced wastewater treatment operators.
Time required for design and construction	Design and construction typically require 12 to 18 months.
Accessibility	Accessibility required for delivery of nutrient chemicals and sludge removal.

variation in concentration by adjusting the flow rate to provide the constant load. However, there may be physical limitations on the range of flows that can be delivered without causing hydraulic upset of the system.

Costs

The order-of-magnitude cost curves shown in Figure 2 and Figure 3 are based on the probable construction costs and operation and maintenance costs for typical treatment facilities in June 2012. The capital cost curves reflect the unit processes that are most typically needed to execute the core technological functions. Individual airports may incur additional costs, beyond those determined from these curves, for support system items (e.g., a building to house the system) based on site-specific needs and owner preference.

The intent of these graphs is to provide order-of-magnitude costs for comparison purposes during the treatment technology screening process. These costs are considered ANSI Class 5 cost estimates. For final selection of technologies and design, costs should be developed for the site-specific conditions.

A 20% uncertainty contingency has been added to capital costs to reflect the detail accuracy of the estimate. Typically, the expected accuracy within the industry of an estimate at the conceptual stage of a project ranges from −20/−50% to +30/+100% of the final cost of the project. Since site-specific conditions have not been considered, the actual site-specific costs may be outside of this range.

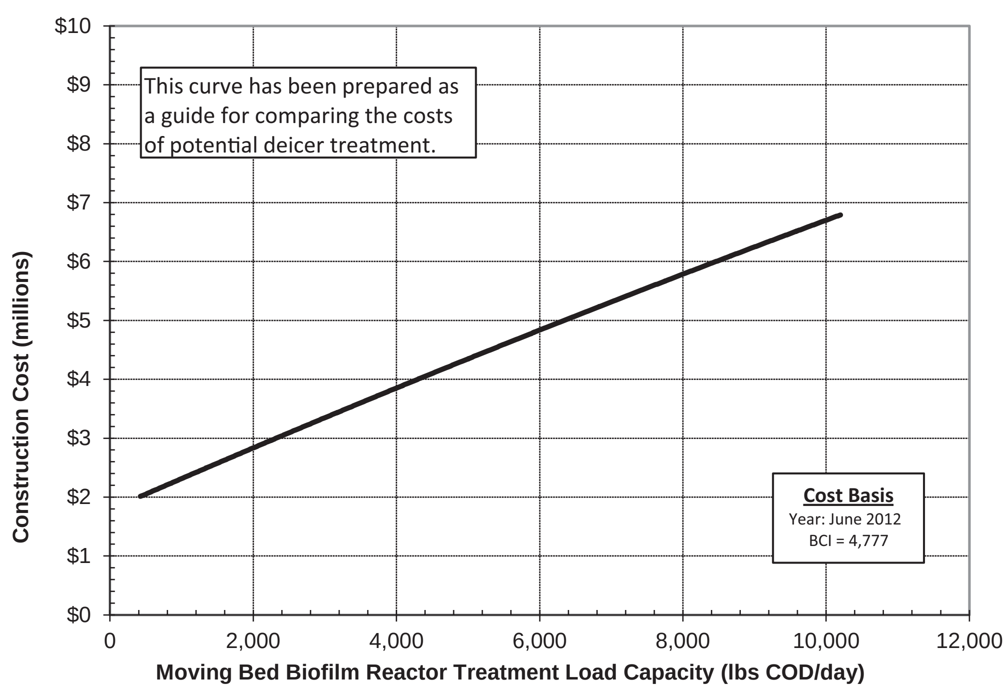


Figure 2. Capital cost curve.

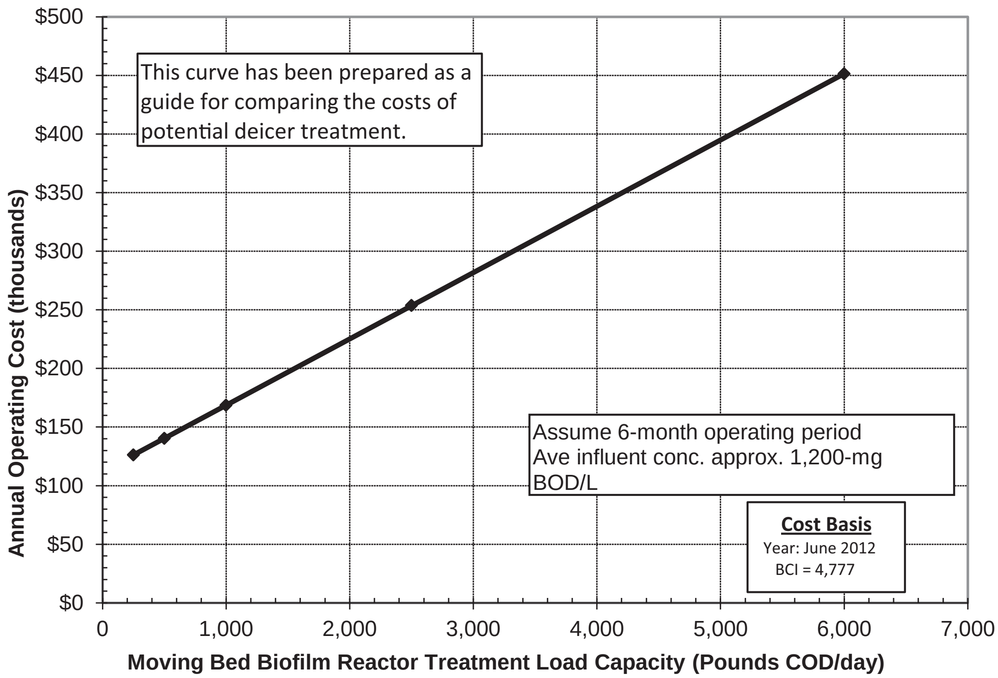


Figure 3. O&M cost curve.

The chart shown in Figure 2 can be used to understand order-of-magnitude costs for the core unit processes for MBBR technology applications. The core unit processes and systems incorporated into the Figure 2 costs include:

- Land acquisition,
- Aeration basin with media,
- Nutrient feed system,
- Screens and clarifier,
- Electrical and control systems, and
- Operator building.

Potential additional MBBR support systems excluded from the Figure 2 costs include:

- Storage/equalization, and
- Sludge storage and dewatering.

Figure 3 provides a means of understanding the order-of-magnitude annual operating costs for an MBBR deicer treatment system. The major operating cost items incorporated into the Figure 3 costs include:

- Labor (two operators),
- Sludge disposal,
- Utilities (power, communications), and
- Nutrients.

The utility costs for mixing and oxygen supply are one of the largest operational costs of the system.

On-Site
Biological Treatment
Aerobic

FACT SHEET 108

Passive Facultative Treatment Systems

1. Description

Process Description

Wastewater treatment relies on chemical, physical, and biological mechanisms to remove pollutants. Passive facultative treatment (PFT) systems are designed to employ these same mechanisms, but with minimal man-made power or equipment. The category encompasses lagoons, wetlands, sand filters, in-situ soil treatment, and similar approaches that provide passive removal of glycols and other deicing compounds from contaminated stormwater. This broad category of technologies is sometimes labeled as “natural treatment systems,” although use of that terminology does not sufficiently differentiate these technologies from other biological treatment technologies, which also rely on naturally occurring biology.

The term “passive” refers to an emphasis on low maintenance; PFT systems do not include mechanical aeration, chemical addition, or other engineered subsystems that require regular attention. Mechanical components are typically limited to influent lift stations, hydraulic control structures, and, potentially, monitoring. The term “facultative” refers to biological processes that occur over a range of oxygen levels. In general, PFT systems clean contaminated water employing facultative processes at the rate at which they occur naturally in the environment.

PFT systems are commonly used for domestic wastewater in smaller communities where land is relatively inexpensive. Properly sized facultative lagoons and treatment wetlands can provide reasonable treatment for organic compounds and suspended solids when flow rates and concentrations have minimal fluctuations.

The variable nature of deicing events and related runoff volumes introduces a challenge to employing PFT systems at airports. Integrated into a stormwater collection system, PFT units provide capacity for removal of suspended solids, like runway grit, and biological glycol degradation. Performance, as measured by percent removal, is highly variable for these systems, and expectations of the level of treatment must be realistically set.

The most common PFT system employed at airports is a facultative storage lagoon. In general, facultative lagoons store stormwater for controlled release. Concentrations of organics measured as COD slowly decrease during the storage period. The rate of decrease is likely to be associated with water temperature, oxygen, and nutrient availability. This approach is reasonable for airports that choose to store contaminated stormwater and release to sewage plants or, as permitted, local waterways.

