Foams in Wastewater Treatment Plants

Subjects: Environmental Sciences

Contributor: Maria Cristina Collivignarelli , Marco Baldi , Alessandro Abbà , Francesca Maria Caccamo , Marco Carnevale Miino , Elena Cristina Rada , Vincenzo Torretta

The formation of persistent foams can be a critical problem in wastewater treatment plants (WWTPs) as it could lead to a series of operational problems, especially the reduction of the overall system performance. To date, the effects of foaming in the WWTPs are a problem that is currently very common and shared, but which to date is treated mainly only at the management level and still too little studied through a globally shared scientific method: the complexity of the phenomenon and the systems have led to numerous partially contradictory descriptions and hypotheses over the years. The goal must be to suggest future research directions and indicate promising strategies to prevent or control the formation of foams in WWTPs. This study examines and investigates the problem of foams by a methodological approach of research through a review on the state of the art: the factors influencing the formation of foams are described first (such as surfactants and/or extracellular polymeric substances (EPSs)), then the known methods for the evaluation of foaming, both direct and indirect, are presented, with the aim of identifying the correct and best (from the management point of view) control and/or prevention strategies to be applied in the future in WWTPs.

foaming chemical and biological foams evaluation method foam test control method WWTP.

1. Introduction

Chemical and biological foaming in conventional activated sludge (CAS) plants [1] has been under study since the 1960s [2], and, in general, in wastewater treatment plants (WWTPs) is an issue that adversely affects worldwide the aeration tank and/or the final clarifier [3][4][5][6][7][8][9][10][11]. Foams are a set of stable bubbles, produced when air or other gases are introduced below the surface of the liquid that expands to enclose the gas with a liquid film called “lamellae” of the foams [12][13]. A condition necessary for foaming is the presence of surface-active components or surfactants in the liquid [14] because these substances settle on the interfaces between the gas and liquid and reduce the surface tension [15]. Gas bubbles in the system are originated from aeration and mixing in oxidation tanks and from gas production in denitrification reactors, anaerobic digesters [16] and in nitrification/anammox reactors [17][18][19]. The formation of persistent foams may be a critical issue as it could lead to a series of operative problems including: (i) reduction in oxygen transfer, (ii) decrease in the concentration of biomass in the biological reactor, (iii) odor problems and (iv) increase of the management and maintenance costs [12][20][21]. The production of uncontrolled foams in large volumes causes a physical hazard for operators due to exposure to pathogens, obstruction of passageways and formation of slippery surfaces causing dangers of falling [20][21].

2. Foaming

In recent years, foaming has also been studied in membrane bioreactors (MBRs) [2][21][22][23]. Membrane processes, by replacing the gravitational sedimentation tank of a CAS process, allow retaining all solids, with a size greater than the porosity of ultrafiltration or microfiltration, inside the reactor. The main management problems that derive from this are (i) the fouling of the membranes and (ii) the formation of biological foams [24][25]. The recirculation of the mixed liquor at the head of the membrane bioreactor worsens these conditions and the tank in which the MBR unit is submerged may become a real trap for foams [5][21].

Foaming represents also one of the most common operating problems in anaerobic digesters (ADs) of WWTPs and the main critical aspect deriving (in addition to those previously described) is the reduction of digester performance, which results in a lower production of biogas and volatile solids degradation [26]. Other serious operational problems that can be encountered are (i) gas mixing blocks, (ii) fouling of the gas collection pipes, (iii) covering of the digester wall with solid foams, (iv) proliferation of pathogenic bacteria due to the reduction of the active volume in the digester, (v) maintenance interventions for cleaning biogas pipes and (vi) foam spills with the formation of slippery areas [26][27]. From the AD management point of view, the economic losses deriving from the phenomenon of foams are another important and not negligible aspect. The estimation of the costs is not easy to quantify because different parameters must be included in the count: the cleaning costs of the digester, the repair costs and the personnel costs for increased monitoring and maintenance are equally essential [28][29][30]. The aspect of worker safety must not be underestimated. For instance, very dangerous explosion phenomena have also been observed in some barns in the USA following the formation of stable and thick foams in ADs [28].

The formation of foams can also reduce the overall WWTP performance, therefore in order to optimize its management, causes, quantification and removal of foams must be investigated [12][20]. As already expressed in literature [31][32] for drinking water treatment plants, also for WWTPs the same approach of monitoring and optimization could be applied. This would guarantee to cope with the increasing presence of industrial contaminants in wastewaters [33][34][35] and would allow producing a sludge that respects strict limits for the reuse in agriculture [36][37].

This entry aims at examination and investigation of the problem of foams through the methodological approach of research to identify the correct control and/or prevention strategies in WWTPs; therefore suggested future outlooks on the basis of previous studies in this topic area are presented and discussed at the end of this work.

References

1. Andrey V. Kiselev; Elena R. Magaril; Elena Cristina Rada; Energy and sustainability assessment of municipal wastewater treatment under circular economy paradigm. *Energy and Sustainability VIII* **2019**, *237*, 109-120, 10.2495/esus190101.

