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Performance of integrated anaerobic/aerobic sequencing batch reactor treating poultry slaughterhouse wastewater

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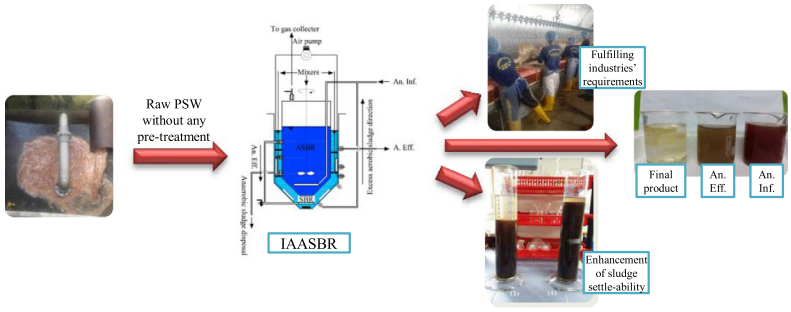
HIGHLIGHTS

- A novel bioreactor configuration (IAASBR) is developed for treating PSW.
- The proposed bioreactor (IAASB) fulfilled most of poultry industries' requirements.
- IAASBR configuration enhanced the sludge settle-ability for aerobic SBR.
- This system produces the high-quality effluents within Malaysian standards.
- In this system, the FOG inhibition effect has been successfully eliminated.

GRAPHICAL ABSTRACT



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ABSTRACT

The present study investigates the performance of a new configuration laboratory-scale bioreactor comprising of two regimes (anaerobic & aerobic) in one reactor with physical separation and it is known as integrated anaerobic/aerobic sequencing batch reactor (IAASBR). The IAASBR is designed for treating high-strength wastewater such as poultry slaughterhouse wastewater (PSW) along with the simultaneous removal of organic carbon and ammoniacal nitrogen (NH_3-N). The IAASBR exhibits that the average removal efficiency of total COD (TCOD), soluble COD (SCOD), NH_3-N, fat, oil & grease (FOG), and total suspended solids (TSS) were (97% ± 2%), (95% ± 3%), (98% ± 1.3%), (90% ± 11%), and (96% ± 3%) respectively. The laboratory comparison test revealed that IAASBR configuration has enhanced the sludge settle-ability for aerobic SBR more than the conventional SBR or settling tank. Furthermore, IAASBR could tolerate the shock loading occurrence, handle organic loading rate (OLR) up to 4.5 kg (TCOD) m^{-3} d^{-1} and produce a high-quality effluent complying with Malaysian standards of industrial's effluents.

1. Introduction

The continuous increase in the meat production for the protein needs of the ever growing world population has some pollution problems also attached to the environment. Poultry slaughterhouse and chicken processing plants are one of the widest spread

Abbreviations: A. Eff, aerobic effluent; An. Eff, anaerobic effluent; An. Inf, anaerobic influent; ASBR, anaerobic sequencing batch reactor.

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plants in Malaysia. These plants produce relatively high amount of wastewater between 8 and 15 L per bird slaughtered (200–700 m^3/day) [1] depending on the production capacity and water management policy that is followed by each plant. Furthermore, the characteristics of the wastewater generated from these plants are classified as a high-strength wastewater [2], where the contaminants' concentrations have relatively high COD (3102 ± 688 mg L^{-1}), suspended solids (SS) (872 ± 178 mg L^{-1}), oil & grease (O&G) (375 ± 151 mg L^{-1}), nitrogen measured as total Kjeldahl nitrogen (TKN) (186 ± 27 mg (N) L^{-1}), and total phosphate (PO_4^{-3}-P) (76 ± 36 mg L^{-1}). These contaminants are there due to the presence of high organic materials such as blood, fat from skin, protein, oil from boiling birds for feather removal. Besides, urine and faeces are also one of the main sources of nitrogen [1,3–7]. The discharge of this wastewater without a proper treatment will have realistic damage on the environment and municipal wastewater treatment plants.

Researchers have spent efforts for treating slaughterhouses wastewater using different kinds of processes or for making a combination between them. Such work includes aerobic, anaerobic [8,9], attached growth [10,11], suspended growth systems [12], mixed anaerobic attached growth and aerobic suspended growth bioreactors in sequence [13,14], anaerobic/anoxic/aerobic (suspended growth system)-biological contact oxidation (attached growth system) integrated separated sludge bioreactors (A^2/O–BCO) [15], and fixed bed granular sludge with/without static activated sludge [16]. The combination of anaerobic-aerobic fixed-film bioreactors connected in series (attached growth system in two reactors) for treating the organic matter of poultry wastewater have achieved high removal efficiency [17]. In another work, Del Pozo and Diez [18] put effort on treating PSW with the integrated anaerobic-aerobic fixed-film reactor (attached growth system in one reactor). Their study shows improvement with an overall high organics and nitrogen removal efficiency, when the anaerobic:aerobic volume ratio was 2:3. Integrated anaerobic-aerobic bioreactor in one reactor (mixed attached growth and suspended growth system) is used for treating high-strength palm oil mill effluent (POME) wastewater [19]. The result shows that the system had achieved a high constituent's removal efficiency of BOD_5, COD, and TSS. This result was previously supported by using anaerobically digested POME as an influent to the aerobic SBR for getting effluent within the discharge limits by changing OLR, sludge loading rate (SLR) and mixed liquor volatile suspended solids (MLVSS) for attaining optimum SBR performance [20].

