Asian Journal of
Science, Technology, Engineering, and Art

e-ISSN : 3025-4507
p-ISSN : 3025-5287
Index : Harvard, Boston, Sydney University, Dimensions, Lens, Scilit, Semantic, Google, etc

https://doi.org/10.58578/AJSTEA.v2i2.2797

BIOCHEMICAL OXYGEN DEMAND MODELING IN WASTE STABILIZATION POND MODEL

Phoummixay Siharath[1], Somchay Vilaychaleun[2], Khampasith Thammathevo[3], Soulyphan Kannitha[4], Chankhachone Sonemanivong[5], Phaiphana Siharath[6], Sangkhom Singharaj[7], Thongsalak Saktikoun[8], Keoduangchai Keokhamphui[9]
National University of Laos, Lao PDR
phoummixay2011@gmail.com

Article Info:

Submitted:	Revised:	Accepted:	Published:
Feb 20, 2024	Mar 7, 2024	Mar 10, 2024	Mar 13, 2024

Abstract

The objective of the study is to optimize the kinetic reaction value and model the Biochemical Oxygen Demand (BOD_5) on remaining and removal in the waste stabilization pond model, therefore, the waste stabilization pond system includes an anaerobic, facultative and maturation ponds, the study are employed the initial concentration of BOD_5 (44.67±6.79 mg/l) from the wastewater sources at Huakhua village, Xaysettha District, Vientiane Capital, additionally, the evaluation are conducted in 3 hydraulic schemes that includes: plug flow, complete mix(single cell) and complete mixed (equal cells in series), consequently, according to the results found that: kinetic reaction values is 0.49 d^{-1} and the coefficient of determination (R^2) are 0.99, 0.95 and 0.98, respectively.

Keywords: Anaerobic, BOD_5 , Facultative, Kinetic Reaction, Maturation

AJSTEA Journal is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License

INTRODUCTION

Currently, Waste Stabilization Pond(WSP) is common method to treat waste water by natural based solution with biological treatment(Islami, et al. , 2022) and also popular to employs in the urban, large communities to improve water quality (Sunarsih Sunarsih, 2018), wastewater treatment is very crucial process to reduce high concentration of pollutant contamination in water and conserve sustainable water and ecosystem (Siharath, Sonemanivong, et al. , 2023; Siwiec, et al. , 2011), The WSP system includes an anaerobic, facultative and maturation ponds(Siharath, et al. , 2024). Therefore, Biochemical Oxygen Demand (BOD) is a vital parameter to indicate the requirement of oxygen in water (Ogarekpe, et al. , 2012), BOD is a measure of the dissolved oxygen consumed by microorganisms(Gitta Agnes, et al. , 2017; Mekaoussi, et al. , 2023; S Sunarsih, et al. , 2020) during the oxidation of reduced substances in waters and wastes(Shekarabi, 2023; Siharath, Vilaychaleun, Thammathevo, Sonemanivong, Kannitha, Nhaovarath, et al. , 2023), the use of mathematical models describing wastewater treatment is taken into consideration. the BOD concentrations were used in the first order kinetics parameters(Shekarabi, 2023) (ultimate BOD and BOD reaction rate constant) determination using various methods(Khusravi, et al. , 2013; Mazumder & Bhaduri, 2020; Oke, et al. , 2016; Siharath, Vilaychaleun, Thammathevo, Sonemanivong, Kannitha, Phommakone, et al. , 2023).

METHODS

Waste Stabilization Pond model

The WSP system is set up to model and treat wastewater(Siharath, Xayyamunh, et al. , 2023), to reduce and minimize the organic content or gets rid of pathogen in wastewater(Adibe & Ugwuanyi, 2019; S Sunarsih, et al. , 2021), in particular, the system includes 3 components such: aerobic pond , facultative ond and maturation pond as depicted in Figure1.