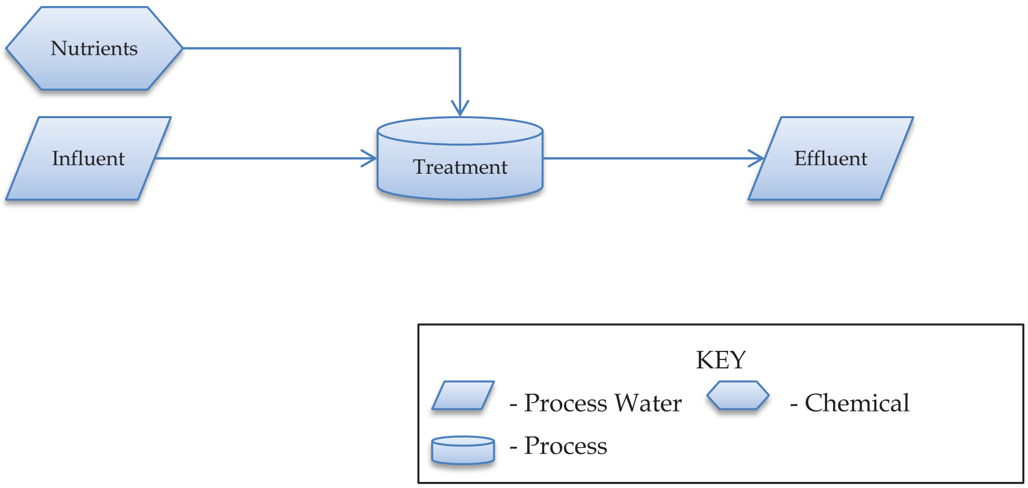


Figure 1. Passive facultative treatment process flow chart.

Although a number of PFT systems have been installed for the purpose of treatment of deicing fluid, few have provided strong evidence of stable performance. This can be due to a number of factors:

- Variability of flow and concentration.
- Low water temperature and bacterial growth rate.
- Nutrient deficiency.
- Oxygen deficiency.
- Poor design or operation.

Any of these factors can disrupt the treatment process. A successful design must take into account each factor and consider how it will affect the expected performance of the system. Passive facultative systems that have been well researched

Figure 2. Facultative lagoon and treatment wetland at Edmonton International Airport. (Courtesy of Mark Liner)

and tested and that provide the required degree of control for limiting excessive loadings, such as the irrigation-based system at the Zurich International Airport, can be successful.

Advantages

1. Low labor, chemical, and electrical costs.
2. Basic construction involving civil contractors (earthwork, precast concrete, etc.).

Disadvantages

1. Large areas required.
2. For some technology variations, animal attractant aspects (i.e., open water) must be mitigated around airfield.
3. For some systems, treatment performance is highly variable. This is not well understood and often is not predictable.
4. Odors.

Required Support Systems

1. Hydraulic control structure to maintain appropriate water elevations or flow rates.
2. Routine ground maintenance to control vegetation and animals.

Current Applications of Passive Facultative Technology

Installed Systems:	Frankfurt International Airport (FRA) – Media Based Treatment
	Toronto Pearson (YYZ) – Treatment Wetland
	Washington Dulles Airport (IAD) – Biological Treatment Unit
	Westover Air Reserve Base (CEF) – Treatment Wetland
	Zurich International Airport (ZRH) – Irrigation System

Variant Technologies

Surface flow and subsurface flow wetlands are variant processes. Subsurface wetlands are constructed as a gravel bed through which the water to be treated flows. The organic loading of the systems is limited based on the oxygen that can be transferred into the water. Since the oxygen transfer is based on the diffusion of oxygen between air and water, the systems must be very large for treatment of deicer. Treatment in subsurface flow wetlands is carried out by aerobic bacteria, similar to aerated gravel beds.

Surface flow wetlands allow the water to flow across the surface. However, the degradation of organic chemicals is still performed by aerobic bacteria either floating in the water or attached to the bottom sediment. Plants may be added to aid in transferring oxygen into the water, but the plants do not provide any significant treatment.

The non-aerated lagoon is also a variant process. Non-aerated lagoons, also called facultative ponds or polishing ponds in conventional wastewater treatment, rely on three zones:

- An aerobic zone at the surface of the pond.
- A facultative zone at the intermediate depth where either aerobic or anaerobic treatment can occur.
- An anaerobic zone at the bottom of the pond for the digestion of biological solids.

Algae may be encouraged in the pond to provide aeration. Algae are plants that give off dissolved oxygen as part of their respiration process. However, the respiration only occurs during hours of sunlight, so the production of dissolved oxygen is limited.

An issue with the non-aerated lagoon for deicer treatment is that it can become unstable for two reasons:

1. The pond layers maintain stratification mainly because of temperature. At cold temperatures, the densities of the colder bottom temperature and the warmer top temperature are not significantly different, and the layer may mix or invert.
2. In cold temperatures, the anaerobic treatment may slow down and accumulate a reservoir of untreated biosolids on the bottom. When the temperature warms up, there will be a sudden treatment demand that may cause the entire pond to become anaerobic.

In-situ soil treatment is also a variant process. Water to be treated is sprayed onto the ground surface and allowed to infiltrate the ground. Bacteria in the soil degrade the organic compounds. The organic loading rate is limited based on the oxygen transfer below the ground. Since this transfer rate is low, the area required is typically large for deicer treatment systems.

2. Data for Technology Selection Process

The information in this section can be used in conjunction with the methodologies presented in Chapter 4 and Chapter 5 of the guidebook to facilitate the assessment and selection of deicer treatment technologies.

Potential Applications

Passive facultative systems are best suited for airports with large land areas available, low COD concentrations in collected stormwater, and the ability to test and monitor system performance. Several existing applications of the technologies are associated with runoff from runways and taxiways that may contain deicers.

The data provided in this section are based on the most typical composition of the passive facultative treatment technologies, which includes a nutrient feed system and a series of treatment cells operating in parallel and in series. Effluent concentration data represent the optimal potential performance based on collected field data (when available). Other variations of the passive facultative treatment

Table 1. Passive facultative treatment process selection criteria.

Technology Parameter	Value or Rating	Description
Most applicable influent stream	Very dilute	Very low concentration runoff streams from the airfield runoff or a dilute fraction from aircraft deicing areas.
Minimum COD concentration	None	Not limited by deicer concentration.
Typical area (footprint)	>1 acre	Majority of footprint is the land area required.
Typical building/ equipment height	<20 ft	Buildings for housing nutrient systems or flow management system may be used.
Open water surface	Open water or no open water	Depending on technology used, may have open water.
Reliance on other entities	No reliance	Treatment does not rely on recycling or glycol market or POTW acceptance.
Maximum capital funding	See Figure 3	
Maximum annual O&M funding	See Figure 4	

systems may provide different results. In addition, the characteristics of individual influent stormwater streams and operational decisions may affect the performance on a site-by-site basis.

Criteria Useful to Screening Analysis of Potential Treatment Technologies

See Table 1 for passive facultative treatment process selection criteria.

Criteria Useful in Comparative Analysis to Potential Treatment Technologies

See Table 2 for passive facultative treatment process effluent concentration information and Table 3 for passive facultative treatment process selection criteria.

Table 2. Passive facultative treatment example effluent concentrations.

Parameter	Concentration or Value	Description
COD	<30 mg/L	Soluble COD directly from the main treatment process without clarification. Number is based on Zurich irrigation system. Achievable COD is highly dependent on the system and degree of load control, and many less-sophisticated passive facultative systems may not be able to achieve these levels.
NH_3-N	N/A	Feed as a nutrient but controlled to 1 mg/L–5 mg/L.
Phosphorous	N/A	Feed as a nutrient but controlled to <1 mg/L.
Flow	Varies	Flow into passive facultative systems is often not controlled and is allowed to vary freely.
pH	Varies, but near 7.0	Near 7.0 for optimum rate.
DO	Varies	Varies based on design and loading.
TSS	Varies	Solids generally are low for most configurations.
TDS	Same as influent	Salts generally not removed.
Temperature	Ambient	If influent is warm, will cool to ambient air temperature.

Table 3. Passive facultative treatment selection criteria.

Effects of presence of fuels	Free-product fuel spills will inhibit bacteria.
Effects of presence of metals	Inhibition of aerobic bacteria occurs at high metals concentrations.
Susceptibility to fouling and clogging	Grit removal and screening are required so that clogging does not occur.
Site contamination	Consideration must be given to existing site contamination because systems are generally excavated.
Utility requirements	Requires electrical utility connection for influent pumps.
Effects of groundwater conditions	Groundwater within approximately 6 ft–8 ft of the surface will affect system design.
Treatment plant operation needs	Treatment plant operation can be performed by airport personnel.
Time required for design and construction	Design and construction typically require 12 to 18 months.
Accessibility	Accessibility required for delivery of nutrient chemicals.

Technology-Specific Considerations

1. Land use
   PFT systems use large land areas relative to other systems, and land planning must be carefully undertaken so as not to interfere with current or future land uses.
2. Bird attractant
   Appropriate animal mitigation must be considered during design.
3. Performance
   Performance of passive facultative systems for treatment of deicer can vary significantly with the details of the application, especially the degree of influent load control, the ability to avoid short-circuiting, and nutrient addition. Adequate performance data on existing systems with lesser controls and monitoring are difficult to obtain.
4. Cleaning
   Infrequent maintenance results in accumulation of solids and other debris as well as excessive plant growth. System design must factor in prolonged periods of minimal maintenance and access for occasional desludging or vegetation removal.

Costs

The order-of-magnitude cost curves shown in Figure 3 and Figure 4 are based on the probable construction costs and operation and maintenance costs for typical treatment facilities in June 2012. The capital cost curves reflect the unit processes that are most typically needed to execute the core technological functions. Individual airports may incur additional costs, beyond those determined from these curves, for support system items (e.g., a building to house the system) based on site-specific needs and owner preference.