A combination of anaerobic-aerobic SBR system in two reactors (suspended growth system) was conducted by Bernet et al. [12] for treating piggery wastewater. The work concentrates on the effect of the recycle-to-influent ratio for biological nitrogen and carbon removal. The removal of total organic carbon (TOC) and TKN were fairly high. However, the high hydraulic retention time (HRT = 22.5 d) in this study made it less suitable for practical purposes.

Del Pozo and Diez [17] described the significance of using the anaerobic stage for treating high-strength and high variance of wastewater's characteristics before the aerobic stage. They suggested conducting characterization for the wastewater before designing the treatment plant. Anaerobic pre-fermentation stage is essential in practical slaughterhouse wastewater treatment for high COD, NH_3-N and total phosphate (PO_4^{-3}-P) removal efficiency before entering SBR [21,22]. Del Nery et al. [23] further deduced that the effluent of an individual anaerobic process fails to meet discharge requirements, and the aerobic process alone requires more area and relatively high operating costs. The above statements are important with respect to the applicability of the present study by using the raw wastewater generated from poultry slaughterhouse as influent for the IAASBR.

The current investigation on the reactor configuration is motivated by and parallel to the work [24]. The new reactor configurations are not only a necessity as an alternative to already established systems but are of prime importance to develop optimized configurations that provide maximum performance, operational safety, and minimum cost [24,25]. Therefore, this study focuses on developing a novel configuration for existing technique (SBR) to contribute and achieve the objectives stated afterward in an integrated manner (anaerobic/aerobic processes in one reactor with physical separation using suspended growth system only) and its practical use.

An attempt has been made to explore the performance efficacy of the proposed reactor configuration that is IAASBR for simultaneous removal of carbonaceous organic matter and ammoniacal nitrogen from PSW. This is, in conjugation with offering a suitable practical solution for achieving the balance between the broiler chicken producer's requirements (needs for cheap, efficient, flexible, small footprint, less maintenance, and less sludge disposal treatment technique) and the restricted regulations that are imposed by the environmental protection agencies [26]. These requirements were necessary due to the several critical issues which were found in the existing conventional treatment plants. These challenges include high-cost of chemicals usage, non-compliance of effluents to standard specifications, especially for NH_3-N, and the defect of handling shock-loading.

2. Methodology and materials

2.1. Poultry slaughterhouse wastewater (PSW) characterization

PSW was collected from selected poultry slaughterhouse located in Johor (Southern state of Malaysia Peninsular) called AYAMAS Food corporation Sdn. Bhd. This corporation is one of the biggest poultry slaughterhouses in the state and has a production rate of 30,000–45,000 birds/day with average wastewater flow rate of 800 m^{-3} d^{-1}. All samples used in this study were collected from the flow coming from the fixed strainer instrument which is located after feathers removal equipment. The characterizations of PSW are based on six visits; each visit lasts for one working day. Equal volumes of samples were taken every 2 h and gathered in a container. Composite PSW had been analysed in a triplicate manner and presented in Table 1.

2.2. Reactor setup

Lab-scale IAASBR was made from acrylic, and it consists of two compartments. The first compartment is for the anaerobic process with a maximum water volume of 12 L. This compartment was

Table 1
Characterization of PSW used in this study.

Parameter	Unit	Average ± SD
TCOD	mg L^{-1}	2711 ± 487
$TBOD_5$	mg L^{-1}	930 ± 96
TN-N	mg L^{-1}	153 ± 32
NH_3-N	mg L^{-1}	85 ± 32
PO_4^{-3}-P	mg L^{-1}	51 ± 2
FOG	mg L^{-1}	281 ± 63
Alkalinity	mg L^{-1} as $CaCO_3$	160 ± 21
TSS	mg L^{-1}	835 ± 162
TVSS	mg L^{-1}	813 ± 168
TDS	mg L^{-1}	917 ± 135
pH		6.8 ± 0.2
Temperature	°C	29 ± 0.7
Turbidity	NTU	>1000
EC	μs cm^{-1}	795 ± 109