Resources

[i]https://ec.europa.eu/knowledge4policy/publication/food-2030-innovative-eu-research-ensures-food-system-future-ready_en
[ii]www.fao.org/3/a-a1554e.pdf
[iii]https://propepper.net
[iv]www.allergenonline.org/
[v]https://comparedatabase.org/
[vi]www.allergome.org/
[vii]www.allergen.org/
[viii]www.uniprot.org/

[1]European Food Safety Authority (EFSA), via Carlo Magno 1A, 43021 Parma, Italy
[2]Division of Infection, Immunity and Respiratory Medicine, School of Biological Sciences, Manchester Institute of Biotechnology, Manchester Academic Health Sciences Centre, The University of Manchester, Manchester, UK
[3]Department of Immunohematology and Blood Transfusion, Leiden University Medical Centre, Leiden 2333, ZA, The Netherlands
[4]Instituto de Investigación en Ciencias de la Alimentación, CIAL (CSIC-UAM), C/Nicolás Cabrera, 9, Campus de la Universidad Autónoma de Madrid, 28049 Madrid, Spain

*Correspondence:
antonio.fernandezdumont@efsa.europa.eu (A. Fernandez).
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Forum

Enhanced Strategies for Antibiotic Removal from Swine Wastewater in Anaerobic Digestion

Qi Zhou,[1,2,4] Xiang Li,[1,2,4] Shaohua Wu,[1,2,4] Yuanyuan Zhong,[1] and Chunping Yang[1,2,3,*]

There is a need for techniques that ensure antibiotic removal in anaerobic digesters for robust methane production. In this article, we discuss recent strategies for enhanced antibiotic removal from swine wastewater and offer insights on anaerobic digestion (AD) process design for improved antibiotic removal.

Antibiotic Removal in Aqueous and Sludge Phases

In the past two decades, the quantity of veterinary antibiotics used as disease prevention agents in animal feed has considerably increased. For example, veterinary antibiotic usage grew at a rate of 6000 tons per annum in China, surging from 97 000 t in 2010 to 132 000 t in 2016 [1]. However only 10–30% of consumed veterinary antibiotics are metabolized by livestock, causing a substantial amount of antibiotics to be excreted into swine wastewater as metabolites or in their original form, at concentrations of up to hundreds of micrograms per liter [1]. Swine wastewater has become a major pollution source of antibiotics. Thus, treatment of antibiotics in swine wastewater has also become a hot topic in research.

Biosorption and biodegradation are the two dominant antibiotic removal pathways during anaerobic digestion (AD) [2]. Biosorption processes involve bridging hydrophobic partitioning, cation exchange, electrostatic interactions, surface complexation, and electron donor–acceptor interactions (i.e., hydrogen bonding), where the extracellular polymeric substance (EPS) plays an important role due to the abundant functional groups on its surface. However, biosorption is only a phase-transfer phenomenon and cannot fully exclude the risk of antibiotic release into the environment [2]. Thus, biodegradation is typically needed to further transform (e.g., intermediates) or remove (e.g., complete mineralization) the remaining antibiotics from swine wastewater. Three principal degradation mechanisms for antibiotics have been reported: antibiotics as a growth substrate, organic matter as an electron acceptor, and co-metabolism. AD is generally a process using a sludge-dominated system for which the absolute mass of antibiotics in the sludge phases is expected to be higher than that in the aqueous phases [3].

Thus, removal of antibiotics in sludge typically occurs in the following order: rapid sludge sorption, followed by rapid sludge desorption, and then biodegradation (Figure 1). However, numerous experimental studies have demonstrated that anaerobic digesters are only moderately effective (40–77%) for antibiotic removal during AD treatment [2]. Accumulation of antibiotics remains a

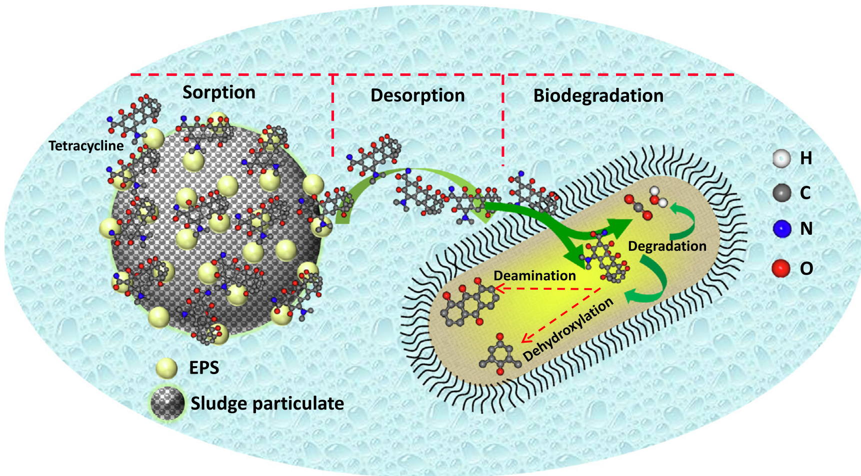

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Figure 1. A Schematic Diagram of Antibiotic Removal in Sludge. Abbreviation: EPS, extracellular polymeric substance.

problem that limits biogas production in anaerobic digesters and various techniques are still needed to further improve antibiotic removal.

