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Emerging Technology Assessment: Preliminary Status of Airplane Deicing Fluid Recovery Systems

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EXECUTIVE SUMMARY

PRELIMINARY STATUS OF AIRPLANE DEICING FLUID RECOVERY SYSTEMS

BACKGROUND

Section 402 of the Clean Water Act requires the U.S. Environmental Protection Agency (EPA) to establish permit requirements under the National Pollutant Discharge Elimination System (NPDES) for storm water discharges from industrial activity including airport operations. As airport management has applied for storm water permits, the control of the release of airplane deicing fluid (ADF) into the environment has become of interest to airlines, airport management, air safety specialists and Federal, state and local environmental protection agencies.

This document presents the results of a preliminary technical evaluation of commercially available ADF recovery processes. This report explores design-related questions, identifying weaknesses or limitations, provide cost data and are beneficial in the investigation of operation and maintenance (O&M) problems. In addition, the results of the preliminary evaluation identifies a specific range of conditions under which the process or technology demonstrates levels of performance efficiency. This preliminary technology evaluation is an essential first step in disseminating actual data on selected processes or techniques. This report is not intended to establish ADF recovery systems as the preferred approach nor preclude other systems or methods for the control of ADF or ADF contaminated storm water

OBJECTIVES

The primary objective of this report is to evaluate the technologies that are currently being used to recover used ADF. On-site ADF recovery is a new application of proven technologies: filtration, ion exchange, distillation, and sometimes reverse osmosis. At this time, ADF recovery technology has had limited application. There is only one on-site application of ADF recovery in the United States; therefore, this report has only limited data on costs, and operations and maintenance. The associated cost and performance data discussed in this report was provided by firms marketing on site ADF recovery systems in North America. Before using an ADF recovery system, it is advisable that more data be obtained as it becomes available from onsite installations within the United States. Accordingly, along with ADF recovery systems, other system, technologies or methods should be investigated before selecting a final approach for the control of ADF or ADF contaminated storm water. The specific ADF recovery processes that are currently being marketed are described in detail.

FINDINGS AND CONCLUSIONS

ADF recovery systems are based on a series of proven processes including primary filtration, ion exchange or nanofiltration, distillation, and reverse osmosis. The purpose of primary filtration is to remove suspended solids entrained in the ADF. Ion exchange may be employed to remove dissolved solids and nanofiltration may be employed to remove polymeric additives which were in the glycol-based ADF to meet deicing/anti-icing performance requirements. Expensive preconcentration steps such as reverse osmosis may be employed to concentrate dilute streams ($<15\%$ glycol) in advance of the distillation process. The key process step in the overall ADF recovery system is distillation. Distillation is capable of separating glycol from water with little degradation. Product with high purity ($>90\%$) can be obtained by two stage distillation provided that the process economics are not prohibitive. The product may be sold to chemical manufacturers for use in other glycol based products, such as automotive anti-freeze, synthetics or reused as ADF. Before reuse as ADF, the product must receive certification for compliance with the Society of Automotive Engineers (SAE)

performance based standards.

Recovery of collected ADF may be cost effective when the glycol concentration is 15% or greater. At higher concentrations processes such as reverse osmosis may not be required in advance of the distillation process. However, storm water permit requirements of individual airports may require the collection and recovery of lower concentrations of waste glycol solutions due to the oxygen demanding environmental effects of glycol. One method to satisfy such a requirement is to add a preconcentration step such as reverse osmosis to an ADF recovery system. This additional step may add considerably to the capital and operating cost of an ADF recovery system. Centralized deicing on a dedicated collection pad is another method for obtaining spent ADF which exceeds the minimum glycol content. Centralized deicing systems may be impractical for all but the largest airport operations due to the associated capital and operation cost, and physical size of the system. However, for established airports, a switch to a centralized deicing system may present operational and logistical problems.

Another significant limitation of this technology is that a mixture of ethylene and propylene glycols cannot be recovered and separated efficiently in a single batch process because the glycols will not separate easily in the distillation process. A recovered mixture consisting of ethylene and propylene glycol has little commercial value.

Non-uniform application of glycols may result in the ADF recovery system being cost prohibitive, because of the requirements for two systems and segregated application/recovery areas. Uniform application of either glycol at one time may allow for a single recovery system to be utilized by adjusting the distillation temperature. ADF recovery process performance is uniformly good. However, individual airport-specific conditions and economic considerations will determine the suitability of ADF recovery at any airport, not technology-based issues or process performance.

Additional research is recommended as data becomes available from the operation of

facilities proposed for the St. Louis Airport, The new and expanded Denver International Airport and other airports not discussed in this report that are currently installing recovery processes. Additional research is also recommended for studying the effectiveness of alternative collection systems such as vacuum trucks and roller sponges.

SECTION 1

INTRODUCTION TO AIRPLANE DEICING FLUID RECOVERY SYSTEMS

BACKGROUND

The employment of chemical deicers is recognized by the FAA as an effective safety procedure in airborne transportation. However, a result of these airplane deicing/anti-icing operations is that portions of the chemicals from the chemical deicers will ultimately enter the storm water system of the airport. This report considers management practices which will enable airport tenants to continue their deicing practices without compromise while implementing changes to minimize the discharge of deicing chemicals to surface or groundwater.

The most common aircraft deicing chemicals currently approved by the FAA are ethylene glycol and propylene glycol. The environmental impact of deicers in airport storm water runoff has been investigated over the last 5 years (Sills and Blakeslee, 1992). Since EPA established NPDES permit application regulations for storm water discharges from airports (Federal Register, 1990), airport management and operations have directed ADF recovery from research oriented efforts to practical applications of available technologies. EPA and authorized NPDES States have, or are in the process of writing permits for point source discharges from airports, including discharges containing deicing fluids. Of particular note is a general permit EPA intends to issue, which specifically addresses deicing chemical management (Federal Register, 1993).

