Evaluation on Affecting Factors on Dissolve Oxygen and Oxygen Uptake Rate Profiles by Activated Sludge Model Simulation

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**ABSTRACT**
A dynamic mathematical model of the activated sludge process based on IWA’s ASM1 (International Water Association; Activated Sludge Model No 1) has been established by using STELLA simulation software. The microbial kinetics model is based on the ASM1 structure, modified to include dissolve oxygen (DO) and oxygen uptake rate (OUR). A series of CFSTR model is used as the reactor model. Parameter values are based on the typical influent and effluent water quality indices, and operational conditions in Malaysia. OUR and DO profiles are analyzed in detail for the efficacy of DO control system in terms of energy savings and effluent qualities. There are four DO temperatures that were analyzed in the first objective which is at 20°C, 21°C, 22°C and 28°C. Then, as the DO at 21°C was considered as most favourable for the set of conditions, different flow rate and HRT was measured to further analyzed the simulation, in which, the optimum energy efficiency condition chosen, the energy demand for the aerator was calculated in the third objective.

**Keywords:** Dissolved Oxygen, Simulation, Sludge Model, Uptake Rate profiles

**1. Introduction**

71% of the earth surface is covered by water and the remaining is land, which is the major and most important component of the environment that sustains the lives and ecosystem on the earth. Under the current circumstances of rapidly increasing world population, and industrialization and urbanization, maintaining both qualities and quantities of safe water resources for a sustainable world is an urgent issue to be addressed globally.

Wastewater by definition means water that has been contaminated by inorganic and organic matters from the sources including industries, commercial facilities, houses and any other social activities [1]–[7]. A wastewater or known as effluent from a point source and non-point source, can overload environment if released to the receiving body of waters without proper treatment.

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Aside from toxic materials, major concern on wastewater is its organic contaminants, which are commonly measured and expressed by biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Therefore, the essential function of wastewater treatment is to reduce the BOD and COD in the raw wastewater.

BOD is the measure of the biochemically oxidizable material present in the wastewater, which is expressed by the term of the amount of oxygen needed to oxidize microbiologically. It also can be expressed as the amount of oxygen needed to oxidize the organic carbon present in a wastewater by the microbial activities called as respiration [8]–[10]. Meanwhile, COD is another standard method of evaluating the amount of oxygen depletion as a result of chemical reaction. The COD test uses a strong oxidizing chemical (potassium dichromate or potassium permanganate) to chemically oxidize the organic material in wastewater, which determines the amount of total organic material in the wastewater. The COD is normally 1.3 to 1.5 times greater than the BOD of the same [11]–[17].

The treatment of wastewater is highly important in the industries as the amount of BOD and COD are the highest from their production activity. However, the sewage from the households and municipal is also in need to be treated due to its huge daily discharge. Sewage is mostly composed of human body waste (faeces and urine) from toilet utilities and water from personal washing, laundry and kitchen work. Typical composition of human faeces and urine is shown in Table 1.1. Furthermore, in Malaysia, with a warm climate for most of the year, wastewater can soon lose its content of dissolved oxygen and so it will become ‘septic’ wastewater which will produce offensive odour due to hydrogen sulphide [18]–[30]. Therefore, a wastewater treatment, typically by activated sludge process for large scale implementation, is needed for sewage.

### Table 1. Composition of Human Feces and Urine

<table>
<thead>
<tr>
<th>Type</th>
<th>Faeces</th>
<th>Urine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content (%)</td>
<td>66-80</td>
<td>93-96</td>
</tr>
<tr>
<td>Organic matter content (%)</td>
<td>88-97</td>
<td>65-85</td>
</tr>
<tr>
<td>Phosphorus (as P$_2$O$_5$) (%)</td>
<td>5.0-7.0</td>
<td>15-19</td>
</tr>
<tr>
<td>Potassium (K$_2$O) (%)</td>
<td>3.0-5.4</td>
<td>2.5-5.0</td>
</tr>
<tr>
<td>Carbon (%)</td>
<td>1.0-2.5</td>
<td>3.0-4.5</td>
</tr>
<tr>
<td>Calcium (CaO) (%)</td>
<td>40-55</td>
<td>11-17</td>
</tr>
</tbody>
</table>

The International Water Association (IWA), which is the largest international association on water, states that water is at the heart of sustainable development, development, environmental sustainability, human well-being, and it is critical for economics [31]–[35]. Therefore, to fulfill the agenda of IWA, wastewater that was produced from human activity needs to be treated efficiently.
This, in turn, has led to the necessity of establishing activated sludge wastewater treatment mathematical models. The most widely used mathematical models, Activated Sludge Models (ASMs), were developed by IWA working groups of specialists. The ASMs are the library of math models for activated sludge process that are most widely used to describe activated sludge wastewater treatment processes all over the world since the introduction of the first model 31 years ago. The ASM models can be used to further improve the efficiency of sewage treatment plants in Malaysia.