Conductive Materials

Recently, conductive mediators have been introduced into anaerobic systems for improved micropollutant removal and methane production [4,5]. Carbon-based materials are commonly utilized conductive mediators that promote the performance and activity of bacterial communities in AD [4]. Conductive carbon material, such as granular activated carbon (GAC), biochar, single-walled carbon nanotubes (SWCNTs), multiwalled carbon nanotubes (MWCNTs), graphene, and zero-valent iron (ZVI), can increase the conductivity of mixed culture systems and thus promote the methanogenesis of microorganisms via direct interspecies electron transfer (DIET) [5]. Zhang and colleagues [4] found that the abundance of *Treponema* increased from 8.95% to 14.29% after the addition of GAC/ZVI.

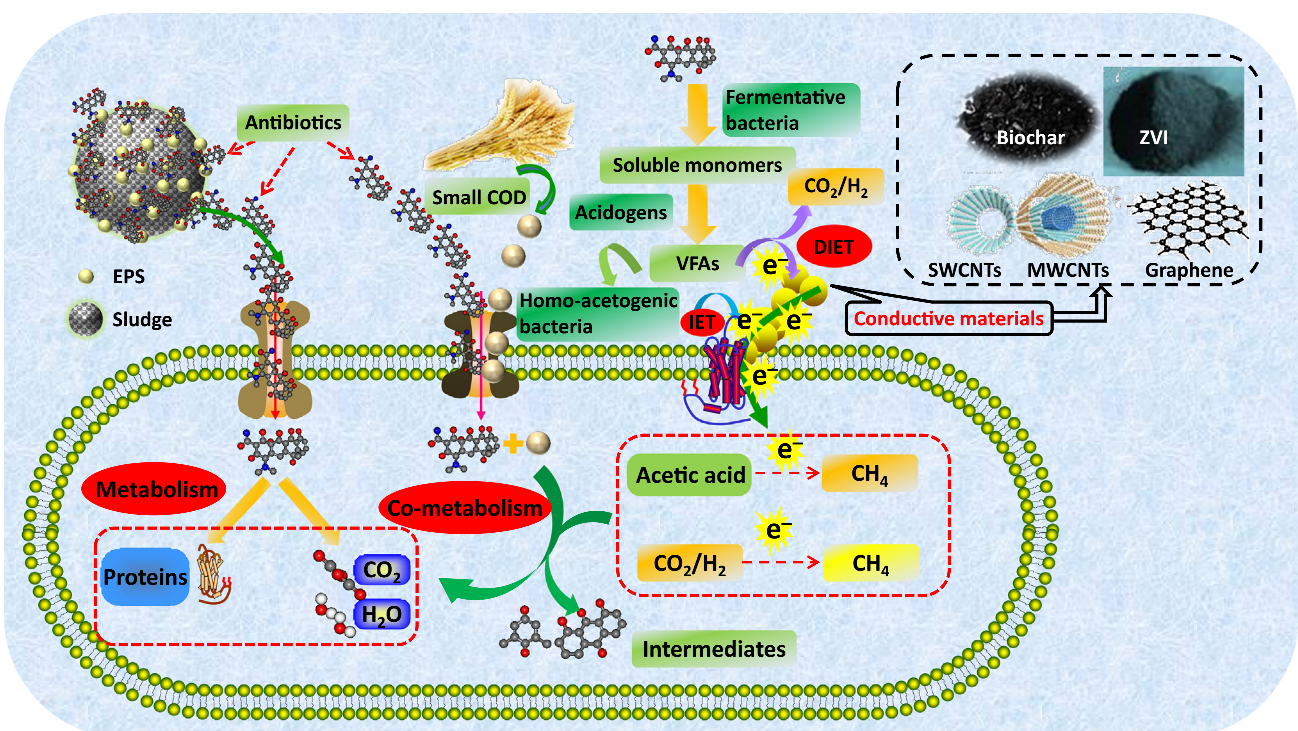

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Figure 2. A Schematic Diagram of the Mechanisms and Strategies for Enhanced Removal of Antibiotics. Abbreviations: COD, chemical oxygen demand; DIET, direct interspecies electron transfer; EPS, extracellular polymeric substance; MWCNTs, multiwalled carbon nanotubes; SWCNTs, single-walled carbon nanotubes; VFAs, volatile fatty acids; ZVI, zero-valent iron.

This GAC/ZVI promoted the growth of *Treponema*, which is capable of effective antibiotic degradation. The introduction of conductive mediator materials into anaerobic digesters not only transformed biogas output in antibiotic digesters [6], but also reinforced the metabolic activity for antibiotics via co-metabolism or electron transfer.

