

Efficacy of Polyfluoroalkyl Substances Filtration with Low-Cost Organic Fiber Filter

Gautham Das, Edward Morrone, Erik Treble, Clinton Binder

Abstract—The purpose of this study was to evaluate the efficacy of a low-cost filter regarding per- and polyfluoroalkyl substances (PFAS). PFAS is a commonly used man-made chemical that can be found in a variety of household and industrial products with deleterious effects on humans. The filter consists of a combination of low-cost materials which could be locally procured. Water testing results for 4 different PFAS contaminants indicated that for Perfluorooctane sulfonic acid (PFOS), the Agency for Toxic Substances and Disease Registry (ATSDR) regulation is 7 ppt, the initial concentration was 15 ppt, and the final concentration was 3.9 ppt. For Perfluorononanoic acid (PFNA), the ATSDR regulation is 10.5 ppt, the initial concentration was 15 ppt, and the final concentration was 3.9 ppt. For Perfluorooctanoic acid (PFOA), the ATSDR regulation is 11 ppt, the initial concentration was 15 ppt, and the final concentration was 3.9 ppt. For Perfluorohexane sulfonic acid (PFHxS), the ATSDR regulation is 70 ppt, the initial concentration was 15 ppt, and the final concentration was 3.9 ppt. The results indicated a 74% reduction in PFAS concentration in filtered samples. Statistical data through regression analysis showed 0.9 validity of the sample data. Initial tests show the efficiency of the proposed filter described could be far greater if tested at a greater scale. It is highly recommended further testing to be conducted to validate the data for an innovative solution to a ubiquitous problem.

Keywords—PFAS, PFOS, PFOA, PFHxS, low-cost filter.

I. INTRODUCTION

PFAS or Polyfluoroalkyl substances are manmade compounds. Due to the excessive use of these compounds, they are found universally in the abiotic and biotic environment [1]. Due to their unique physio-chemical properties, PFAS chemicals are present in various commercial products such as food packing textiles and in aqueous film forming foams (AFFFs) used for firefighting purpose [3]-[5]. PFAS has several half-lives which range from several years to decades in the human body and are extremely persistent, they are sometimes known as forever chemicals [6]. Health conditions such as high cholesterol and blood lipid levels, decreased fertility, and certain types of cancer have been linked to individuals exposed to PFASs [6], [8], [5]. PFAS compounds have been detected in drinking water in North America and several European Union Nations as well [22]-[24]. In 2016, the US EPA therefore recommended a health advisory limit of 70 ppt for sum of PFOS and PFOA in drinking water [25]. The National Food Agency in Sweden recommends an action level of 90 parts per trillion (ppt) or the

sum of 11 PFASs (i.e., C3eC9 perfluoroalkyl carboxylic acids (PFCAs): PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA; C4, C6, C8 perfluoroalkyl sulfonic acid (PFSAs): PFBS, PFHxS, PFOS; 6:2 fluorotelomer sulfonic acid: 6:2 FTSA) in drinking water and advises the level should be reduced as low as possible [26].

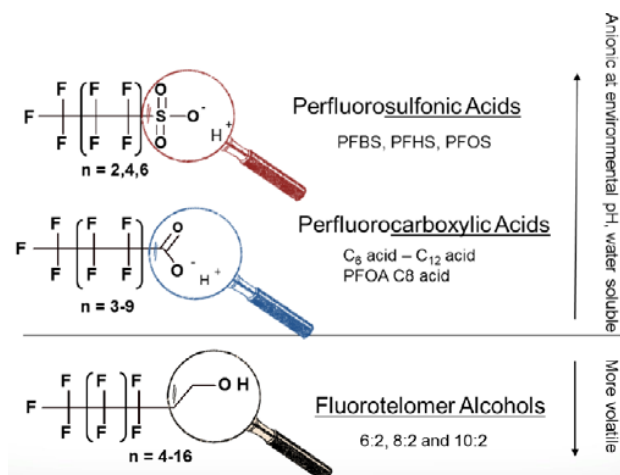


Fig. 1 Common PFAS Structures [2]