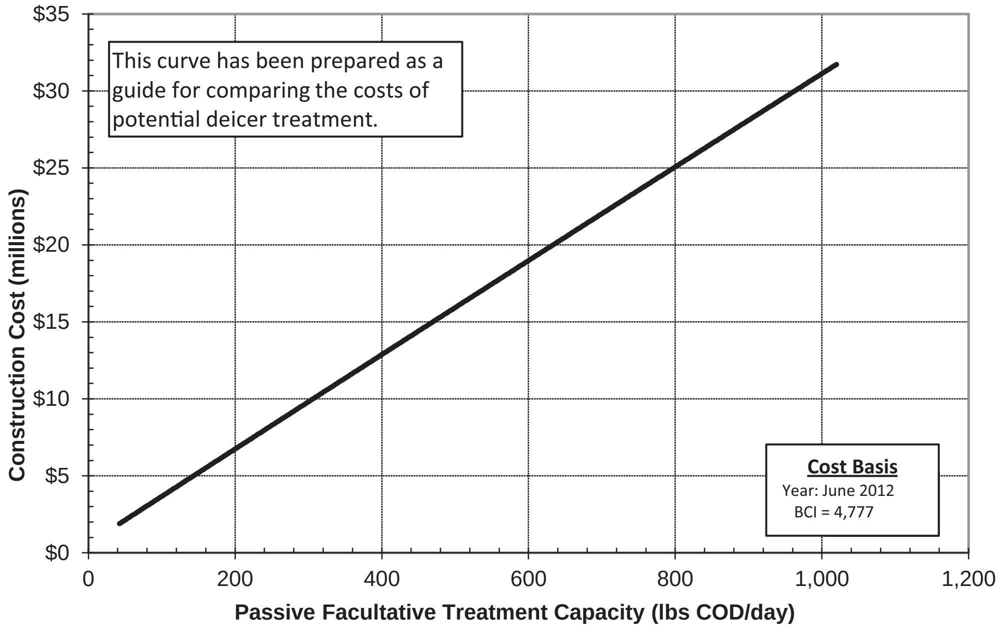


Figure 3. Capital cost curve.

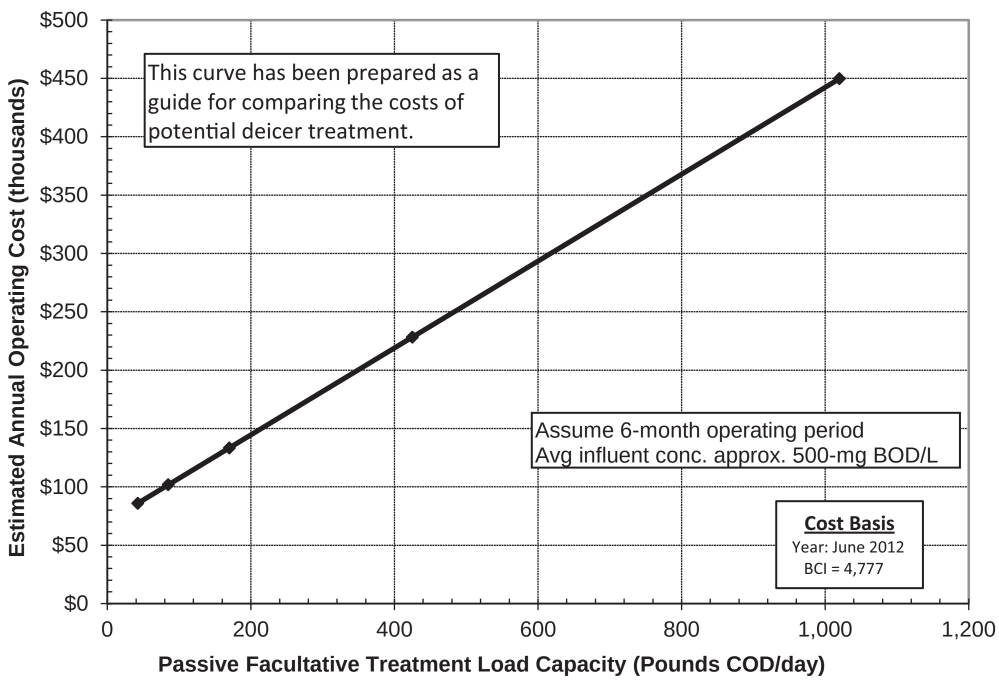


Figure 4. O&M cost curve.

The intent of these graphs is to provide order-of-magnitude costs for comparison purposes during the treatment technology screening process. These costs are considered ANSI Class 5 cost estimates. For final selection of technologies and design, costs should be developed for the site-specific conditions.

A 20% uncertainty contingency has been added to capital costs to reflect the detail accuracy of the estimate. Typically, the expected accuracy within the industry of an estimate at the conceptual stage of a project ranges from –20/–50% to +30/+100% of the final cost of the project. Since site-specific conditions have not been considered, the actual site-specific costs may be outside of this range.

The chart shown in Figure 3 can be used to understand order-of-magnitude costs for the core unit processes for passive facultative treatment technology applications. The core unit processes and systems incorporated into the Figure 3 costs include:

- Land acquisition,
- Lined in-ground treatment units,
- An influent flow distribution system in cells,
- An effluent discharge system, and
- Operator building.

Potential additional passive facultative treatment technology support systems excluded from the Figure 3 costs include:

- Storage/equalization,
- A nutrient feed system, and
- Solids storage and dewatering.

Figure 4 provides a means of understanding the order-of-magnitude annual operating costs for a PFT system. The major operating cost items incorporated into the Figure 4 costs include:

- Labor (one operator),
- Utilities, and
- Chemicals.

FACT SHEET 109

Public Wastewater Treatment Facilities

1. Description

Process Description

Stormwater containing aircraft deicing fluid (ADF) is collected at an airport and discharged to a publically owned treatment works (POTW) where it combines with other domestic and industrial wastewater and is treated by the POTW to remove pollutants. The POTW's treatment system biologically degrades organic pollutants present in the municipal wastewater (including the principal components of ADF: propylene glycol or ethylene glycol). The POTW discharges its treated effluent in compliance with the conditions of a National Pollutant Discharge Elimination System (NPDES) permit issued by the state environmental control agency (or, in some states, by the U.S. Environmental Protection Agency).

The airport must obtain a permit (or equivalent authorization) from the POTW in order to discharge to the public sewer. This permit contains various conditions, restrictions, and discharge limitations with which the airport must comply. The conditions may include restrictions on the volume or flow rate to be discharged, when the discharge may occur, the maximum allowable concentration of pollutants (measured as COD) that may be discharged, and the maximum increase in discharge load from one day to the next.

The airport will also be required to pay user charges for the wastewater treatment service provided. The fees will typically include a charge based on the volume of stormwater discharged, plus a surcharge based on the mass loading of pollutants (COD). The surcharge provides payment to the POTW for the extra costs of treating high-strength organic pollutants in the airport stormwater.

Technology Considerations

POTWs provide biological treatment in order to remove organic pollutants from the wastewater they receive, including domestic sanitary wastewater and industrial process wastewater. If an airport discharges its ADF-contaminated stormwater to the public sewer system, it is combined with all other wastewater received by the POTW. Both of the primary organic compounds used in ADF—propylene glycol and ethylene glycol—are highly biodegradable and can readily be treated by the POTW treatment system.

A principal consideration by the POTW is whether the treatment facility has adequate process capacity to treat the total loading of organic matter from all sources. Since ADF-contaminated stormwater frequently has a much higher COD concentration than domestic sanitary wastewater, it often becomes a significant fraction of the total organic loading to the POTW, even if its volumetric fraction is low. POTWs use aerobic biological treatment processes, which require oxygen to be transferred into the wastewater from the atmosphere. POTWs commonly use either large air compressors or mechanical aerators to dissolve oxygen from the air into the wastewater so that the oxygen is available for bacterial degradation of the organic matter. Accordingly, the maximum oxygen transfer capability of the POTW's aeration system determines the maximum organic loading that can be treated.

The POTW's collection system (the network of sewers and pumping stations that conveys raw wastewater to the treatment facility) must have the capacity to carry the airport stormwater in addition to its other wastewater flows without resulting in backups or overflows. Accordingly, the POTW will determine what maximum discharge flow it can accept from the airport. It may be possible to construct additional conveyance capacity (e.g., a new gravity sewer from the airport into a larger existing sewer line, or perhaps a new force main and pump station from the airport). The capital cost of new sewer lines would be paid by the airport, to the extent it provides service for the airport.

Figure 1 presents a simplified process flowchart for a public wastewater treatment facility, showing its basic treatment processes. Note that while airport stormwater would be discharged into the municipal sewer system and enter the POTW at the beginning of its process train, the waste ADF is only treated in the secondary (biological) treatment process.