The data collected by Sills and Blakeslee show the following usages of glycol in airport operations:

Application	Glycol Used
Annual U.S. ADF Usage	11,500,000 gal/yr (McGreevey, 1990; Roberts, 1990)
Annual Detroit Met. Airport	780,000 gal/yr (Morse, 1990; McGreevey, 1990; Roberts, 1990)
Large Commercial Aircraft	500-1000 gal/plane/flight (Comstock, 1990)

The amount of deicer required to adequately deice a plane is highly dependent on applicator variability, plane size and the weather conditions. Several airport operators reported (AAAE Conference on Aircraft Deicing, August 23, 1993) that the annual volume of ADF employed by the U.S. airlines has increased three fold since the airplane accident at La Guardia Airport in 1992 in which icing was a factor. As implied by this statement by employing a factor of three to the data reported above, nearly 35 million gallons of ADF may be used annually in the U.S. Depending on specific site and variable weather conditions, the actual amount of ADF used annually can vary. Since safety concerns are paramount in air travel, minimization of the volumes of ADF employed are not recommended. However, collection and recovery of the chemicals must be considered.

There are two types of ADF formulations: Type I and Type II. Both formulations are deicers and anti-icers which remove ice and remain on the aircraft to prevent subsequent reicing. Both Type I and Type II formulations are glycol-based but have different additives and different glycol concentrations. Type I fluids have rust and precious metal corrosion

inhibitors, surfactants, and wetting agents. In addition, Type II fluids contain thickening agents, usually polymers, which provide improved anti-icing properties and longer holdover times than Type I fluids.

Typically, Type I fluids are relatively easy to process and recover the glycol present in the fluids. Type II fluids pose more of a challenge as they contain numerous complex polymers that are used to create some of the special characteristics in Type II fluids. These complex polymers present in Type II fluids pose unique handling problems for filtering and processing systems.

Of the Type I deicing solution applied to aircraft, almost half will fall to the apron (Transport Canada, State of the Art Report on Aircraft Deicing/anti-icing, AK 75-09-129, November, 1985). Approximately 35 percent of the ADF is dispersed to the air and the remainder is retained on the aircraft. The diluted product that is applied to aircraft typically contains about 58 percent glycols which gives the minimum freezing point of -56.7 °F (FAA, AC150/5320-15, 1991). Unless it is captured for recycling, recovery or treatment, this glycol-laden solution flows away to be further diluted and possibly mixed with runway runoff, parking lot runoff, and other local sources of storm water. This data coupled with a possible annual usage of 35 million gallons, suggest that if the storm water runoff from aircraft deicing operations are not adequately treated or contained, substantial amounts of deicing chemicals may be released to the ground, and may ultimately contaminate ground or surface waters.

ENVIRONMENTAL EFFECTS OF AIRPLANE DEICING FLUIDS

The biodegradation of glycols released into the aquatic environment, which is variable relative to temperature, can be rapid and extremely oxygen demanding. Glycol contaminated storm water runoff can deplete dissolved oxygen levels and threaten oxygen-dependent aquatic

life in receiving waters. The BOD_5 at 20° C for ethylene glycol has been reported to be in the range of 400,000 to 800,000 mg O_2/l (FAA, AC150/5320-15, 1991), or 0.4 to 0.7 g/g (Verschueren, 1983). The BOD_5 of propylene glycol is considerably higher (about 1 g/g). Diluted ethylene glycol in storm water runoff, at concentrations of 1 percent to 0.1 percent, would be expected to exert a BOD_5 of roughly 5,000 to 500 mg/l. Based upon physical properties, neither ethylene nor propylene glycol released into the environment is expected to be retained in the tissue of organisms and increase with continued exposure (bioaccumulate).

Human Health Effects

Ethylene glycol exhibits relatively low acute and chronic toxicity to humans and laboratory animals. It has not been found to cause cancer or mutations; however, it is a teratogen. The life time drinking water health advisory for ethylene glycol is 7 mg/l and the one day health advisory is 18.86 mg/l (Health Advisory, 1987). Mammalian toxicity data for both ethylene glycol and propylene glycol is presented in Table 1.1. The mammalian toxicity data indicates that propylene glycol is less toxic than ethylene glycol.

ADF mixtures contain various types of additives in addition to glycols which constitute the primary component. These additives include precious metal corrosion inhibitors, rust inhibitors, thickening agents, and surfactants. The following contaminants may also be present in glycol-based ADF: diethylene glycol, ethylene oxide, dioxane, and acetaldehyde (trace levels only). Dioxane and acetaldehyde are suspected carcinogens or teratogens.

Environmental Health Effects

High concentrations of glycols (greater than 10,000 mg/l) are required to cause acute aquatic toxicological effects (Hartwell, et. al. 1993) Although the ethylene and propylene

TABLE 1.1

MAMMALIAN TOXICITY DATA FOR ETHYLENE GLYCOL AND PROPYLENE GLYCOL[1]

Toxicity Test		Dose ml/kg Ethylene Glycol	Dose ml/kg Propylene Glycol
Rat:	single oral LD_{50}[2]	5.50	32.5
Guinea pig:	single oral LD_{50}	7.35	--
Mouse:	single oral LD_{50}	13.1	--
Rabbit:	single oral LD_{50}	--	18.5
Dog:	single oral LD_{50}	--	9.6
Human:	single lethal oral	1.4	--

[1] From Verschueren (1983).
[2] LD_{50} is the lethal dose for 50% of the exposed organisms.

glycols in ADF have a low potential to exhibit aquatic toxicity, the contaminants and additives in ADF pose a greater concern when released into the environment. Corrosion and rust inhibitors are highly reactive which translates into high biological toxicity. Surfactants are also very toxic to aquatic organisms (Hartwell et. al. 1993).

The Maryland Department of Natural Resources (Hartwell et. al. 1993) conducted aquatic toxicity testing with both ethylene glycol deicer solution and propylene anti-icer solution. Test results indicated that the ADF solutions were more toxic than the literature values for pure glycol substances. The higher toxicity was concluded to be due to the presence of additives. The specific additives in the Type II fluid were significantly more toxic than the Type I fluids. Type I deicer exhibited acute toxicity to fish at 8.75 ml/L or a 0.87% solution. Type II deicer exhibited acute toxicity at 0.063 ml/L. Measurements of ADF concentrations in Baltimore Washington International Airport storm runoff detected peak concentrations of Type I ADF at 89.1 ml/L and of Type II ADF at 154.5 ml/L (Lubbers, 1993).

