http://dx.doi.org/10.14500/aro.12033

Performance Evaluation of Membrane Bioreactor Operational Design in Sewage Treatment Plant using GPS-X Software

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***Abstract*—This study evaluates the operational performance of a full-scale membrane bioreactor wastewater treatment plant located in Kuala Lumpur using GPS-X 8.0 simulation software. Key performance indicators–including mixed liquor suspended solids (MLSS), transmembrane pressure (TMP), dissolved oxygen, and effluent total suspended solids (TSS)–were monitored over 30 days. The simulations were conducted using the advanced mode and calibrated with actual plant data. Results show that although the plant complies with Malaysian effluent discharge standards, it operates well below its design capacity, with MLSS levels significantly lower than recommended. This operational underload contributes to increased energy consumption and reduced treatment efficiency, particularly in terms of TSS and chemical oxygen demand removal.**

***Index Terms*—Characteristic of sewage, GPS-X modeling, Membrane bioreactor, Membrane filtration, Sewage treatment processes.**

I. Introduction

Acquiring and preserving a sufficient source of water has always been one of the most essential components of human community formation. The quantity of water available was a significant consideration in the early stages. However, the growing population has put a burden on the remaining clean water supply, and pollution of water with urban, industrial, and rural contaminants has caused water quality to degrade in many other sources (Razak, 2010). Simultaneously, water quality standards have tightened, toxicology testing skills have advanced, and the public has become more aware of and picky about water quality. As a result, when it comes to water supply development, the quality of a water source cannot be disregarded. Almost all sources of water must be treated before being used for drinking. Water treatment is the process of changing water into a quality that fits the objectives or guidelines set by the user or the government regulators of a community. Aims and guidelines involve legal standards, supplemental demands imposed by a local area, and cover all aspects of certain industries (Crittenden, et al., 2012).

To meet the rising need for strict standards relating to the quality of effluent released into receiving water, a call for the deployment of innovative technical solutions is required (Mucha, et al., 2019). New technologies such as the membrane bioreactor (MBR) are emerging. Membrane separation mechanisms rely on variations in the permeability of water components. Water is pushed across the surface of a membrane, resulting in the formation of product and waste streams. A synthetic material <1 mm thick is semipermeable, meaning it is highly permeable to some components but less or not permeable to others. Impermeable components are retained on the feed side, while permeable components pass through. The product stream has few impermeable elements, but the waste stream contains many (Crittenden, et al., 2012).

There are four membrane processes: microfiltration, ultrafiltration (UF), nanofiltration, and reverse osmosis. Membrane processes can be classified by separation duty, with pore size characterized either by diameter in microns or by molecular weight cutoff (MWCO) in Dalton's. In UF, selectivity is characterized by MWCO. Pressure is used to drive water through all four types of membrane processes.

Membrane materials may be polymeric, ceramic, or metallic, although metallic membranes are rare in MBR. The membrane structure is typically anisotropic, with a selective surface layer and a porous support for mechanical stability. Polymeric membranes often have high surface porosity and narrow pore size distribution to maximize throughput and selectivity. They must also withstand temperature, pH, and chemical extremes during cleaning (Krzeminski, Iglesias and Van der Graaf, 2017).

MBR systems combine activated sludge and membrane separation. With pore sizes typically <0.1 μm, they

ARO-The Scientific Journal of Koya University
Vol. XIII, No.2(2025), Article ID: ARO.12033. 10 pages
DOI: 10.14500/aro.12033
Received: 31 January 2025; Accepted: 13 July 2025
Regular research paper; Published: 25 August 2025
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produce treated water that is well clarified and disinfected. Concentrating biomass allows smaller tank volumes and better treatment performance. Treated water typically has low levels of organic matter and ammonia. Because MBR does not rely on settling, they avoid the shortcomings of traditional activated sludge systems, although organic or hydraulic shocks can still disrupt operation (Judd, 2010).

MBR offers advantages such as operational flexibility, technical stability, high-quality effluent, and compact design. They are well-suited for expanding treatment capacity in existing wastewater treatment plant or deploying in areas with limited space. Containerized MBR systems have even been developed for emergency or remote use (Barreto, Alzate Marin and Judd, 2017). However, MBR systems require significant energy, are prone to fouling, and demand skilled operation. Therefore, simulation tools like GPS-X are essential for predicting performance, diagnosing operational issues, and validating design assumptions (Al-Sayed, et al., 2023; Smith, et al., 2023; Medellín-Castillo, et al., 2023).

The objectives of this research are to evaluate the performance of a full-scale MBR wastewater treatment plant in Kuala Lumpur using GPS-X simulation software, to assess the operational efficiency of the MBR system, and to validate the accuracy of the simulation in designing MBR treatment plants using only the design parameters and membrane properties provided by the manufacturer.

II. Materials And Methods

This section outlines the materials and methods used in this research to achieve the project objectives. The sequence of approaches adopted in this study is illustrated in the flowchart shown in Fig. 1. These approaches include data collection, sampling, laboratory testing, and model development using GPS-X software.

The GPS-X simulation software was employed to model the MBR system and evaluate its performance under various operational conditions. Detailed procedural steps for model configuration, influent parameter setup, process unit selection, and performance analysis using GPS-X can be found in (Dawood, 2022). This reference offers a comprehensive framework for simulating and optimizing wastewater treatment processes using GPS-X.

Recent studies have applied similar modeling techniques to evaluate MBR systems and optimize wastewater treatment processes through simulation and statistical analysis (Mabrouki, et al., 2022; Bencheikh, et al., 2020; Fattah, et al., 2023).

This project is divided into:

1. Data collection and wastewater sampling
2. Sample analysis
3. Performance assessment of the MBR treatment plant
4. Creating an MBR model using GPS-X software
5. Model calibration
6. Checking the validity of the simulation in designing an MBR treatment plant.

