Performance of Aerobic Granular Sludge Bioreactor Seeded with Flocculated Activated Sludge From an Iraqi Municipal Wastewatere Treatment Plant

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ABSTRACT

Aerobic granular activated sludge is an attractive and promising process for intensive and high-rate biological nutrient removal (BNR) and secondary clarification in a single reactor. This work reports the performance of aerobic granular sludge sequential batch reactor (SBR) seeded with flocculated activated sludge collected from an Iraqi municipal wastewater treatment plant, using synthetic wastewater**.** The conditions under which the successful cultivation of aerobic granular sludge was done are as follows: influent chemical oxygen demand (COD) was 1100 mg/l, volumetric exchange rate was 50%, aeration time was 10 hr, anoxic time was 2 hr aeration and sludge settling time was about 0.5 min. After 90 days, the dominant granules size was 1.5-3.5 mm. The granules became regular in shape with smooth surface, sharp boundaries and compact in structure. The biomass concentration in the reactor in terms of MLSS was 4100 mg/l. Sludge volume index (SVI) was 60 ml/g. High synthetic COD removal and simultaneous nitrification and denitrification during aerobic phase was observed. Subjection of the mature granules to a low COD municipal wastewater the activity of the granules was significantly reduced.

Keywords: Aerobic granular sludge; Sequencing batch reactor; Settling velocity.

أداء المفاعل البيولوجي الهوائي ذو الحمأة المنشطة الحبيبية والمبذور بحمـأة منشطة متكتلة من أحدى محطات معالجة الصرف الصحي العراقية

الخلاصة

تعتبر تقنية الحمأة المنشطة الحبيبية من التقنيات المؤملة وذات الكفاءة العالية في أزالة المغذيات بايولوجيا من المياه وعمل الترسيب الثانوي وفي حيز واحد. بين هذا البحث التعرف على أداء المفاعل البايولوجي المتعاقب ذو الحمأة المنشطة الحبيبية. والذي غذي عند البدء بحمأة منشطة جلبت من أحدى المنظومات التقليدية لمعالجة مياه الصرف الصحي في مدينة بغداد. وقد أستخدامت مياه ذات مغذيات أصطناعية في هذا العمل. تتلخص الظروف التشغيلية والتي تم فيها الحصول بنجاح على حمأة منشطة حبيبية هي كالاتي: تركيز متطلب اوكسجين كيمياوي في الماء الداخل بحدود 1100 ملغم/لتر، نسبة مئوية للأستبدال الحجمي للماء في المفاعل البايولوجي وفي كل دورة 50%، فترة تهوية 10 ساعة، فترة هوائية محددة 2 ساعة، فترة ترسيب بحدود 0,5 دقيقة. كان الحجم السائد للحبيبات، وبعد حوالي 90 يوما من بدأ عمل المفاعل البايولوجي، ضمن المدى 1,5 – 3,5 ملم. كانت الحبيبات الناتجة منتظمة الشكل وواضحة الحواف وذات سطح أملس وتركيب مكتنز. كان تركيز المواد الحية وبدلالة تركيز المواد العالقة الكلية بحدود 4100 ملغم/لتر. وكان مؤشر حجم الحمأة بحدود 60 ملغم/لتر. تمت ملاحظة الكفاءة العالية لأزالة متطلب الأوكسجين الكيمياوي وتزامن عمليتي النترجة وأزالة النتروجين في فتر التهوية. أن تعريض الحمأة الحبيبية الناتجة من هذا البحث الى مياه صرف صحي حقيقية أدى الى انخفاض في فعاليتها.

INTRODUCTION

Aerobic granular sludge (AGS) is one of the novel technologies for biological wastewater treatment. Although it had been thoroughly investigated during the last decade but still under development [1]. Aerobic granule based sequential batch reactors (SBRs) have been proven to be applicable for successful granulation of flocculated activated sludge to achieve sustainable treatment of wastewaters from various industries as well as municipal wastewater. Compared with conventional sludge flocs, it is an attractive process for secondary clarification and intensive and high-rate biological nutrient removal (BNR) in a single reactor. Stable dense and fast-settling aerobic granules with tailored metabolic activities for the simultaneous removal of organic matter, nitrogen, and phosphorus from the wastewater can be achieved in a single reactor unit [2, 3, 4 and 5].