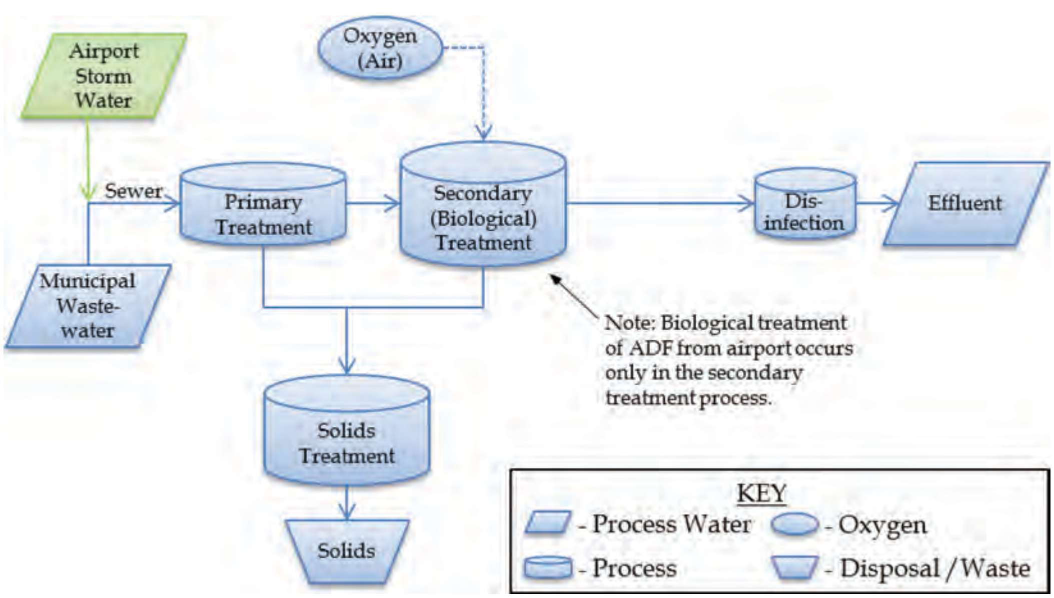


Figure 1. Off-site treatment: public wastewater treatment facility process flowchart.

The POTW will place restrictions on the maximum allowable discharge of ADF stormwater based on the following considerations:

1. Pollutant loading
   - Average discharge mass loading of organic pollutants (measured as COD) must not exceed the long-term average biological treatment capacity of the POTW.
   - Instantaneous or short-term discharge mass loading of organic pollutants must not exceed the short-term maximum or peak biological treatment capacity of the POTW.
   - Large/rapid swings in pollutant mass loading are difficult for the POTW to treat since bacterial population needs to be balanced with the organic loading, and it takes time for the biomass to grow or to be wasted.
2. Discharge volume
   - The discharge flow rate of airport stormwater (plus existing wastewater flow to the POTW) must not exceed at any time the hydraulic conveyance capacity of the public sewer or the pumping capacity of any pump stations used to convey this plus other wastewater to the POTW. Otherwise, an overflow of wastewater would occur—including likely sewer backups into residences and commercial buildings.

Note that during periods of wet weather, when the volume of stormwater collected at the airport is likely to be greatest, the POTW will also be receiving its greatest flow rates because of wet weather inflow and infiltration into the sewer system. Accordingly, the airport's worst-case flow and loading will be a key factor for the POTW to consider in determining allowable discharge.

To a degree, the airport controls the concentration of ADF in its stormwater. The way that ADF-contaminated stormwater is collected is a primary determinant of both volume and concentration. For example, if centralized deicing pads are used at the airport, the total mass of ADF collected for discharge will be contained within a smaller collection area than if decentralized deicing is performed at gates. Accordingly, the total mass of ADF will be combined with a smaller volume of precipitation, thereby producing a higher concentration.

Advantages

1. No on-site treatment system is required.
2. No capital cost for on-site treatment system.
3. No need for trained operators or process control staff.
4. Compliance reliability should be greater than on-site treatment alternatives.

Disadvantages

1. Requires permit from the control authority (usually issued by POTW, but in some cases by state agency or U.S. EPA).
2. Must comply with permit conditions for discharge rate or volume, or discharge COD mass loading.
3. Must pay discharge fees and surcharges to POTW. (These pay for the cost of service in lieu of operating costs for on-site treatment at airport.)

4. May require on-site storage (to equalize high flows in order to comply with daily loading restrictions).
5. May require construction of additional sewer (may be gravity, or pumped force main) to connect to public collection system. Capital cost would be paid by airport.

Required Support Systems

1. Discharge flow measurement, and some form of discharge flow rate control will also likely be required.
2. Storage or equalization for excess stormwater (i.e., the amount exceeding the POTW's restriction for volume or load) collected at the airport. The retained excess stormwater would then be discharged over a longer period following the stormwater collection event. Storage/equalization facilities would typically include large, open basin(s)—usually an earthen construction with a liner. A pumping system will likely be required to pump out of the storage basin(s).
3. Pumping may also be required if the airport's collection system cannot drain by gravity into the public sewer system.

Monitoring and Reporting Requirements

Monitoring and reporting requirements will be included in the POTW discharge permit. Some POTWs perform all sampling and analyses, while others also require self-monitoring by the permit holder. If self-monitoring is required, the airport will likely have to collect 24-hour composite samples using automatic samplers. Samples would be sent by the airport to a contract laboratory for analysis of specified pollutants (including COD). At least one POTW has required continuous monitoring using a TOC analyzer. Frequency of monitoring will be specified in the permit. Monitoring—whether performed by the POTW or the airport—may be required a few consecutive days on a monthly basis during deicing season, but could be more frequent or even daily.

Discharge flow data and sampling analytical results (from the airport's contract laboratory) will have to be reported to the POTW, typically on a monthly or quarterly basis.

Potential Process Alternatives with Public Wastewater Treatment Facilities

The discharge of airport stormwater to a public wastewater treatment facility as described simply provides off-site treatment of the waste ADF material contained in the stormwater. However, there are two specific circumstances in which the ADF in airport stormwater may actually be used beneficially as a resource for the POTW.

1. *Feed to anaerobic digester.* High-strength (COD) stormwater could be fed directly to the POTW's anaerobic digester, thereby increasing biogas production, which in turn could be used to increase power generation. This would not be feasible at most POTWs at the present time, but it is technically feasible. As many public facilities look for ways to become more energy efficient, a

few have started to accept high-strength organic wastes as an additional feed source for their anaerobic digesters and use the additional biogas generated.

One POTW, the East Bay Municipal Utility District wastewater treatment plant in Oakland, CA, has reported that it presently generates more electrical power than it uses, and sells the excess back to the grid. The plant accepts hauled wastes from a variety of sources: poultry processors, wineries, dairies, animal processing and rendering plants, and food service facilities (fats, oils, and greases), and accepts septage and other industrial wastes. These wastes are fed directly into the plant's anaerobic digesters (which have been converted to a high-temperature thermophilic process mode in order to increase the allowable organic loading rate). Although this plant does not receive waste ADF in airport stormwater, their experience with other high-COD wastes demonstrates the potential viability for this process alternative for an airport.

For a POTW to be able to use high-strength ADF stormwater from an airport for this use, several conditions would have to exist:

a. The POTW must have anaerobic digestion and a means of collecting and storing the biogas generated. While anaerobic digestion is a common solids treatment process used for sludge stabilization prior to solids disposal at wastewater treatment facilities, many POTWs use alternative processes.
b. The POTW must have a biogas-fueled generator to produce electrical power. POTWs with anaerobic digestion more commonly do not have generators, but instead burn their biogas to produce steam or heat, or flare their excess biogas. However, many POTWs are evaluating installation of biogas-fueled generators, and their application is expected to increase in the future.
c. There would have to be a practical means of conveying the stormwater to the POTW, other than via existing public sewers (since this would dilute the stormwater with other municipal wastewater). The airport stormwater would either be sent via a separate direct pipeline or hauled by truck directly to the POTW. Either of these alternatives is likely to be costly.
d. Separate collection of more concentrated ADF-bearing stormwater at the airport would be necessary. Storage/equalization at the airport would be required since a more even feed would be beneficial for the POTW process operation.

2. *Feed to denitrification process.* For POTWs that have total nitrogen removal requirements in their NPDES discharge permits, high-strength (COD) stormwater could be fed directly to the denitrification reactor for use as an external carbon source. When biological denitrification is performed at a POTW, there must be a source of readily degradable organic matter (i.e., a carbon source), which is not normally present in the wastewater at that point in the process train. This is commonly provided by chemical addition of purchased methanol (or another readily degradable organic compound) to the denitrification reactor. The potential use of propylene glycol or ethylene glycol from the waste ADF in stormwater would substitute for some of the purchased methanol, thereby reducing costs for the POTW.

   For a POTW to be able to use high-strength ADF stormwater from an airport as a carbon source for denitrification, several conditions would have to exist:

   a. The POTW must have a separate-stage denitrification process that requires augmentation by the addition of an external carbon source.

b. There would have to be a practical means of conveying the stormwater to the POTW, other than via existing public sewers (since this would dilute the stormwater with other municipal wastewater). The airport stormwater would either be sent via a separate direct pipeline or hauled by truck directly to the POTW. Either of these alternatives is likely to be costly.

c. Separate collection of more concentrated ADF-bearing stormwater at the airport would be necessary. Storage/equalization at the airport would be required since a more even feed would be beneficial for the POTW process operation.

Either of these possible alternative process uses for ADF stormwater at a POTW is only feasible given the existence of all the specific conditions noted. In addition, from the POTW's perspective, accepting airport stormwater for either use would be less than ideal, since the resource would only be available on a seasonal basis, and there is likely to be significant daily variability in the quantity of ADF stormwater from the airport. Nonetheless, either of these alternatives represents a step toward increasing environmental sustainability since the waste ADF would be used as a resource rather than a waste material to be treated and disposed of.

Figure 2 presents a simplified process flowchart for POTWs showing these two possible alternative process feed points.

Current Applications of Discharge to Public Wastewater Treatment Facilities

See Table 1 for sample airports using POTWs.

