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Rapid cultivation of aerobic granular sludge in a continuous flow reactor

Bei Long[a,b], Chang-zhu Yang[a,*], Wen-hong Pu[a], Jia-kuan Yang[a], Fu-biao Liu[a], Li Zhang[a], Kai Cheng[a,*]

[a] College of Environmental Science and Engineering, Huazhong University of Science and Technology, Luoyu Road 1037, Wuhan 430074, PR China
[b] School of Architectural and Surveying & Mapping Engineering, Jiangxi University of Science and Technology, Hongqi Ave. 86, Ganzhou 341000, PR China

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ABSTRACT

Aerobic granular sludge (AGS) was successfully cultivated in a double column cyclic aerobic granular reactor (DCCAGR) within 18 days by inoculating with 30% (w/w) mature aerobic granules and 70% activated sludge, while granulation process and reactor performance was investigated in the continuous flow reactor. The AGS cultivated was white or pale yellow, while granule's SVI, average particle size, granulation rate, extracellular polymeric substances, polysaccharides/proteins ratio and water content were about 46 mL/g, 1.2 mm, 92%, 37 mg/g MLVSS, 1.4 and 98.3% on the 20th day. Observed from the microscopic structure of the cultivated AGS, a large number of microorganisms tightly adhered together inhibited inside the granules, including coccus, bacillus and protozoa. Finally, effluent chemical oxygen demand, total inorganic chemical demand, ammonium nitrogen and total phosphorus of the system were 33 mg/L, 8.46 mg/L, 7.3 mg/L and 1.26 mg/L, and their removal rates were 97%, 88%, 90% and 87% respectively. Effective hydraulic selection pressure can be created in DCCAGR, while inoculated AGS had positive significance to the agglomeration of other flocculent sludge, which greatly reduced the startup time and consumption of mature aerobic granules.

1. Introduction

Aerobic granular sludge (AGS) has many incomparable advantages compared with activated sludge [2,28], such as regular shape, compact structure, high settling velocity, tolerance to high organic load and toxicity, simultaneous nitrogen and phosphate removal, etc. Owing to these advantages, AGS is considered to be a prospective biological treatment technology in the future. In 1991, AGS was firstly discovered in a continuous flow reactor under extreme operating conditions [22]. However, according to quantities of further studies [13,2,3,25,28], sequencing batch reactor (SBR) was considered to be more appropriate for AGS's formation. Compared with aerobic granular SBR (AGSBR), conventional continuous flow reactors usually have weak mass transfer driving force and uncontrollable sludge selection effect, where filamentous bulking are easy to happen [4,15]. And that is why most of the research achievements of AGS were achieved from SBR until now.

Typically, SBR is suitable for small amount wastewater treatment subjected to automatic control level, and it is unfavorable to connect to continuous operational constructions. By contrast, continuous flow reactor is popular and widely applied in engineering, which has many advantages, such as flexibility, high utilization rate of equipment, etc. Under this circumstance, some CFAGRs were proposed by researchers [8,17,24,9,32,20], which proved AGS could existed in continuous flow reactor under specific conditions. However, no persuasive data related to aerobic granulation from activated sludge to mature AGS was reported in these CFAGRs. Different from static settling in AGSBR, the selection of different characteristic sludge was mainly depend on three phase separator. However, there is quite little successful experience of aerobic granular separators until now. In addition, high aeration rate in aerobic granular reactors required more sophisticated and effective separators, which greatly increased the design difficulty.

Research indicated that aerobic granulation time was affected by inoculums [5]. By summarizing the existing research, it was found that CFAGR was usually started by inoculating with activated sludge, mature AGS or biofilm. However, CFAGR started by inoculating with mixture of activated sludge and mature AGS was rarely reported, and there is little information concerning the function of mature AGS during aerobic granulation in both CFAGR and SBR. By gradually reducing the settling time, aerobic

* Corresponding author. Fax: +86 27 87792101.
E-mail address: 15007173775@163.com (C.-z. Yang).

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granulation was usually achieved within two month in SBR [7,31,27,18,33]. Strangely, AGS was usually cultivated less than 30 days in CFAGR. Although directly inoculating with mature AGS could greatly reduce the startup time [26,30], it is not economical for large quantities of inoculation as there are still few projects operated worldwide. Therefore, inoculating with part of mature AGS for cultivation is more appreciated.

As there were a few successful CFAGRs at present, this paper proposed a novel designed continuous flow reactor, namely double column cyclic aerobic granular reactor (DCCAGR). Design of the reactor used the experience of LUCAS, which was a varietal continuous process of SBR. Granulation process in DCCAGR was investigated by inoculated with part mature AGS, which aimed to provide technical support for research and development of CFAGR.

2. Methods

2.1. Equipment

Working volume of DCCAGR was 24.2 L, which included two equal, uniform reactors, namely R_1 and R_2 (Fig. 1). Working volume of the single reactor was 12.1 L, which included the main reaction column (8.4 cm in diameter, 188 cm in height and H/D ratio of 22.4), inclined tube (3.0 cm in diameter and 17 cm in height) and baffle settling tank (7.0 cm in diameter and 37 cm in height). Each single reactor (R_1 and R_2) could realize separation of sludge, gas and liquor. The settling tank was equipped with a removable baffle, while variation of the baffle depth (defined as height of the baffle under effective water level) could create different selection pressure (the relationship between selection effect and baffle depth could be seen in Supplementary material). Fine air bubbles for aeration and mixing were supplied through a dispenser at the bottom of the reactor.

