氏名	郑 炜
学位の種類	博　士（環境学）
学位記番号	博　甲　第　8376　号
学位授与年月日	平成　29年　9月　25日
学位授与の要件	学位規則第４条第１項該当
審査研究科	生命環境科学研究科

学位論文題目 Biological Treatment of Anaerobically Digested Swine Wastewater and Subsequent Nutrients Recovery by *Spirulina platensis* Cultivation

（嫌気性消化した養豚廃水の生物学的処理および栄養源回収のための *Spirulina platensis* の培養）

主査	筑波大学教授	博士（農学）	張　振亜
副査	筑波大学准教授	工学博士	雷　中方
副査	筑波大学准教授	博士（農学）	清水　和哉
副査	筑波大学准教授	博士（理学）	内海　真生

論　文　の　要　旨
Abstract of thesis

The objective of this research is mainly to find an effective and economic way to treat anaerobically digested swine wastewater (ADSW) so as to satisfy the new and strict national discharge standards for wastewaters from livestock and poultry industry, and to control the environmental pollutions caused by ADSW discharge. The author pointed out that, as the effluent from anaerobic digestion of swine wastewater, ADSW still contains high concentrations of organics, total nitrogen (TN) and total phosphorous (TP). Especially, it is still a big challenge to use single biological process or single nutrients recovery process for ADSW treatment to achieve the new discharge requirements for TN and TP.

Therefore, this research tried to establish an integrated process combining biological treatment with nutrients recovery to enhance the removal of TN and TP from ADSW. Firstly, the research used a novel biological nitrogen removal reactor called intermittently aerated sequencing batch reactor (IASBR) to remove most of ammonium nitrogen (NH_4^+-N), TN and antibiotics from ADSW. Then the IASBR effluent was used to cultivate *Spirulina platensis* to further remove and recover nutrients (nitrogen and phosphorus). This combination process is expected to not only qualify final effluent with TN and TP concentrations satisfying the discharge standards, but also achieve high-value feed additives. The author emphasized that the single use of IASBR or *Spirulina platensis* cultivation couldn't meet discharge standards directly. Although IASBR could enhance the removal of NH_4^+-N and TN, the effluent TN and TP still couldn't meet the discharge requirements. *Spirulina platensis* cultivation then could further remove and recover N and P. In fact, without the pretreatment of IASBR, *Spirulina platensis* needs to be cultivated in diluted ADSW which exhibited negative effects due to the existence of inhibitory and toxic substances such as NH_4^+-N and antibiotics.

In chapter 1, the author gave a literature review on the previous studies related to the ADSW treatment. This chapter also addressed the difficulties and existing problems in the ADSW treatment when using single biological treatment process or single nutrients recovery process to achieve the discharge limits for TN and TP in an effective and economic way. Research objectives were arrived at the end of this chapter.

In chapter 2, the author explored the removal characteristics of nitrogen in a lab-scale IASBR system. The IASBR system was found to achieve significantly high removal rates of 97.5±1.4% and 93.8±12.8% for NH_4^+-N and TN under

a chemical organic demand (COD) to TN (COD/TN) ratio of 2.4, hydraulic retention time (HRT) of 3 days and temperature above 20℃. Partial nitrification-denitrification was detected in IASBR with nitrite accumulation rate greater than 80%, possibly caused by inhibition to nitrite oxidizing bacteria (NOB) during the whole operation. This chapter also investigated the effects of COD/TN ratio, nitrogen loading, and temperature on the removal of NH_4^+-N and TN. An extremely low influent COD/TN ratio and lack of enough carbon source exerted unexpectedly negative effects on denitrification process, resulting in large accumulation of nitrite (NO_2^--N) and deterioration of TN removal. The increase in free ammonia (FA) concentration at lower COD/TN ratio inhibited the growth of ammonium oxidizing bacteria (AOB), followed by worsen NH_4^+-N removal. Both NH_4^+-N and TN loading increased when IASBR was run at a shorter HRT, mainly leading to the increase in FA concentration and restrained the partial nitrification. Besides, denitrifying bacteria were noticed to be much more sensitive than nitrifying bacteria to lower temperatures, resulting in dramatic increase in FA concentration, thus inhibiting both nitrification and denitrification processes.