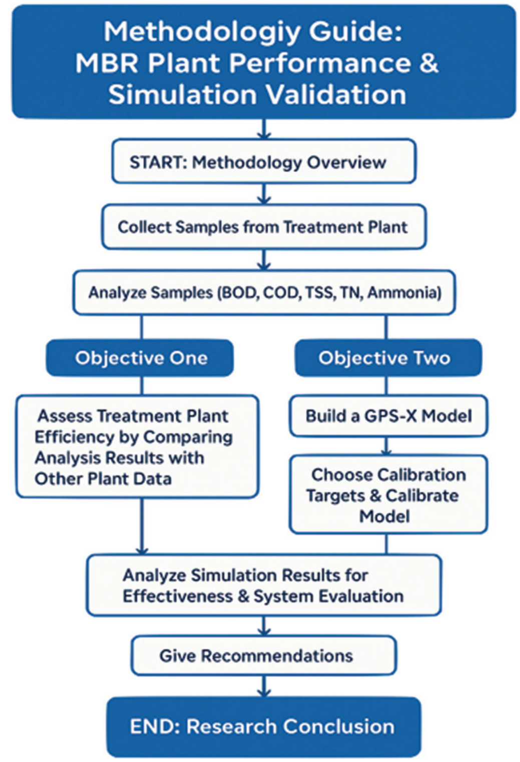

Fig. 1. Flowchart illustrates the research methodology for the performance assessment of the membrane bioreactor plant and simulation validation.

A. Data Collection and Wastewater Sampling

The wastewater treatment plant is located in Kuala Lumpur, where ambient temperatures range from 25°C to 35°C, with an average wastewater temperature of approximately 31°C. The facility is situated at an elevation of 94 m above sea level. The design information and layout of the wastewater treatment plant were provided by the design firm. Wastewater samples were collected at an ocean treatment facility in Kuala Lumpur on April 20, 2022, and again from June 28 to July 1, 2022. Samples were taken from four key locations: The influent, following the nitrification and denitrification processes, the bioreactor, and finally the plant effluent. Each grab sample was collected at a designated, well-mixed point representative of the respective water or wastewater stream. Immediate preservation upon collection was essential to ensure the integrity of the analytes before laboratory analysis. The preservation protocols for each parameter followed the American Public Health Association (APHA) standard methods, as outlined below:

Chemical oxygen demand (COD): Samples were collected in clean, inert containers and immediately acidified to a pH below 2 using concentrated sulfuric acid (H_2SO_4), as per APHA Method 5220. They were then chilled to 4°C and stored at this temperature until analysis. The maximum holding time was 28 days. Biochemical oxygen demand (BOD): Samples were collected in clean, inert containers and preserved by immediate cooling to 4°C, in accordance with APHA method 5210 B. Because BOD is a biological test, acidifying was not applied to avoid inhibiting microbial

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activity. Analysis was initiated within 6 h of collection and no later than 48 h, even under refrigeration. Ammonia: In line with APHA Method 4500-NH_3, samples were collected in clean, inert containers, acidified to a pH below 2 using concentrated sulfuric acid (H_2SO_4), and then chilled to 4°C. They were stored at 4°C with a maximum holding time of 28 days. Nitrate: As per APHA Method 4500-NO_3, nitrate samples were preserved by acidifying to a pH below 2 using concentrated sulfuric acid (H_2SO_4) and chilled to 4°C. They were maintained at this temperature until analysis, with a maximum holding time of 28 days.

B. Sample Analysis

The samples were analyzed for COD, total suspended solids (TSS), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), and heavy metals (including total calcium, total magnesium, total potassium, and other residual cations and anions) to verify the design data provided by the design firm. The analytical methods used followed the guidelines specified in the Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 2012).

The specific reference sections from the APHA Standard Methods manual used in this study are as follows:

1. Part 3000 - Metal analysis
2. Part 2540 - Solids analysis
3. Part 4500 - Ammonia as Nitrogen (NH_3-N) analysis
4. Part 5210 - Biochemical oxygen demand (BOD) analysis
5. Part 5220 - COD analysis.

C. Performance Assessment of the MBR Treatment Plant

The laboratory analysis results were compared with data from other treatment plants worldwide. By evaluating key parameters such as BOD, COD, TSS, and total nitrogen (TN), the performance of the MBR treatment plant can be effectively assessed.

D. Creating an MBR Model Using GPS-X Software

The simulation model was developed using GPS-X 8.0 and employed the MANTIS2 library to represent biological processes, membrane resistance, and sludge dynamics. The model was configured using the advanced mode, which incorporates membrane fouling, cake layer formation, backwashing, and dynamic water level control through feedback mechanisms (Serdarevic, Spanjers, and Van Lier, 2016). This mode provides a comprehensive representation of full-scale MBR operations, making it suitable for long-term performance evaluation and operational optimization (Hydromantis, 2020; Le, 2024; Jasim and Aziz, 2020).

When creating a GPS-X model, several critical steps must be followed to ensure accurate simulation and reliable performance predictions (Phillips, Rathnayake and Sewell, 2009):

1. Set up the layout with the correct physical and environmental specifications
2. Select an appropriate influent model that accurately represents the characteristics of incoming wastewater
3. Choose calibration targets based on key operational parameters
4. Perform calibration, which includes
   a. Running the simulation
   b. Identifying parameters that require adjustment
   c. Modifying those parameters to align simulated outputs with observed data.
5. Validate the model using a separate testing data set to confirm its predictive accuracy (Schraa, Spanjers and Van Lier, 2010).

To ensure simulation accuracy, the model was calibrated and validated using actual operational data collected over 30 days in May 2022.

The calibration process involved the following key steps

1. Mixed liquor suspended solids (MLSS) and TSS fitting: The solid capture rate and sludge yield were adjusted to align the model outputs with observed MLSS and TSS values.
2. Volatile suspended solids (VSS)/TSS ratio and organic fraction calibration: VSS and organic fractions were fine-tuned to accurately reflect the observed BOD and COD ratios.
3. Dissolved oxygen (DO) control: A proportional–integral–derivative controller was implemented to manage aeration and maintain target DO concentrations.
4. Backwash and cross-flow air adjustments: Airflow rates were calibrated to simulate realistic transmembrane pressure (TMP) behavior and membrane fouling dynamics.

