Environmental Technology & Innovation 3 (2015) 46–62

Contents lists available at ScienceDirect

Environmental Technology & Innovation

journal homepage: www.elsevier.com/locate/eti

Understanding and managing de-icer contamination of airport surface waters: A synthesis and future perspectives

Andrew I. Freeman [a,*], Ben W.J. Surridge [a], Mike Matthews [b], Mark Stewart [c], Philip M. Haygarth [a]

[a] Lancaster Environment Centre, Lancaster University, Lancaster, LA1 4YQ, UK
[b] Peak Associates Environmental Consultants ltd, Lancaster Office, Lancaster Environment Centre, Lancaster University, Lancaster, LA1 4YQ, UK
[c] Manchester Airport Group Plc, Manchester Airport, Environment Department, 5th Floor Olympic House, M90 1AA, UK

HIGHLIGHTS

- De-icer transport and fate within airport environments conceptualised.
- Synthesis of existing technologies for treatment of de-icer chemicals. reported.
- Potential of sub-surface flow treatment wetlands considered.
- Opportunities for optimising artificial aeration in wetlands reviewed

ARTICLE INFO

Article history:
Received 21 October 2014
Received in revised form
21 December 2014
Accepted 6 January 2015
Available online 9 March 2015

Keywords:
Aircraft de-icing fluid
Pavement de-icing fluid
De-icer management system
Biochemical oxygen demand
Artificially aerated subsurface flow treatment wetlands

ABSTRACT

De-icers containing propylene glycol and potassium acetate are a major source of organic pollution in airport surface waters. Direct discharges of these pollutants into receiving waters, even at very low concentrations, can result in detrimental environmental impacts and may breech regulatory requirements. The airport operator is responsible for devising a de-icer management plan (DMP) which outlines the pollution prevention strategies adopted to manage contaminated runoff. This poses one of the most significant environmental management challenges in the aviation sector. Within this review article, we conceptualise the transport and fate of de-icing fluids in the environment and consider the implications for management of runoff from airports. We examine the treatment technologies that are currently incorporated into DMPs in the aviation industry. Finally, we review the current application of subsurface flow treatment wetlands, an eco-innovative technology for advanced treatment of industrial strength wastewaters, and consider priorities for future research related to this emerging technology.

1. Introduction

The application of aircraft de-icing fluids (ADF), aircraft anti-icing fluids (AAF) and pavement de-icing fluids (PDF), collectively termed de-icers, is required at airports during the winter to facilitate safe air travel. As a safety precaution, all airlines follow the clean aircraft concept ISO11076 by ensuring that there is no frozen contamination (ice, snow or frost) on critical aircraft surfaces during take-off (Airport Cooperative Research Program, 2009). This is achieved through the application of an ADF, an AAF or a combination of the two as part of a two stage de-icing approach. A typical ADF/AAF formulation contains approximately 88% freeze point depressant (FPD), 10%–11% water and 1%–2% proprietary additives (Johnson, 2012; Airport Cooperative Research Program, 0000). The most commonly used FPD is currently propylene glycol ($C_3H_8O_2$) which is a low molecular weight alcohol (Barbelli et al., 2012). AAFs are used proactively in anticipation of a frozen precipitation event. The main difference between ADF and AAF is the increased addition of polymer based thickening agents to AAF, which improves adherence to aircraft surfaces resulting in increased holdover time. The airport authority has responsibility for ensuring the safe operation of runways, taxiways and operational areas at all times, regardless of weather conditions (Huttunen-Saarivirta

* Corresponding author. Tel.: +44 0 1524 510211.
E-mail address: a.freeman@lancaster.ac.uk (A.I. Freeman).

http://dx.doi.org/10.1016/j.eti.2015.01.001
2352-1864/

et al., 2011). Potassium acetate ($C_2H_3KO_2$) based PDF are most commonly applied to runways, taxiways and operational areas to remove frozen contamination and provide increased friction for ground handling vehicles and aircraft (Corsi et al., 2008; Fay and Shi, 2012). Due to improved environmental performance, the use of $C_2H_3KO_2$ has replaced urea as the PDF of choice at most international airports.

Although critical for airport operations, de-icers are also major sources of organic compounds that can contaminate airport surface waters during the de-icing season. The compounds used in de-icer formulations are linked to a range of detrimental environmental and ecological effects, particularly if they are discharged into receiving surface waters prior to treatment. These effects include the development of thick biofilm growths near to the location of discharge, resulting in adverse aesthetic and olfactory effects (Koryak et al., 1998; ACRP, 2008). Ecological effects include macro-invertebrate and fish fatalities (Turnbull and Bevan, 1995) and loss of migratory fish species such as salmon and sea trout (Environmental Protection Agency, 2000). Toxicity towards aquatic flora (Pillard and DuFresne, 1999) and fauna (Pillard, 1995) is a concern and primarily relates to the additive ingredients alkylphenol ethoxylate, a surfactant, and benzotriazole, a corrosion inhibitor, which are found in ADF and AAF (Airport Cooperative Research Program, 0000). Within a PDF, the FPD is the primary source of toxicity (Airport Cooperative Research Program, 0000). Where surface water runoff at an airport is not adequately contained, soil and groundwater contamination may also occur. This is a particular concern because proprietary additives, such as benzotriazole, degrade slowly in the natural environment or can produce highly toxic degradation by-products (Airport Cooperative Research Program, 0000).