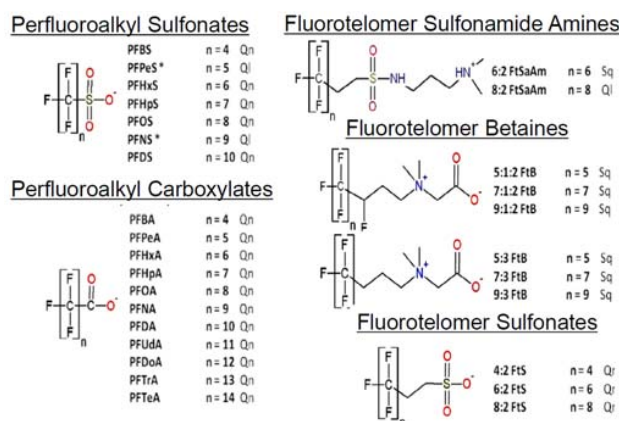


Fig. 2 More PFAS Structures [2]

As PFAS compounds are being highlighted and are getting linked to various health conditions, the drinking water guidelines are getting more stringent and additional recommendations are implemented on the acceptable daily intake (ADI) [7]. Wastewater treatment plants, municipal landfills, mono ash landfills, numerous industrial activities and fire training facilities are known sources of point source PFAS

Gautham Das* is Associate Professor and Erik Treble and Clinton Binder are Research Assistants with Civil Engineering, Wentworth Institute of Technology, Boston, MA 02115, United States (*e-mail: treblee@wit.edu).

Edward Morrone is Co-Founder and CEO, DasMore Solutions, Westerly, RI, 02891.

contamination [8], while surface runoff or precipitation can be considered as non-point sources of PFAS contamination [1]. PFASs are extremely mobile in the water and if ingested pose a significant risk, conventional drinking water treatment processes such as sand filtration, disinfection, etc., do not work for the removal of the PFASs. [9]. The presence of PFASs in drinking water at concentrations greater than permissible limits requires the incorporation of new innovative treatment methods for drinking water treatment plants (DWTPs). Conventional methods such as ion exchange, nanofiltration, reverse osmosis and sand filtration with granulated activated carbon (GAC) are efficient in the removal of PFASs [4], [9]-[17]. While adsorption to synthetic material like anion exchange resins show high levels of PFAS removal, they are expensive to operate on large scale operations like DWTPs [18], [19]. Sand filtration with GAC is conventionally used in most DWTPs and has been effective for the removal of certain PFAS compounds; however, GAC needs to be replenished or replaced frequently hence it creates an additional waste stream. Furthermore short-chain PFASs (PFASs with ≤ 6 carbons and PFCAs with ≤ 7) break through rapidly [13], [16] and even long-chain PFASs break through after a limited time [21], [12], [9], [16], [20]. Hence drinking water treatment and respective GAC filtration need to be reconsidered as filter material in regards to PFASs [21], [9].

In this study, the removal of PFASs was examined by reducing the amount of GAC and replacing the GAC with low-cost organic fibers. The specific objectives are to: 1) test the efficacy of the filter regarding PFAS reduction with low-cost organic fibers; 2) optimize the design of the filter, and 3) Decipher the breakdown of PFAS by the organic fibers.

II. MATERIALS AND METHODS

The source of water for testing for PFAS was obtained from 3 locations: 1) Control: De-ionized water obtained from reverse osmosis; 2) City of Boston: Tap water; and 3) Water from a known source of PFAS contamination.

Filter Construction



Fig. 3 Unprocessed Organic Fiber

The organic fibers were obtained from an online source as

shown in Fig. 3. The organic fibers were processed by removing the large clumps and straightening the fibers as shown in Fig. 4.



