

## Supplemental Material C.

### Preparation, Operation and Maintenance of Membrane Bioreactor System

#### 1. Preparation of Synthetic Wastewater

- 1.1. Weight each component of synthetic wastewater in Table \*\*\*, and transfer them into a 2 L beaker. It is recommended to make concentration synthetic wastewater (10X) and dilute it for daily use.
- 1.2. Add 1.9 L of DI water. Mix the solution for 2 h.
- 1.3. Adjust the pH to 7.5, and finalize the volume to 2 L with DI water. Mix for 1 hour.
- 1.4. Store the synthetic wastewater at 4 °C for no more than 10 days.

#### 2. Activated Sludge Incubation

- 2.1. Collect fresh secondary (mixed liquor) from local wastewater treatment plant.
- 2.2. Incubate the sludge in 25 L glass tank with synthetic wastewater (step 1) for 3 months. Remove clogged sludge with fish net.
- 2.3. Daily measurement of mixed liquor suspended solids (MLSS) is required (step 3). Remove extra sludge with pipette, and replace it with DI water. The volume of wasted sludge is calculated by Equation C-1:

$$V_w = \frac{(C_m - C_0)V_0}{C_m} \quad [C-1]$$

Where,

$C_0$ : original MLSS concentration, g/L

$V_0$ : volume of activated sludge, L

$C_m$ : measured MLSS concentration, g/L

$V_w$ : volume of wasted sludge, L

- 2.4. Prior to experiments with membranes, maintain the volume of the activated sludge at 20 L with MLSS concentration of 4.5 g/L for at least two weeks.

#### 3. MLSS Measurement

- 3.1. Weight glass-fiber filter (0.45 µm) in aluminum crinkle dish using a balance.
- 3.2. Pre-wet the glass-fiber filter with DI water. Insert the filter into filtration apparatus.
- 3.3. Transfer 20 mL of activated sludge into the filtration apparatus. Apply vacuum until all water is removed.
- 3.4. Transfer glass-fiber filter with sludge sample in to aluminum dish.
- 3.5. Dry the sludge sample in an oven at 108 °C for 1 h.
- 3.6. Weight the sludge sample (with glass-fiber filter and aluminum dish) using a balance. The MLSS concentration is calculated by Equation C-2:

$$MLSS = \frac{m_2 - m_1}{V} \quad [C-2]$$

Where,

$m_1$ : weight of filter, mg

$m_2$ : weight of filter + dried sludge sample, mg

$V$ : sludge sample volume, mL

#### 4. Membrane Preparation

4.1. Cut the hollow fibers into 80 cm long segments and assembled by looping and potting them in a short (~10 cm) piece of 1/2" ID PTFE tubing using an adhesive (Loctite). The total membrane surface area are calculated in Equation C-3:

$$A = n \cdot \pi \cdot d \cdot l \quad [C-3]$$

Where,

$A$ : membrane surface area,  $m^2$

$n$ : number of membrane loops

$d$ : diameter of hollow fiber membrane, m

$l$ : length of each membrane loop, m

4.2. After the glue is completely dry, soak the membrane units in DI water for at least 24 h before use.

4.3. Prior to use, filter the membrane with DI water at flow rate of 70-80ml/min for 12 h.

#### 5. Permeability/Membrane Resistance Test

5.1. Connect membrane unit, pressure gauge, and peristaltic pump as shown in Figure C-1. Submerge the membrane loops under DI water.

5.2. Setup the flow rate of peristaltic pump at 60 ml/L\*, and then start the pump.

\*Note: this may not be the real flow rate. The volume of outflow will be determined in the following steps.

5.3. Wait until the reading of pressure gauge become constant. Collect outflow with a graduated cylinder for 1 minute (outflow volume can also be determined by a balance).

