

REMEDIAL METHODS AND STRATEGIES FOR PFCs

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Background

Avinor, the Norwegian aviation authority who owns, operates and develops a nationwide network of over 40 civilian airports, instigated in 2011 further investigations of its airports as part of their efforts to map the environmental status at their facilities.

Fire fighting foam is used to suppress fires at fire fighting sites at airports, potentially resulting in contamination of soil and groundwater by perfluorinated compounds (PFCs) including PFOS and PFOA. In addition, PFCs may also be present at other fire fighting sites as well as a large number of industrial facilities where they have been in use.

Several PFCs have physicochemical properties that renders commonly used remedial methods (ex situ, in situ, containment and protective measures) and strategies mostly obsolete. As a consequence, Avinor has initiated the present project to determine possible remedial methods and strategies for PFOS and PFOA.

Aim and scope

The aim of the project has been to identify possible methods for PFC remediation that are viable options in the long term and to develop work methods/strategies that can be used to manage contamination of these substances. Since most methods for full scale remediation are under development the focus is partly on the level of development/progress, underlying plausibility/theory and appropriateness for full scale remediation when assessing results from lab scale experiments, pilot scale implementations and full scale remedial projects.

A number of studies focusing on treatment options for fluorinated compound have been assessed. An important focus has been to examine methods and strategies from a number of sites world-wide where the occurrence of PFOS and PFOAS is being handled.

A decision support methodology has also been developed to assist the short and long term decisions on remedial options at Avinors fire fighting sites.

Properties of PFCs affects remedial options

Physicochemical properties of PFCs complicates remediation of soil and groundwater:

1. There are extreme differences in physiochemical properties within the PFC group of substances (e.g. Figure 1). Consequently, methods that may be viable for one set of substances may not be viable for others. In practice, remedial options always has to consider the substance with the least suitable properties. For instance, some PFCs are relatively volatile (e.g. 6:2 FTS and 8:2 FTS) while others can be classified as being almost non-volatile (e.g. PFOA). Thus remedial methods based on target substances being volatile can only be applied when volatile PFCs are targeted, which is unlikely at fire fighting sites since volatile and less volatile PFCs co-occur there (STF 2008).
2. Several important PFCs (PFOS and PFOA in particular) does not biodegrade in the natural environment, in waste water treatment plants or in the laboratory (Parsons et al. 2008) Furthermore, several of the PFCs that are biodegradable have PFOA and PFOS as degradation end products which may be one reason why influent concentrations are sometimes higher than effluent concentrations in municipal and industrial WWTPs