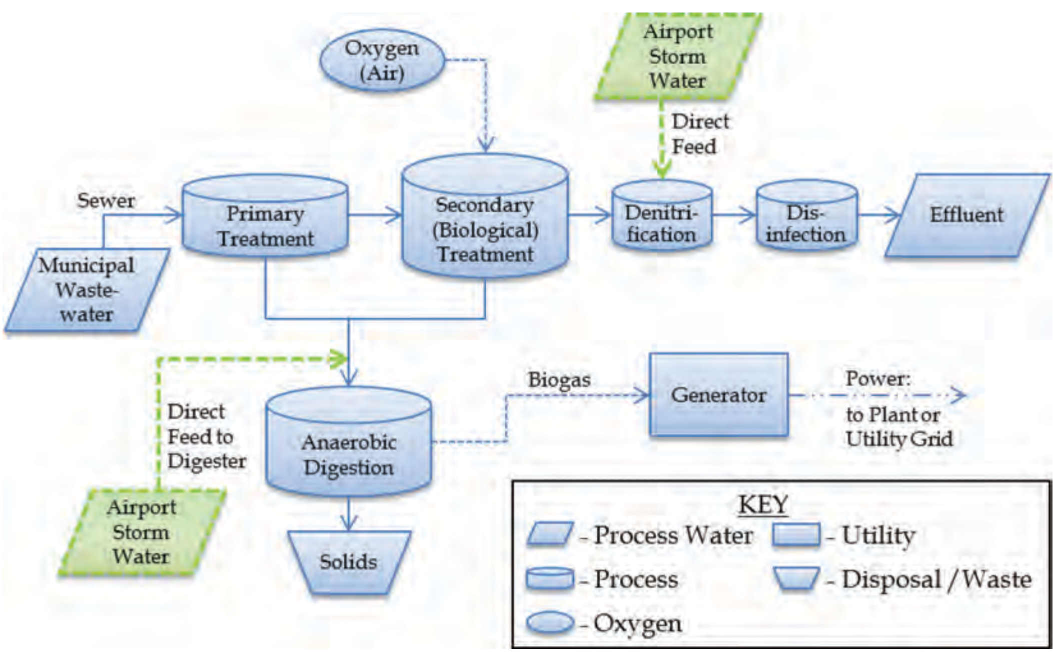


Figure 2. Alternative feeds to public wastewater treatment facility: process flowchart.

Table 1. Examples of current applications of POTWs used to treat deicer-affected stormwater.

Airport	POTW	Application
Detroit (DTW)	Wayne County – Downriver WWTP	Discharged via sewer for wastewater treatment
Dayton (DAY)	City of Dayton – AWT Plant	Discharged via sewer for wastewater treatment
Cleveland (CLE)	Northeast Ohio Reg. Sewer District – Southerly WWTC	Discharged via sewer for wastewater treatment
Milwaukee (MKE)	Milwaukee Metro. Sewerage District – South Shore WRF	High-strength ADF hauled by truck, discharged to anaerobic digesters

Notes: AWT = advanced wastewater treatment, WWTC = wastewater treatment center, WRF = water reclamation facility.

2. Selection Criteria

The information in this section can be used in conjunction with the methodologies presented in Chapter 4 of the guidebook to facilitate the assessment and selection of deicer treatment technologies.

Potential Applications

Discharge to a POTW is potentially applicable whenever the following conditions are met: (1) a connection to a sanitary sewer is available, (2) the POTW agrees to grant the airport a permit, and (3) the economics of POTW discharge are better than the economics of on-site treatment.

Critical Parameters for Successful Implementation to Consider In Selection Process

See Table 2 for POTW selection criteria.

Initial screening of treatment alternatives to evaluate feasibility of wastewater treatment by local POTW will include the following steps:

1. Identify local POTW and its industrial pretreatment program coordinator or manager. Initiate preliminary discussion with the POTW to determine whether it may be willing to accept ADF-contaminated stormwater.
2. Develop a preliminary estimate of ADF-contaminated stormwater collection volume at the airport. This should include estimates of deicing season total volume, maximum weekly volume, and maximum daily volume of stormwater. Review data from extreme wet weather periods that occurred coincident with deicing activity.
3. Using available analytical data (COD concentrations analyzed on stormwater samples), calculate preliminary estimate of the range and average mass loadings for potential stormwater discharge to a POTW.
4. Evaluate potential impact of anticipated POTW restrictions for airport stormwater discharge.
5. Determine POTW's likely cost/fee structure for airport stormwater discharge into its sewer system.

Table 2. POTW selection criteria.

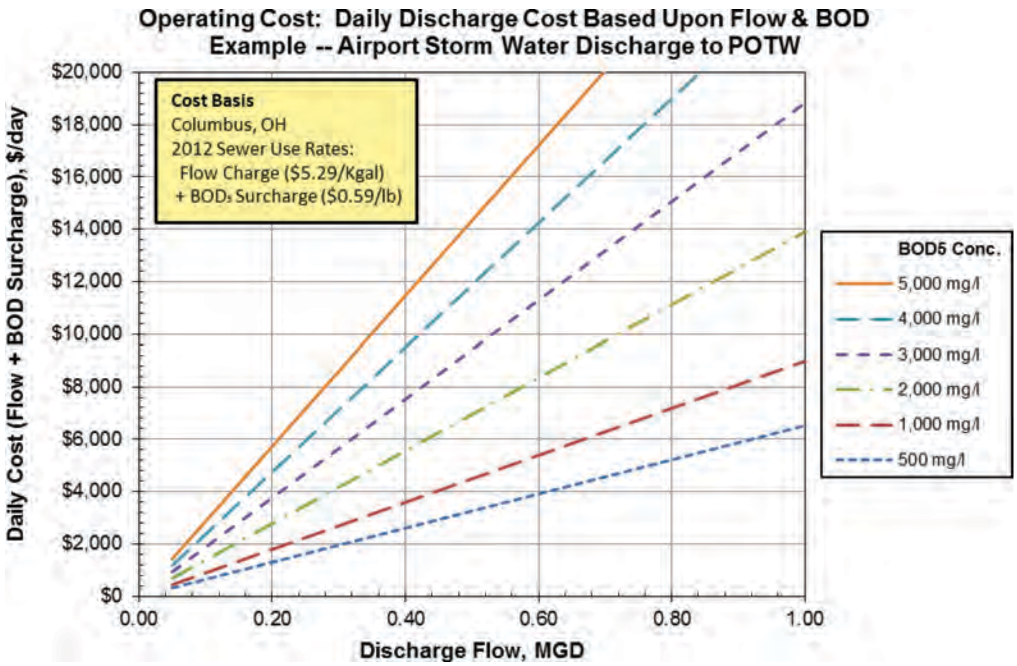
Parameter	Description/Comments
Reliance for disposal on outside entities	Treatment relies on outside entity, the POTW, which is the local control authority for the industrial pretreatment program. A state regulatory agency or U.S. EPA may also become involved if significant noncompliance occurs.
Technology application	Discharge of ADF-bearing stormwater from airports to POTWs is a widely used and proven technology.
Treatable stormwater constituent mix	POTWs can treat BOD/COD, PG, EG, acetate, formate, ammonia-nitrogen, and TSS. POTWs generally cannot treat TDS. Capacity limits may apply.
Regulatory	The airport must apply for a discharge permit issued by the POTW (in some cases, by the state or U.S. EPA). The POTW has legal authority to enforce compliance with permit conditions.
Airport stormwater characterization	Engineering evaluation to determine anticipated stormwater flows and organic (COD) concentrations under various weather conditions.
Organic loading treatment capacity of POTW	Discharge to the POTW is limited by available organic loading capacity for treatment.
Discharge flow capacity of POTW and sewers	Discharge to the POTW is limited by available hydraulic capacity of collection system (including local sewer or interceptor closest to airport) and wastewater treatment plant.
Control requirements	Control discharge flow rate and timing of discharge to meet permit requirements.
Stormwater collection	Collection and possible storage/equalization should minimize collection of dilute stormwater in order to minimize total volume.
Staffing	Very limited airport staffing required (compared with on-site treatment).

Costs

Costs for off-site treatment and disposal of airport stormwater by a POTW will be paid as user charges to the POTW (typically a municipality or sewer authority). The POTW likely has an existing user charge system, including surcharges for high-strength wastewater (which would apply to the high COD concentrations in airport stormwater). Costs are unique to each POTW entity based on their specific circumstances and costs of providing service, including their capital debt service. Accordingly, comparison of POTW costs from other locales is not meaningful.

The POTW's user charge structure and rates are typically developed based on an engineering/financial evaluation of cost of services. The rates are authorized by the local political entity with legal responsibility for the POTW (e.g., city, county, or separate wastewater/sewer agency or authority). It may be possible to negotiate a specific rate structure for the airport as a separate class of industrial user. The POTW must have uniform and equitable rates for all users within a class, but may establish different rates for different classes of users.

One significant issue for the POTW is that the treatment capacity necessary to treat airport ADF stormwater is generally needed only during the deicing season and would be unused during the remainder of the year. While the variable portion of operating costs would not be incurred when this treatment capacity is unused, the fixed operating costs and capital debt service still must be paid continuously.



(Note: BOD_5 surcharge applies only to portion of concentration that exceeds standard strengtth of 250 mg/L.)

Figure 3. Example operating cost for airport stormwater discharge to POTW.

Figure 3 shows an example cost chart for airport stormwater discharge to a POTW. The example is based on the 2012 sewer use rate schedule from the city of Columbus, Ohio. The charges shown in the chart would apply to any industrial user—they include a commodity (flow) charge and an extra-strength BOD_5 surcharge. POTWs typically also have extra-strength surcharges for suspended solids and ammonia-nitrogen, although ADF stormwater generally does not contain significant amounts of these pollutants. As is common with many POTWs, Columbus also has a monthly billing charge and a monthly industrial user charge that covers a proportional share for administration of the industrial pretreatment program. However, these fixed charges are minor in comparison with the flow and load charges.