E. Physical Layout Set-up and Operational Specification

The design parameters used in the model development are presented in Table I. This table outlines the critical specifications, such as membrane type, dimensions, MLSS concentration, and flow rate required for accurately configuring the GPS-X simulation of the MBR system. These parameters serve as the foundation for representing the physical and operational characteristics of the treatment plant within the simulation environment.

The pollution levels in the raw wastewater entering the system are presented in Table II. These values are essential for simulating the treatment load and evaluating the MBR plant's performance. Key parameters include organic loads such as BOD and COD, solid content represented by TSS, nutrients such as TN and ammonia nitrogen (NH_3-N), as well as other contaminants such as oil and grease.

Table III presents the concentrations of selected heavy metals in the influent, which may influence biological treatment processes and membrane performance. Calcium (Ca) and magnesium (Mg) contribute to water hardness and scaling, while potassium (K), although an essential nutrient, can cause operational challenges at elevated levels.

The following equations were used in the model to determine TSS and BOD:

$$x = \frac{vss}{ivsstotss} \tag{1}$$

TABLE I
The Model Development's Design Parameters

Parameter	Value	SI unit
MBR brand	Econity	---
Pore size	0.1	µm (micrometers)
Permeability	2	$L\cdot m^{-2}\cdot h^{-1}\cdot bar^{-1}$
TMP	−0.2	bar (1 bar=10^5 Pa)
Flux	19	$L\cdot m^{-2}\cdot h^{-1}$
Filtering area	14,802	m^2
MBR tank volume	455	m^3
Oxic tank volume	1980	m^3
Anoxic tank volume	447	m^3
Water depth in the MBR tank	5	m
Water depth in the oxide and anoxic tank	4.5	m
Flow rate	30,000	PE (population equivalent)
MBR design MLSS	8000	$mg\cdot L^{-1}$
O_2 concentration	2	$mg\cdot L^{-1}$
Backwash period	60	S
Frequency of backwash	Every 15 min	---
Backwash flow	2000	$m^3\cdot d^{-1}$
Air scouring method	Coarse bubble	-----
Crossflow air flow	19,000 m^3/d	$m^3\cdot d^{-1}$
Cleaning frequency	Every 3 months	----
Solid capture rate	0.986	Dimensionless

TMP: Trans-membrane pressure

TABLE II
Influent Wastewater Characteristics

Parameter	Value	SI Unit
Biochemical oxygen demand	250	$mg\cdot L^{-}1$
Chemical oxygen demand	500	$mg\cdot L^{-1}$
Total suspended solids	300	$mg\cdot L^{-1}$
Total nitrogen	50	$mg\cdot L^{-1}$
Ammonia nitrogen (NH_3-N)	30	$mg\cdot L^{-1}$
Oil and grease	50	$mg\cdot L^{-1}$

TABLE III
Influent Heavy Metal Concentrationss

Parameter	Value	SI unit
Calcium (Ca)	17	$mg\cdot L^{-1}$
Potassium (k)	15.5	$mg\cdot L^{-1}$
Magnesium (mg)	2.49	$mg\cdot L^{-1}$

Where

x = TSS: These are solid particles suspended in water or wastewater, including both organic and inorganic matter.

vss = (VSS): This represents the organic portion of the suspended solids, which includes biodegradable material such as bacteria, organic matter, and VSS

ivsstotss = VSS/TSS ratio: This ratio indicates the proportion of volatile solids to total suspended solids.

$$bod = \frac{sbod}{xbod} \tag{2}$$

bod = total BOD: Total BOD

sbod = soluble BOD: The portion of BOD that is dissolved in water and can be directly consumed by microorganisms

xbod = particulate BOD: Particulate BOD

By adjusting the organic fractions, the values of VSS, particulate BOD, and soluble BOD can be calibrated.

This schematic illustrates the process flow of a full-scale MBR treatment plant, comprising key units such as the influent line, anoxic tank, oxic tank, membrane module, and effluent discharge point. The layout serves as the structural basis for replicating the treatment sequence in the GPS-X simulation model.

In this study, each process unit, as shown in Fig. 2, was represented in the GPS-X environment using appropriate reactor blocks and configuration settings. The anoxic and oxic (aerobic) tanks were modeled as continuously stirred tank reactors, a standard approach in dynamic simulations due to its assumption of complete mixing, which is suitable for capturing biological processes such as nitrification and denitrification.

The membrane tank was simulated using the GPS-X membrane module, which enables the analysis of critical membrane processes such as fouling, back washing, and cake layer formation. This modeling approach ensures that the simulation accurately reflects the physical and operational characteristics of the actual treatment plant.

Users can define key attributes such as tank volume, depth, surface area, and mixing characteristics. This configuration supports accurate modeling of denitrification processes by simulating an oxygen-depleted environment within the MBR system.

Tank geometry, liquid depth, and aeration parameters. Proper setup of this unit is essential for simulating biological oxidation and nitrification under aerobic conditions.

F. Selection of influent Model and Calibration Targets

To ensure that the simulation accurately represents the treatment plant's real-world performance, an appropriate influent model was selected using the MANTIS2 library in GPS-X. The model inputs were based on the influent wastewater characteristics presented earlier (Tables II and III).

The COD-states model was used to specify influent fractions, including:

1. Soluble inert COD (Si)
2. Readily biodegradable COD (Ss or Slf)
3. Particulate inert matter (Xi)
4. Biomass components (Xbh, Xba, Xbp)
5. Non-biodegradable products (Xu).

Fig. 3 shows the interface for defining these influent components.

G. Calibration Target

Each MBR system has unique operating conditions and influent variability. Thus, selecting appropriate calibration targets is essential to improve model accuracy and ensure realistic simulation performance. For this MBR system, the key calibration targets were:

1. Influent characteristic and MLSS (Meng, et al., 2017)
2. Solid capture rate (Phillips, Rathnayake and Sewell, 2009)
3. Sludge production (Schraa, Spanjers and Van Lier, 2010)
4. DO concentration (Yoon, 2015).