However, the primary environmental concern associated with airport de-icing activities is oxygen (O_2) depletion in receiving waters (Airport Cooperative Research Program, 0000; Corsi et al., 2012). This occurs during biodegradation whereby heterotrophic bacteria aerobically oxidise organic compounds in a process that consumes dissolved O_2 (DO). The potential O_2 demand associated with contaminated runoff from airports can be quantified through determination of Biochemical Oxygen Demand (BOD). The standard analytical determination of BOD involves a five day sample incubation period in which DO consumed by microbial respiration is quantified (BOD_5) (HMSO, 1988). The BOD_5 concentrations for a typical 75% concentrate type IV ADF and a 50% concentrate PDF are 354,000 mg/L and 250,000 mg/L respectively. When diluted in storm waters and snow melt, BOD_5 concentrations >20,000 mg/L are not uncommon (Environmental Protection Agency, 2000; Corsi et al., 2012). Over the course of a de-icing season more than 1,000,000 litres of ADF/AAF may be applied to aircraft at an international hub airport, alongside similar volumes of PDF (Castro et al., 2005).

Due to the frequency, scale and possible environmental consequences of de-icer applications, surface waters contaminated with de-icers are increasingly subject to stringent regulations. For example, the European Water Framework Directive (WFD) provides a framework for all member states in Europe to achieve good chemical and ecological status for inland waters by 2015 (DEFRA, 2013b). To assist in meeting the objectives of the framework in England and Wales, the environmental permitting regulations (EPR) 2010 were developed and implemented. These regulations state that all industrial discharges into receiving waters, including lakes, rivers, and streams, must comply with environmental permits to discharge (previously called discharge consents) (DEFRA, 2013a). Environmental permits are designed to constrain the release of pollutants, including BOD_5, into the environment and are set on the basis of site-specific conditions. Typically, BOD_5 EPR discharge limits for airport surface waters range between 10 and 40 mg/L. Failure to meet EPR requirements may result in prosecution and payment of appropriate damages.

In compliance with EPR limits, airports often convey contaminated runoff to a local water authority's public sewer for treatment at a Wastewater Treatment Plant (WwTP), as part of an airport de-icer management plan (DMP). This is currently the management strategy adopted by 45% of international airports (ACRP, 2013). As a consequence of increased demand for air transport and the projected growth in the global aviation sector, increased application of de-icing fluids will be required in the future. However, long term constraints on sewer network capacity and increasing conveyance, reception and treatment costs are of growing concern, defining the need for sustainable treatment solutions. In this context, this review article focuses on the characteristics of airport runoff contaminated with de-icer fluids and the implications for treatment. Our objectives are to: (i) conceptualise pollutant transport pathways within the airport environment; (ii) synthesise current treatment alternatives and associated considerations for implementation; and (iii) define an innovative technology with the potential to meet future demand for de-icer treatment in a sustainable manner.

2. Environmental impact assessment of airport surface waters

Understanding the mechanisms by which de-icers are applied, dispersed and transported across the airport landscape is required in order to assess the environmental risks associated with the use of de-icer chemicals. In addition, these mechanisms often have important implications for the development of an airport DMP and the selection and operation of appropriate de-icer treatment technologies (ACRP, 2008).

2.1. Application

ADF is applied by handling agents contracted by the airlines operating from an airport. Handling agents operate to the Association of European Airlines (AEA), Civil Aviation Authority (CAA) and Federal Aviation Administration (FAA) recommendations for de-icing and anti-icing aircraft on the ground. The SAE International Aerospace Recommended Practice (ARP) advises that aircraft de-icing is performed using specifically designed vehicles. These typically have a highly manoeuvrable aerial boom, in which a de-icing/anti-icing spraying system can be deployed by an operator (SAE International, 2013). ADFs are typically heated to 65 °C–80 °C and applied to aircraft on de-icing stands, designated de-icing pads, at the gate, or at a combination of locations depending on airport operations, layout and infrastructure (EPA, 2012). All ADF products must conform to the aerospace material specifications (AMS) 1424 and 1428E (Corsi et al., 2012). Additionally PDF must conform to AMS 1435 for liquids and 1431B for solids (Environmental Protection Agency, 2000). Despite this, the environmental characteristics and performance of de-icers vary considerably in relation to the specific product and dilution ratio used (Table 1).

Application volumes for de-icing fluids vary primarily in relation to weather, thickness of frozen contamination, aircraft type and airline or handling agent policy. For example, Manchester Airport is situated on the southern edge of Manchester in the United Kingdom (UK), and is owned by the UKs largest airport operator Manchester Airport Group Plc. (MAG). In 2013 annual passenger numbers at Manchester Airport were 20,687,423 (Aero, 2014) and these are projected to increase to 50,000,000 by 2030 (MAG, 2007). Annual aircraft movements were 159,000 in 2013 and these are projected to increase to 353,000 by 2050 (MAG, 2007). Previously unpublished data from the period