FACT SHEET 110

Private Recycling Facilities

1. Description

Process Description

The deicer treatment technology option of using private recycling facilities involves the collection and transport of high-glycol–concentration deicer-affected stormwater to a glycol recycling facility off of the airport site that is normally owned and operated by a company that specializes in the handling, processing, and reclamation of various industrial waste streams. Deicer-affected stormwater is collected at an airport, temporarily held in storage tanks, potentially processed on-site to increase glycol concentration/decrease water volume, and transported to an off-site recycling facility. The airport can ship this fluid without any treatment or can partially treat the fluid on-site before shipping in an effort to remove some of the water content and reduce the overall volume to be treated by the third-party recycling provider.

These facilities normally comply with the effluent limitations established by the EPA for the Centralized Waste Treatment Point Source Category. In general, this regulation includes wastewater discharge standards for facilities that treat or recover metal-bearing, oily, and organic wastes, wastewater, or used material received from off-site. These facilities typically have discharge permits issued by POTWs to discharge the effluent wastewater produced from recycling activities.

Private recycling facilities vary depending on the primary waste or wastes that are treated on-site. For the recycling treatment centers that can handle deicer-affected stormwater, there are usually installed processes that can reclaim glycol, the main component of ADF. The technologies typically used include membranes, mechanical vapor recompression, thermal vapor recompression, other evaporation systems, and distillation. By separating and reclaiming the glycol from the deicing-affected stormwater, the recycling provider can generate revenue from the sale of the glycol.

For smaller commercial airports and military installations that generate a low volume of deicer-affected stormwater, on-site recycling can be cost-prohibitive. Trucking of fluid to an off-site recycling facility can be advantageous when considering the capital investment for a recycling facility, the processing equipment, and associated operating expenses. These costs can be avoided by providing on-site storage for spent ADF as a temporary measure to handle volumes generated from precipitation-related deicing events. After an event has subsided, the fluid can be trucked to a regional recycling center. Depending on the distance to the off-site facility and the volumes of glycol generated from the airport, a cost analysis can be conducted to determine if this option is the most economical. In general, unless an airport generates in excess of 200,000 gallons to 300,000 gallons of recovered deicing fluid feedstock (between 1% and 25% glycol concentrations) per year, it is not cost-effective to install recycling equipment on-site. Many small airports can benefit from a regional recycling facility by avoiding the capital investment and fixed operating expenses. In many cases, each airport that uses a centralized recycling facility may only pay a price per gallon for transportation and recycling since these costs are consumed during a deicing season. The advantages to the airport are that it does not have fixed expenses directly related to recycling, and it only pays for the volume treated each season.

The operational cost of recycling is dependent on the concentration and amount of fluid to be recycled. Therefore, the private recycler may impose minimum limits on the amount of deicer and the concentration of it that they will accept. Minimum concentrations of 30% PG for distillation or 1% PG for MVR and reverse osmosis are typical economic limits. Rates may be negotiated that allow for a sliding scale based on the PG concentration and the volume to be treated.

For examples of technologies used by private recycling facilities, see the fact sheets on distillation, mechanical vapor recompression, and reverse osmosis.

Advantages

1. In many cases, each airport that uses a centralized recycling facility may only pay a price per gallon for transportation and recycling as these costs are accrued during a deicing season. The advantages to the airport are that it does not have fixed expenses directly related to on-site recycling, and it only pays for the volume treated each season.
2. Less spent-ADF storage needs to be provided on-site at the airport since in most cases the off-site recycling facility can provide storage.
3. The recycling facility operator is required to secure and maintain all necessary permits to treat the spent ADF.

Figure 1. Private recycling facility in Troy, Indiana.

Disadvantages

1. The airport as the generator of the spent-ADF waste must ensure proper chain of custody and assumes liability to ensure that the waste is being treated in accordance with all local, state, and federal requirements.
2. With an off-site option, there is a disadvantage with unpredictable weather conditions during the winter that could halt transportation altogether and cause potential storage issues at the airport.
3. Staff at the airport are required to manage accounting and logistics of fluid moved off-site.

Required Support Systems

1. Storage tanks for spent ADF must be installed at the airport to hold the fluid before it is trucked off-site.
2. Truck or railcar loading stations with metering and pumping systems need to be installed for transfer of spent ADF from storage tanks for off-site shipping.

Monitoring and Reporting Requirements

Monitoring and reporting requirements will be included in the private recycling contract. Analyses will be required to comply with billing and process requirements. Each batch sent to the recycling facility may be required to be tested. Examples of analyses that may be required include those for PG or EG, COD, TSS, pH, and TDS.

Current Applications of Private Off-Site Recycling Facilities

Demonstrated Systems:	Many airports truck off-site to another airport facility that acts as the centralized deicing private recycler.

2. Selection Criteria

The information in this section can be used in conjunction with the methodologies presented in Chapter 4 of the guidebook to facilitate the assessment and selection of deicer treatment technologies.

Potential Applications

Use of an off-site recycler depends on several factors, including proximity to the nearest off-site recycling facility, conditions imposed by the recyclers for the quality and quantity of the product, and economics (see Table 1).

Criteria Useful When Comparing to Other Treatment Technologies

See Table 2 for private recycling facility selection criteria.

Table 1. Private recycling facility process selection criteria.

Technology Parameter	Value or Rating	Description
Most applicable influent stream	Concentrated	Transport of dilute stormwater is not typically cost-effective. The higher the concentration transported, the lower the cost. Often, to use these methods, deicer-affected stormwater volume must be low or pretreatment must be applied to reduce water volume.
Minimum COD concentrations	Either 300,000-mg/L COD if private recycler has distillation process, or 10,000-mg/L COD if recycler has MVR or RO process	Treatment can be performed below this concentration; however, generally it is not economically feasible.
Typical area (footprint)	Not applicable	Requires storage tanks.
Typical building/ equipment height	Not applicable	No on-site infrastructure (other than storage tanks).
Open water surface	No open water	No on-site infrastructure.
Reliance on other entities	Reliance	Relies on outside vendor for treatment.
Maximum capital funding	Not applicable	No on-site infrastructure (other than storage tanks).
Maximum annual O&M funding	Varies	Depends on negotiated contract.

Technology-Specific Application Considerations

1. Amount of ADF used at the airport and the amount of glycol that can be reclaimed
   The larger the volume of glycol that can be recycled, the more cost-effective the recycling system becomes.
2. Storage and collection costs
   Some stormwater collection and infrastructure are required.

Table 2. Private recycling facility selection criteria.

Effects of presence of fuels	Free-product fuel spills may cause batch to be rejected for treatment or increase cost.
Effects of presence of metals	Metals may cause batch to be rejected for treatment or increase cost.
Susceptibility to fouling and clogging	If there is a high TSS concentration, private recycler may add costs for solids removal and disposal.
Site contamination	Not applicable.
Utility requirements	Not applicable.
Effects of groundwater conditions	Not applicable.
Treatment plant operation needs	None.
Time required for design and construction	None, but time will be required for negotiation of contract.
Accessibility	Accessibility required for removal of stormwater by tanker trucks.

3. Pretreatment on airport site
   In some cases, transport and disposal at a private recycling facility are only economically feasible if some pretreatment is performed at the airport site to increase the glycol concentrations and decrease the water content for transportation.
4. Transportation access
   Access for trucks or rail at the airport to convey stormwater on an ongoing basis is necessary.
5. Average concentration of spent ADF
   Private recycling systems are typically economically feasible above PG concentrations of approximately 1%, if transportation costs allow.

Costs

For smaller commercial airports and military installations that generate a low volume of spent ADF, on-site recycling can be cost-prohibitive. Trucking of fluid to an off-site recycling facility can be advantageous when considering the capital investment for a recycling facility, the processing equipment, and associated operating expenses. These costs can be avoided by providing on-site storage for spent ADF as a temporary measure to handle volumes generated from precipitation-related deicing events. After an event has subsided, the fluid can be trucked to a regional recycling center. Depending on the distance to the off-site facility and the volume of glycol generated by the airport, a cost analysis can be conducted to determine if this option is the most economical. Many small airports can benefit from a regional recycling facility by avoiding capital investments and fixed operating expenses. In many cases, each airport that uses a centralized recycling facility may only pay a price per gallon for transportation and recycling as these costs are accrued during a deicing season. The advantages to the airport are that it does not have fixed expenses directly related to recycling, and it only pays for the volume treated each season.

The itemized costs can be summarized as follows:

- Transportation costs (per gallon).
- Disposal cost (may be dependent on load concentration).
- Contaminant surcharges (if applicable).
- Infrastructure to support implementation of the off-site transportation, including:
  - Pretreatment to reduce water content.
  - Stormwater conveyance.
  - Storage.
  - Vehicle loading and access.

On-Site
Physical Treatment
Membrane Filtration

FACT SHEET 111

Reverse Osmosis

1. Description

Process Description

Reverse osmosis (RO) uses a membrane that is semipermeable, allowing the fluid that is being purified to pass through it while rejecting the contaminants that remain and allowing the membrane to continually clean itself. As some of the fluid passes through the membrane, the remaining fluid continues downstream, sweeping the rejected constituents away from the membranes. Reverse osmosis is capable of rejecting constituents of aqueous streams such as bacteria, salts, sugars, proteins, particles, glycols and dyes.