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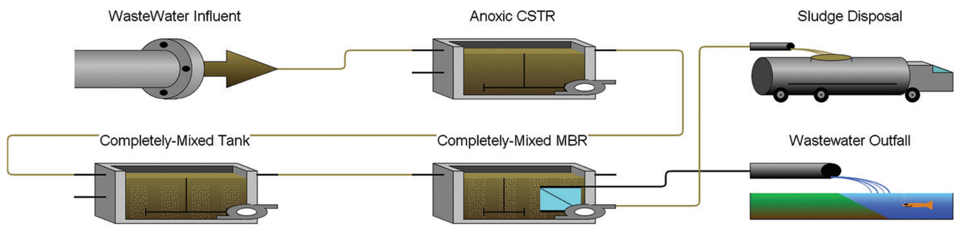
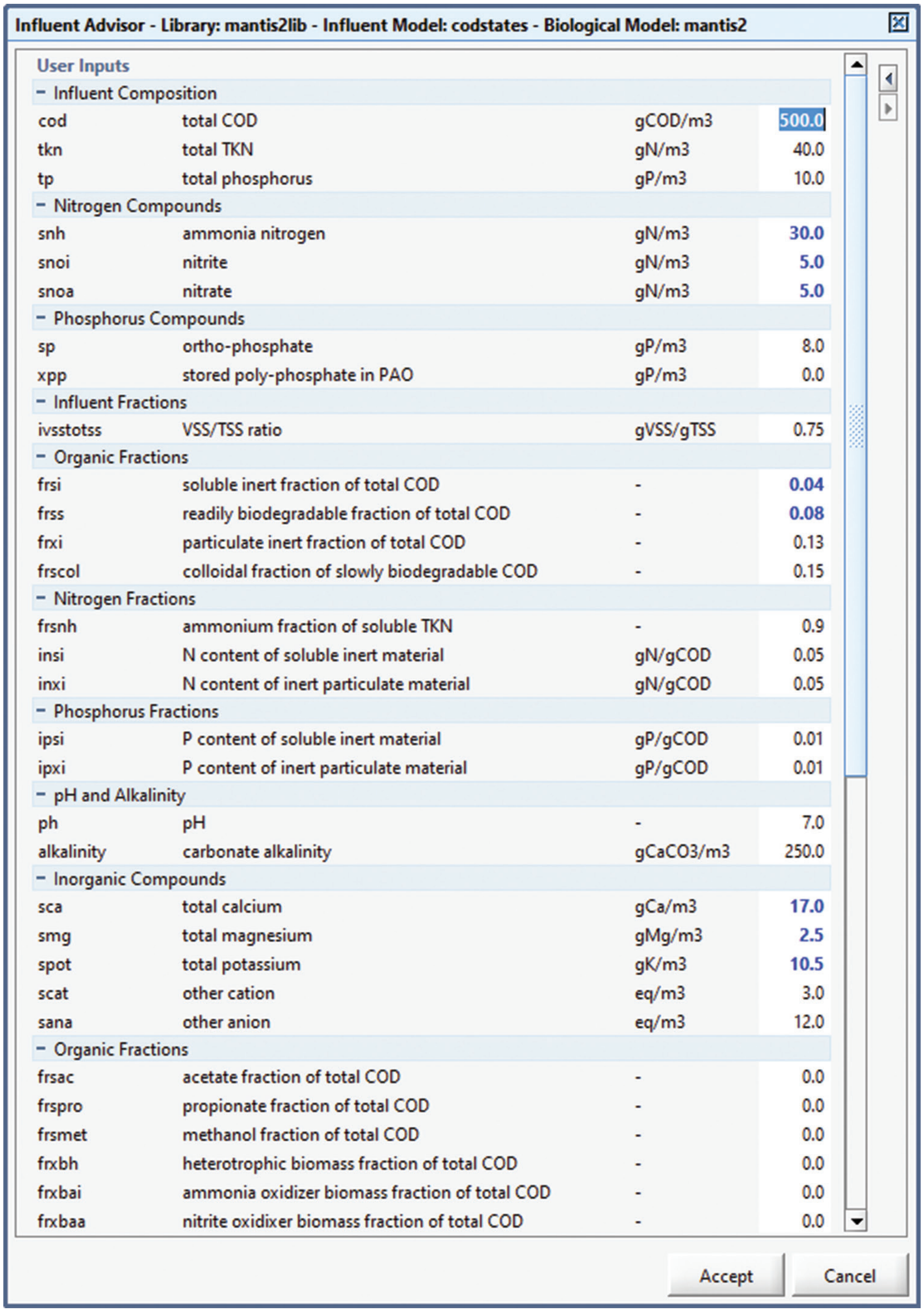


Fig. 2. Layout of the membrane bioreactor treatment plant.



Influent Advisor - Library: mantis2lib - Influent Model: codstates - Biological Model: mantis2

User Inputs

− Influent Composition			
cod	total COD	gCOD/m3	500.0
tkn	total TKN	gN/m3	40.0
tp	total phosphorus	gP/m3	10.0
− Nitrogen Compounds			
snh	ammonia nitrogen	gN/m3	30.0
snoi	nitrite	gN/m3	5.0
snoa	nitrate	gN/m3	5.0
− Phosphorus Compounds			
sp	ortho-phosphate	gP/m3	8.0
xpp	stored poly-phosphate in PAO	gP/m3	0.0
− Influent Fractions			
ivsstotss	VSS/TSS ratio	gVSS/gTSS	0.75
− Organic Fractions			
frsi	soluble inert fraction of total COD	-	0.04
frss	readily biodegradable fraction of total COD	-	0.08
frxi	particulate inert fraction of total COD	-	0.13
frscol	colloidal fraction of slowly biodegradable COD	-	0.15
− Nitrogen Fractions			
frsnh	ammonium fraction of soluble TKN	-	0.9
insi	N content of soluble inert material	gN/gCOD	0.05
inxi	N content of inert particulate material	gN/gCOD	0.05
− Phosphorus Fractions			
ipsi	P content of soluble inert material	gP/gCOD	0.01
ipxi	P content of inert particulate material	gP/gCOD	0.01
− pH and Alkalinity			
ph	pH	-	7.0
alkalinity	carbonate alkalinity	gCaCO3/m3	250.0
− Inorganic Compounds			
sca	total calcium	gCa/m3	17.0
smg	total magnesium	gMg/m3	2.5
spot	total potassium	gK/m3	10.5
scat	other cation	eq/m3	3.0
sana	other anion	eq/m3	12.0
− Organic Fractions			
frsac	acetate fraction of total COD	-	0.0
frspro	propionate fraction of total COD	-	0.0
frsmet	methanol fraction of total COD	-	0.0
frxbh	heterotrophic biomass fraction of total COD	-	0.0
frxbai	ammonia oxidizer biomass fraction of total COD	-	0.0
frxbaa	nitrite oxidixer biomass fraction of total COD	-	0.0

Accept Cancel

Fig. 3. Influent chemical oxygen demand-state model inputs using MANTIS2 library.