2. Marco Capodici; Gaetano Di Bella; Salvatore Nicosia; Michele Torregrossa; Effect of chemical and biological surfactants on activated sludge of MBR system: Microscopic analysis and foam test. *Bioresource Technology* **2015**, *177*, 80-86, 10.1016/j.biortech.2014.11.064.
3. Feng Guo; Zhi-Ping Wang; Ke Yu; Tong Zhang; Detailed investigation of the microbial community in foaming activated sludge reveals novel foam formers. *Scientific Reports* **2015**, *5*, 7637, 10.1038/srep07637.
4. R.J. Davenport; R.L. Pickering; A.K. Goodhead; Thomas P. Curtis; A universal threshold concept for hydrophobic mycolata in activated sludge foaming. *Water Research* **2008**, *42*, 3446-3454, 10.1016/j.watres.2008.02.033.
5. Jenkins, D.; Richard, M.G.; Daigger, G.T. Manual on the Causes and Control of Activated Sludge Bulking, Foaming, and Other Solids Separation Problems, 3rd ed.; CRC Press: Boca Raton, FL, USA, 2003; ISBN 1-849-046-9.
6. Pitt, P.; Jenkins, D. Causes and control of Nocardia in activated sludge. Res. J. Water Pollut. Control Fed. 1990, 62, 143–150.
7. E.M. Seviour; C.J. Williams; R.J. Seviour; J.A. Soddell; K.C. Lindrea; A survey of filamentous bacterial populations from foaming activated sludge plants in Eastern States of Australia. *Water Research* **1990**, *24*, 493-498, 10.1016/0043-1354(90)90234-w.
8. E.M. Seviour; C. Williams; B. DeGrey; J.A. Soddell; R.J. Seviour; K.C. Lindrea; Studies on filamentous bacteria from australian activated sludge plants. *Water Research* **1994**, *28*, 2335-2342, 10.1016/0043-1354(94)90049-3.
9. J. A. Soddell; R.J. Seviour; Microbiology of foaming in activated sludge plants. *Journal of Applied Bacteriology* **1990**, *69*, 145-176, 10.1111/j.1365-2672.1990.tb01506.x.
10. R. Pujol; Ph. Duchène; S. Schetrite; J.P. Canler; Biological foams in activated sludge plants: Characterization and situation. *Water Research* **1991**, *25*, 1399-1404, 10.1016/0043-1354(91)90118-a.
11. Jiri Wanner; Iveta Ruzicková; Petra Jetmarová; Olga Krhutková; Jana Paraniaková; A national survey of activated sludge separation problems in the Czech Republic: filaments, floc characteristics and activated sludge metabolic properties. *Water Science and Technology* **1998**, *37*, 271-279, 10.2166/wst.1998.0643.
12. Jacqueline Heard; Emma Harvey; Bruce B. Johnson; John D. Wells; M. J. Angove; The effect of filamentous bacteria on foam production and stability. *Colloids and Surfaces B: Biointerfaces* **2008**, *63*, 21-26, 10.1016/j.colsurfb.2007.10.011.
13. Linda L Blackall; Anne E. Harbers; P. F. Greenfield; A. C. Hayward; Activated sludge foams: Effects of environmental variables on organism growth and foam formation. *Environmental Technology* **1991**, *12*, 241-248, 10.1080/09593339109385001.

14. K. Schilling; Matthias Zessner; Foam in the aquatic environment. *Water Research* **2011**, *45*, 4355-4366, 10.1016/j.watres.2011.06.004.
15. Lucie Moeller; Andreas Zehnsdorf; Dana Pokorná; Jana Zabranska; Foam Formation in Anaerobic Digesters. *Advances in Bioenergy* **2018**, *3*, 1-42, 10.1016/bs.aibe.2018.02.001.
16. Hug, T. Characterization and Controlling of Foam and Scum in Activated Sludge Systems. Ph.D. Thesis, ETH Zurich, Zurich, Switzerland, 2006.
17. Adriano Joss; David Salzgeber; Jack Eugster; Roger König; Karin Rottermann; Sabine Burger; Peter Fabijan; Susanne Leumann; Joachim Mohn; Hansruedi Siegrist; Full-Scale Nitrogen Removal from Digester Liquid with Partial Nitritation and Anammox in One SBR. *Environmental Science & Technology* **2009**, *43*, 5301-5306, 10.1021/es900107w.
18. Shou-Qing Ni; Na Sun; Houling Yang; Jian Zhang; Huu Hao Ngo; Distribution of extracellular polymeric substances in anammox granules and their important roles during anammox granulation. *Biochemical Engineering Journal* **2015**, *101*, 126-133, 10.1016/j.bej.2015.05.014.
19. Susanne Lackner; Eva M. Gilbert; Siegfried E. Vlaeminck; Adriano Joss; Harald Horn; Mark Van Loosdrecht; Full-scale partial nitritation/anammox experiences – An application survey. *Water Research* **2014**, *55*, 292-303, 10.1016/j.watres.2014.02.032.
20. Martin Fryer; Eoghan O'Flaherty; Nick F. Gray; Evaluating the Measurement of Activated Sludge Foam Potential. *Water* **2011**, *3*, 424-444, 10.3390/w3010424.
21. Gaetano Di Bella; Michele Torregrossa; Foaming in membrane bioreactors: Identification of the causes. *Journal of Environmental Management* **2013**, *128*, 453-461, 10.1016/j.jenvman.2013.05.036.
22. Jun Nakajima; Iori Mishima; Measurement of Foam Quality of Activated Sludge in MBR Process. *Acta hydrochimica et hydrobiologica* **2005**, *33*, 232-239, 10.1002/aheh.200400575.
23. Gaetano Di Bella; Michele Torregrossa; Gaspare Viviani; The role of EPS concentration in MBR foaming: Analysis of a submerged pilot plant. *Bioresource Technology* **2011**, *102*, 1628-1635, 10.1016/j.biortech.2010.09.028.
24. Di Bella, G.; Durante, F.; Torregrossa, M.; Viviani, G. Start-up with or without inoculum? Analysis of an SMBR pilot plant. Desalination 2010, 260, 79–90.
25. Giorgio Mannina; Gaetano Di Bella; Comparing two start-up strategies for MBRs: Experimental study and mathematical modelling. *Biochemical Engineering Journal* **2012**, *68*, 91-103, 10.1016/j.bej.2012.07.011.
26. Bhargavi Subramanian; Krishna R. Pagilla; Mechanisms of foam formation in anaerobic digesters. *Colloids and Surfaces B: Biointerfaces* **2015**, *126*, 621-630, 10.1016/j.colsurfb.2014.11.032.

