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Modelling and Simulation of Energy-Saving Potential of Sequential Batch Reactor (SBR) in the Abatement of Ammoniacal-Nitrogen and Organics

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The ammonical nitrogen removal in discharged effluents from a typical sewerage treatment plant has not been consistent with the stringent discharge standards. There is the need to optimize the energy consumption as well as improve the ammonical nitrogen removal in the treatment plant. This study reports the investigation of the behaviour of process dynamicity of ammoniacal-nitrogen (NH_3-N) removal in a Sequencing Batch Reactor (SBR) through Activated Sludge Model No.1 (ASM1) and standard SBR design computation for optimal aeration time, while meeting the treatment requirements. The study further evaluates the performance of NH_3-N removal based on the data obtained from an existing SBR system. The time profile of process dynamics and the minimum required aeration time with maximum nitrogen removal was studied while taking into account the system's energy consumption. Moreover, the simulation results by MATLAB Software suggested that the process dynamicity of the carbon and NH_3-N concentration is 7 hour batch time with one fill and 1.5 hours aeration time. For computation of SBR standard design, the reduction from current 1.5 hours to 1.35 hours of aeration for 80% to 93% of NH_3-N removal brought about the total energy saving of up to 10 percent.

Key words: Simulation, Sequential batch reactor, Aeration time, Energy, Ammoniacal-nitrogen, ASM1.

Water covers 70.9 percent of the Earth's surface and is essential for all known forms of life especially in supporting human being through drinking, maintaining households and daily consumption such as bathing, washing and cleaning. Water is also vital in sustaining the growth of plants and animals life. Indeed, it is a part of life itself, since the protoplasm of most living cells contains about 80% of water. Nevertheless, water sources which are suitable for human consumption only covered less than 1 percent of the whole volume of total global water on the Earth and this includes rivers, lakes and groundwater. These water bodies also, serve as wastewater receiving points after treatment processes[1,2,3].

According to Hammer[4], municipal wastewater is a term usually applied to liquid collected in sanitary sewers and treated in a municipal treatment plant. It also refers to the water discharged from residences, office buildings, restaurants, institutions, manufacturing plants and factories areas[5]. For most treatment systems, the major objective is to reduce or eliminate all the potential pollutants in the wastewater for safe discharge into watercourse after the effluent must have been certified to meet the appropriate discharge standards. This certainly prevents waterborne diseases and thereby protects the

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health of the community while eliminating the unpleasant and exorable water pollutions.Besides safeguarding the human health, it also erases the adverse effects these pollutions might have on the aquatic life[6].

Nitrogen is a nutritious element which is essential for the growth of microorganisms, plants and animals. The primary sources of nitrogen are the nitrogenous compounds originated from plants, animals, sodium nitrate and atmospheric nitrogen. In his report, Hammer[4] stated that nitrogen in municipal wastewater basically comes from human excreta as the greatest sources, ground garbage and food manufacturing areas where the consumption of protein is the main reason for nitrogen pollution.

NH_3-N is a form of nitrogenous constituents in wastewater. Nutrient enrichment in water can cause more severe consequences since it is identified as the main ground for *algal bloom* phenomena or *eutrophication* aside from the phosphorus element[7,8]. As a result, all the aquatic organisms will die due to the scarcity of oxygen, and the release a bad smell when they start to decay[9]. In addition, the ammonia in water is toxic to fish, and high level of nitrates in the drinking water causes *methemoglobinemia* in infants when the nitrates are converted into nitrites in the baby's belly and interfere with the oxygen-carrying capacity of the haemoglobin in blood[10].

The sequencing batch reactor (SBR) is a wastewater treatment system, which normally include a biological nutrient removal process, based on the conventional activated sludge (CAS) through the operation method of sequential filling and drawing cycles as shown in Fig. 1[11,12]. The unit operations involved in an SBR are equivalent to those of CAS, hence, aeration and sedimentation-clarification are performed. The difference between the systems is that, in conventional systems, these two processes take place in two different tanks whereas, in SBR systems, they occur sequentially in the same tank[11]. The SBR system is one of the proposed systems forthe upgrading ofMalaysian wastewater treatment plants to mechanical plants. SBR system stand the scrutiny of replacing CAS systems as this brings about improved quality for both domestic and industrial wastewater treatments[13].

To optimize the performance of this system, Mahvi[12] reported that two or more batch reactors could be used in a predetermined sequence of operations. Besides the ability of SBR to achieve nutrient removal using alternation of anoxic and aerobic periods, the systems have been successfully used to treat both municipal and industrial wastewater and have been found to exhibit high efficiency in BOD and suspended solids removal[12]. This makes the SBR system to be an excellent biological treatment of wastewater.