Similar studies conducted at Stapleton Airport, Denver, Colorado, confirmed that ADF formulations exhibited significantly more acute toxicity than pure glycol products (ENSR Consulting and Engineering, 1993). In chronic studies, ENSR found that the concentration that inhibits growth and reproduction in 25% of the exposed organisms (IC_{25}) of formulated propylene glycol ADF was 112 mg/L for fathead minnows; while the IC_{25} for pure propylene glycol was observed to be 6,941 mg/L.

Data concerning the toxic potential of storm water runoff containing ADF at airport is preliminary and subject to an ongoing debate. Initial peer review comments of the data provided by the two studies, has raised several concerns that need to be addressed. To address these concerns, duplicate testing and additional studies, with peer review, are needed before confirming the toxicity of storm water runoff containing ADF.

ENVIRONMENTAL REGULATION OF ETHYLENE GLYCOL

Under the 1990 Amendments to the Clean Air Act, national emission standards were established for hazardous air pollutants from stationary sources. Congress established a list of 189 hazardous air pollutants. Ethylene glycol is included on this list, however, propylene glycol is not.

Under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), if a substance is regulated under other legislation, such as the Clean Air Act, it is included by reference as a CERCLA (Superfund) hazardous substance. As such, ethylene glycol is a CERCLA hazardous substance while propylene glycol is not. All CERCLA hazardous substances without specific promulgated reportable release quantities fall under the statutory reportable amount of one pound. The reporting limits on ethylene glycol has been raised to 5000 pounds, effective July 12, 1995 (Federal Register, 1995). Therefore, there is a requirement to report all releases to the environment of ethylene glycol that exceed 5000 pounds unless the release is covered by other environmental protection programs, such as the storm water NPDES permit program. This necessitates reporting requirements for releases of ethylene glycol, in amounts that exceed 5000 pounds, to the air or to the ground as part of land disposal practices or accidental spills.

Neither ethylene glycol nor propylene glycol are hazardous wastes under Resource Conservation and Recovery Act (RCRA). Contaminants in ethylene or propylene glycol, particularly metals, may make still certain bottoms or residues from ADF recovery a hazardous waste if the waste fails the toxicity characteristic limits for metals.

REQUIREMENTS AND STANDARDS FOR THE REUSE OF ADF

The Society of Automotive Engineers (SAE) develops standards for deicing and anti-icing fluids for aircraft and runways. Both Type I and Type II ADF have performance requirements identified in AMS 1424 and AMS 1428. Because of the interest in the recovery of ADF, SAE issued a policy statement that recycled fluids be certified to original specifications (Committee J, SAE, 1993). Consequently, recycled fluids must meet the same requirements as virgin glycol. Certification that ADF meets the appropriate standards (AMS 1424 or AMS 1428) is provided by the chemical industry. All recovered ADF used in the U.S. must be certified prior to reuse in the airline industry. Certification of recovered ADF fluid at on-site recovery systems is impractical due to performance testing requirements. Unless the industrial practices are changed to an ADF composition basis, it is unlikely the recovered ADF fluid will be recycled directly to aircraft at the airport. In regards to runway deicers, FAA requires certifications to AMS 1426.

OBJECTIVES

The goal of this study was to evaluate technologies that could be used to recover spent aircraft deicing fluid for reuse in aircraft deicing, runway deicing or other applications. This study had the following critical objectives:

- Evaluate the effectiveness of commercially available recycling units in generating products that may be reused.
- Evaluate the waste reduction potential.

SECTION 2

DESCRIPTION OF COMMERCIALLY AVAILABLE ADF RECOVERY PROCESSES

There are three companies which are currently marketing ADF recovery systems for use on-site at airports in North America. Each of the three processes is briefly described in the following subsections. A complete description of each process is provided in Section 6. At this time, there is only one on-site application of ADF recovery in the United States. This is a pilot-scale operation located at Continental Airlines at the Denver Stapleton Airport. The operation is designed and run by a cooperative effort of Gylcol Specialists, Inc. and Zenon Environmental, Inc.

The technology of ethylene or propylene glycol recovery by primary filtration, ion exchange or nanofiltration, and distillation has been proven in other industries where glycol recovery is utilized, such as the petroleum industry. Chemical waste service companies have provided offsite treatment of ethylene glycol for the automotive and gas processing industries.

Each of the glycol recovery systems is comprised of the three process units:

- Primary Filtration: To remove suspended solids entrained in the ADF from contact with the aircraft and asphalt. Suspended solids must be removed to avoid plugging of downstream processes and spray machinery.
- Ion-Exchange: To remove dissolved solids such as chlorides and sulfates.