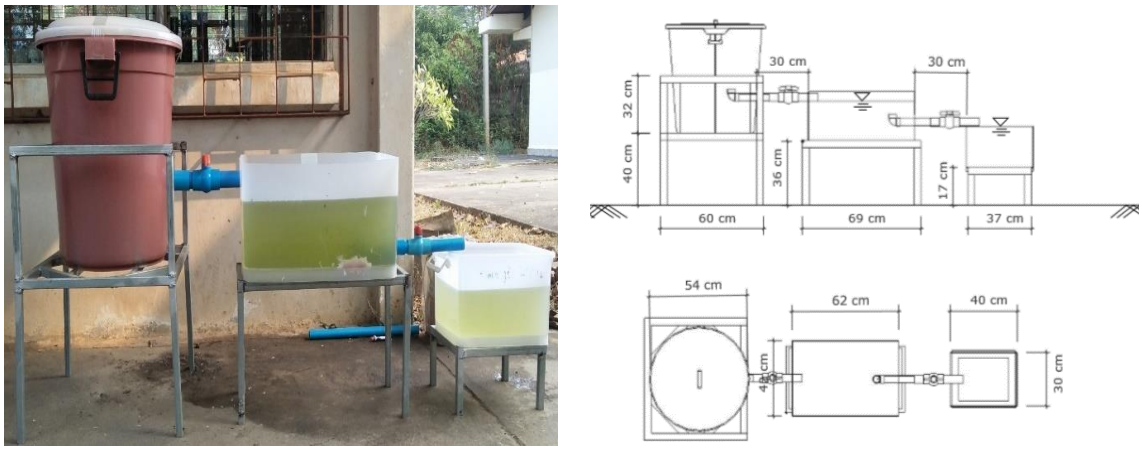


Figure 1: Waste Stabilization Pond Model

Table1: Results of the wastewater treatment in the waste stabilization pond model(Siharath, et al. , 2024)

No	Parameter	Unit	Waste Stabilization Pond			
			Wastewater	Anaerobic pond	Facultative pond	Maturation pond
01	BOD_5	mg/L	44.67±6.79	15.47±0.95	12.83±0.76	11.67±1.26

BOD modelling and Equations

The study is employed formulas to evaluate and calibrate the BOD concentration of remaining and removal in the hydraulic regime(Alavi, et al. , 2022; Ammary, et al. , 2014; Sunarsih Sunarsih, et al. , 2021; Von Sperling, 2007) as below:

1.Plugflow scheme $s = s_0 e^{-Kt}$ (i)

2.Complete mix (Single cell) $s = \frac{s_0}{1+Kt}$ (ii)

3.Complete mixed (equal cells in series) $s = \frac{s_0}{(1+\frac{Kt}{n})^n}$ (iii)

Where:

s_0: Total influent BOD concentration (mg/l)

s: Soluble effuent BOD concentration (mg/l)

K: BOD removal coefficient (d^{-1})

t: Total detention time in the system (d)

n: Number of series pond in series

$$4.R^2 = \frac{\sum_{i=1}^{n}(BOD_{pred,i}-\overline{BOD_{pred}})(BOD_{obs,i}-\overline{BOD_{obs}})}{\sqrt{\sum_{i=1}^{n}(BOD_{pred,i}-\overline{BOD_{pred}})^2 \sum_{i=1}^{n}(BOD_{obs,i}-\overline{BOD_{obs}})^2}} \quad \text{(iv)}$$

$$5.RMSE = \frac{\sum_{i=1}^{n}(BOD_{pred,i})^2}{\sum_{i=1}^{n}(BOD_{pred})^2} \quad \text{(v)}$$

Where:

R^2: Coefficient of determination

RMSE: Root mean square error

BOD_{pred}: BOD prediction in the model(mg/l)

BOD_{obs}: BOD observation in the model(mg/l)

$\overline{BOD_{pred}}$: The mean of BOD prediction in the model(mg/l)

$\overline{BOD_{obs}}$: The mean of BOD observation in the model(mg/l)

n: number of observation

$$6.\eta = \frac{(BOD_1-BOD_2)}{BOD_1} \times 100\% \quad \text{(vi)}$$

Where:

η: Waste Stabilization pond efficiency, (%)

BOD_1: Effluent concentration, (mg/l)

BOD_2: Discharge concentration, (mg/l)

RESULTS AND DISCUSSION

The Kinetic reaction was set, the ranges are 0.09- 0.7 d^{-1}, they were conducted with trial-and-error values in the model, based on the equation employment(i, ii and iii)(Islami, et al. , 2022; Pattnaik, et al. , 2021; Von Sperling, et al. , 2020), consequently, it was calibrated and found that the optimized value of kinetic reaction value is 0.49 d^{-1} and

finally, the RMSEs in the model (RMSE1(plug flow), RMSE2(complete mix (single cell)) and RMSE3(complete mixed (Equal cells in series)) are found that 7.87 mg/l, 5.065 mg/l and 6.88 mg/l, respectively, as indicated in Table2.

