Journal of Hazardous Materials 357 (2018) 253–270

Contents lists available at ScienceDirect

Journal of Hazardous Materials

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

Recent advances on biosorption by aerobic granular sludge

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ARTICLE INFO

Keywords:
Aerobic granule
Biosorption
Water treatment
Surface modification
Mechanism

ABSTRACT

Aerobic granular sludge is a form of microbial auto-aggregation, and a promising biotechnology for wastewater treatment. This review aims at providing the first comprehensive, systematic, and in-depth overview on the application of aerobic granules as biosorbents. The target pollutants encompass heavy metals (both cationic and oxyanionic), nuclides, dyes, and inorganic non-metal substances. Different granule types are discussed, i.e. intact and fragmented, compact and fluffy, original and modified, and the effects of granule surface modification are introduced. A detailed comparison is conducted on the characteristics of granular biomass, the conditions of the adsorption tests, and the resultant performance towards various sorbates. Analytical and mathematical tools typically employed are presented, and possible interactions between the pollutants and granules are theorized, leading to an analysis on the mechanisms of the adsorption processes. Original granules appear highly effective towards cationic metals, while surface modification by organic and inorganic agents can expand their applicability to other pollutants. Combined with their advantages of high mechanical strength, density, and settling speed, aerobic granules possess exceptional potential in real wastewater treatment as biosorbents. Possible future research, both fundamental and practical, is suggested to gain more insights into the mechanism of their function, and to advance their industrial application.

1. Introduction

1.1. Aerobic granules

Aerobic granulation is considered as one of the most promising biotechnologies in present-day wastewater treatment, whose core feature is its biological agent-aerobic granules. Formation of bio-granules in anaerobic reactors, e.g. up-flow anaerobic sludge blanket reactors (UASB) is well documented for high-strength wastewaters, while aerobic granular sludge is a relatively new development. Aerobic granules are self-aggregation of microbial cells under aerobic conditions without supporting carriers [1,2]. More specifically, in some fully aerated bioreactors, microorganisms originally existing as dispersed flocs might auto-aggregate of their own accord, and form dense particles of near-spherical shape, with defined boundary from the reactor's bulk liquid. An example can be seen in Fig. S1A, where a mature granule particle is displayed in a scanning electronic microscopy image. Some researchers also consider aerobic granules to be a special case of biofilm composed of self-immobilized cells [3], but the former requires no supporting materials for their formation, which can considerably simplify reactor operation and reduce cost.

The development of aerobic granules in reactors was first reported in 1991 by Mishima and Nakamura [4], and since then this microbial self-aggregate has been successfully cultivated in various reactors by many researchers [5–10]. High shear force and harsh conditions are often provided in these reactors, and the granules formed usually have big size, compact structure, high density and mechanical strength. Therefore a distinctive advantage of an aerobic granular sludge blanket reactor (AGSB) is that it requires very short settling time (i.e. several minutes), and when settled, the granules form a compact sludge bed (shown in Fig. S1B). The enhanced settling ability can greatly improve the throughput of an AGSB reactor and the quality of its effluent, which in turn reduced its footprint and land usage.

The high settling velocity is a direct consequence of aerobic granules' feature as aggregated microbial cells. Two major kinds of physical structure have been observed so far, namely compact and fluffy (shown in Fig. 1). The former is believed to be predominated by various bacteria populations, which bind tightly with each other and are embedded

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https://doi.org/10.1016/j.jhazmat.2018.06.010
Received 12 February 2018; Received in revised form 23 May 2018; Accepted 3 June 2018
Available online 04 June 2018
0304-3894/