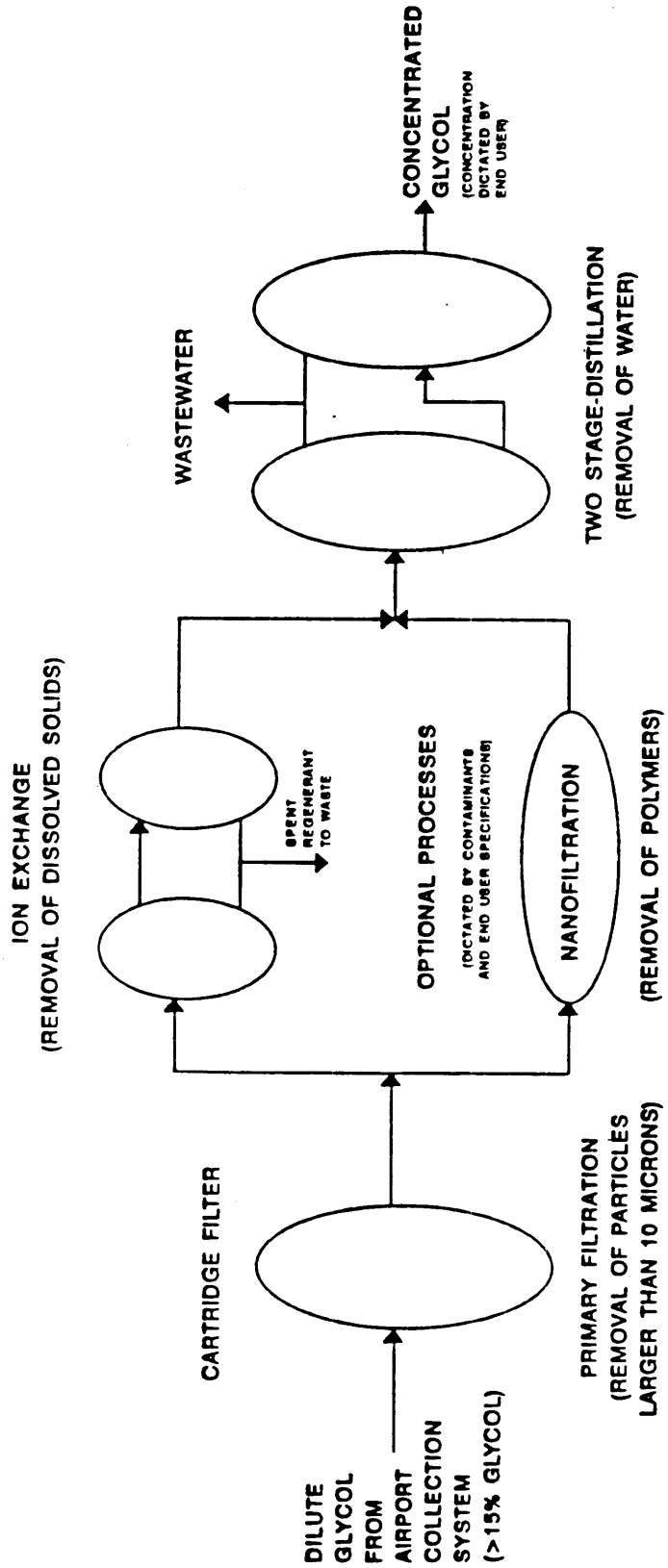
and/or

- Nanofiltration: To remove polymeric ADF additives such as corrosion inhibitors, surfactants, and wetting agents.
- Distillation: To remove water which has contaminated the ADF due to ice melt and storm water dilution.

Figure 2-1 presents a schematic of the general glycol recovery process.

The key process step in the overall ADF recycling system is distillation. Distillation is defined as the separation of more volatile materials (in this case, water) from less volatile materials (glycol) be a process of vaporization and condensation. Distillation has been used for many years for purification in chemical manufacturing and in processes involving internal solvent recycling (Freeman, 1989). Distillation is capable of recovering volatile species with little degradation, which is an important advantage in this application where the recovered product can be sold or recycled: Product purity of any desired level can theoretically be obtained by distillation, however the cost to the process can become prohibitively expensive. In the separation of water from the glycol mixture of ADF, two stages of distillation are employed to remove enough water to produce a minimum 50% glycol content in the recovered ADF. The recovered glycol is a stable material and can theoretically be stored for an entire wet weather season (6 months).

The details of the distillation process that each vendor employs are proprietary. Design variables include temperature, distillation column design (number of stages, type of packing, size) and reflux ratio (ratio of their cycle flowrate to the overhead product flowrate). Batch distillation systems are employed due to the variation in the composition of the influent and the irregular supply of the feed. Reverse osmosis may also be employed to concentrate very dilute glycol (< 15%) prior to the distillation step.



NOTE: SPENT CARTRIDGE AND NANOFILTER ELEMENTS MUST BE DISPOSED OF AS SOLID WASTE

FIGURE 2-1 GENERAL GLYCOL RECOVERY PROCESS

CHEMICALS REQUIRED

Sodium hydroxide (NaOH) and hydrochloric acid (HCl) are required for regeneration of the ion exchange process unit. Anti-foam agents are required in the distillation tower. Care should be taken when handling these chemicals to avoid contact with skin. Eye protection should be worn.

DESIGN CRITERIA

Prior to designing an ADF recovery system, information on several parameters must be collected. Data in the following areas is required to design an ADF recovery system:

- Deicing Fluid Data
  - Type
  - Concentration
  - Total consumption per season
  - Total consumption per peak-day
  - Average consumption per aircraft

- Airport Operations Data
  - Length of deicing season
  - Number of deicing days per season
  - Future traffic extension plans

- Spent Fluid Data
  - Volume Generated
  - Glycol Concentration
  - Contaminants

- Reuser Specifications
  - Glycol Concentration
  - Acceptable Impurities.

END-USE SPECIFICATIONS

In Europe, recovered ADF can be reused at the same airport location as the recovery operations. Therefore, the glycol content in recovered Type I ADF is targeted to the 58% glycol content for direct use on aircraft after the addition of any necessary additives. In the U.S. and Canada, the recovered glycol must be returned to the chemical industry for performance-based testing and reformulation into ADF. The end-use specification in North America, therefore, is for higher glycol content in order to have a reusable end-product.

SECTION 3

TECHNOLOGY ASSESSMENT

ADF COLLECTION

In order for the spent ADF to be recovered or regenerated, it must first be collected at the airport. The implementation of ADF collection must respond to the unique requirements of each airport. The feasibility of recovery glycol is dependent on the ability of the collection system to contain a relatively concentrated waste stream without significant contamination by other storm water components. It may not be cost-effective to distill and recycle waste glycol solutions at low concentrations (< 15%), because additional expensive processes, such as reverse osmosis, may be needed to concentrate the solutions to a lower concentration before the distillation step. However, storm water NPDES permit requirements of individual airports may require the collection and recovery of lower concentrations of waste glycol solutions due to the oxygen demanding environmental effects of glycols in general.

Remote or centralized deicing with the containment and collection of used glycol is one method for collecting concentrated used glycol. However, centralized deicing systems may be impractical for all but the largest airport operations due to the cost and physical size. For established airports, a switch to centralized deicing systems would present a number of operational and logistical problems. In lieu of a centralized facility, used glycol can be collected via vacuum trucks and fluid collections containers to siphon glycol from runway aprons. Employment of vacuum trucks has shown good results. Roller sponge devices were employed at the Toronto Airport with mixed results due to uneven frozen surfaces.

At Denver's Stapleton Airport a centralized collection facility consisting of a sloped pad,

underground storage tank (UST), storm water diversion and piping and pumps is employed by Continental Airlines to collect ADF. The system reportedly captures the used glycol solution at 25 to 40 percent glycol concentration.