H. Influent Characteristic and MLSS Concentration Calibration

While COD, ammonia, TN, and heavy metals from Tables II and III can be directly entered into the influent advisor window of the COD-states model (Hydromantis, 2020), values for TSS and BOD must be derived through calibration. This is achieved by adjusting the VSS/TSS ratio and organic fractions. The VSS/TSS ratio was determined to be 0.8 based on laboratory analysis (Nemerow, 2010).

To replicate the fluctuating organic load in the influent, a sinusoidal load type with an amplitude scaling factor of 0.5 was applied (Serdarevic, Spanjers and Van Lier, 2016).

I. Solid Capture Rate Calibration

The solid capture rate has been manually calibrated. The equation below illustrates how to determine the solid capture rate by determining the average difference between the MBR MLSS and outflow TSS concentration (Judd, 2010).

$$SCR = \frac{MBR\ MLSS - effluent\ TSS}{MBR\ MLSS} \quad (3)$$

Where
SCR = Solid capture rate (dimensionless)
$TSS_{effluent}$ = Total suspended solids concentration in the effluent (mg/L)
MLSS = MLSS concentration in the MBR tank (mg/L).

J. Sludge Production

The solid retention time (SRT) is calculated using the equation below (Barreto, Alzate Marin and Judd, 2017):

$$SRT = \frac{V\ x\ X}{Qw\ x\ Xw} \quad (4)$$

Where
SRT: SRT (days)
V: Volume of the bioreactor (m^3)
X: MLSS concentration in the bioreactor (mg/L or kg/m^3)
Qw: Waste sludge flow rate (m^3/day)
Xw: Concentration of solids in waste sludge (mg/L or kg/m^3).

K. DO Concentration

DO concentration is a key operational parameter and was configured using the DO controller settings in GPS-X. Maintaining appropriate DO concentrations is critical for supporting aerobic biological processes within the MBR system.

III. Results and Discussion

A. Water Quality Analysis Results

This section presents the wastewater testing results for both influent and effluent samples. Each water quality parameter measured is essential for evaluating the treatment process. The parameters analyzed include COD, BOD, TSS, TKN, Ammonia, TN, and heavy metals, all of which serve as key water quality indicators. In addition, the MLSS in the MBR and effluent TSS analyses were conducted to assess the solid capture rate. TSS also serves as an important indicator of membrane removal efficiency (Meng, et al., 2017; Abbasi, Ahmadi and Naseri, 2021).

The remaining parameters were used to evaluate the overall performance of the simulation by comparing predicted values with laboratory results. These parameters also help assess the operational capabilities of the treatment plant.

Similar studies have emphasized the value of simulation-based analysis and data-driven optimization in wastewater treatment systems, particularly in modeling MBR performance and influent variability (Mabrouki, et al., 2022; Bencheikh, et al., 2020; Fattah, et al., 2023).

Fig. 4 presents the effluent water quality results from May 2022. The COD values in the effluent ranged between 45 mg/L and 76.9 mg/L, indicating moderate organic content after treatment. Despite the variability in influent loading, the effluent COD remained below the regulatory limit of the Malaysian standard (Standard B: 100 mg/L; Standard A: 50 mg/L), demonstrating that the MBR system effectively reduced organic pollutants to acceptable levels. While the MBR system meets some regulatory limits, its performance, particularly concerning the elevated TSS and higher BOD/COD readings, is below the typical efficiency expected from MBR plants worldwide. This indicates areas for potential optimization in the system's operation or membrane maintenance.

The COD levels in these streams fluctuate between 200 mg/L and 1655 mg/L. This fluctuation is related to the inconsistency of treatment plant performance and presents challenges for the calibration of simulation models, which assume more stable input conditions.

The higher maximum value is consistent with the presence of industrial wastewater or illegal discharge into the sewer system. Such high organic loads are observed to correspond with overwhelming of biological treatment capacity, accelerated membrane fouling, and reduced overall efficiency of the MBR system. This also contributes to the difficulty in calibrating the GPS-X model, as the actual influent characteristics were not uniform or predictable.

Fig. 5 shows that effluent samples collected in June 2022 and analyzed at University Sains Malaysia confirmed continued compliance with Malaysian Standard B for COD (100 mg/L). These results further validate the MBR system's performance in maintaining acceptable effluent quality under operational conditions.

B. Calibration Results

To validate the GPS-X simulation model, calibration was performed using actual operational data from the MBR tank at the treatment plant. The goal was to match the model's predicted MLSS values with real measurements. The measured data collected over a 30-day period in May 2022 includes DO, TMP, MLSS concentrations, incoming flow-rate, and a SRT of 10 days. These values are summarized in Table IV and were used as the benchmark for calibrating the model.

Table V presents daily operational data from the MBR tank for May 2022, including measurements of DO, TMP, MLSS, and incoming flow rate (Qin). This data set is essential for GPS-X model calibration and validation, as it allows comparison between simulated and observed plant performance under variable operational conditions.

Fig. 6 illustrates the relationship between simulated MLSS values (line) and actual measured MLSS values (dots) based on operational data from May 2022 (Table IV). This comparison highlights the discrepancy between the model output and real-world measurements before calibration. The figure demonstrates that, without adjustment, the simulation does not adequately capture the dynamic biological behavior of the MBR system, particularly in response to fluctuating operational conditions.