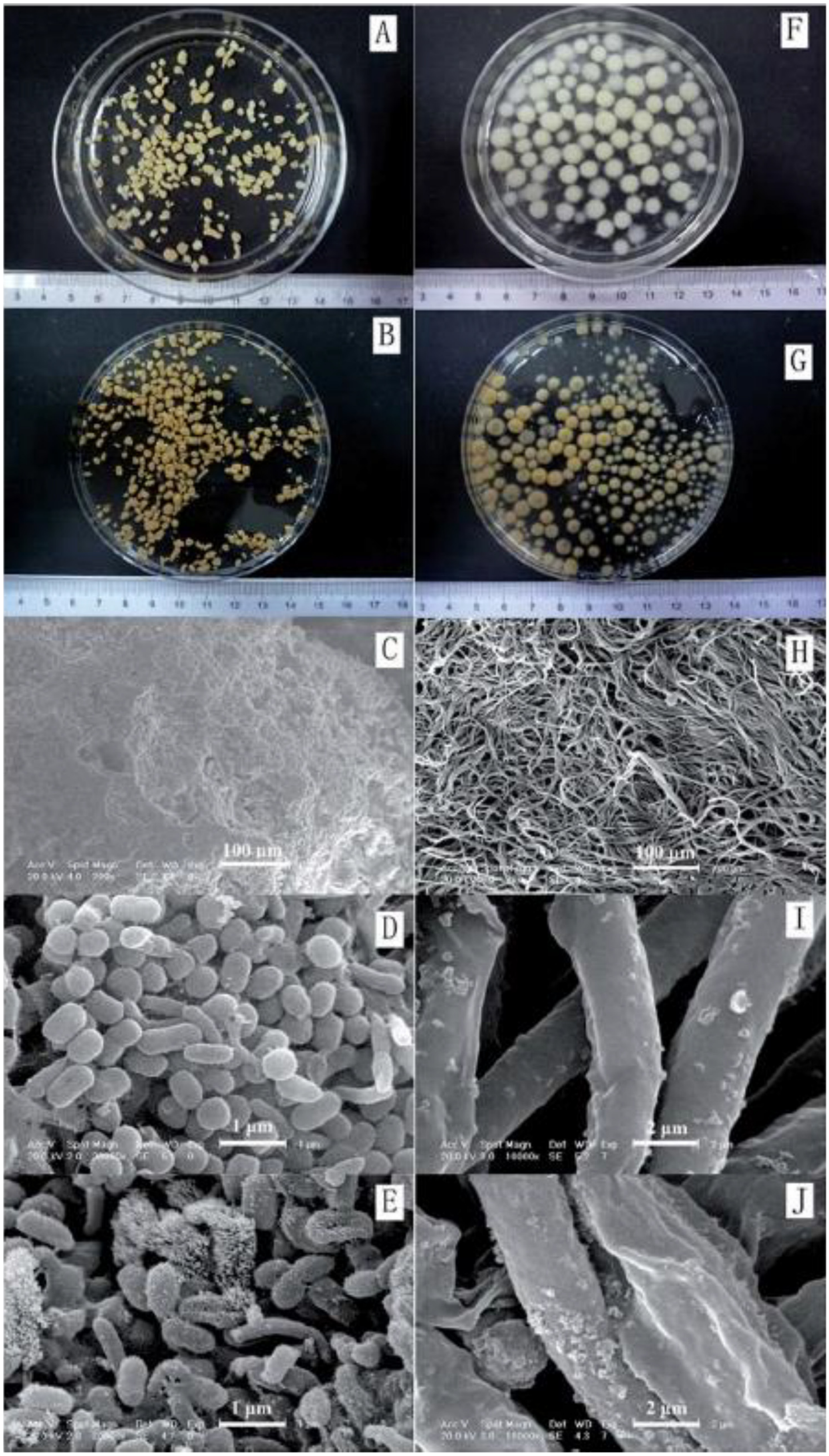

Fig. 1. Morphological observations of the bacterial and fungal granules. (A) original bacterial granules (B) Fe(III) modified bacterial granules; (C) original bacterial granules' surface; (D) original bacterial granules' surface (detailed); (E) bacterial granules' surface after modification; (F) original fungal granules; (G) Fe(III) modified fungal granules; (H) original fungal granules' surface; (I) original fungal granules' surface (detailed); (J) fungal surface after modification [72].