A centralized system is proposed for the St. Louis Lambert Airport. A pad has been proposed by Findett Engineering that will be capable of holding more than one narrow body airplane at one time. The fluid is collected from the pad and held in a storage tank for processing. A skid mounted processing unit will reportedly treat the ADF when the system is started up.

PERFORMANCE DATA

Performance data was provided by three firms, Deicing System, Canadian Chemical Recovery (CCR), and Glycol Specialists. Data supplied by Deicing System was from their full-scale operation in Munich, Germany and by Glycol Specialists from their recovery system at Continental Airlines at Stapleton Airport. Performance data was provided by CCR from the pilot recovery system at the Toronto Airport. The ADF streams prior to recovery had an average glycol content between 10 to 28%. The recovery systems produced an effluent stream with an average glycol content of between 55.1 and 98.5%. The glycol content of the recovered solution was dictated by the needs of the reuser and does not reflect performance limitations. Table 3-1 shows the average performance data for these three systems.

OPERATION & MAINTENANCE

Recovery processes based on distillation tends to be complex operations due to the inherent thermodynamic constraints. Distillation-based processes have a number of practical limitations on usefulness. Distillation is a batch operation. Batch operation, because of its cyclic nature, involves frequent start-ups and shutdowns and must be operated by highly skilled

TABLE 3.1

ADF RECOVERY SYSTEM PERFORMANCE DATA SUMMARY

Process	Location	Average Influent Glycol Content (%)	Average Effluent Glycol Content (%)	Minimum Glycol Specification by End-User (%)
Deicing System, Inc.	Munich	18.6	55.1	50
Canadian Chemical Recovery	Toronto	10-20	87	80
Glycol Specialists, Inc.	Denver	28	98.5	90-95

Notes:

1. Data supplied by Deicing Systems, Inc., Canadian Chemical Recovery; Glycol Specialist, Inc.

2. Concentrations measured in laboratory.

personnel. Second, distillation equipment is expensive, and capital recovery charges usually constitute the major portion of the product recovery costs. Third, recovery by distillation is energy-intensive, with nominal energy requirements being about 5.81×10^5 to 2.79×10^8 J/kg of feed (250 to 1200 BTU/lb of feed).

TECHNOLOGY COSTS

ADF recovery is a new application of existing technology. Due to the limited full-scale operation of ADF systems in the country, information on technology costs are limited. Cost estimates discussed here have been provided by GSI. Based on pilot studies performed at the Denver Stapleton Airport, The total capital cost for the complete project, including deicing/anti-icing application equipment, collection piping, storage facilities, and the glycol recovery system has been estimated to be between six and seven million dollars. The construction cost for the ADF collection system, storage and handling facilities, piping and recovery system has been estimated at approximately $600,00.

The total capital cost for the new Denver International Airport, including deicing/anti-icing application pads and equipment, drainage and collection piping, storage and handling facilities, and a complete glycol recovery system is currently estimated to be between 20 to 25 million dollars. These costs are based on a complete package including planning, engineering design, equipment, construction and installation, start-up services and other contingencies. The construction costs for the ADF collection system, storage and handling facilities, piping, controls and instrumentation, and a complete recovery system is currently estimated at five million dollars.

The GSI cost for recovering collected ADF, assuming the used ADF is 28% glycol, is approximately 35¢/gallon. The greatest annual cost with the ADF recovery system is the cost for the energy used in the distillation process.

SECTION 4

ENVIRONMENTAL IMPACTS

As discussed in Section 1, up to 35 million gallons of ADF may be used in a single year, depending upon variable weather conditions. Based upon this estimate, the percentage of glycol typically found in ADF and the percentage of ADF that falls to the pavement during application, as much as 75 million pounds of glycol can be released into the environment in a single year. Insignificant amounts of Type II glycol is released to the runway when the airplane takes off. The capture and reuse of ADF that occurs as the result of ADF recovery operations will reduce the amount that is either released into the environment or captured for disposal.

DISTILLATION

There is a potential for volatile-organic emissions to the air from the distillation process through losses from condenser vents, accumulator tank vents, and storage tank vents. Since the amount of glycol which is vaporized during normal operations is small, VOC emissions to the air are likely to be insignificant.

RESIDUALS GENERATED

Ion-exchange flush and spent regenerant are generated by the recovery process and may be disposed of, if permitted, after neutralization by the addition of acids or bases, to the sanitary sewer. Spent filter cartridges, containing dirt, oil and other solids, may be disposed of as non-hazardous waste. Only insignificant traces of glycol will be retained in the filtration solids. Under CERCLA, Section 103, any wastes containing over 5000 pounds of ethylene glycol have additional reporting requirements. As of July 12, 1995, the reporting limit on ethylene glycol was adjusted from one pound to 5000 pounds (Federal Register, 1995). Any release of ethylene

glycol to the air or ground, as part of land disposal practices or accidental spills, will have additional reporting requirements. Propylene glycol, alone as a waste, does not have any reporting requirements under CERCLA. However, local authorities should be contacted to determine if any requirements have to be met for the disposal of spent filter cartridges containing propylene glycol. Distillation condensate, with less than 1.5% glycol, is also generated and may be reused in airport operation or (if permitted) disposed of to the sanitary sewer. Local pretreatment requirements might limit the amount of oxygen demanding wastewater discharged to a municipal sewer system and wastewater treatment works.

SECTION 5

SUMMARY OF FINDINGS

Although the on-site application of ADF recovery is new ADF recovery technology has been proven in other industries, such as the automotive industry. Distillation-based ADF recovery systems are capable of recovering glycol with little degradation and a high product purity. Product purity, typically with a minimum of 50%, is dictated by the end-user; however, high product purity (over 90%) can be obtained provided the process economics are not prohibitive.

APPLICATIONS

Glycol recovery systems are applicable at any airport that collects ADF with a minimum concentration of approximately 15% glycol. Collection and recovery of dilute glycol (<15%) is driven by the storm water NPDES permit requirements of individual airports. Since spent ADF mixtures with lower glycol content are impractical to recover via distillation without expensive preconcentration steps such as reverse osmosis, dilute streams are typically discharged to POTWs, subjected to destruction of organics or removed by chemical waste companies. Ultimately, the site specific application of on-site ADF recovery will be based on local permit requirements and economic considerations including spent ADF collection costs, recovery economics, end-product purity and disposal or treatment costs.