Fig. 7 presents the relationship between predicted and measured MLSS values following calibration of the GPS-X model. After adjusting key parameters such as inflow rate and applying a sinusoidal load profile with an amplitude scaling factor of 0.5, the model's predictions are more closely aligned with actual observations. This figure underscores how calibration improves model fidelity by accounting for real-world variability in organic loading and biomass dynamics.

Fig. 8 explores the correlation between incoming flow rate and MLSS concentration during the study. It reflects the impact of diurnal fluctuations in influent loading on MLSS dynamics within the MBR tank. The use of a sinusoidal

TABLE IV
Operational Data of the MBR Tank (May 2022)

Date	DO in MBR (mg/L)	TMP (bar)	MLSS MBR in Tank (mg/L)	Flow-rate Incoming (Qin) (m^3/day)
May 1, 2022	60	0.2	1360	N/A
May 2, 2022	45	0.3	1250	1,390
May 3, 2022	56	0.3	1120	2,001
May 4, 2022	29	0.3	1160	3,343
May 5, 2022	37	0.3	1460	3,478
May 6, 2022	31	0.32	1400	4,309
May 7, 2022	40	0.3	1200	3,240
May 8, 2022	42	0.32	1320	975
May 9, 2022	36	0.32	1540	3,274
May 10, 2022	32	0.32	1340	3,960
May 11, 2022	40	0.3	1120	2,272
May 12, 2022	47	0.3	1540	2,414
May 13, 2022	31	0.3	1240	2,999
May 14, 2022	32	0.25	1340	2,710
May 15, 2022	36	0.25	1320	2,027
May 16, 2022	23	0.32	1320	2,103
May 17, 2022	32	0.2	1240	2,231
May 18, 2022	38	0.2	1960	2,687
May 19, 2022	40	0.3	1380	2,870
May 20, 2022	41	0.3	1300	2,976
May 21, 2022	0	0.25	1380	2,143
May 22, 2022	0	0.25	1380	3,200
May 23, 2022	16	0.32	1500	2,425
May 24, 2022	29	0.32	1360	2,726
May 25, 2022	25	0.2	1580	3,469
May 26, 2022	31	0.3	1760	1,644
May 27, 2022	27	0.2	1740	2,955
May 28, 2022	0	0.2	1480	1,932
May 29, 2022	0	0.2	1700	3,051
May 30, 2022	0	0.3	1400	2,438

MBR: Membrane bioreactor, MLSS: Mixed liquor suspended solids, TMP: Trans-membrane pressure

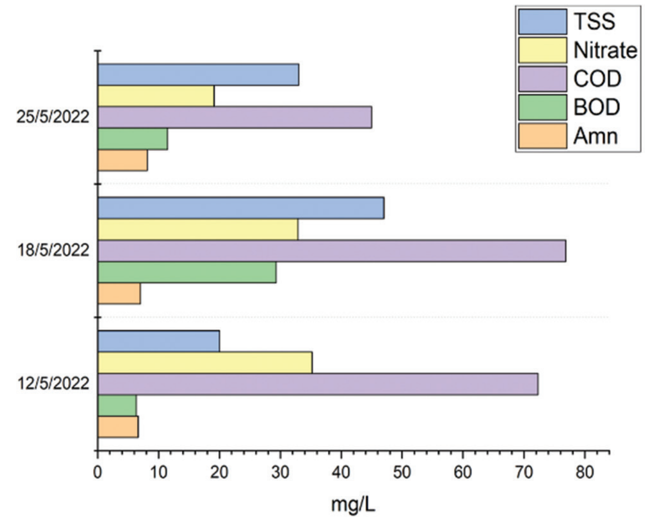


Fig. 4. Effluent water quality analysis (May 2022).

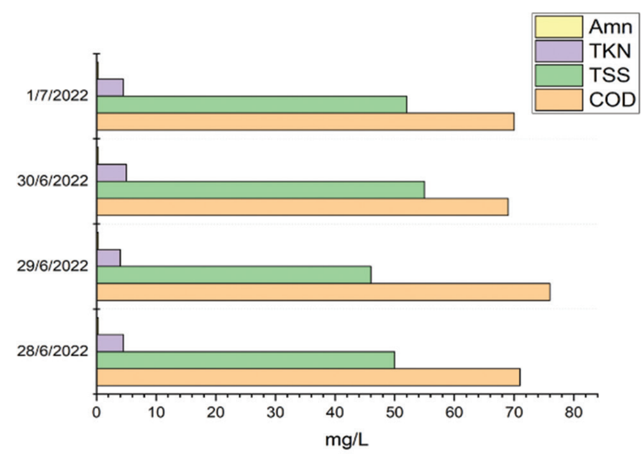


Fig. 5. Effluent water quality analysis (June 2022–USM laboratory results).

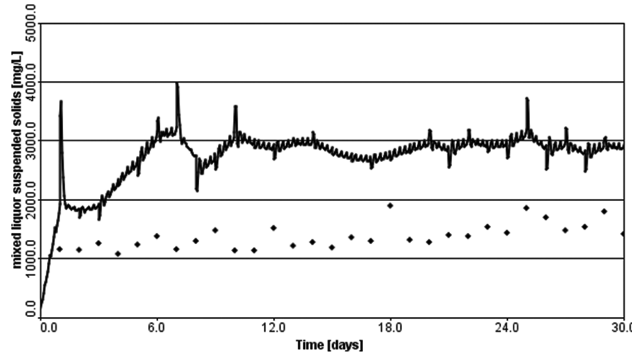


Fig. 6. Mixed liquor suspended solids: Predicted versus measured (before calibration).