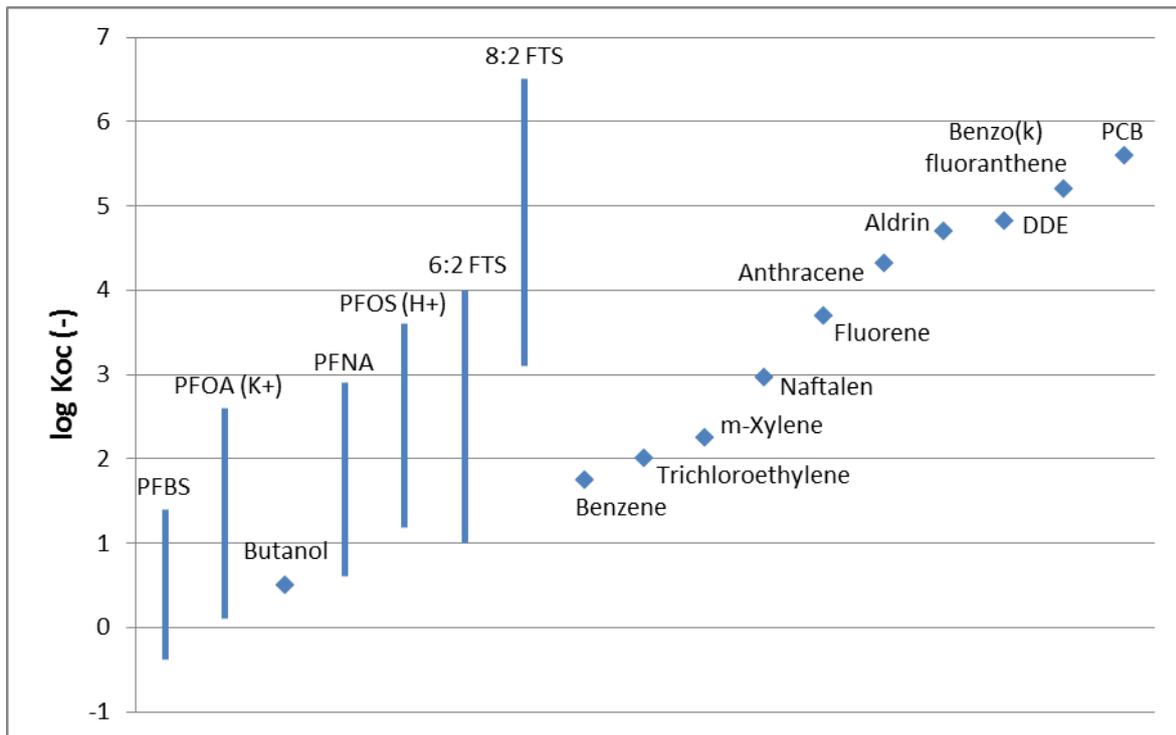


Figure 1. Partition coefficients between organic carbon and water (K_{oc}) for a number of different PFCs as well as a number of common soil- and groundwater contaminants. Several of these PFCs are common at fire fighting sites where fire fighting foam has been used. Data for PFCs is taken from Gellrich and Knepper (2012) except 6:2 FTS and 8:2 FTS where values have been obtained using the models EPISUITE and ACD/Labs. Note logarithmic scale.

(Federal Office for the Environment 2009, Yu et al. 2009). This precludes any bioremediation treatment methods.

3. The environmental behaviour, partition between matrices and concentrations in matrices (e.g. K_d , K_{oc} , water solubility) is highly variable for individual PFC substances (e.g. Figure 1) and controlled by complex interactions between e.g. ion exchange properties of the solid phase, organic carbon properties of the solid phase and substance properties (Gellrich and Knepper 2012). This complicates or hinders predictive modelling of PFC substance fate which is often a pre-requisite for application of advanced in situ methods.

Evaluation of remedial methods

Table 1 gives an overview of how well different remediation technology categories are suited for PFC remediation at Avinors fire fighting sites given a number of criteria. The table is based on a review of > 100 articles and reports of which only a few address PFC remediation directly.

Although there are a large number of studies on treatment technologies for PFCs in waste and drinking water, there is a very substantial lack of studies and scientific works on innovative soil and groundwater remediation technologies for PFCs. Consequently many of the conclusions in the table are inferred from knowledge of the technologies described and the very specific demands that has to be fulfilled in order for successful PFC remediation.

A main conclusion is that there are no technologies that are optimized for PFCs at present.

Table 1. Overview of appropriateness of different remedial technology categories for PFCs, with some focus on fire fighting sites at Avinors airports. Numbers indicate on a scale from 1-5 how well the technology category fulfils the criteria where 5 indicates a good fulfilment and 1 a very poor fulfilment.