LIMITATIONS

In order for the ADF to be recovered or regenerated, it must first be collected at the airport. The implementation of ADF collection must respond to the unique requirements of each airport. The feasibility of recovery glycol is dependent on the ability of the collection system

to contain a relatively concentrated waste stream without significant contamination be other storm water components. It may not be cost-effective to distill and recycle waste glycol solutions at low concentrations ($\leq$ 15%). Remote or centralized deicing with the containment and collection of used glycol is one method for collecting concentrated used glycol. However, centralized deicing systems may be impractical for all but the largest airport operations due to the cost and physical size. For established airports, a switch to centralized deicing systems would present a number of operational and logistical problems.

In lieu of a centralized facility, used glycol can be collected via vacuum trucks and fluid collections containers to siphon glycol from runway aprons. Roller sponge devices may also be employed. However, previous experiences with roller sponge devices at the Toronto Airport have had limited success do to uneven frozen surfaces.

Glycol recovery systems are designed specifically for ethylene or propylene - type deicing fluids. Mixtures of ethylene and propylene glycols cannot be recovered and separated effectively in a single batch process because the glycols will not separate easily in the distillation systems. Processing of a mixture of both glycols through a typical two tower distillation-based recovery system will result in a recovered, concentrated mixture of ethylene and propylene glycol with little commercial value. A prohibitively expensive and elaborate distillation system would be required to separate ethylene and propylene glycol from each other because of the closeness of their boiling points. Airports which desire to recover their spent ADF must use only one type of solution or segregate application and runoff areas if both types of solutions are employed. The SAE performance-based standards for ADF indirectly limit the on-site application of ADF recovery since all recovered product must be returned to glycol suppliers for performance-based recertification.

Studies into the effectiveness of these alternative collection systems should be considered in the future. These studies should also investigate both cost and environmental benefit.

SECTION 6

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Sources for information for Section 6:

U. S. Dept. of Commerce
National Technical Information Services (NTIS)
5285 Port Royal Road
Springfield, Virginia 22161

Telephone:	(703) 487-4650
(Rush Orders Only)	1-800-553-6847
FAX	(703) 321-8547

Education Resources Information Center/Clearinghouse for Science, Mathematics and Environmental Education (ERIC/CSMEE)
1929 Kenny Road
Columbus, Ohio 43210-1015

Telephone:	(614) 292-6717
FAX:	(614) 292-0263

Office of Water Resource Center (OWRC)
RC 4100
401 M Street, SW
Washington, D. C. 20460

Telephone:	(202) 260-7786
FAX:	(202) 260-4383

APPENDIX A

CASE STUDIES AND EVALUATION

The following section presents specific information on the ADF recovery processes evaluated for this report. The information is provided in a checklist format.

DEICING SYSTEM INCORPORATED

1. **Company Address**:

   North America Office:
   8737 Red Deer Circle
   Louisville, Kentucky, 40220

   Head Office:
   S-951 84 Lulea
   Sweden

2. **Contact Name**: Mr. Bernt Lidstrom

   Phone: (502) 499-8609
   Fax: (502) 491 7881

3. **Current Status of Applications**

   Deicing System has provided large ADF recovery systems in three locations in Europe:

Location	Capacity	Start-up Date
Lulea, Sweden	80 gal/hr	1984
Oslo, Norway	530 gal/hr	1989
Munich New Airport, Germany	1,320 gal/hr	1992

Process data for the Munich Airport system has been obtained and is presented below.

For the North American market, Deicing System has developed a mobile recovery plant for deicing aircraft fluid. The mobile recovery plant has the capacity to recover deicing fluid from one airport or several smaller airports. All processing equipment is contained in a semitrailer, easily hitched to a truck. Once the mobile recovery plant is positioned, it is connected to the available energy supply at the airport, and to holding tanks for collected and recovered deicing fluid. The processing equipment is similar to that of the large plants for fluid recovery that Deicing System has developed and installed at the airports in Europe.

To date, Deicing System does not have any North American field applications of their recovery system.

4. Process Description

The glycol recovery plant employed by Deicing System in Europe consists of a three-stage process shown in Figure A.1. The recovery process was constructed in a building with a floor area of 6,000 sq ft and is 30 ft high. The building has a steel framework and has a cladding of double steel sheeting with an insulation in between the sheetings. The steam-boiler, control room, electrical distribution and chemical storage are each located in separate rooms.

The first stage of the recovery process is filtration to remove suspended solids, such as sand, from the fluid. Filters F-01 and F-02 have a mesh width of 50 and 10 microns, respectively. Duty and standby filters are provided for continuous operation of the process.

The second step of the process is an ion exchange system (DM-01) where positive and negative ions, e.g. chlorides and sulfates, are removed. The conductivity of the effluent from