Magnetic Nanoparticles

The application of nanoparticles to improve the performance of anaerobic treatment has been limited by their easy loss [7]. However, magnetite nanoparticles can resolve these drawbacks because they are easy to recycle. In addition, many studies have illustrated that the addition of magnetite nanoparticles in anaerobic systems can promote the degradation of organic matter (e.g., formate, propionate, volatile fatty acids, ethanol, acetate) [6], since magnetite can accelerate interspecies electron transfer (IET) between co-cultures. Magnetite can also facilitate micropollutant degradation [8]. Thus, adding magnetite to anaerobic systems may improve antibiotic biodegradation during AD processes. Yang and colleagues [8] found that the biodegradation efficiency of ciprofloxacin with magnetite was 67% higher than that without. *Stenotrophomonas*, a group of iron-reducing bacteria, was enriched following the addition of magnetite. Magnetite nanoparticles can also work as adsorbents to remove antibiotics from wastewater. Additionally, Fe_3O_4/polyacrylonitrile (PAN) composite nanofibers were observed to remove 58.6% of tetracyclines by adsorption [9]. These findings offer a method to enhance antibiotic biodegradation by the use of magnetite nanoparticles during the AD processes.

Co-substrate

Co-digestion can improve the degradation of antibiotics in the AD process due to co-metabolism of antibiotics and exogenous chemical oxygen demand (COD) [2]. Straws, a low-cost exogenous COD, are widely used in anaerobic digesters to perform co-metabolism for antibiotic removal. In addition to co-metabolism, straws can also absorb antibiotics from aqueous phases as their surfaces have many adsorption sites [10]. Jin and colleagues [11] achieved 97% removal of sulfachloropyridazine following the addition of rice straws, compared with 72.8% in a control group, in the AD of swine manure. The addition of straws can help to remove antibiotics via enhanced co-metabolism and adsorption. Chen and Xie [12] also found that co-digestion with rice straws can improve the degradation of sulfonamides. Co-digestion leveraged by straws has emerged as one of the most promising treatments that promote substrate availability and microorganism activities for complete removal of antibiotics.

The mechanisms and strategies for enhanced removal of antibiotics from swine wastewater in AD are summarized in Figure 2.

Concluding Remarks and Future Perspectives

Currently, anaerobic digesters for antibiotic removal are only moderately effective during AD. Biosorption and biodegradation mechanisms play vital roles in AD processes with swine wastewater. Enhanced strategies include the introduction of conductive mediator materials, magnetite nanoparticle materials, and straws, all of which can more effectively remove antibiotics from swine wastewater. These mechanisms and enhanced strategies for improved antibiotic removal have helped to elucidate the antibiotic degradation process, enhance performance, and reduce the release of antibiotics into the environment.

However, challenges must be addressed before we can make the antibiotic removal processes more economic and competitive. First, some enzymes (e.g., glucosidase, protease, phosphoesterase) may also play important roles in the biodegradation of antibiotics in AD. At the molecular level, genes and proteins need to be better characterized to understand the biodegradation mechanisms in anaerobic treatment processes. Potential toxicity to microorganisms of intermediates should also be considered by coupling biological assays with biodegradation studies. Second, studies of the relationship between AD processes (e.g., hydrolysis, acidogenic fermentation, hydrogen-producing acetogenesis, methanogenesis) and antibiotic degradation are lacking due to the complexity of metabolism under anaerobic conditions. Molecular biology tools with superior accuracy, such as metagenomic analysis, are likely to be more successful in elucidating these issues. Third, antibiotic resistance genes (ARGs) accumulated as antibiotics are biodegraded pose a potential hazard to human health and the environment. Finally, although advanced enhanced treatment systems work effectively on various antibiotics, the cost of these technologies may be too high.

Over the past two decades, microalga-based and duckweed-based technologies have attracted more attention in swine wastewater treatment. Some studies demonstrated that microalgae and duckweed can assimilate organic matter and nutrients from swine wastewater for their growth, and the harvested microalgae and duckweed can be utilized as a biofuel due to their higher lipid and starch content [13–15]. Integration of anaerobic treatment with microalga-based and duckweed-based technologies might not only remove antibiotics, but also allow recycling of resources and can be applied in anaerobic digesters in resource-limited areas.

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[1]Guangdong Provincial Key Laboratory of Petrochemical Pollution Processes and Control, School of Environmental Science and Engineering, Guangdong University of Petrochemical Technology, Maoming, Guangdong 525000, China
[2]College of Environmental Science and Engineering, Hunan University and Key Laboratory of Environmental Biology and Pollution Control (Hunan University), Ministry of Education, Changsha, Hunan 410082, China
[3]Hunan Provincial Environmental Protection Engineering Center for Organic Pollution Control of Urban Water and Wastewater, Changsha, Hunan 410001, China
[4]These authors contributed equally to this article

*Correspondence:
yangc@hnu.edu.cn (C. Yang).

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