Fig. 4 Processed Organic Fiber

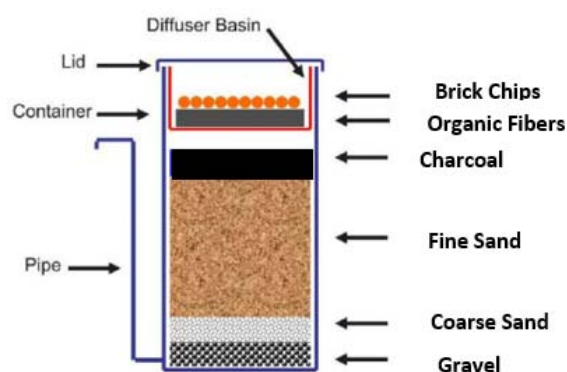


Fig. 5 Schematic of Filter (Not drawn to scale)



Fig. 6 Construction of the filter

Fig. 6 shows the construction of the filter as described in above sections. Three filters were constructed as shown in Fig. 7.



Fig. 7 Constructed filters

PFAS Testing

The PFAS testing was conducted using method 537 version 1.1. US EPA Method 537.1 is a solid phase extraction (SPE) liquid chromatography/tandem mass spectrometry (LC/MS/MS) method for the analysis of 18 selected PFAS, including PFOS and PFOA, in drinking water. Multiple Reaction Monitoring (MRM) is used to enhance selectivity, and quantification relies on internal standard correction. The PFAS testing was conducted by Pace Analytical Labs in Woburn Massachusetts. Fig. 8 shows the EPA Method 537 protocol.

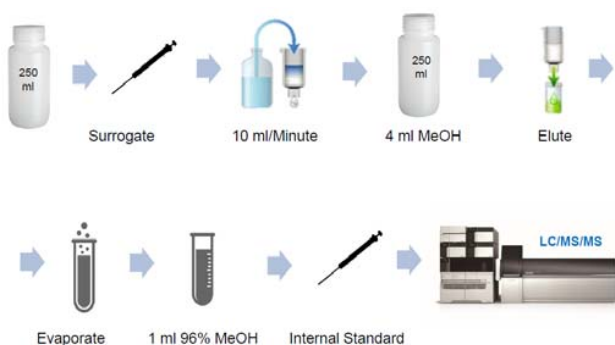


Fig. 8 EPA Method 537 Protocol

III. RESULTS AND DISCUSSION

In May 2016, the USEPA established a non-regulatory lifetime health advisory (LHA) for two of these chemicals; PFOS and PFOA. The LHA for PFOS and PFOA is 70 ppt combined, or individually if only one of the chemicals is present. Most states in the US adopted the 70 ppt combined limit as well. However, a few states and regulatory institutions are recommending lower limits. The ATSDR has proposed lower limits as shown in Table I.

As this is an ongoing project, the complete results were not received at the time of writing this manuscript. Table II shows initial results obtained from PaceAnalytical labs.

TABLE I
REGULATIONS FOR PFAS BY ATSDR AND USEPA

	Current State Regulations	Agency for Toxic Substances Disease Registry Report (Proposed)
PFOS (Perfluorooctane Sulfonic acid)	70 ppt	7 ppt
PFNA (Perfluorononanoic acid)	N/A	10.5 ppt
PFOA	70 ppt	11 ppt
PFHxS	N/A	70 ppt

TABLE II
RESULTS OF PFAS TESTING

Contaminant	ATSDR Regulations	Initial Concentration	Final Concentration
PFOS	7 ppt	15 ppt	3.9 ppt
PFNA	10.5 ppt	5 ppt	0 ppt
PFOA	11 ppt	15 ppt	0 ppt
PFHxS	70 ppt	15 ppt	0 ppt

The reduction of PFAS is attributed to the binding forces which are found in the proteins of the organic fiber. Proteins, as biomacromolecules, have cavities and surfaces which give rise to hydrophobic forces, electrostatic interactions, hydrogen bonding, Van der Waals forces etc. all of which are encompassed by the terms physisorption or chemisorption. Further testing is required to determine the mechanisms of the PFAS removal by the organic fiber.