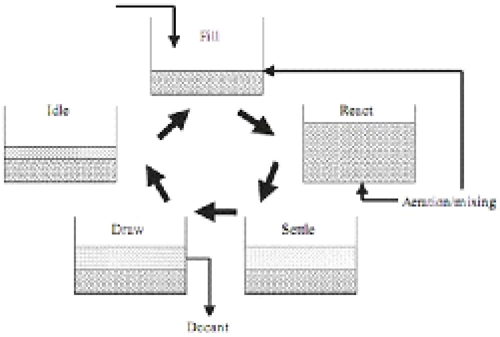

Fig. 1. Typical Cycles in SBR systems [11, 12]

Aeration is a very crucial unit operation in SBR treatment process to provide necessary oxygenation and mixing.Aeration systems for conventional wastewater activated sludge plants typically account for 45 to 60 % of a treatment facility's total energy use[14]. The aeration facilities must meet the oxygen demand of the process and maintain the dissolved oxygen in aeration tank minimum of about 1-2 mg/L which is necessary for proper development of biological sludge. In addition to supply dissolved oxygen, the aeration devices have also to provide adequate mixing ad agitation so that the mixed liquor suspended solids do not settle down. This way aeration increases the contact opportunity between the floc and sewerage.Organic matters in the wastewater become the microorganism food and theprocess used up the dissolved oxygen needed for aquatic life. If the organic matters are in sufficient quantity, this can lead to nearly all the dissolved oxygen being usedup, aquatic life killed, and to anaerobic conditions in which an aerobic microorganism produces hydrogen sulfite and other odorous constituents are produced. In waste water treatment, the purpose of aeration is to ensure continued aerobic conditions for themicroorganism to degrade the organic matters.

Mathematical models provide meaningful insights for the design and prediction of complex biological processes. Activated Sludge Model 1 (ASM1) has been developed for biological processes and the model-based influent characterization in wastewater treatment systems and has been widely used. ASM1 was originally developed by the IAWPRC Task Group to simulate the uptake of organic matter, nitrification, and de-nitrification in a continuous flow activated sludge system.The model as proposed since 1987[15,16,17] consists of 4 process, 13 parameters and 8 process equations includes the kinetic expressions of aerobic growth of heterotrophic and autotrophic bacteria, anoxic growth of heterotrophs, decay of heterotrophs and autotrophs, organic nitrogen mineralization, hydrolysis of nitrogenous and organic matter retained in the biofloc, and stoichiometric coefficients for each of the identified processes[17].

The objectives of this study are to study the process dynamic simulation of NH_3-N removal in SBR using ASM1, thereby computing the required aeration time for its removal. Ultimately, the system's improvement as regards the reduction in energy consumption and evaluation of its performance forNH_3-N removal of an existing SBR system.

Methodology

The SBR plant being studied treats municipal wastewater stream from residential area of Bandar TunRazak (BTR) southeast of Kualar Lumpur, Malaysia. The plant was designed to accommodate a 100,000 population equivalent (Eq).

There are two sampling points, the influent point and effluent tank. The influent tank is the point where wastewater is kept before the screening process. For effluent, the final point which is also called measurement tank where the treated wastewater is kept before being released to the watercourse. All sampling and analyses were performed on site. Sampling of inlet wastewater was carried out using an automatic sampler. All data are based on the normal sampling and operation control. Later, about 20L of wastewater were taken from each influent and effluent sample points and characterized using the Standard Methods for the Examination of Water and Wastewater[18], for the model validation.

The available data of wastewater characterization from the treatment plant and experimental process were converted into a data set that can be used as input for the ASM1. The first step involved a detailed analysis of the chemical and physical characteristics of the wastewater. These characteristics provided the information that allowed the development of suitable treatment process for the wastewater. The experimentally determined parameters and characterized wastewater were used to run a computer simulation. For any wastewater treatment plant design, either for discharge or reuse program, the first step is to determine the anticipated influent characteristics of the wastewater and the effluent requirements for the proposed system as this will allow the analysis of possible feasibilities of specific and available treatment options[19].

The performance of the SBR system for the simultaneous removal of T-N and COD was investigated by studying the separate effects of substrate fill concentration on the removal efficiencies of T-N as well as COD with the aid of computer simulation. For this, a set of nonlinear ordinary differential equations was solved simultaneously by using ODE solver, ODE45 of MATLAB 7.0 (The Mathworks Inc.). All thedefault values for kinetic and stoichiometric parameters were adjusted based on the values suggested by the ASM1 model.