TABLE V
Summarizing of Feed and Treated Water Quality of MBR system (Kitagawa, Matsushita and Hara, 2012)

Parameter	Feed water high	Feed water low	Feed water average	Treated water high	Treated water low	Treated water average
pH	7.5	6.8	7	7.9	6.4	7
TSS mg/L	347	106	180	<10	<10	<10
BOD mg/L	481	65	264	5.6	<2	<2
COD mg/L	600	220	382	80	<50	<50
TOC mg/L	56.3	17.9	38.3	7.8	5.1	6
TN mg/L	52.2	36.2	44.1	12.6	8.7	11
TP mg/L	12.9	8.4	10.6	6.6	11.8	3.6

TSS: Total suspended solids, BOD: Biochemical oxygen demand, COD: Chemical oxygen demand, TN: Total nitrogen, MRB: Membrane bioreactor

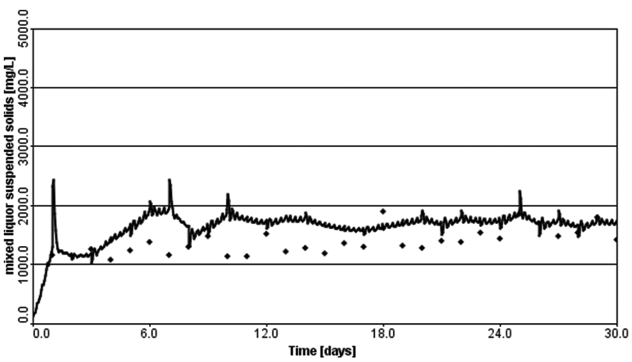


Fig. 7. Mixed liquor suspended solids: Predicted versus measured (after calibration).

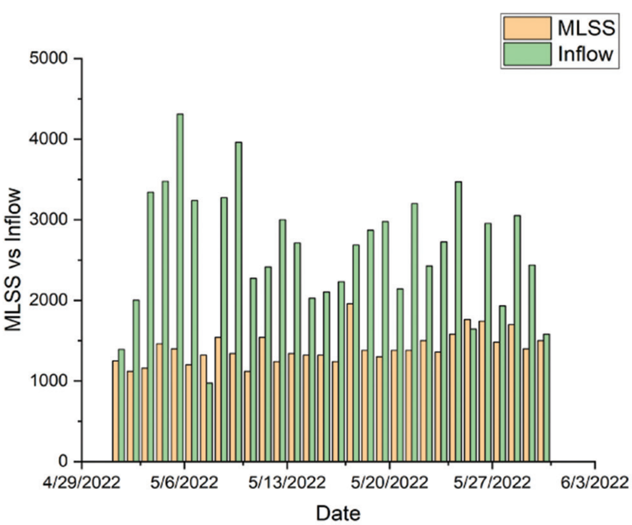


Fig. 8. Relationship between incoming flow-rate and mixed liquor suspended solids concentration.

inflow pattern in the model helped simulate this variability. Notably, MLSS sampling was performed at 9:00 a.m., a period typically associated with lower flow and organic load, which may influence the observed values and affect model calibration outcomes.

Fig. 9 shows the relationship between predicted and actual effluent concentrations for key water quality parameters. While the general trend is captured, the figure reveals deviations, particularly around day 12, where the influent experienced a spike in organic load (COD = 1655 mg/L, TSS = 1430 mg/L, BOD = 620 mg/L). This mismatch

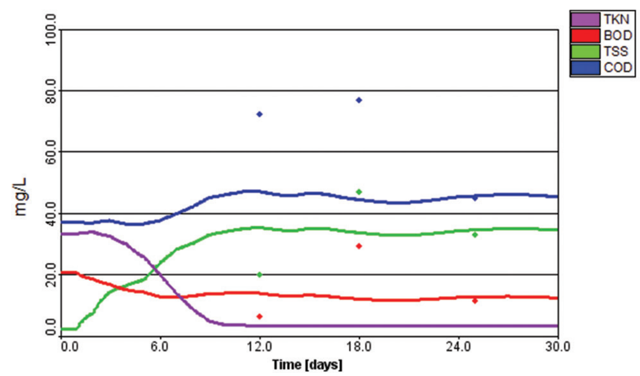


Fig. 9. Predicted versus measured effluent concentrations.

highlights the sensitivity of effluent quality to influent fluctuations and the limitations of current simulation input resolution. The results emphasize the importance of high-frequency influent monitoring to enhance the accuracy of model predictions (Serdarevic, Spanjers and Van Lier, 2016; Meng, et al., 2017).

C. System Evaluation

MBR systems are designed to operate under high MLSS concentrations and low food-to-microorganism (F/M) ratios. High MLSS supports extended SRT, allowing sufficient time for microbial acclimatization and enhanced pollutant degradation.

Table IV presents operational data from the MBR tank, including DO, TMP, MLSS, and influent flow rate. While the current system meets Malaysia's effluent standards based on the prevailing organic loading and flow rates, its performance remains suboptimal when benchmarked against typical MBR efficiency standards.

First, the TSS removal is inadequate. Standard MBR systems typically achieve over 99% TSS removal, with effluent concentrations ranging between 5 and 10 mg/L. In contrast, the current system discharges TSS levels between 20 and 50 mg/L.

Second, the system exhibits energy inefficiencies. It was originally designed for operation at an MLSS concentration of 8000 mg/L and TMP of 0.2 bar (Judd, 2010). However, the actual MLSS levels are consistently below 2000 mg/L, and TMP ranges between 0.2 and 0.3 bar. Despite this, the system continues to employ the same air scouring intensity required for 8000 mg/L MLSS,

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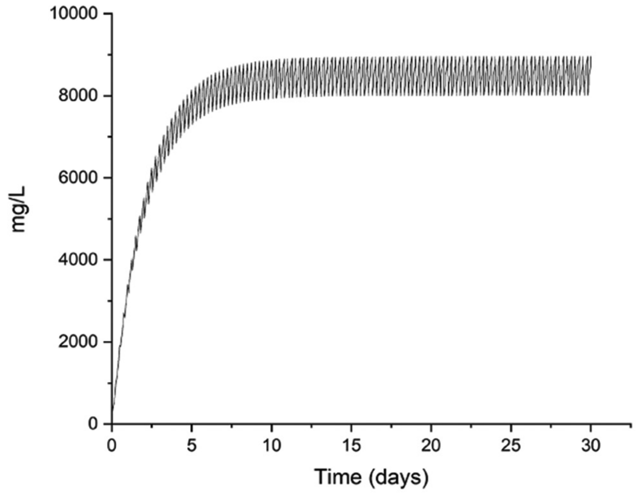

Fig. 10. Mixed liquor suspended solids in membrane bioreactor (detailed simulation).