IV. CONCLUSIONS

The use of low-cost fibers in a filter as a possible solution to PFAS remediation from contaminated water has been successfully demonstrated in this research. The removal efficiency was > 74% of the main contaminants of PFOS and PFHxS in less than 1 h of contact time. The PFAS testing was at the very initial stages at the time of submitting this manuscript. Additional testing using as batch testing and FTIR testing is recommended to evaluate the binding of PFAS to the proteins in the organic fibers.

REFERENCES

- [1] Ahrens, L., 2011. Polyfluoroalkyl compounds in the aquatic environment: a review of their occurrence and fate. *J. Environ. Monit.* 13 (1), 20e31.
- [2] Backe WJ, Day TC, Field JA. Zwitterionic, cationic, and anionic fluorinated chemicals in aqueous film forming foam formulations and groundwater from U.S. military bases by nonaqueous large-volume injection HPLC-MS/MS. *Environ Sci Technol.* 2013 May 21;47(10): 5226-34. doi: 10.1021/es3034999. Epub 2013 May 1. PMID: 23590254.
- [3] Buck, R.C., Franklin, J., Berger, U., Conder, J.M., Cousins, I.T., de Voogt, P., Jensen, A.A., Kannan, K., Mabury, S.A., van Leeuwen, S.P., 2011. Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integrated Environ. Assess. Manag.* 7, 513e541.
- [4] Appleman, T.D., Higgins, C.P., Quiñones, O., Vanderford, B.J., Kolstad, C., Zeigler-Holady, J.C., Dickenson, E.R., 2014. Treatment of poly- and perfluoroalkyl substances in U.S. full-scale water treatment systems. *Water Res.* 51, 246e255.
- [5] Biegel-Engler, A., Vierke, L., Apel, P., Fetter, E., Staude, C., 2017. Mitteilungen des Umweltbundesamtes zu per- und polyfluorierten Chemikalien (PFC) in Trinkwasser (in German). *Bundesgesundheitsblatt* 60, 341e346.
- [6] Lindstrom, A.B., Strynar, M.J., Libelo, E.L., 2011. Polyfluorinated compounds: past, present, and future. *Environ. Sci. Technol.* 45, 7954e7961.
- [7] Knutsen, H., Alexander, J., Barregård, L., Bignami, M., Brüschweiler,