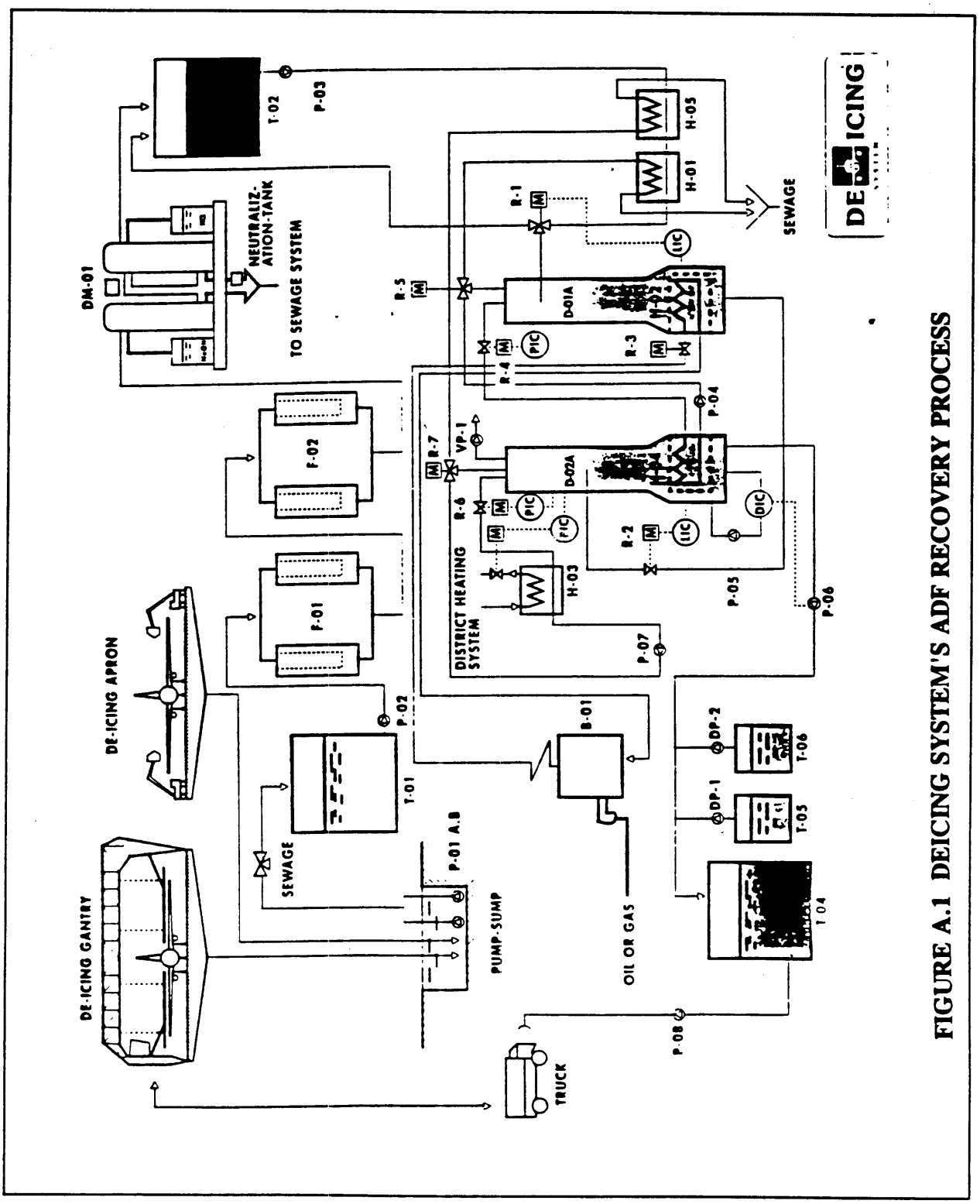

FIGURE A.1 DEICING SYSTEM'S ADF RECOVERY PROCESS

the ion exchange columns is measured. When it reaches a predetermined value, a regeneration of the columns is initiated. The columns are regenerated by flushing with water, followed by NaOH in the first column and HCl in the second column, and a final flush with water prior to going back on-line. The flush waters and spent regeneration chemicals are collected in a neutralization tank prior to discharge to the sanitary sewer.

The effluent from the ion-exchange columns is stored in Tank T-2. From Tank T-2 the fluid is fed through heat exchanges H-01 and H-05 and then sprayed into distillation tower D-01. A portion of the water is removed from the fluid in this tower. The fluid is then sprayed into distillation tower D-02 for further removal of water. The concentration of the effluent product is measured with a densiometer. When the concentration of the fluid has reached the predetermined value, the fluid is fed to the ready tank T-04.

The water content of the distillation effluent can be guaranteed at a minimum of 50%. The glycol content in the condensate is guaranteed to not exceed 1.5%.

In Europe, a wetting agent and a corrosion inhibitor must be added to the recovered product prior to reuse as airplane deicing fluid. The whole process is fully controlled by a process computer and PLC.

5. Performance Data

Performance data was provided by Deicing System from the recovery system at the Munich Airport. Table A.1 shows that the influent stream had an average glycol content of 18.6%. The recovery system produced an effluent stream with an average glycol content of 55.1%.

TABLE A.1

AIRPLANE DEICING FLUID RECOVERY SYSTEM PERFORMANCE DATA FROM MUNICH AIRPORT, GERMANY

Time Hours	Influent Glycol Concentration %	Effluent Glycol Concentration %
1	20.4	56.5
2	20.7	55.4
3	20.9	55.4
4	20.9	55.4
5	20.9	56.1
6	20.8	55.1
7	20.4	54.6
8	20.2	55.4
9	11.3	54.0
10	9.8	53.0
Average	18.6	55.1

Notes:

1. Data supplied by Deicing Systems Inc.
2. Concentrations measured in the laboratory.

6. Process Reliability

In the data provided for the Munich Airport, the process reliably produced an effluent with a glycol content over 50%.

7. Maintenance and Energy Requirements

Steam is required by the recovery system. The system has been designed to employ excess heat from the distillation columns in other units. In the system shown in Figure A.1, steam is produced in boiler B-01. The heating media can be oil or gas.

CANADIAN CHEMICAL RECLAIMING LTD. (CCR)

1. Company Address:

610 Prairie Meadows Close
Brooks, Alberta, T1R OC9

2. Contact Name:

Mr. Howard Ames
Phone: (403) 362-6229
Fax: (403) 362-6202

3. Current Status of Applications

CCR provided a mobile treatment and recovery system at the L.B. Pearson International Airport in Toronto, Canada in the winter of 1992. CCR's patented technology was developed with the assistance of the Canadian National Research Council, Alberta Research Council, and Environment Canada.

CCR has provided chemical refining services to the gas processing and petrochemical refining industries for 15 years. Ethylene glycol recovery systems, based on the distillation process, have been provided by CCR in these industries. CCR is transferring the technology they have gained in ethylene glycol recovery to ADF recycling.

4. Process Description

At the Toronto Airport, the ADF was collected from the ramp and deicing areas, used by various carriers, with vacuum or roller sponge devices and delivered to the storage facility built by CCR. In certain designated areas where significant deicing occurs, a simple containment system has been used with pump out and temporary storage capabilities. This

material is then transferred to the tank farm for processing. When volumes dictate, the collected fluid is processed by CCR's refining equipment.