Settling velocity of granules determined the efficiency of solid-liquid separation during secondary clarification which is a critical parameter for wastewater symptoms. The settling velocity varied from 25 to 70 mhr^{-1} and is significantly higher than that of sludge floc (7 to 10 mhr^{-1}). High settling velocity increases the biomass retention capacity of the bioreactor and subsequently enhances the organic degradation capability [5]. Granules characteristics are dependent heavily on many factors, such as the type of organic substrate, loading rate, fluid shear rate caused by aeration intensity, feast-famine regime, applied selection pressures in the forms of settling time and volume exchange ratio [4, 5, 6, 7 and 8].

Unlike the conventional BNR process which is based on several bioreactors where aerobic, anoxic and anaerobic zones are separately provided, granular structure provides different spatially distributed redox zones, due to substrate mass transfer limitations, inside the granule. Moreover, operation in sequencing batch mode allows the introduction of periods with and without aeration that is necessary for nitrification and denitrification processes [9]. The microbial consortia in the aerobic granule consist of two main different microbial groups, i.e., autotrophic and heterotrophic bacteria. The autotrophs are responsible for nitrification, whereas the heterotrophs are responsible for organic carbon oxidation and denitrification. Both of them play a vital role in the removal of nitrogen and conversion of a wide diversity of organic matters present in wastewater [3, 10, 11, 12 and 13].

The bacterial community residing in activated seed sludge is important for aerobic granulation process as the hydrophilic bacteria would be less likely to attach to sludge flocs compared with the hydrophobic counterpart, which constitutes the majority of the of free bacteria in the influent from a full-scale treatment plant. The greater the number of hydrophobic bacteria in the seed sludge the faster the aerobic granulation with excellent settleabity [6]. How to cultivate active and compact aerobic granules with a low-strength municipal wastewater is crucial for its full application [7].

Recently, water resources in Iraq experienced deterioration in both quantity and quality [14, 15 and 16]. Most of the municipal wastewater treatment plants in Iraq are mature. They are designed mainly to reduce the organic load in the influent water by using aerobic bioreactor. These plants do not have enhancing processes to remove nutrient (nitrogen and phosphorous) from the wastewater. However, the effluent water that resulted from the treatment plants is discharged to rivers as receiving bodies. As a result to the steady increase in the nitrogen and phosphorous concentrations in the rivers water due to the effluent discharge from these treatment plants, these concentrations may exceed the maximum permissible concentrations according to Iraqi standard specifications for river's water in the near future.

This situation necessitates a new wastewater treatment and water reuse management strategy based on an efficient integrated biological removal process of nitrogen and phosphorus together with the carbon in the wastewater. Aerobic granular sludge technology has a potential to be used in Iraq. A study regarding the applicability of this technology in Iraq is lacking. The aim of this study is to investigate the performance of aerobic granular sludge SBR, seeded with flocculated activated sludge collected from an Iraqi municipal wastewater treatment plant, using synthetic wastewater.

Material and Methods

A laboratory batch reactor was used for growing aerobic sludge granules. The reactor was a graduated cylinder (H 49 cm x I.D8.5 cm) with working volume of 2 liter. Aeration was supplied from the bottom of the column through an air diffuser by an air pump at flow rate of 1.2 l/min. The experimental procedures were as follows:

- The reactor was seeded with flocculated activated sludge collected from the aeration tank of a membrane bioreactor wastewater treatment unit in a domestic community in Baghdad city.
- The activated sludge was filtered through 0.2 mm screen to remove large debris. Initial mixed liquor suspended solid (MLSS) concentration in the reactor was 2000 mg/l.
- The reactor was fed once every 12 hr.
- Synthetic acetate-based wastewater was used as the feed influent and consisted of CH_3COONa 1200 mg/l, Urea ($CO(NH_2)_2$) 200 mg/l, K_2HPO_4 40 mg/l. Tap water was used to prepare the synthetic wastewater.

