INSTRUCTIONS TO CANDIDATES

1. Answer ALL questions in the Answer Booklet.
2. Begin EACH answer on a new page.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate ALL assumptions, if any.
5. Do not open this Question Booklet until instructed.

Note:  
i. There are ELEVEN (11) pages in this Question Booklet including the cover page and APPENDICES.
   ii. Graph paper will be provided.
1. a. Propose a treatment process for an industrial wastewater with characteristics given in TABLE Q1. Describe the functions of each unit provided in the process.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Discharge limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>3.4</td>
<td>6.0-9.0</td>
</tr>
<tr>
<td>Suspended solids, mg/L</td>
<td>600</td>
<td>50</td>
</tr>
<tr>
<td>BOD, mg/L</td>
<td>3500</td>
<td>20</td>
</tr>
<tr>
<td>Zn, mg/L</td>
<td>250</td>
<td>0.5</td>
</tr>
</tbody>
</table>

[10 marks]

b. A factory wastewater with no ammoniacal-nitrogen is treated anaerobically. However, during the treatment, an engineer noticed rising ammonia concentration in the reactor effluent.

i. Justify why there is rising ammonia concentration in the effluent.

[2 marks]

ii. If the rising ammonia concentration is not stopped, predict THREE (3) impacts on the reactor performance.

[3 marks]

c. An anaerobic reactor operating at 30 °C treats 600 m³/d of wastewater. If an accidental spill increased the influent sulphate concentration by 1000 mg/L, determine the expected daily decrease in methane production when 1 g sulphate reduction requires 0.67 g COD and 1 g COD is equivalent to 0.4 L methane.

[10 marks]
2. a. Differentiate the fundamental theories between nitrification and denitrification in wastewater treatment. [4 marks]

b. You are an engineer in a consultancy company, Nice Water Sdn. Bhd. and are tasked to design an activated sludge system with nitrification for a sewage treatment plant company. The characteristics of the raw influent are as follows:

**TABLE Q2**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
<td>8000 m³/day</td>
</tr>
<tr>
<td>COD</td>
<td>250 mg/L</td>
</tr>
<tr>
<td>TKN</td>
<td>40 mg/L</td>
</tr>
<tr>
<td>TP</td>
<td>4 mg/L</td>
</tr>
<tr>
<td>Sludge age</td>
<td>35 days</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>135 as CaCO₃</td>
</tr>
<tr>
<td>MLVSS</td>
<td>6000 mg/L</td>
</tr>
<tr>
<td>MLVSS:MLSS</td>
<td>0.85</td>
</tr>
<tr>
<td>SVI</td>
<td>100</td>
</tr>
<tr>
<td>Alkalinity used for nitrification</td>
<td>7.14 g CaCO₃/g NH₄-N</td>
</tr>
<tr>
<td>Residual alkalinity</td>
<td>equivalent to 70 g/m³ as CaCO₃</td>
</tr>
<tr>
<td>concentration to maintain pH 7</td>
<td></td>
</tr>
</tbody>
</table>

Use the following kinetic coefficients:

\[
\begin{align*}
    k &= 15 \text{ g COD/g VSS\cdot day} \\
    \mu_m &= 6 \text{ g VSS/g VSS\cdot day} \\
    K_s &= 20 \text{ g COD/m}^3 \\
    Y &= 0.4 \text{ g VSS/g COD} \\
    k_d &= 0.12 \text{ g VSS/g VSS\cdot day} \\
    f_d &= 0.15 \text{ g/g} \\
    Y_n &= 0.12 \text{ g VSS/g NH}_4\text{-N} \\
    k_{dn} &= 0.08 \text{ g VSS/g VSS\cdot day}
\end{align*}
\]
i. How much sludge would be produced? [8 marks]

ii. Calculate the volume, in m³. [2 marks]

iii. Calculate the oxygen demand, in kg/h. [4 marks]

iv. How much alkalinity needs to be added in kg/day NaHCO₃. [5 marks]

v. Calculate nitrogen and phosphorus to be added in mg/L? [2 marks]
3. a. Sequencing batch reactor (SBR) is one of the aerobic treatment systems. Illustrate and explain the treatment process using SBR. [5 marks]

b. Why does sloughing occur in a trickling filter? [2 marks]

c. Suggest **TWO (2)** suitable criteria for packing media used in a trickling filter. [2 marks]

d. A 28 m diameter trickling filter (recirculation ratio 1:1.5) with a 2 m depth is fed with a 5000 m³/d wastewater with an average BOD of 130 mg/L. The temperature-activity coefficient of 1.035 is a typical value for trickling filters.

Determine:

i. the hydraulic load, and [6 marks]

ii. the anticipated effluent BOD at 20 °C and 16 °C, in mg/L. [10 marks]
4.  
a. Compare and contrast gravitational settling and dissolved air floatation.  