Table 2: Kinetic reaction and Root mean square error relationship in Waste Stabilization Pond

Run	Kinetic reaction(d^{-1})	RMSE1(mg/l)	RMSE2(mg/l)	RMSE3(mg/l)
1	0.09	4.6554	6.223703	5.160349
2	0.11	3.9224	5.307795	4.2451
3	0.13	3.6483	4.601216	3.667982
4	0.16	3.7983	3.859476	3.330783
5	0.19	4.2410	3.43259	3.432859
6	0.22	4.7460	3.256308	3.754704
7	0.25	5.2326	3.263965	4.156487
8	0.28	5.6790	3.392058	4.571925
9	0.31	6.0835	3.590572	4.973862
10	0.34	6.4500	3.825731	5.352589
11	0.37	6.7835	4.076785	5.705777
12	0.4	7.0890	4.331642	6.034123
13	0.43	7.3705	4.5835	6.33946
14	0.46	7.6317	4.828668	6.623943
15	**0.49**	**7.8752**	**5.065268**	**6.889697**
16	0.52	8.1035	5.292472	7.138686
17	0.55	8.3186	5.510057	7.372658
18	0.58	8.5221	5.718143	7.593155
19	0.61	8.7154	5.917043	7.801517
20	0.64	8.8995	6.107165	7.998913
21	0.67	9.0755	6.288963	8.186359
22	0.7	9.2441	6.462903	8.364738