In the world, the sewage treatment plants in use are variants of the activated sludge process, which include sequencing batch reactor, modified oxidation ditch, advanced conventional activated sludge (ACAS), advance oxidation ditch and extended aeration [36]–[42]. These sewage treatment processes in Malaysia are an aerobic process, in which a supply of oxygen from the blower and aerator is needed for a high rate microbial process.

The amount of sewage being discharged to a sewage treatment plant daily is very large at about 36,301 m³/day for ACAS in Kuala Lumpur [43]–[51]. Furthermore, as Malaysia is a rapidly developing and urbanizing country, it is expected to have an fast growing population from the local population and the influx of immigrants from other neighbouring countries as shown in Figure 1-2. Malaysian population, which is now 32,389,047 and expected to continue to grow rapidly (Figure 3-4). As a result, demand on more centralized sewage treatment plants with expansion of sewerage networks shall remain high in near future.

![Figure 1 Components of Population Change (Malaysia Population, 2019)](image URL)
Over the year, the number of wastewater treatment plants in Malaysia, the majority of which are managed by Indah Water Konsortium (IWK), has been increasing. The operating cost of the sewage treatment plant in 2013 shows that about 32% of cost (Table 2.1 in Chapter 2) was due to the aeration. Therefore, an issue of increasing energy demand due to the sewage treatment in Malaysia needs to be addressed. One of the possible approaches is to establish mathematical models, based on fundamental model structures such as ASM1, and simulate process behaviours under different operational and control conditions for better efficiency while maintaining effluent qualities. A mathematical microbial kinetic model needs to be established in attempt to maximize the efficiency of aeration to maintain high enough microbial activities to break down organic matters while minimizing operational cost of blowers to achieve the Sustainable Development Goals (SDGs).

2. STELLA Model Framework of ASM1
The model framework for a CFSTR in STELLA was made as shown, in which there are three main components that build the model. These components are COD (S), Microbes (X) and DO. The model framework was conditioned at a 100% air saturation of DO at 20°C. The ASM1 model was first executed to simulate without a recycle sludge stream. The result is shown in Figure 4.1 and Figure 4.2. From the graphs, it is shown that the value of X, which is at 2000 initially, decrease to 47, while for the value of S, the COD that should be treated, is only simulated to decrease by 16% of its initial value; 242 mg/l. Therefore, the result shows that, when there is no recycle stream, microbes are washed off in the effluent, thus decreased the degradation activity to reduce the wastewater pollutants, S. As a result, an unsuccessful treatment of the sewage water is predicted. A return sludge stream was added to the model framework of ASM1.
2.1 STELLA model framework for a series of CFSTR at different DO.

2.1.1 STELLA model framework at 20°C DO

The basic model framework was conditioned at a 100% air saturation of DO at 20°C (9.092 mg/l) with a return sludge stream as shown in Figure 5-7.
Figure 5: Microbes (X) at 20° C vs Time (hour)

Figure 6: COD(S) at 20° C vs Time (hour)
The 100% air saturation was chosen for DO saturated because it is the equilibrium point for gases in water as the gas molecules diffused between the atmosphere and the water’s surface. According to Henry’s Law, the dissolved oxygen content of water is proportional to the percent of oxygen (partial pressure) in the air above it. The observed graph shows that, when DO at (20°C), the value of X decreased rapidly, thus, only 1% of the COD value was treated in the wastewater. This is due to the 0 mg/l rate of oxygen uptake by the microbes which thus rendered the growth of the aerobic microbes X. Therefore, it was concluded that at 240 m3/day mass air flow rates, the DO at 20°C is not suitable for the growth of microbes X for wastewater treatment.

2.1.2 STELLA model framework at 21°C DO
The model framework was then further conditioned at a 100% air saturation of DO at 200C (9.092 mg/l) with a DO at 21°C as shown in Figure 8-10.
The observed graph shows that, when DO at (21°C), the value of X is almost constant throughout the reactor. Furthermore, the COD value was that treated in the wastewater produced the intended treated wastewater which is at 20 mg/l. This is due to the 0.13 mg/l rate of dissolve oxygen uptake by the microbes which thus enabled the growth of the aerobic microbes X through respiration. Therefore, it was concluded that at 240 m³/day mass air flow rates, the DO at 21°C are suitable for the growth of microbes X for wastewater treatment.

2.1.3 STELLA model framework at 22°C DO
The model framework was then further conditioned at a 100% air saturation of DO at 20°C (9.092 mg/l) with a DO at 22°C as shown in Figure 11-13.
Figure 11: Microbes(X) at 22°C vs Time (hour)

Figure 12: COD(S) at 22°C vs Time (hour)
The graph shows that, when DO is 22°C, the value of X is also almost constant throughout the reactor, however, the growth is higher than at 20°C. Furthermore, the COD value was that treated in the wastewater produced the is indeed at below the intended treated wastewater which is at 3.5 mg/l. This is due to the 0.38 mg/l rate of dissolve oxygen uptake by the microbes which thus enabled the growth of the aerobic microbes X rapidly through respiration. Therefore, it was concluded that at 240 m3/day mass air flow rate, the DO at 22°C is suitable for the growth of microbes for wastewater treatment, but, as it decreased the COD value more than the intended value, the mass air flow rate should be decreased for better energy savings.