RO can be used to separate glycols from deicer-affected stormwater. The deicer-affected stormwater is subjected to high pressures that encourage the water molecules to pass through a semipermeable membrane to a dilute stream termed “permeate,” which is near atmospheric pressure. Throughout this process, the deicing-affected stormwater is concentrated into a stream termed “reject” or “concentrate,” which can be recycled or disposed of. The dilute, permeate stream can be discharged to stormwater or a POTW, or it can be used for other applications.

In the application of using RO units for deicer-affected stormwater treatment, these systems can be designed to serve two different purposes:

1. Treatment of deicer-affected stormwater of from 0.1% to 5% concentrations (1,700-mg/L to 85,000-mg/L COD) to remove large volumes of water quickly from storage tanks at an airport in an effort to separate higher concentrations of glycol to be recycled or disposed of. This process concentrates the reject stream up to anywhere from 2% to 10% glycol, depending on RO configuration and manufacturer. When the units are designed for a particular airport, as the concentration of glycol in stormwater increases, the driving force required to continue concentrating the fluid increases. As result, the higher the concentration of glycol in the stormwater, the more pressure is required to force the fluid through the membrane and the larger the pump required on the RO system.

   It is important to note that using the RO for this application always requires some type of pretreatment or filtration ahead of the RO system in an effort to protect the RO membranes. Typically, this can be conducted by chemical pretreatment, nanofiltration, ultrafiltration, or a combination of these technologies.
2. Treatment of dilute streams of deicer-affected stormwater from 0.01% to 1.5% concentrations (170-mg/L to 25,500-mg/L COD) to improve the permeate stream for discharge to stormwater or airports with stringent POTW discharge requirements. Using the RO for this purpose can produce permeate streams with undetectable levels of COD or a desired level based on permitting requirements.

Reverse osmosis systems can be configured in multiple stages to accomplish both of the aforementioned purposes. Manufacturers of this equipment typically design and build RO units specific to each airport's particular requirements. These units are assembled off-site and arrive at an airport on steel skid units whether for installation in a building or in stand-alone containers for remote operations. Advanced RO systems can be operated with programmable logic controllers for ease of operation or can be designed to run manually. Throughput flow rates vary according to glycol concentration and membrane configuration. Spirally wound desalination membranes are commonly used for spent-ADF treatment, but there are other options depending on the RO manufacturer and type of system in use.

Each RO system usually requires one feed storage tank for influent, one storage tank for the permeate stream, and another tank for the reject or concentrate stream. Typical components of an RO system are piping, control valves, canister filters, a pH adjustment system, high-pressure pump(s), membrane vessels, membranes, and control panel(s).

Most RO membranes are pH sensitive, so caustic injection systems are installed and continually run while in operation to ensure that the pH is maintained at an optimal level. In terms of maintenance, the RO system is continually monitored for pressure readings and permeate quality. This gives an indication when fouling is occurring and the unit needs to be stopped for flushing. Pressures gradually climbing and COD increasing in the permeate discharge are typical indications that an RO unit needs to be shut down for washing. The system is flushed with a mild cleaning solution to clean the membranes. Liquid waste is produced from the cleaning process and is typically hauled off-site for disposal at an appropriate treatment facility.

Advantages

1. Reverse osmosis systems can be an efficient means to quickly remove water from stormwater contaminated with aircraft deicing fluid, thus minimizing the volume to be treated or discharged.
2. RO units can be used in conjunction with other complementary recycling technologies, such as MVR systems, to increase the amount of glycol that can be reclaimed from collected deicer fluid.
3. RO units can be designed to be modular, which means they can be installed in a relatively small footprint, and additional units can be added if increased capacity is required.

Disadvantages

1. Variability in influent deicer concentrations affects throughput. Generally, the higher the concentration of deicer in the stormwater, the slower the processing rate or the larger the RO pump required.
2. The desired effluent concentration of the concentrate stream affects the influent processing rate and directly affects permeate quality for RO systems. For example, the higher the concentration of glycol, the higher the glycol level in the permeate.

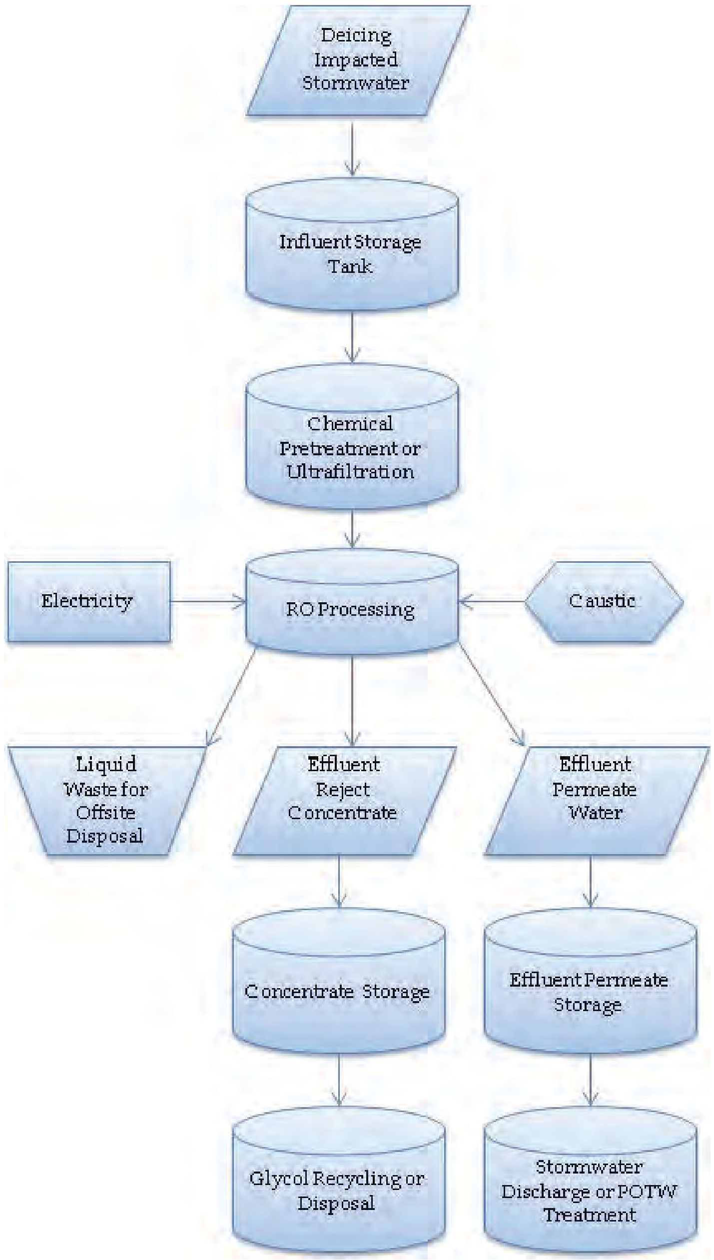


Figure 1. Reverse osmosis flowchart.

3. Reverse osmosis units usually require some type of pretreatment or filtration ahead of the RO system in order to protect the membranes.
4. To eliminate potential biological growth, membranes must be treated with biocide if the processing systems sit idle for extended periods.
5. The permeate stream from RO units contains COD and other contaminants that need to be evaluated for their ability to be discharged to surface waters or the POTW based on permit conditions.

Figure 2. RO system at Bradley International Airport.

Required Support Systems

1. Storage tanks
   a. Provide storage for the effluent streams until discharge or removal from the airport.
2. Filtration systems
   a. Filtration prior to RO treatment is normally required to protect the membranes.
3. Other recycling technology
   a. Most glycol concentrate reclaimed from RO systems requires additional treatment equipment for recycling or requires a means of disposal.
   b. The liquid waste generated from the cleaning of the membranes is typically disposed of through an off-site treatment facility.
4. Adjustment of pH
   a. Normally, pH adjustment systems and canister filters are installed on or before an RO unit.

Current Applications of Reverse Osmosis Technology

Installed Systems:	Bradley International Airport (BDL)
	Portland International Jetport (PWM)
	Salt Lake City International Airport (SLC)
	Pittsburgh International Airport (PIT)
	Dallas/Fort Worth International Airport (DFW)

2. Selection Criteria

The information in this section can be used in conjunction with the methodologies presented in Chapter 4 and Chapter 5 of the guidebook to facilitate the assessment and selection of deicer treatment technologies.

Potential Applications

RO systems are applicable to situations where recycling of glycols is desired. The technology is limited, for economic reasons, to processing concentrations of greater than 1% glycol. The dilute (permeate) water stream may have a concentration of PG in excess of local discharge limits and may require treatment or be discharged to a sanitary sewer.

The data provided in this section are based on the most typical composition of RO technology, which includes chemical pretreatment or ultrafiltration, a pH adjustment system, and RO membranes operating in series and parallel. While an RO system typically discharges permeate to a POTW or other treatment technology to reduce BOD concentration, this step is considered external to the core RO process, and data presented in the following do not reflect the effect of the additional permeate treatment step. Effluent concentration data represent the optimal potential performance based on collected field data (when available). Other variations of the RO system may provide different results. In addition, the characteristics of individual influent stormwater streams and operational decisions may affect the performance on a site-by-site basis.

Criteria Useful for Screening of Potential Treatment Technologies

See Table 1 for RO treatment process selection criteria.