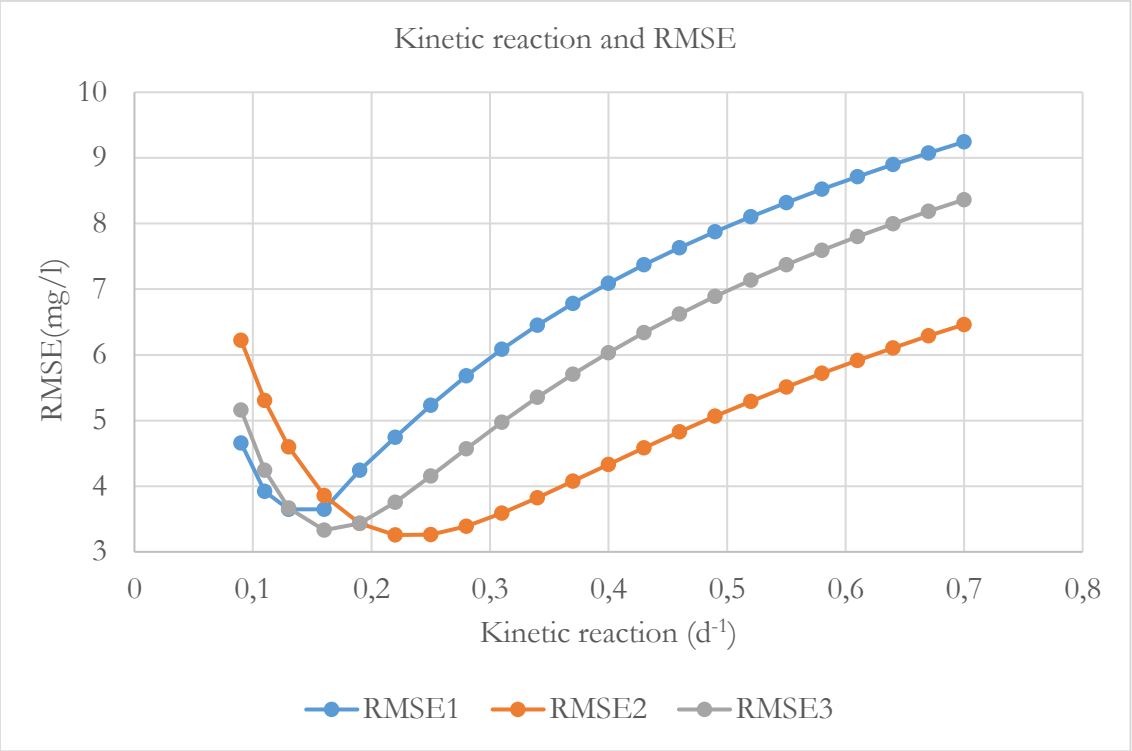


Figure 2: Kinetic reaction and Root mean square error relationship

The Plug flow model indicates that the RMSE1 concentrations are ranged from 6.633±1.898 mg/l as shows in Figure2, when the kinetic reactions are between 0.9-0.13 d^{-1}, RMSE1s are declined between 4.6554 mg/l -3.6483 mg/l, and the kinetic reactions are greater than 0.13 d^{-1}, the RMSE1s are increasing from 3.6483 mg/l to 9.2441 mg/l, simultaneously, Figure3 depicts that the BOD_5 remaining and removal are fitted in the model of plug flow with appropriated Coefficient of determination is 0.99.

Figure4 illustrates the BOD_5 remaining and removed concentration in plug flow hydraulic regime, in anaerobic pond, facultative pond and maturation pond:

- At day 5 the remaining concentrations are 7.36 mg/l, 5.39 mg/l and 5.84, mg/l, during this period, the removed concentrations are 9.03 mg/l, 6.609 mg/l 7.1599 mg/l, respectively.
- At day 10 the remaining concentrations are 3.309 mg/l, 2.42 mg/l and 2.623 mg/l, in the meantime, the removed concentrations are 13.09 mg/l, 9.578 mg/l, 10.376 mg/l, respectively.

- At day 15 the remaining concentrations are 1.486 mg/l, 1.0879 mg/l and 1.17858 mg/l, in this period, the removed concentrations are 14.0139 mg/l. 14.913 mg/l, 10.912 mg/l and 11.82 mg/l, respectively.
- At day 30 the remaining concentrations are 0.134 mg/l, 0.0986 mg/l and 0.1068 mg/concurrently, the removed concentrations are 16.26 mg/l, 11.901 mg/l and 12.893 mg/l and, respectively.
- At day 60 the remaining concentrations are 0.0011 mg/l, 0.0008 mg/l, 0.00087 mg/l, simultaneously, the removed concentrations are 16.398 mg/l. 11.999 mg/l and 12.999 mg/l, respectively.