2.1.4 STELLA model framework at 28°C DO
The model framework was then further conditioned at a 100% air saturation of DO at 200C (9.092 mg/l) with a DO at 28°C are shown in Figure 14-16.
Figure 14 Microbes(X) at 28°C vs Time (hour)

Figure 15 COD(S) at 28°C vs Time (hour)
The graphs show that, when DO is 280°C, the value of X decreased at the first hour, then it rapidly increased later. The growth rate of X is much higher than intended. This is because, at the first phase, supersaturated water caused gas bubble disease in the microbes which also caused significant death rates occur when DO remains above 115%-120% air saturation for a period of time. Then, as time elapsed, the DO supply decreased which caused the growth of the microbes. Therefore, as the microbial population decreased in the first phase, the COD value was not removed from the wastewater, moreover, it increased in the first phase as a lot of microbes decayed and increased particulate matters. This is due to the 0.004 mg/l rate of dissolve oxygen uptake by the microbes which thus cause the death of aerobic microbes X. Therefore, it was concluded that at 240 m3/day mass air flow rates, the DO at 280°C are not suitable for the growth of microbes X for wastewater treatment, as it further increased the COD value at the treated wastewater.

2.2 Dynamic simulation at different flow rate and HRT for 21°C DO

The simulation that was conducted at different flow rate was conducted at 210°C DO. It was selected due to most efficient usage of mass air flow rate at 240 m3/day which also followed the COD value needed by the regulation. The first flow rate can be observed at figures 17-19, show the behaviors of X, S and DO at 18,150 m3/day flow rate.
Figure 17 Microbes(X) at F2 vs Time (hour)

Figure 18 COD(S) at F2 vs Time (hour)
From the observed graph, the value of X was observed decreased but also almost constant throughout time at 400-300 as the rate of DO uptake rate was at 0.09. Furthermore, the COD was observed to be treated more which the treated water contained the value at 7.9 mg/l compared with the flowrate in section 4.3.2. Therefore, it can be concluded that DO at 21°C is optimum for mass air flow rate of 240 m³/day, however, to use the energy efficiently, the mass air flow rate can be reduced for this flow rate at this temperature.

Then, the simulation was further conducted at different flow rate of 54,451 m³/day flow rate which was also conducted at 21°C DO. Figures 20-22 shows the behavior of X, S and DO.
From the observed graph, the value of X was observed decreased but also almost constant throughout time at 360-300 as the rate of DO uptake rate was at 0.07. However, although the COD was observed to be treated, it does not achieve the intended value as per the regulation, which is at 66 mg/l. Therefore, it can be concluded that DO at 210°C is need to increased it mass air flow rate for more than 240 m3/day.

Next, the simulation that was conducted at different HRT at 210°C DO and F1 flow rate. The first HRT can be observed at graphs 23-25 shows the behavior of X, S and DO at 0.67 HRT.
Figure 23 Microbes(X) at H2 vs Time (hour)

Figure 24 COD(S) at H2 vs Time (hour)
From the graph, the value of X was observed to decrease, but also almost constant throughout the period at 420-390 as the rate of DO uptake rate was at 0.14. Furthermore, the COD was observed to be treated, and it overachieve the intended value as per the regulation, which is at 8.7 mg/l. Therefore, it can be concluded that DO at 210C is balanced at the mass air flow rate for 240 m3/day. Lastly, the simulation was conducted at HRT of 1 day, at 210C DO and F1 flow rate. Figures 26-28 shows the behavior of X, S and DO.
From the graph, the value of X was also observed to decrease but almost constant throughout the period at 460 - 400 which is higher than others. The rate of DO uptake rate was at 0.19. Furthermore, the COD was observed to be treated in the most overachieved value which is at 4.6 mg/l. Therefore, it can be concluded that DO at 210°C is over optimum at the mass air flow rate for 240 m3/day and HRT of 1 day.

4. Conclusions
The simulation framework for ASM1 on STELLA software that was observed and have shown that the simulation of the ASM1 of sewage in Malaysia as successful. Furthermore, it can be concluded that, at 240 mass air flow rates, for the influent data taken from Malaysia sewage, the most optimum DO is at 0.13 mg/l and a higher SA about 6.6 day and above will produce a higher quality effluent. Therefore, to obtained to optimum treated COD value, the value of DO at different temperature can
be controlled by the amount of mass air flowrate inlet in which it should be manipulated to achieve the optimum DO rate and SA value.

References

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