- The reactor was operated on 12 hr cycles, consisting of 5 min of influent feeding (no mixing, no aeration), 115 min anoxic period (no aeration with intermittent manual mixing), 10 hr aerobic period (aeration), Discharge of slow settling sludge flocs from the column reactor was conducted at the end of each 12 h cycle.
- Effluent was siphoned after a sludge settling period through a rubber tube with draw the effluent from a point located at mid high of the mixed liquor column. The resultant volumetric exchange ration was 50% per cycle.
- The feeding solution had an organic concentration in terms of chemical oxygen demand (COD) of 1100 mg/l, and the corresponding volumetric organic loading of the reactor was about 1.1 g COD/l/d.
- The sludge settling time was 5 min during the first 37 days to avoid sever washing out of the seeded biomass from the reactor. After that the sludge was sieved with cloth of 0.2 mm opening to separate the granulated sludge from flocculated sludge. The sludge settling time was 2 min on day 38 and gradually decreased to be 0.5 min on day 65 as the granules became larger, corresponding to a settling velocity of 24 mhr^{-1}.
- The settling velocity of the individual granule was measured by recording the time taken to fall from a certain height in a measuring cylinder. A glass column with a diameter of 2.5 cm and a height of 120 cm was used to determine the settling velocity of granules in water.
- The morphology of the flocculated sludge and the aerobic granule was examined under an optical microscope equipped with a digital camera.
- The size distribution of the aerobic granules was determined by analysis of images taken by a digital camera for random samples of granules groups collected with a Petri dish.

The experiments were done in Environment and Water Directorate – Iraqi Ministry of Science labs during the period from18 May to 9 October, 2013. The ambient temperature throughout the operation period was in the range of 25-30°C. The performance of the system was monitored in terms quality of wastewater samples collected from the reactor. The samples were allowed to settled for 0.5 min prior to the supernatant analysis. Chemical oxygen demand (COD), ammonium, nitrate and pH were measured with pHotoFlex photometer, WTW. Dissolved oxygen was measured using Oxi 315i oxygen meter, WTW. MLSS was measured by total suspended solids dried at 103-105ºC method. Sludge volume index (SVI) was measured by settled sludge volume method. Procedures followed for analysis has been in accordance with standard methods [17].

Results and Discussion

Plate 1 shows the micrograph of the fluffy, irregular, loose structure and transparent flocculent activated sludge that had been used to seed the reactor. The flocs size was ranged from 20 to 100 micron. As the granulation process progressed, floc size increased continuously and granules became more evident since then. The aerobic granular sludge gradually became mature and less transparent. It was dense and rich in microorganisms, at the same time the surface of granular sludge rich with massive protozoa and rotifers; shown in Plate 2. The rich microorganisms in aerobic granular sludge play an important role in the removal of pollutants in the wastewater.

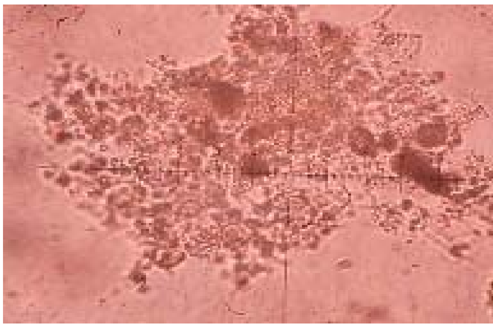


Plate 1: Seeded flocculated activated sludge micrograph

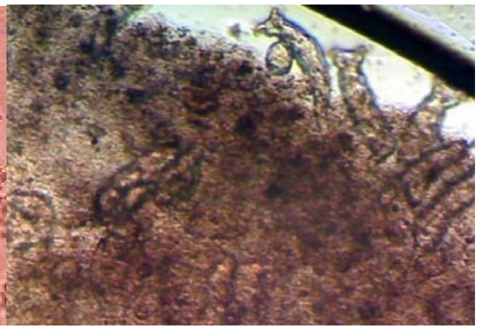


Plate 2: A granule surface micrograph

During the granulation process the sludge colour gradually changed from brown to yellow. After 7 days from the beginning of the experiment a small granules began to appear in the sludge. The number and size of granule was increasing with time. Plate 3 shows sample of relatively small granules in the reactor collected on day 38, while Plate 4 shows sample of mature granules on day 90 from the beginning of the experiment. The granules became regular in shape with smooth surface, sharp boundaries and compact in structure. It was notable that after sieving the sludge on day 37 the biomass became totally granulated after which there was a fast increase in size and number of granules. The MLSS was 1700 mg/l on day 74 and increased gradually to 3320 mg/l on day 84 then to a quasi steady state after day 90 with MLSS of 4100 mg/l and SVI of 60 ml/g. The pH of the sludge in the reactor was in the range 8-9.