5.4. Determine membrane resistance using Equation C-4.

$$J = \frac{V}{A \cdot t} = \frac{P}{\mu \cdot R_m} \quad [C-4]$$

Where,

$J$ : flux, m/s

$V$ : outflow volume,  $m^3$

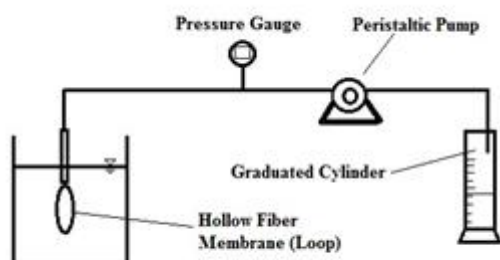
$A$ : membrane surface area,  $m^2$

$t$ : filtration time, s

P: transmembrane pressure, Pa

$\mu$ : viscosity, Pa s

$R_m$ : membrane resistance



**Figure C-1.** Schematic and photograph of permeability test setup

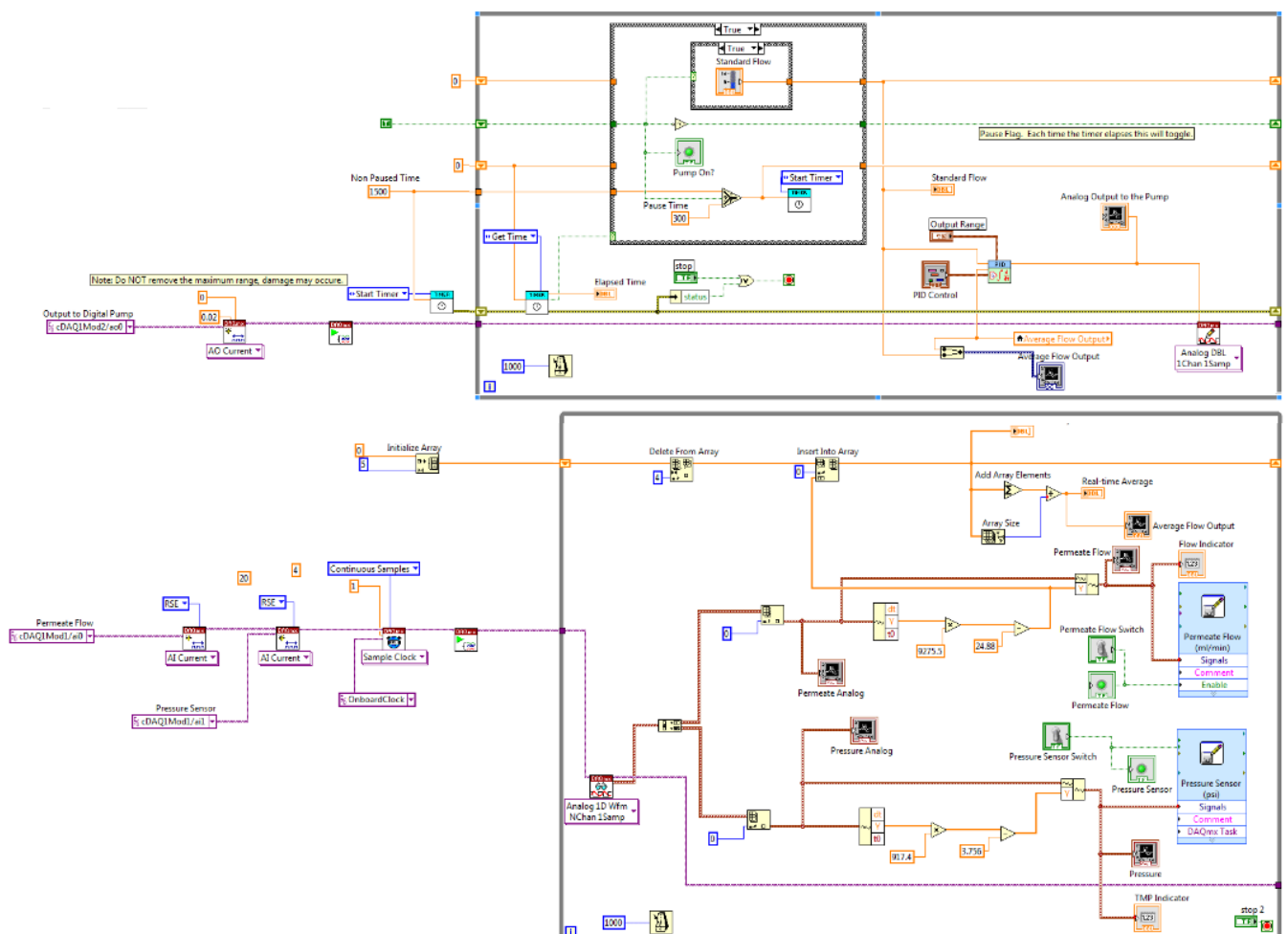
## 6. Description and Operation of the Bench-scale MBR System

Schematic and photograph of the designed bench-scale MBR system in this study is presented in Figure 4-1 and Figure C-2, respectively. It consists of 5 components: activated sludge reactor, feed system, aeration system, waste sludge system, and membrane system. The activated sludge reactor has a total volume of 25L. The feeding pump is a manual control metering pump (LE44SA-VTC1, Pulsafeeder) with max flow rate of 116 mL/min. The permeate pump is a peristaltic digital pump (model 07523-80, MasterFlex L/S) that can receive analog signal from PC. Flow rates and trans-membrane pressure are measured by a digital flow meter (model 106-4-C-T4-C10, McMillan) and digital pressure sensor (Cole-Parmer, 68075-00), and transferred to PC. LabView was employed to acquire the data from electronic equipments, and adjust flow rate by sending analog signal to the vacuum pump. The labView code is presented in Figure C-3. Diffusers are installed on the bottom of the reactor, and the aeration is at the rate of  $0.57 \text{ m}^3/\text{h}$ .

Start the MBR system as described in Section 7. When the system is running, take the measurements of pH and MLSS at least once every day. Adjust pH with NaOH or HCl. Remove extra sludge as described in section 2.3. Check the volume of sludge (water level) as frequently as possible. If the sludge volume is less than 20 L, add DI water and adjust pH afterward. If the sludge volume is less than 20 L, stop the feeding pump until the volume decreased to 20 L, then restart the feeding pump. Calibrate the flow meter at least once every day as described in section 8. Between experiments, it is acceptable to maintain the system as convention wastewater treatment systems without membranes, as described in section 2.