- B., Ceccatelli, S., Cottrill, B., Dinovi, M., Edler, L., Grasl-Kraupp, B., et al., 2018. Risk to human health related to the presence of perfluorooctane sulfonic acid and perfluorooctanoic acid in food. *EFSA Journal* 12.
- [8] Post, G.B., Cohn, P.D., Cooper, K.R., jul, 2012. Perfluorooctanoic acid (PFOA), an emerging drinking water contaminant: a critical review of recent literature. *Environ. Res.* 116, 93e117.
- [9] Rahman, M.F., Peldszus, S., Anderson, W.B., 2014. Behaviour and fate of perfluoroalkyl and polyfluoroalkyl substances (PFASs) in drinking water treatment: a review. *Water Res.* 50, 18e340.
- [10] Vecitis, C.D., Park, H., Cheng, J., Mader, B.T., Hoffmann, M.R., 2009. Treatment technologies for aqueous perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA). *Front. Environ. Sci. Eng. China* 3, 129e151.
- [11] Carter, K.E., Farrell, J., mar, 2010. Removal of perfluorooctane and perfluorobutane sulfonate from water via carbon adsorption and ion exchange. *Separ. Sci. Technol.* 45, 762e767.
- [12] Eschauzier, C., Beerendonk, E., Scholte-Veenendaal, P., Voogt, P.D., 2012. Impact of treatment processes on the removal of perfluoroalkyl acids from the drinking water production chain. *Environ. Sci. Technol.* 46, 1708e1715.
- [13] Flores, C., Ventura, F., Martin-Alonso, J., Caixach, J., 2013. Occurrence of perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA) in n.e. Spanish surface waters and their removal in a drinking water treatment plant that combines conventional and advanced treatments in parallel lines. *Sci. Total Environ.* 461e462, 618e626.
- [14] Chularueangakorn, P., Tanaka, S., Fujii, S., Kunacheva, C., 2014. Adsorption of perfluorooctanoic acid (PFOA) onto anion exchange resin, non-ion exchange resin, and granular-activated carbon by batch and column. *Desalination and Water Treatment* 52, 6542e6548. <https://doi.org/10.1080/19443994.2013.815589>.
- [15] Zhang, S., Lu, X., Wang, N., Buck, R.C., 2016b. Biotransformation potential of 6:2 fluorotelomer sulfonate (6:2 FTSA) in aerobic and anaerobic sediment. *Chemosphere* 154, 224e230.
- [16] Zaggia, A., Conte, L., Falletti, L., Fant, M., Chiorboli, A., 2016. Use of strong anion exchange resins for the removal of perfluoroalkylated substances from contaminated drinking water in batch and continuous pilot plants. *Water Res.* 91, 137e146.
- [17] Franke, V., McCleaf, P., Lindegren, K., Ahrens, L., 2019. Efficient removal of per- and polyfluoroalkyl substances (PFASs) in drinking water treatment: nanofiltration combined with active carbon or anion exchange. *Environ. Sci.: Water Res. Technol.* 5, 1836e1843.
- [18] Merino, N., Qu, Y., Deeb, R.A., Hawley, E.L., Hoffmann, M.R., Mahendra, S., 2016. Degradation and removal methods for perfluoroalkyl and polyfluoroalkyl substances in water. *Environ. Eng. Sci.* 33, 615e649.
- [19] Crittenden, J.C., Trussell, R.R., Hand, D.W., Howe, K.J., Tchobanoglous, G., 2012. *MWH's Water Treatment: Principles and Design*, third ed. John Wiley & Sons, Inc.
- [20] McCleaf, P., Englund, S., Östlund, A., Lindegren, K., Wiberg, K., Ahrens, L., 2017. Removal efficiency of multiple poly- and perfluoroalkyl substances (PFASs) in drinking water using granular activated carbon (GAC) and anion exchange (AE) column tests. *Water Res.* 120, 77e87.
- [21] Takagi, S., Adachi, F., Miyano, K., Koizumi, Y., Tanaka, H., Watanabe, I., Tanabe, S., Kannan, K., jul, 2011. Fate of perfluorooctanesulfonate and perfluorooctanoate in drinking water treatment processes. *Water Res.* 45, 3925e3932.
- [22] Ericson, I., Domingo, J.L., Nadal, M., Bigas, E., Llebaria, X., van Bavel, B., Lindström, G., 2009. Levels of perfluorinated chemicals in municipal drinking water from Catalonia, Spain: public health implications. *Arch. Environ. Contam. Toxicol.* 57, 631e638.
- [23] Post, G.B., Louis, J.B., Cooper, K.R., Boros-Russo, B.J., Lippincott, R.L., 2009. Occurrence and potential significance of perfluorooctanoic acid (PFOA) detected in New Jersey public drinking water systems. *Environ. Sci. Technol.* 43, 4547e4554.
- [24] Ullah, S., Alsberg, T., Berger, U., 2011. Simultaneous determination of perfluoroalkyl phosphonates, carboxylates, and sulfonates in drinking water. *J. Chromatogr. A* 1218, 6388e6395.
- [25] USEPA, 2016. *Drinking Water Health Advisories for PFOA and PFOS*. (Accessed January 2017).
- [26] Ankarberg, E.H., Lindberg, T., 2016. Riskhanteringsrapport- Risker vid förorening av dricksvatten med PFAS. *Tech. rep., Livsmedelverket*. 3 (7).