[2 marks]

b. Differentiate discrete particle settling and flocculent settling.  

[3 marks]

c. **TABLE Q4** shows the settling data obtained for an activated sludge with initial solids concentration of 2500 mg/L. The height of settling column was 1.5 m. The inflow is 1000 m$^3$/day and the thickened sludge concentration required is 25,000 mg/L. Determine the area of thickener.

<table>
<thead>
<tr>
<th>Settling time, min</th>
<th>Interface height, m</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td>10</td>
<td>0.8</td>
</tr>
<tr>
<td>20</td>
<td>0.36</td>
</tr>
<tr>
<td>30</td>
<td>0.2</td>
</tr>
<tr>
<td>40</td>
<td>0.14</td>
</tr>
<tr>
<td>50</td>
<td>0.12</td>
</tr>
<tr>
<td>60</td>
<td>0.1</td>
</tr>
</tbody>
</table>

[20 marks]

-END OF PAPER-
Appendix

Clarifier

\[ H_u = \frac{C_o H_o}{C_u} \]

\[ A = \frac{Q t_u}{H_o} \]

Activated Sludge System

For completely mixed activated sludge,

\( g_c \) = mean cell residence time, time

\( V \) = volume of aeration tank, unit volume

\( Q \) = influent wastewater flow, unit volume/time

\( Q_w \) = rate of excess sludge wasting, unit volume/time

\( X \) = concentration of MLVSS in aeration tank, mass/unit volume

\( X_e \) = concentration of VSS in effluent, mass/unit volume

\( Y \) = growth yield

\( Y_{obs} \) = observed growth yield, g of MLVSS/g of soluble BOD

\( F/M \) = food/microorganism ratio, g/d of soluble BOD per g of MLVSS

\( E \) = soluble effluent BOD removal, %

\( k_d \) = microbial decay coefficient, d\(^{-1}\)

\( K_s \) = saturation constant, mass/unit volume

\( k \) = max. rate of substrate utilization per unit mass of biomass, time\(^{-1}\)

\( S_o \) = influent substrate concentration, mass/unit volume

\( S_e \) = effluent substrate concentration, mass/unit volume

\( U \) = specific substrate utilization rate, time\(^{-1}\)

\[ = k Y \]

\( X_{vss} \) = Volatile biomass concentration in return sludge, mg/L
Mean cell residence time,

$$g_c = \frac{VX}{Q_w X + (Q - Q_w) X_e}$$

$$\frac{1}{g_c} = \frac{Y (F / M) E}{100} - k_d$$

$$\frac{1}{g_c} = \frac{YkS_e}{K_s + S_e} - k_d$$

$$\frac{1}{g_c} = YU - k_d$$

Food/Microorganism ratio, g/d of soluble BOD applied per g of MLVSS in the aeration tank

$$F / M = \frac{Q S_o}{VX} = \frac{S_o}{\theta X}$$

Effluent substrate concentration

$$S_e = \frac{K_s (1 + k_d g_c)}{g_c (\mu_m - k_d) - 1}$$

Volume of aeration tank,

$$V = \frac{g_c Y Q (S_o - S_e)}{X (1 + k_d g_c)}$$

Kinetic model for completely activated sludge:

$$\frac{1}{U} = \left( \frac{K_s}{k} \right) \left( \frac{1}{S_e} \right) + \frac{1}{k}$$
Observed growth yield, g of MLVSS/g of soluble BOD

\[ Y_{obs} = \frac{Y}{1 + \theta_c k_d} \]

Amount of total waste solids \( P_{x,TSS} \)

\[ P_{x,TSS} = \frac{X_{TSS} (V)}{\theta_c} \]

Production of excess biomass in waste activated sludge

\[ P_{x,vss} = \frac{Q Y (S_o - S_e)}{1 + k_d \theta_c} + \left( f_d \right) k_d \frac{Q Y (S_o - S_e)}{1 + k_d \theta_c} + \frac{Q Y_n (NO_x)}{1 + k_{dn} \theta_c} \]

Oxygen Requirement, \( R_0 \), kg/day

\[ R_0 = Q (S_o - S) - 1.42 P_{x,vss} + 4.33 Q (NO_x) \]

The nitrogen mass balance, based on the assumption of 0.12 g N/g biomass (CsH7NO2 for biomass) is as follows:

\[ NO_x = TKN_0 - N_e - 0.12P_{x,bio}/Q \]

Where

- \( NO_x \) = nitrogen oxidized, mg/L
- \( TKN_0 \) = influent TKN concentration, mg/L
- \( N_e \) = effluent NH4-N concentration, mg/L
- \( Q \) = flowrate, L/day

Nitrogen required by biomass = \( 0.12P_{x,bio}/Q \)
Phosphorus required by biomass = \( 0.02P_{x,bio}/Q \)