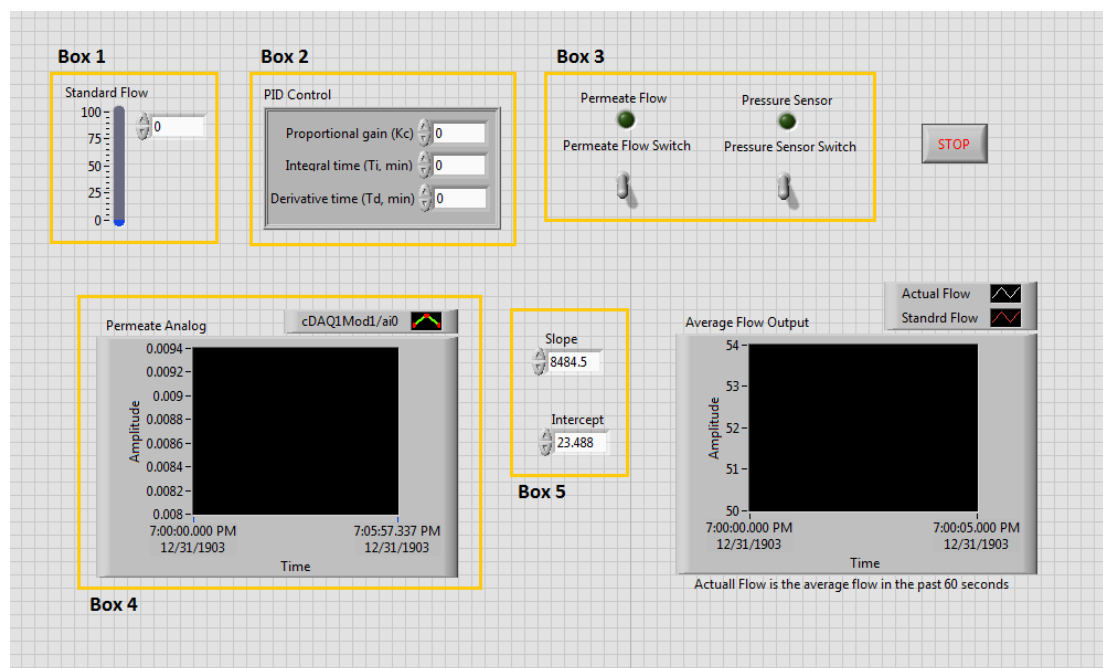
**Figure C-2.** Photograph of the designed bench-scale MBR system



**Figure C-3.** LabView code

## 7. MBR System Initiation

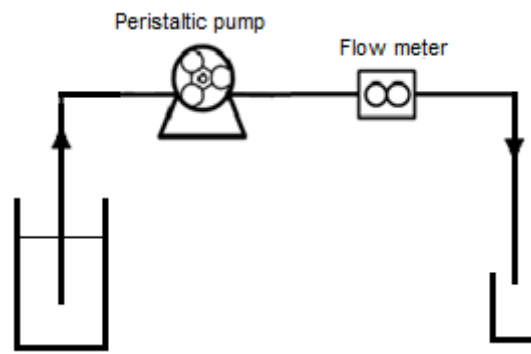
- 7.1. Set the permeate pump to “current input” mode.
- 7.2. Double click the “Bench-scale MBR.vi”. Window in Figure C-4 should show up.
- 7.3. Setup the standard flow rate at Box 1 in Figure C-4.
- 7.4. Setup the PID control parameters in Box 2 ( $K_c = 0.00003$ ,  $T_i = 0.5$ ,  $T_d = 0.04$ ).
- 7.5. Click the bottoms in Box 3 in order to save the data.
- 7.6. Run the program.
- 7.7. Start the pumps.



**Figure C-4.** Control board of LabView program

## 8. Flow Meter Calibration

- 8.1. Connect flow meter and peristaltic pump as shown in Figure C-5.
- 8.2. Set the permeate pump to “local” mode. Set the flow rate as 70 mL/min on the pump (note: this may not be the real flow rate).
- 8.3. Double click the “Bench-scale MBR.vi”. Window in Figure C-3 should show up.
- 8.4. Start the pump. Wait for ~30 s until the flow is constant.
- 8.5. Start the LabView program.
- 8.6. Collect the outflow with a beaker for 60 s. Determine the outflow volume with a balance.
- 8.7. Stop the LabView program. Right-click the chart in Box 4. Select “Export data” and the analog data will be extracted in an excel sheet. Calculate the average value of analog signal.
- 8.8. Set the flow rate as 60, 50, 40, 30 mL/min on the pump, respectively (note: this may not be the real flow rate). Repeat step 8.1 – 8.7.
- 8.9. Plot the outflow volume against the average value of analog signal. Apply linear regression. Redo the calibration if  $r^2 < 0.97$ .
- 8.10. Input slope and intercept of the calibrated curve in Box 5.



**Figure C-5.** Schematic graph of flow meter calibration setup