The recovery system is a three stage process of filtration, ion exchange, and vacuum distillation. The unit's production capacity is 1200 Imperial Gallons per hour. The refined glycol product is resold for reuse in automotive antifreeze. The water condensate is disposed to the sanitary sewer.

5. Performance Data

Performance data was provided by CCR from the recovery system at the Toronto Airport. Table A.2 shows that the influent stream had an average glycol content of between 10 to 20%. The recovery system produced an effluent stream with an average glycol content of 87%.

6. Process Reliability

In the data provided for the Toronto Airport, the process reliably produced an effluent with a glycol content over 80% as required by the reuser.

7. Maintenance and Energy Requirements

Steam is required by the recovery system. The system has been designed to employ excess heat from the distillation columns in other units.

TABLE A.2

AIRPLANE DEICING FLUID RECOVERY SYSTEM PERFORMANCE DATA FROM TORONTO AIRPORT, CANADA

Sample #	Influent Glycol Concentration (%)	Effluent Glycol Concentration (%)
1	10 - 20	89.7
2	10 - 20	86.1
3	10 - 20	79.0
4	10 - 20	90.4
5	10 - 20	91.5
Average	10 - 20	87.3

Notes:

1. Data supplied by Canadian Chemical Reclaiming Ltd.
2. Concentrations measured in the laboratory.

GLYCOL SPECIALISTS, INC. (GSI)

1. Company Address:

5915 North Broadway
Denver, CO 80216

2. Contact Name:

Mr. Jim Hamilton
Phone: (303) 292-2000
Fax: (303) 292-0429

3. Current Status of Applications

GSI owns and operates a glycol recovery system in Denver, CO. GSI has accepted and treated the glycol contaminated runoff from 25% to 35% of the deicing fluid volume generated at the Denver Stapleton Airport for the last 4 years. The area collected from at the airport is Continental Airline's terminal. The collected runoff is stored in aboveground tanks adjacent to the airport property and is transported to the glycol recovery facility. The tanks have a total capacity of 160,000 gallons. It is estimated that a heavy storm generates between 30,000 to 100,000 gallons of contaminated runoff.

The recovery system is located 5 miles away and operates year round. GSI accepts glycol contaminated liquids from sources other than the airport. Approximately 450,000 gallons per season of glycol contaminated runoff from the airport are treated at the recovery facility. The 1993 season continued until June of that year due to the deicing requirements of the MD80 airplane.

GSI will treat the runoff from 80% of the new Denver International Airport (DIA) when it opens.

4. Process Description

The recovery system is a three stage process of primary filtration, nanofiltration, and distillation. Oils, greases, grit and suspended solids are removed during the primary filtration stage using a disposable cartridge filter. The filter is rated for removal of solids to 0.1 micron.

Polymeric additives, such as corrosion inhibitors and surfactants, are removed in the nanofiltration stage. Only those additives with a molecular weight greater than 500 are removed. Typically, additives make up 1% - 2% by weight of the glycol that is used on airplanes. The filtration membranes were supplied by Zenon Environmental.

The effluent stream from the nanofilter is fed through heat exchanges and then discharged to a distillation tower. There are three distillations towers in series at the recovery facility. During the distillation stage, water is removed from the liquid stream. The GSI facility operates at 5,000 gpd. Antifoaming agents are added to the glycol solution at the inlet to the distillation tower because of the surfactants in the glycol. Dissolved salts have not been detected in the spent ADF collected at Stapleton, so the removal of ionic species has not been required by an ion exchange unit.

5. Performance Data

Typically, the contaminated runoff from Stapleton Airport has an average glycol content of 28%. The recovery system produced an effluent stream with an average glycol content of 98.5%, with the remaining portion being water.

6. Process Reliability

The recovery system must produce an effluent that meets performance specifications set by the reuser. GSI indicated that the system consistently produces an effluent that meets those specifications.

7. Maintenance and Energy Requirements

No backwashing is required for the filters. Filter residuals, containing non-toxic solids, are landfilled. Periodic maintenance is required for the pumps and heat exchanges.

8. Costs

The greatest cost associated with the recovery system is the cost for the fuel that is used in the distillation process. Therefore, it is most cost effective when the contaminated runoff contains a high percentage of glycol. According to the vendor, the recovery process is cost effective when there is at least 15% glycol in the contaminated runoff. In addition, the recovery system produces a high glycol percentage (>98%) to reduce transportation costs. Unlike the European airports where glycol can be recovered and reused at the airport at a concentration of 50%, the recovered high percentage glycol is transported to manufacturers in the US. Transportation costs for low percentage recovered glycol are extremely high.

The complete capital cost for the airplane deicing/anti-icing operations and collection and processing of contaminated runoff at the new Denver Airport is estimated at 20 to 25 million dollars. The same complete capital cost for Denver's Stapleton Airport is estimated at 6 to 7 million dollars.

ATTACHMENT B

AIRPLANE DEICING FLUID RECOVERY SYSTEMS

INFORMATION CHECKLIST

1. Company Name:

2. Company Address:

3. Contact Name:

   - phone
   - fax

4. Current Status of Application

Locations	Capacity (gal/hr)	Startup Date

5. Process Description

   (attach process flow diagram if available)

6. Performance Data

(provide operating data including influent and effluent glycol content %, and other contaminant levels if measured)

7. Process Reliability

8. Maintenance and Energy Requirements

(include information on any wastes produced and disposal requirements)

9. Costs

ATTACHMENT B

AIRPLANE DEICING FLUID RECOVERY SYSTEMS

INFORMATION CHECKLIST

1. Company Name:

2. Company Address:

3. Contact Name:

   - phone
   - fax

4. Current Status of Application

Locations	Capacity (gal/hr)	Startup Date

5. Process Description

   (attach process flow diagram if available)

6. Performance Data

(provide operating data including influent and effluent glycol content %, and other contaminant levels if measured)

7. Process Reliability

8. Maintenance and Energy Requirements

(include information on any wastes produced and disposal requirements)

9. Costs

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Indicate how you are best described:

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EMERGING TECHNOLOGY REPORT:
Preliminary Status of Airplane Deicing
Fluid Recovery Systems

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