Remedial method category	Availability of experienced contractors	Maturity of technology - not PFCs ²	Scale at which methodology has been tested for PFCs ³	Efficiency of methodology considering PFC fate/behaviour at fire fighting sites ⁴	Efficiency of methodology considering PFC chemical properties ⁵	Time frame for remediation ⁶	Disturbance on existing operations at the site ⁷	Cost Efficiency ⁸
Excavation and ex situ treatment	5	5	Full scale	2-5	2-4*	4-5	1-4	1-3
Pump and ex situ treatment of groundwater	4-5	4-5	Full scale	4-5	3-4*	1-2	4-5	1-5
In Situ chemical oxidation	5	3-5	Laboratory scale	3-5	2-5	3-5	4-5	2
In Situ soil flushing		2-4	Laboratory scale	Unknown	Unknown	Unknown	3-5	2-5
Thermal in situ methods	3	3-5	Laboratory scale	4-5	3-5	4-5	4-5	2-5
Stabilization/solidification	3-5	4-5	Laboratory scale	Unknown	Unknown	Unknown	1-5	Unknown
Barriers (immobilization/treatment)	1-2	2-4	Unknown	Unknown	Unknown	1-5	2-4	Unknown

¹ The degree to which experienced contractors are available in the Nordic countries. 5 indicates very good availability, 1 indicates no availability.

² Technology maturity in general (not PFCs). 5 indicates very well-known and tested technology, 1 indicates new and untested technology.

³ At which scale has the methodology been tested for PFCs.

⁴ To which degree is the technology applicable given the fate/behaviour of PFCs that are present from the surface to very large depths and in groundwater. 5 indicates that the technology is applicable for all environmental occurrences.

⁵ To which degree is the technology applicable given the physicochemical properties of PFCs. 5 indicates that the technology is applicable to e.g. the variable Kd values or the strong C-F binding.

⁶ Time for completion of remediation. 5 indicates relatively fast remediation (less than months) while 1 indicates very slow remediation time frame (> 10 years)

⁷ The degree to which existing operations (mainly at Avinors airports) is affected by the technology implementation. 5 indicates no disturbance while 1 indicates that all operations have to cease during remediation

⁸ Costs versus remediation efficiency. 5 indicate a very low cost given the remediation results.

* Low values because many ex situ treatment methods are not optimized for PFCs

Traditional excavation methods may be applicable for PFC removal if the substances have not migrated vertically to large depths (which is often the case, PFCs are commonly found at depth > 5m). Off-site landfill disposal of PFC contaminated soil is in many cases not appropriate since several PFCs (such as PFOS and PFOA) are very water soluble with a very low or no biodegradation potential. Biodegradation of some PFCs will furthermore produce as end products a number of fully persistent and toxic PFCs (such as PFOS and PFOA). Consequently, PFCs will reach the environment through landfill leachate if the leachate is not treated with highly advanced water treatment methods. Other off site treatment methods such as incineration may be much more viable for PFCs.

Pumping and ex situ treatment of groundwater (usually with activated carbon filters on site) to stop off site transport is viable and appropriate method although experience from a number of sites worldwide has shown that the efficiency of activated carbon filters varies to a large degree. There is on-going research to obtain more optimized filter materials. Mass balance calculation from some sites has shown that the groundwater pumping may have to be in place for a large numbers of years (in some cases > 100 years) which is one main disadvantage with this technology. Also, pump and treat technologies do not address on-site risks with PFCs in surface soils.

Strategies for PFCs

Decision support trees/models has been developed within the present project to support the choice of long and short term remediation strategies for PFCs at Avinors fire fighting sites. The decisions support trees take into account:

1. Which PFCs that are present and their physicochemical properties
2. Geohydrological conditions
3. The off-site and on-site risks at present and in the future
4. Acceptable time frames for remediation
5. Technology acceptance and stakeholder involvement
6. Costs for remediation
7. Acceptable disturbance on day to day operations

Given that the remediation technologies for PFCs are under development, the strategies may often involve short term solutions (e.g. pump and treat or administrative measures) until appropriate methodologies for site remediation has been developed.

Conclusion

Some promising methods for field scale remediation were identified that are in development. Most identified methods focus on water treatment which is a good option in the short term, but not always in the long term given the very long time frames for those types of solutions. The correct strategies for each airport will very much depend on the risks at the site, hydrogeological conditions as well as the effects of remedial options on day to day operations.

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