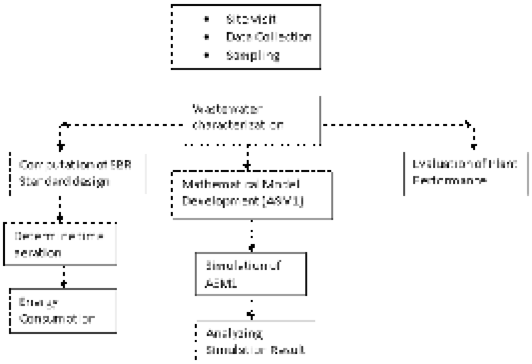

Fig. 2. Methodology Flow Chart

RESULTS AND DISCUSSION

The wastewater characteristics data were validated by laboratory experiment of wastewater samples (Table 1).

Table 1. Laboratory Result of Influent and Effluent Characteristics

Parameters	Influent				Effluent			
	Test 1	Test 2	Test 3	Mean	Test 1	Test 2	Test 3	Mean
Temp, <”C	27.80	28.00	28.30	28.03	28.20	29.00	28.50	28.56
pH	6.10	6.80	7.00	6.63	6.10	6.30	6.20	6.20
BOD, mg/L	125.00	132.00	129.00	128.66	5.20	4.60	5.00	4.93
COD, mg/L	166.00	158.00	158.00	160.66	21.00	15.00	17.00	17.66
TN, mg/L	25.50	28.10	26.40	26.66	Low	1.20	Low	Low
NH_3-N, mg/L	12.28	15.05	13.85	13.72	low	low	low	low
TS, mg/L	130.40	128.50	125.50	128.13	5.20	7.48	7.50	6.72

The results show consistency with the data obtained from the plants and with the typical value of domestic wastewater.

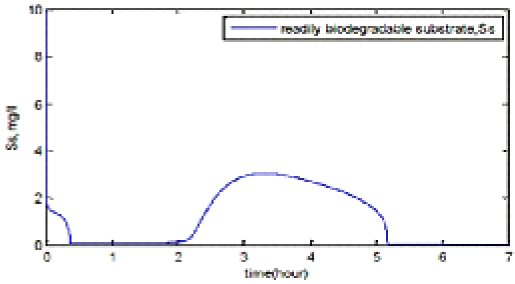

Fig. 3. Time profiles of Ss calculated in optimal conditions for one fill

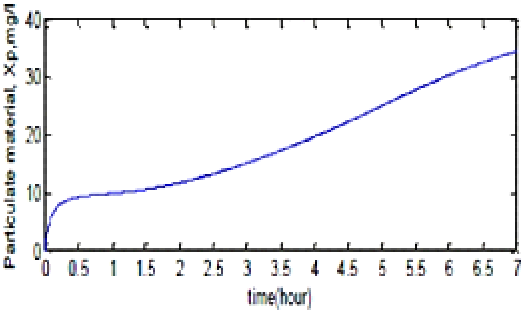

Fig. 5. Time profiles of Xp calculated in optimal conditions for one fill

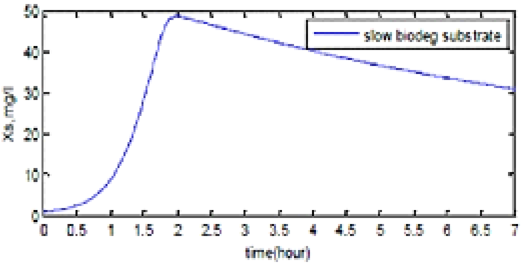

Fig. 4. Time profiles of Xs calculated in optimal conditions for one fill

Simulation of modified ASM1 comprises a SBR with volume of 5 L, simulated for 7 h reaction and it involves aerobic and anoxic phases. Similar to those in municipal-like sewage, the influent wastewater simulated at 200 mg/L of COD and 40 mg/l concentration of ammonia nitrogen (NH_3-N), respectively. Since nitrogen removal occurs only during the reaction phase of aerobic and anoxic phases, the total batch time represents the total reaction times for the aerobic and anoxic phases. The Figs. 2, 3 and 4 below illustrate typical composition of COD and nitrogen profiles associated with the phase operation of the SBR in the steady state. The process dynamics was varied according to chosen initial values and parameters.