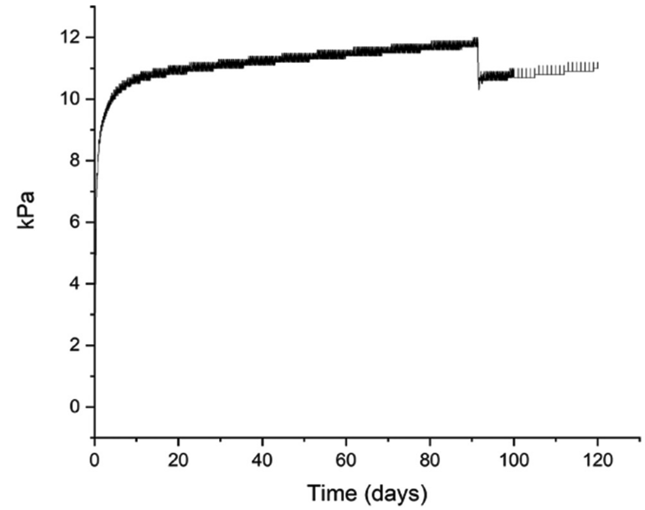

Fig. 11. Transmembrane pressure (detailed simulation).

leading to unnecessarily high DO concentrations and increased energy consumption.

Furthermore, the plant was designed to treat 6750 m^3/day of wastewater, yet current inflow volumes are around 2000 m^3/day. As a result, the plant struggles to deliver effluent quality superior to that of conventional treatment systems. Given the higher operational costs and energy demands of MBR systems (Barreto, Alzate Marin and Judd, 2017), the current setup falls short of meeting the intended MBR objectives.

D. Simulation Results

After completing the calibration process, the simulation was executed using the influent characteristics detailed in Tables II and III under defined operational conditions.

E. Detailed Simulation Approach

The simulation integrates advanced modeling features such as cake layer formation, TMP evolution, and scheduled membrane cleaning events. These mechanisms enable a comprehensive depiction of the MBR system's long-term operational dynamics.

Fig. 10 shows MLSS concentrations between 7500 and 9000 mg/L, indicating stable biomass levels under simulated optimal conditions. This high MLSS range supports better biological treatment performance by enhancing microbial activity and sludge retention time, leading to improved system efficiency.

Fig. 11 shows a gradual increase in TMP over time, with a sharp decline around day 90 indicative of a chemical membrane cleaning event. These cleanings, typically conducted every 2–3 months using agents such as sodium hypochlorite or citric acid (Meng, et al., 2017; Judd, 2010), are crucial for restoring membrane permeability. This trend confirms the model's ability to simulate realistic maintenance schedules and their impact on system performance.

Fig. 12 presents the average daily effluent concentrations of COD, BOD, and TSS over the simulation period. Although

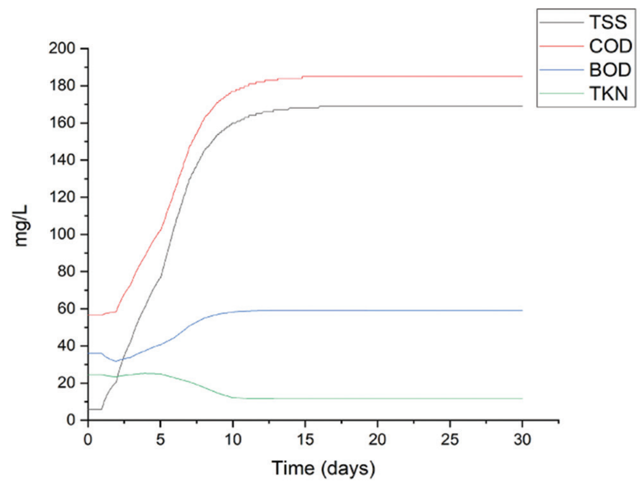

Fig. 12. Average daily effluent concentration (detailed simulation).

slight improvements are observed compared to earlier model outputs, the effluent values still exceed regulatory limits. Nonetheless, the incorporation of membrane fouling and cleaning dynamics provides a more accurate representation of long-term system behavior. This makes the model a valuable tool for operational planning and performance optimization, particularly in full-scale MBR applications (Serdarevic, Spanjers and Van Lier, 2016).

IV. Conclusion

Although the treatment process complies with Malaysia's effluent standards under the current flow and organic load, it operates inefficiently. TSS removal performance is sub-optimal compared to typical MBR systems, with effluent concentrations ranging from 20 to 50 mg/L, rather than the expected 5–10 mg/L. The system also demonstrates energy inefficiency, operating at a TMP of 0.2–0.3 bar and maintaining air scouring rates suitable for an MLSS of 8000 mg/L, whereas actual MLSS remains below 2000 mg/L. Furthermore, the plant is significantly underloaded, treating only approximately 2000 m^3/d of wastewater against its 6750 m^3/d design capacity. This under-utilization results in performance outcomes more characteristic of conventional treatment systems, despite the higher investment and operational costs associated with MBR technology. Model calibration was limited by insufficient operational data; specifically, solid capture and TMP were modeled without incorporating cake layer development, leading to overestimation of effluent concentrations.

V. Recommendation to Improve Model l Accuracy

1. Replace grab sampling with composite sampling to obtain more representative and consistent influent and effluent data, reducing the impact of short-term fluctuations.
2. Acquire long-term operational data from plant operators to establish reliable baselines for model calibration and validation.
3. Conduct wastewater sampling over a minimum 10-day period, ensuring that data collection avoids plant maintenance activities and periods of abnormally low loading to reflect typical operational conditions.
4. Request membrane resistance and solid capture rate specifications directly from the manufacturer, or generate them through pilot-scale MBR testing to improve the accuracy of TMP and TSS modeling.

VI. Acknowledgment

Many thanks to the laboratory technicians for their help while collecting the samples from Kuala Lumpur and to the lead engineer, Muhammed Hariz, and engineer Aslam for providing the data, and Mr. Nick for allowing us to use one ocean treatment plant facility and National Water Research Institute of Malaysia for providing RUI grant and One Ocean Company for providing One Ocean Environment Sdn Bhd Grant.

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