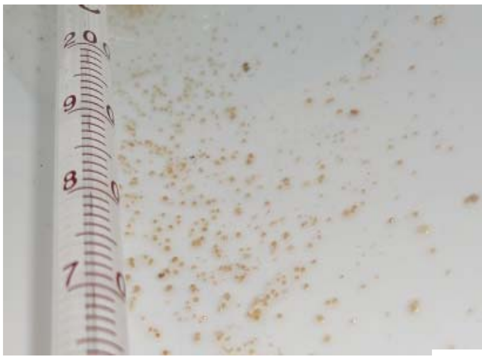


Plate3: Sample of granules on day 38.

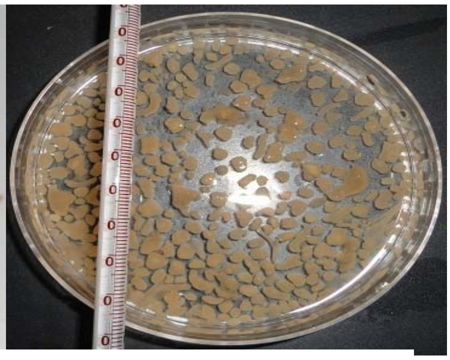


Plate 4: Sample of granules on day 90.

It is clear from Fig.1 that the size of the mature granules were ranged from 0.5 to 5 mm. The granules with size in the range 1.5 - 3.5 mm were dominant in the reactor. Plate 5 showed the granules in the reactor after settling.Figure2 represents the settling velocity of typical individual granules that ranges from 15 to 60 mhr^{-1}. These results are in consistent with that presented by other studies [5, 7, 18, and 19].

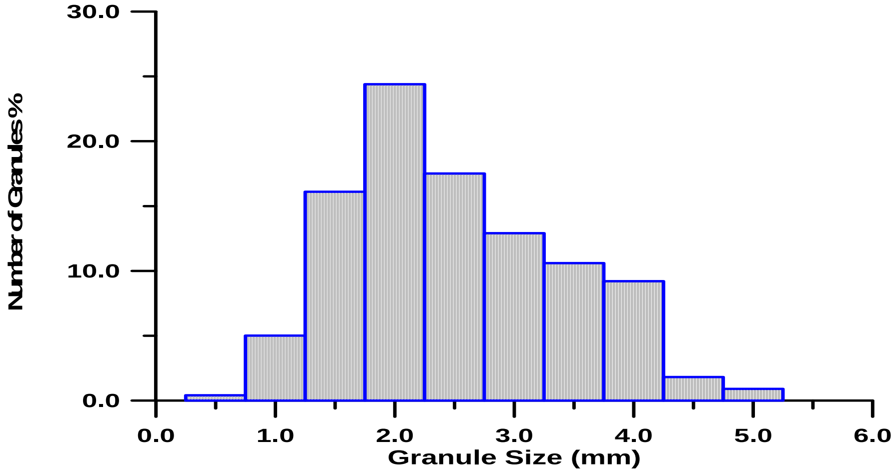


Figure (1): Granular size distribution.

Plate 5: The granules after settling.

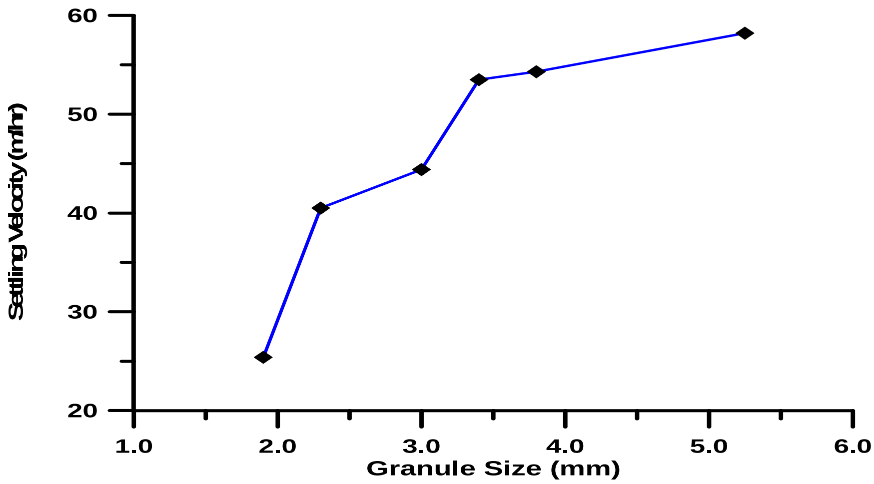


Figure (2): Granular settling velocity.