In chapter 3, the author studied the removal characteristics of 11 veterinary antibiotics (including tetracyclines, sulfonamides, quinolones and macrolides) in IASBR system. Results indicated that both sludge sorption and biodegradation were the major contributors to the removal of antibiotics. Mass balance analysis revealed that greater than 60% of antibiotics in the influent were biodegraded in the IASBR, whereas averagely 24% were adsorbed by sludge under the condition that sludge sorption gradually reached its equilibrium. In addition, the removal of antibiotics was greatly influenced by COD volumetric loading, which could achieve up to 85.1±1.4% at 0.17±0.041 kg COD/(m^3·day), while dropped apparently at higher COD loadings. Tetracyclines, the dominant antibiotics in ADSW, were removed by 87.9% in total at the lowest COD loading, of which 30.4% were contributed by sludge sorption. In contrast, sulfonamides were removed about 96.2%, almost by biodegradation. Long solid retention time (SRT) seemed to have little obvious impact on antibiotics removal, while a shorter SRT of 30-40 days could reduce the accumulated amount of antibiotics. The ratio of COD/TN in the influent was regarded as an unimportant impact factor for the removal of antibiotics.

In chapter 4, the author used *Spirulina platensis* cultivation to further remove and recover nitrogen and phosphorus from the effluent of IASBR. This chapter firstly studied the growth behavior of the local *Spirulina platensis* strain. Results showed that the strain grew fast in a Zarrouk medium as the dosage of sodium bicarbonate, nitrate nitrogen (NO_3^--N) and phosphate phosphorus (PO_4^{3-}-P) were not less than 4.0, 40 and 10 mg/L, respectively, and NH_4^+-N beyond 60 mg/L would inhibit the growth of *Spirulina*. Then an indoor raceway pond was applied to culture *Spirulina platensis* by using the effluent from IASBR. The results showed that the average area biomass productivity could achieve 4.5 g/(m^2·d) in IASBR effluent, lower than that in Zarrouk medium, most probably due to the influence of high chrominance in the IASBR effluent. The *Spirulina platensis* ZJWST-S1 removed almost all NH_4^+-N, 68.7% of TN and 79.1% of TP from the IASBR effluent, among which 91.5±3.4% of TN and 92.4±4.8% of TP reduced from ADSW were converted to *Spirulina platensis* biomass. The concentrations of TN and TP at the end of cultivation could meet the new and strict discharge standards.

審　査　の　要　旨
Abstract of assessment result

This research used an innovatively integrated process of intermittently aerated sequencing batch reactor (IASBR) coupling with *Spirulina platensis* cultivation to deal with anaerobically digested swine wastewater (ADSW). This combination process can not only help to enhance the removal of total nitrogen (TN) and total phosphorous (TP) to satisfy the new national discharge standards, but also help harvest high-profit animal feed grade proteins to attain additional incomes and balance the treatment cost for ADSW. The research emphasized that single use of IASBR or *Spirulina platensis* cultivation couldn't satisfy the requirement for ADSW treatment. On one hand, the effluent TN and TP from IASBR still can't meet discharge standards directly. On the other hand, without pretreatment of IASBR, *Spirulina platensis* needs to be cultivated in diluted ADSW which exhibited negative effects due to the existence of inhibitory and toxic substances such as NH_4^+-N and antibiotics. This research attempted a valuable and practical study on ADSW treatment to control wastewater pollution problems from swine farms. The newly developed integrated process in this study is promising for the ADSW treatment in practice, to a great extent contributing to the sustainable development of large-scale swine farms in China.

The final examination committee conducted a meeting as a final examination on 1st August, 2017. The applicant provided an overview of dissertation, addressed questions and comments raised during Q&A session. All of the committee members reached a final decision that the applicant has passed the final examination.

Therefore, the final examination committee approved that the applicant is qualified to be awarded the degree of Doctor of Philosophy in Environmental Studies.