The system operated in continuous flow with a constant water level. R_1 and R_2 served alternately as the first and the second reactor, while the operational mode was similar to LUCASS (two tanks type). The system was automatically controlled by a programmable logic controller. Wastewater was filled into the reactor from the bottom inlet through a peristaltic pump (BT100-1L, Longer). Flow direction of R_1 and R_2 was controlled through ON/OFF of six electromagnetic valves. Cycle time (refers to the minimum time required for the operational condition of the system returned to the original state) of the system was 4 h, which meant that flow direction of the two reactors switched every 2 h. That was: wastewater was from R_1 to R_2 in the former 2 h, and the sequence switched from R_2 to R_1 in the rest 2 h. Then, the system continuously circulated in the following time (Supplementary material, Fig. s3). Mixed liquor in each reactor was separated through the inclined tube and baffle settling tank. Supernatant fluid was discharged from the upper outlet, while mixture of screened sludge and liquor returned back to the main reaction column. Water temperature was controlled between 10 and 20 °C through a constant temperature heater. Other operational parameters can be seen in Table 1.

2.2. Seed sludge

Inoculum was the mixture of activated sludge and mature AGS, and their mass percentage was 70% and 30% respectively. Initial MLSS of R_1 and R_2 was both controlled to be about 5000 mg/L. The activated sludge was from a secondary sedimentation tank of Tang xun-hu municipal wastewater treatment plant in Wuhan, China. AGS was formerly cultivated in a pilot scale SBR. Working volume of the pilot SBR was 105.5 L (27.7 cm in diameter, 175 cm in height and H/D ratio of 6.3) with an exchange ratio of 60%. The reactor was fed with simulated wastewater, and the COD, TIN and TP were

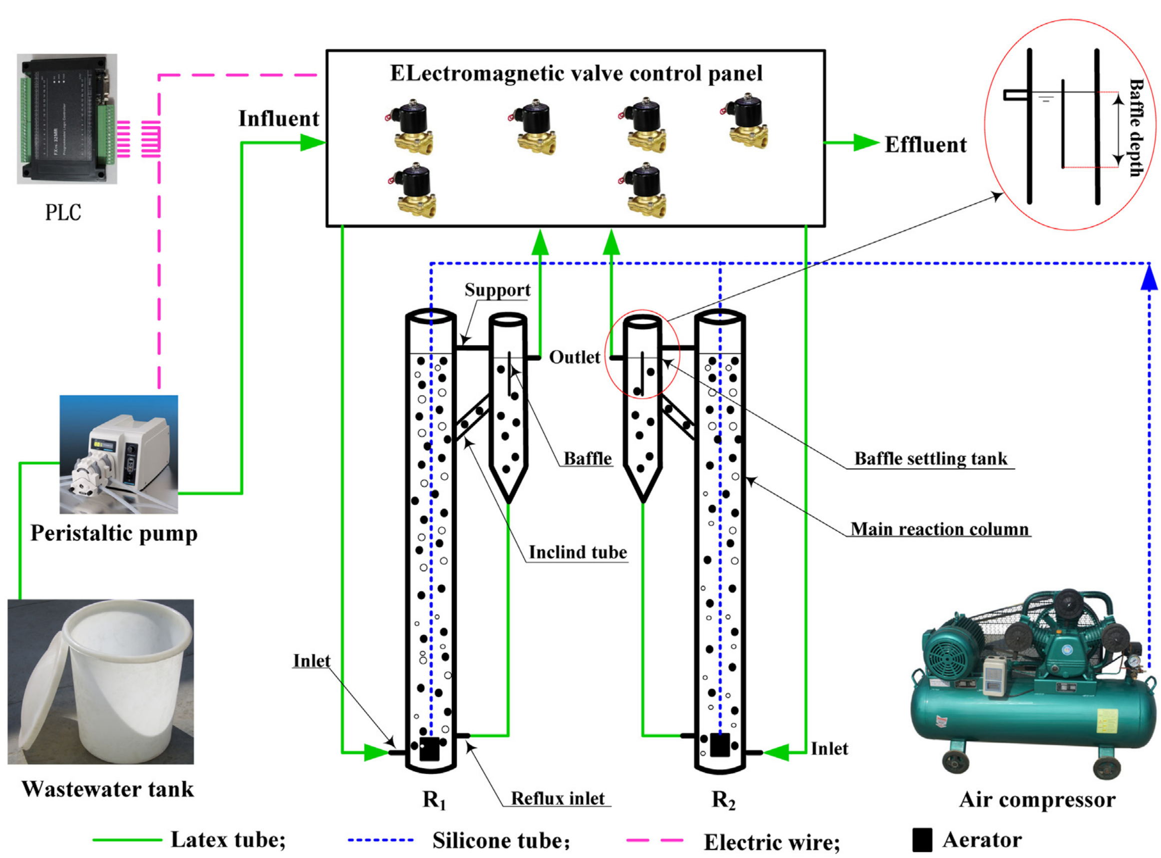

Fig. 1. Schematic diagram of DCCAGR.