The reactor was operated in successive cycle of 12hr each. It can be inferred from Fig.'s 3&4 that all acetate was consumed within less than 2 hr of the aerobic phase. When acetate was depleted, endogenous respiration occurred. The period when acetate was present is referred as feast period. The remainder of the cycle is named famine period. The transition from feast to famine period was directly observed from a sharp increase in the dissolved oxygen (DO) concentration in the reactor. During the feast period the DO in the reactor was low (5.8 mg/l) due to oxygen consumption for acetate uptake and conversion. When all acetate were consumed, the DO immediately increased to almost 7 mg/l air saturation. Simultaneous carbon oxidation and nitrification took place when oxygen was utilized. Similar DO concentration behaviour is reported by other studies [10, 19].

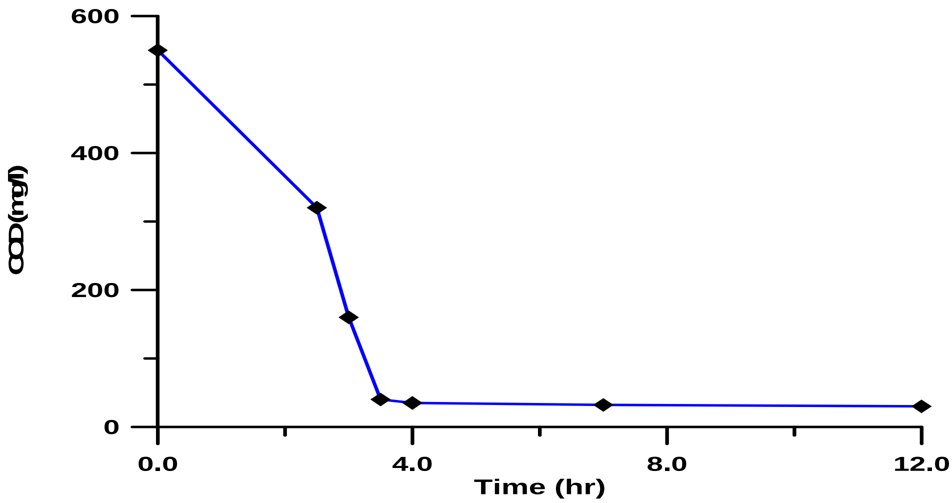


Figure (3): COD variation with time during aerobic phase.

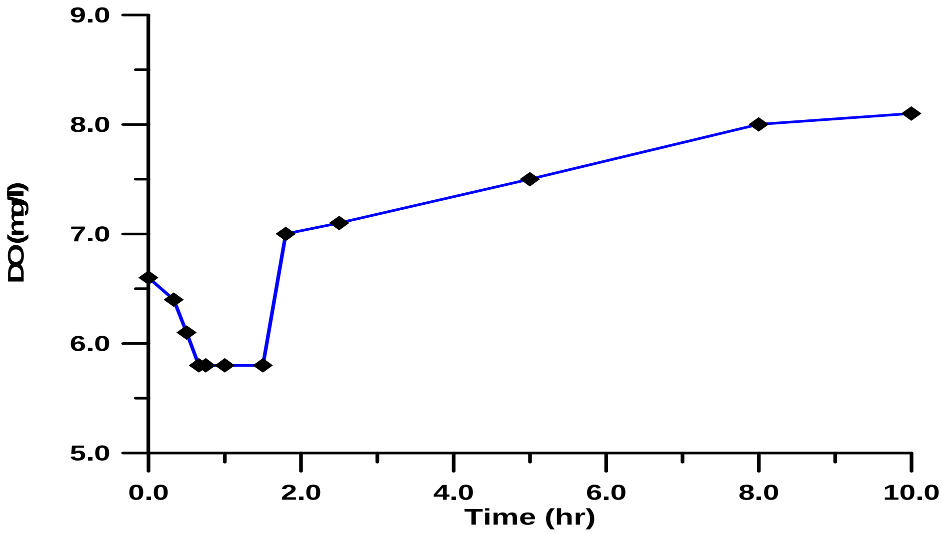
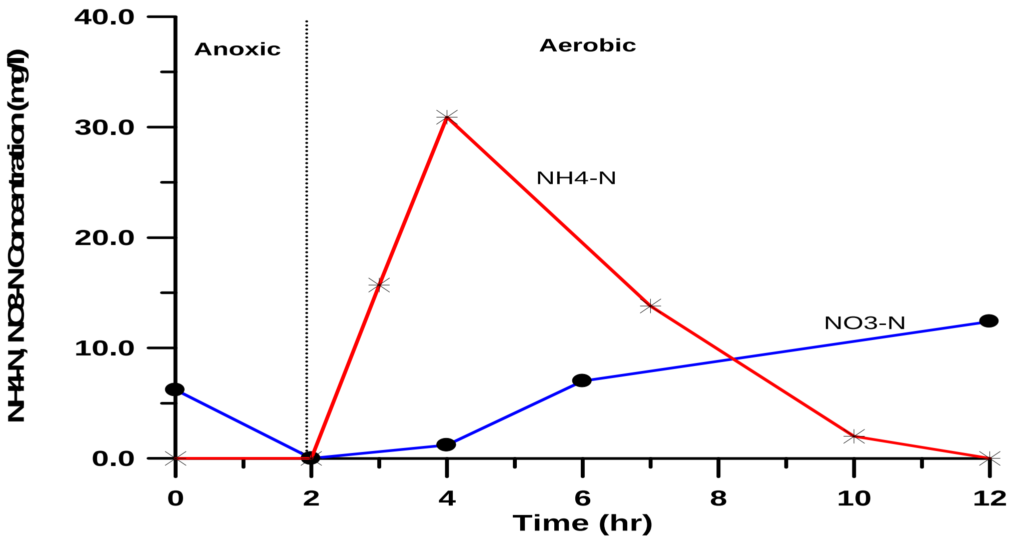