Criteria Useful to Comparative Analysis to Other Treatment Technologies

See Table 2 for RO treatment process effluent concentration information and Table 3 for RO treatment process selection criteria.

Table 1. RO process selection criteria.

Technology Parameter	Value or Rating	Description
Most applicable influent streams	Concentrate	Typically, a minimum of 1% PG concentration is needed for RO to be economical, making RO a good candidate for runoff collected from deicing pads or GRVs.
Minimum COD concentration	Approx. 10, 000-mg/L COD	Treatment can be performed below this concentration; however, energy demands rise in relation to product recovered.
Typical area (footprint)	<1 acre	Includes building, associated structures, equipment, parking, access, and required storage tanks.
Typical building/ equipment height	<20 ft	Equipment can be installed in a building with height ranging from 12 ft to 16 ft, depending on RO manufacturer.
Open water surface	No open water	All treatment occurs in enclosed tanks.
Reliance on other entities	Reliance	If a permit cannot be secured for stormwater discharges, then the effluent permeate must be sent to a POTW for discharge. Reclaimed glycol is usually treated by additional recycling systems on-site or off-site. Small amounts of liquid waste are generated by maintenance activities, and these must be sent off-site to a disposal facility.
Maximum capital funding	See Figure 3	
Maximum annual O&M funding	See Figure 4	

Table 2. RO example effluent concentrations.

Parameter	Concentration or Value	Description
COD	10 mg/L to 1,000 mg/L	Varies depending on type of system and design requirements to meet site-specific discharge requirements.
NH_3-N	None	No nutrients added.
Phosphorous	None	No nutrients added.
Flow	Varies	Sized to meet site-specific requirements.
pH	Typically 6 to 8	Designed to meet discharge requirements.
DO	N/A	N/A
TSS	N/A	Permeate effluent stream is clean. Impurities are concentrated in the reject stream.
TDS	N/A	Permeate effluent stream is clean. Impurities are concentrated in the reject stream.
Temperature	Varies	Varies depending on application and type of system in use.

Note: Concentrations listed are for wastewater stream. The glycol reject stream is typically 5%–10% PG, depending on application.

Technology-Specific Application Considerations

1. Discharge permit required for permeate stream.
   Permeate stream can be discharged to surface water or a POTW, depending on site-specific restrictions.
2. Processing system must have adequate controls to maximize performance.
   Processing throughput is affected by temperature, turbidity, and pH. These must be monitored and controlled on an ongoing basis.
3. Filtration systems prior to RO treatment are normally required.
   For spent ADF to be treated directly from airport storage tanks, a chemical pretreatment system or ultrafiltration system must be used to prevent damage of the RO membranes.

Table 3. RO selection criteria.

Effects of presence of fuels	Free-product fuel spills will contaminate PG stream.
Effects of presence of metals	Metals will concentrate in PG stream.
Susceptibility to fouling and clogging	Grit removal and screening are required before process feed.
Site contamination	Minimal consideration can be given to existing site contamination because process only requires minor excavation.
Utility requirements	Requires electrical and water utility connections.
Effects of groundwater conditions	Minimal consideration can be given to groundwater because all equipment is typically installed above-grade.
Treatment plant operation needs	Treatment plant operation is typically performed by experienced process operators.
Time required for design and construction	Design and construction typically require 18 to 24 months.
Accessibility	Accessibility required for removal of PG stream by tanker trucks.

4. Careful consideration must be given to the average concentration of spent ADF.
   If concentrations are too high, then the RO system may not be the most effective treatment technology. The collection system should facilitate the ability to segregate concentrations ideally suited for RO treatment.

Costs

The order-of-magnitude cost curves shown in Figure 3 and Figure 4 are based on the probable construction costs and operation and maintenance costs for typical treatment facilities in June 2012. The capital cost curves reflect the unit processes that are most typically needed to execute the core technological functions. Individual airports may incur additional costs, beyond those determined from these curves, for support system items (e.g., a building to house the system) based on site-specific needs and owner preference.

The intent of these graphs is to provide order-of-magnitude costs for comparison purposes during the treatment technology screening process. These costs are considered ANSI Class 5 cost estimates. For final selection of technologies and design, costs should be developed for the site-specific conditions.

A 20% uncertainty contingency has been added to capital costs to reflect the detail accuracy of the estimate. Typically, the expected accuracy within the industry of an estimate at the conceptual stage of a project ranges from −20/−50% to +30/+100% of the final cost of the project. Since site-specific conditions have not been considered, the actual site-specific costs may be outside of this range.

The chart shown in Figure 3 can be used to understand order-of-magnitude costs for the core unit processes for reverse osmosis technology applications.

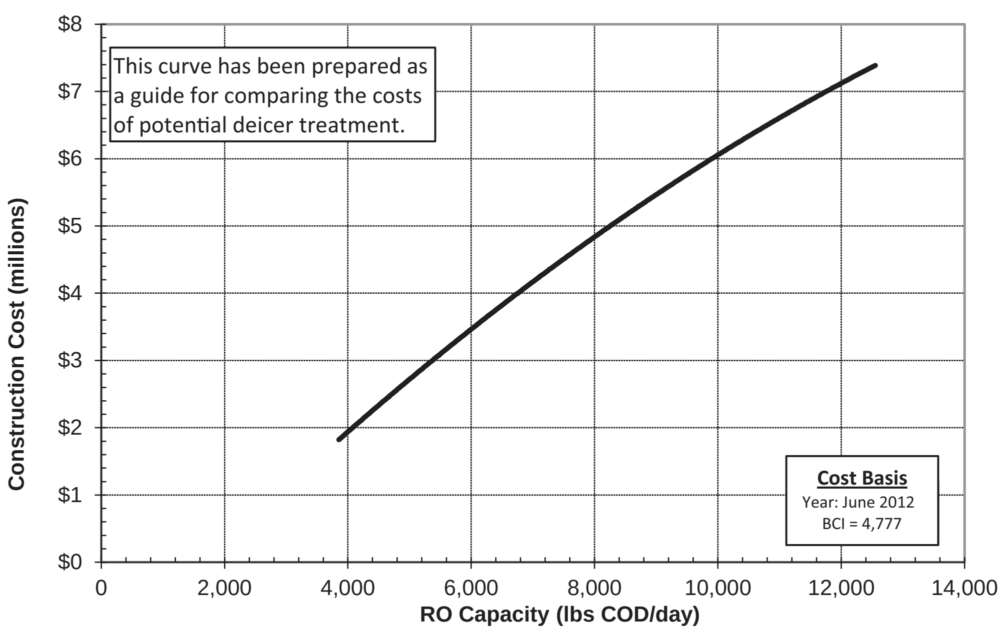


Figure 3. Capital cost curve.

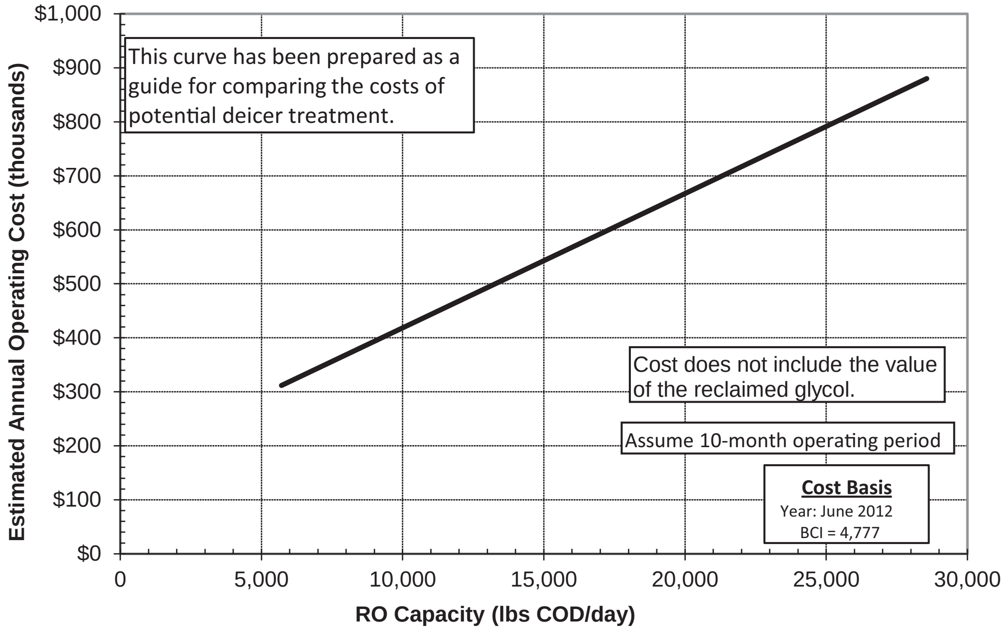


Figure 4. O&M cost curve.

The core unit processes and systems incorporated into the Figure 3 costs include:

- Land acquisition;
- Ultrafiltration membrane units;
- Reverse osmosis membrane units;
- Internal pumps, pipes, and instrumentation for membrane units;
- Electrical and control systems; and
- Treatment building.

Potential additional reverse osmosis support systems excluded from the Figure 3 costs include:

- Storage/equalization,
- An influent pumping system,
- A pretreatment system, and
- Solids storage and dewatering.

Figure 4 provides a means of understanding the order-of-magnitude annual operating costs for a reverse osmosis deicer treatment system. The major operating cost items incorporated into the Figure 4 costs include:

- Labor (two operators),
- Solids disposal,
- Utilities (power, natural gas, communications), and
- Distillate discharge to sanitary sewer.