In the first stage of Fig. 3 (0 to 1 h),this is the filling phase with low but increasing oxygen demand which is due to the initial biomass exponential growth, which could also be a reactivation period of existing biomass. Here, the degradation of Suspended Solid (Ss) is slow. The second stage (1 to 2 h) with high oxygen demand is due to the growth on heterotrophic microorganism. As shown in Fig. 4, once the Ss are all used at 5.2 hr., the oxygen temporarily decreases until the second substrate Xs is utilized. The initial influent of Ss and Xs were adjusted to match this transition. Once the biomass runs out of both substrates at, it gives a low oxygen demand. From Fig. 5, it can be seen that Xp starts to accumulate as a result of endogenous respiration or decay of biomass. Together with the inert particles, they accounted for residual particulate COD[15].

In Table 2 above, it appears there is an optimal aeration time to remove nitrogen and organic matter simultaneously from wastewater while saving energy consumption. The aeration time was changed independently to investigate

Table 2. Computed results of removal of Ammonia-Nitrogen for different aeration time

Time	Runs									
(hr)	1	2	3	4	5	6	7	8	9	10
1.00	60.51	55.01	58.38	61.08	63.29	65.17	66.74	68.12	69.31	70.37
1.05	52.66	57.25	60.75	63.55	65.88	67.80	69.45	70.89	72.13	73.23
1.10	54.73	59.44	63.04	65.97	68.35	70.34	72.06	73.53	74.82	75.98
1.15	56.7	61.57	65.26	68.26	70.74	72.80	74.56	76.08	77.41	78.59
1.20	58.63	63.63	67.46	70.53	73.04	75.15	76.96	78.52	79.88	81.08
1.25	50.60	65.61	69.53	72.67	75.24	77.40	79.24	80.82	82.21	83.43
1.30	82.09	67.56	71.54	74.73	77.34	79.53	81.38	82.98	84.38	85.61
1.35	80.36	81.56	83.42	85.02	86.42	87.64	88.72	89.68	90.54	91.32
1.40	81.25	83.46	85.32	86.91	88.29	89.49	90.54	91.48	92.31	93.05
1.45	80.40	83.05	85.25	87.09	88.66	90.00	91.17	92.18	93.07	93.85
1.50	62.32	84.73	86.9	88.71	90.24	91.54	92.65	93.61	94.44	95.16

the effects on removal efficiencies of NH_3-N and COD under the same operation condition. Obviously, from 1.35 hours to 1.5 hours of total aeration time, the removal efficiency is 80 percent to 95percent.

The aeration time was changed independently to investigate the effects on removal efficiencies of NH_3-N. Longer aeration is beneficial to COD removal while shorter aeration is beneficial to NH_3-N removal. 1.35 hrs.of aeration time in full scale plant gives 80 to 93% of NH_3-N removal. As a result, 10% of total energy reduced compared to current aeration time, 1.5 hrs.

Since the design standard of effluent for NH_3-N is 2 mg/L, the time chosen as optimum time is 1.35 hours because at this time, the effluent is already below 2 mg/L. From the foregoing, it is pertinent reach a compromise in the selection ofan optimum time which will be beneficial to the removal of both pollutants. The batch nature of the process and high organic concentration during the fill phase encourages the growth of organisms with high organic uptake rates. Famine phase at the end of reaction encourages the utilization of organics. The combined effect of the feast and famine phases is the optimal removal of BOD and COD. From literature analysis, C/N ratio had significant influences on nitrogen removal efficiency. High C/N ratio will give better nitrogen removal performance. COD in the influent were utilized as electron donors, which could avoid the negative impact of organic loading on nitrification[7,8].

CONCLUSION

This study has demonstrated that SBR systems are highly efficient to meet the current discharge standards of Malaysian Department of Environment (DOE) if suitable operating conditions are assigned. Moreover, the SBR of BTR wastewater treatment plant could achieve efficiencies between 92-98% for BOD, 81-94% for COD, 81-98% for Suspended Solids and 70-90 % for NH_3-N removals.

Furthermore, ASM1 was able to describe the process dynamics and their relationship in SBR process. Computation of full scale gave higher removal with shorter aeration time in which total energy consumption was reduced by 10%. The selection of an optimal aeration time lead tothe reduction in the aeration time while still meeting the standard requirements. It wasalso observed that better removal of NH_3-N as well as carbon was achieved due to the fact that de-nitrification could be seen not only as a way of mitigating nitrogen pollution, but also as an efficient method of abating organic carbon pollution. Complete de-nitrification was obtained when the C/N ratio was equal to or higher than 1.7.

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