Figure (4): DO variation with time during aerobic phase of the cycle.

Track analysis data on NH_4 and NO_3 concentration in the bioreactor during one cycle is shown in Fig.5. During the aerobic phase the urea is degraded biologically and the organic nitrogen will be converted to ammonium by ammonification process, at the same time the nitrification bacteria acts to convert ammonium to nitrate. The two processes usually happen in two different rates. Taking into consideration that the urea concentration in the effluent water is 200 mg/l, contains about 80 mg/l as N organic nitrogen. Since the feed volumetric exchange ration was 50% per cycle, the organic nitrogen concentration in the reactor at the beginning of aerobic phase will be at least 40 mg/l as N.At the end of the aerobic phase it is clear that the ammonium concentration approaches to zero which is an evidence that the urea is totally hydrolysis during the aerobic phase. The nitrate concentration shows an increase with elapse time during the aerobic phase due to nitrification of ammonium. However, the maximum nitrate concentration at the end of this phase is only 10 mg/l as N. This concentration is significantly lower than total organic nitrogen in the reactor at the beginning of the aerobic phase. The variation in this concentration may be attributes to the occurrence of simultaneous nitrification in the aerobic zone outer side of the granules and denitrification in the anoxic zone inside the granules due to oxygen mass transfer limitation as suggested by several studies [20, 21, and 22]. During anoxic phase the nitrate concentration is decreased as expected due to denitrification under anoxic condition inside and out side the granules.



Figure(5): Variation of NH_4-N& NO_3-N concentration with time.

After 141 days of granulation the SBR reactor was subjected to a low COD (about 156 mg/l) municipal wastewater instead of synthetic wastewater. The organic load of the municipal wastewater was composed of dissolved and particulate organic materials. This mode of operation was lasted for two weeks. During this period some of the particulate matter was adsorbed on the granules surface, which was seen by the naked eye, and the activity of the granules was significantly reduced. The COD removal efficiency at the end of this period was about 14%.No further generation of new granules. This result may be attributed to the low concentration of COD in the influent wastewater causing a reduction in the concentration gradient for the organic materials to penetrate inside the granules. Moreover, not all the organic matter in the influent was readily biodegradable matter and needs a suitable bacteria consortium for exoenzymatic catabolism [23]. More work deals with granulation of flocculated activated sludge using municipal wastewater instead of synthetic wastewater as an influent is needed.

CONCLUSIONS

Successful granulation of activated sludge was achieved in a pilot-scale SBR system seeded with flocculated activated sludge collected from an Iraqi municipal wastewater treatment plant using synthetic wastewater. After 90 days, the dominant granules size was 1.5-3.5 mm with high settling velocity. The granules became regular in shape with smooth surface, sharp boundaries and compact in structure. High synthetic COD removal and simultaneous nitrification and denitrification during aerobic phase were observed. These features make aerobic granular activated sludge an attractive and promising process to be used in Iraq for intensive and high-rate biological nutrient removal (BNR) along with organic load removal. A study deals with granulation of flocculated activated sludge using municipal wastewater instead of synthetic wastewater as an influent is needed.

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