27. Chenjing Jiang; Rong Qi; Liping Hao; Simon J. McIlroy; Per Halkjær Nielsen; Monitoring foaming potential in anaerobic digesters. *Waste Management* **2018**, *75*, 280-288, 10.1016/j.wasman.2018.02.021.
28. Lucie Moeller; Frank Eißmann; Daniel Wißmann; Hans-Joachim Nägele; Simon Zielonka; Roland A. Müller; Andreas Zehnsdorf; Innovative test method for the estimation of the foaming tendency of substrates for biogas plants. *Waste Management* **2015**, *41*, 39-49, 10.1016/j.wasman.2015.03.031.
29. Maria Rothman; Åsa Dillner Westlund; Eva Hagland; Operational aspects on foaming in digesters caused by microthrix parvicella. *Water Science and Technology* **1998**, *38*, 29-34, 10.1016/s0273-1223(98)00674-x.
30. Nafsika Ganidi; Sean Tyrrel; Elise Cartmell; Anaerobic digestion foaming causes – A review. *Bioresource Technology* **2009**, *100*, 5546-5554, 10.1016/j.biortech.2009.06.024.
31. Sabrina Sorlini; Maria Cristina Collivignarelli; Federico Castagnola; Barbara Marianna Crotti; Massimo Raboni; Methodological approach for the optimization of drinking water treatment plants' operation: a case study. *Water Science and Technology* **2014**, *71*, 597-604, 10.2166/wst.2014.503.
32. Sorlini, S.; Collivignarelli, M.C.; Carnevale Miino, M. Technologies for the control of emerging contaminants in drinking water treatment plants. Environ. Eng. Manag. J. 2019, 18, 2203–2216.
33. Maria Cristina Collivignarelli; Alessandro Abbà; Massimiliano Bestetti; Barbara Marianna Crotti; Marco Carnevale Miino; Electrolytic Recovery of Nickel and Copper from Acid Pickling Solutions Used to Treat Metal Surfaces. *Water, Air, & Soil Pollution* **2019**, *230*, 101, 10.1007/s11270-019-4158-1.
34. Maria Cristina Collivignarelli; Alessandro Abbà; Marco Carnevale Miino; Hamed Arab; Massimiliano Bestetti; Silvia Franz; Decolorization and biodegradability of a real pharmaceutical wastewater treated by H2O2-assisted photoelectrocatalysis on TiO2 meshes. *Journal of Hazardous Materials* **2020**, *387*, 121668, 10.1016/j.jhazmat.2019.121668.
35. Maria Cristina Collivignarelli; Marco Carnevale Miino; Marco Baldi; Sabrina Manzi; Alessandro Abbà; Giorgio Bertanza; Removal of non-ionic and anionic surfactants from real laundry wastewater by means of a full-scale treatment system. *Process Safety and Environmental Protection* **2019**, *132*, 105-115, 10.1016/j.psep.2019.10.022.
36. Maria Cristina Collivignarelli; Matteo Canato; Alessandro Abbà; Marco Carnevale Miino; Biosolids: What are the different types of reuse?. *Journal of Cleaner Production* **2019**, *238*, , 10.1016/j.jclepro.2019.117844.
37. Maria Cristina Collivignarelli; Abbà; Andrea Frattarola; Carnevale Miino; Sergio Padovani; Ioannis Katsoyiannis; Vincenzo Torretta; Alessandro Abbà; Marco Carnevale Miino; Legislation for the

Reuse of Biosolids on Agricultural Land in Europe: Overview. *Sustainability* **2019**, *11*, 6015, 10.3390/su11216015.