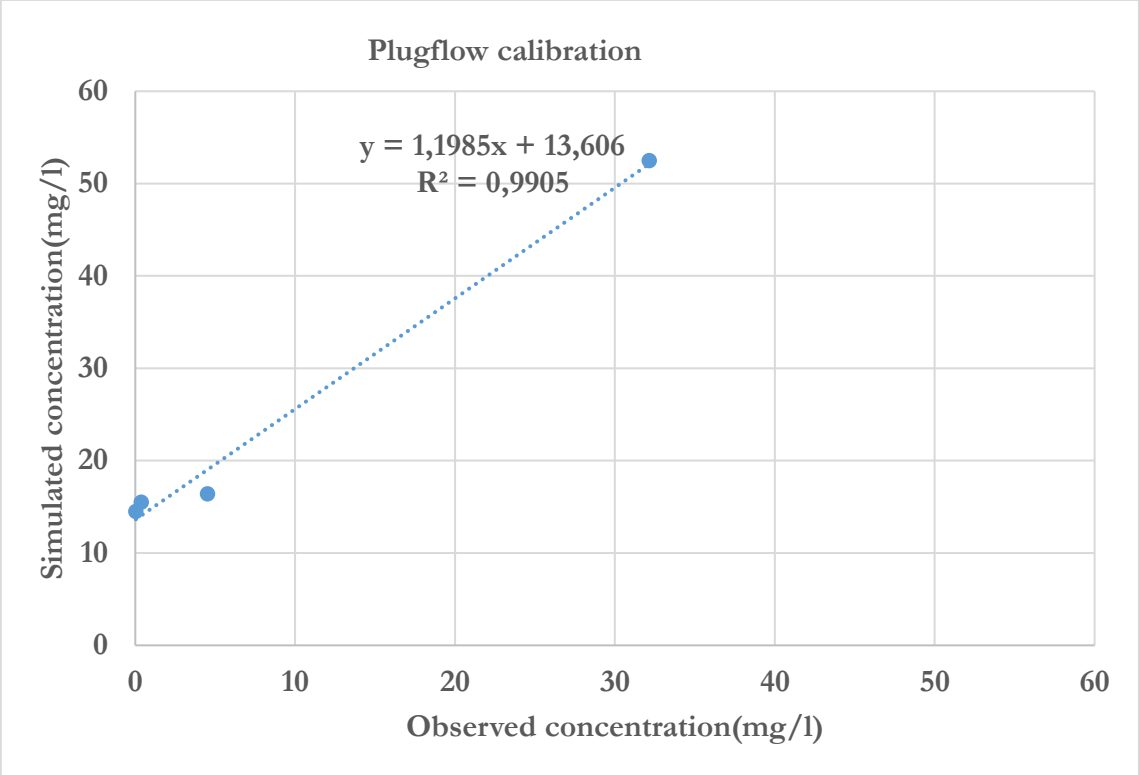


Figure 3: Observed and simulated concentration in Plug flow

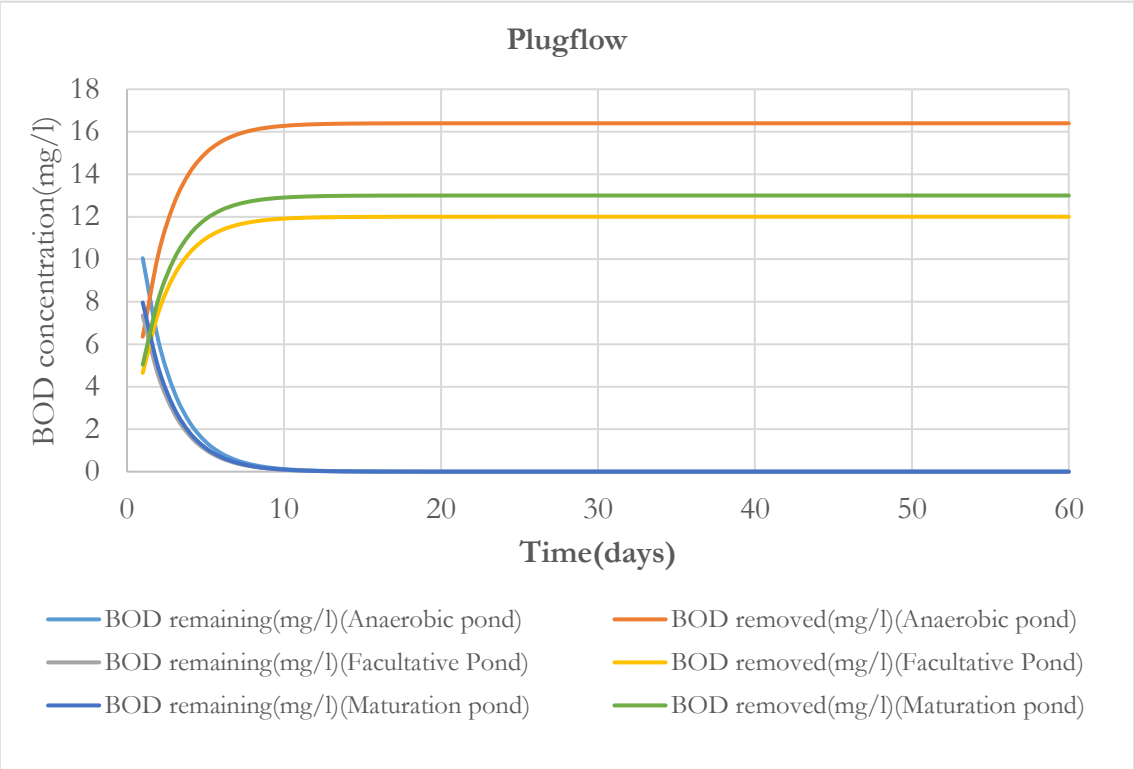


Figure 4: BOD remaining and removal in plug flow

The complete mix (single cell) model shows that the RMSE2 concentrations are ranged from 4.769±1.089 mg/l as indicates in Figure2, when the kinetic reactions are between 0.9-0.34 d^{-1}, RMSE2s are declined between 6.223703 mg/l -3.825 mg/l, and the kinetic reactions are greater than 0.34 d^{-1}, the RMSE2s are increasing from 3.825 mg/l to 6.462 mg/l, in this period, Figure5 depicts that the BOD_5 remaining and removal are fitted in the model of complete mix (single cell) with appropriated Coefficient of determination is 0.956.

Figure6 depicts the BOD_5 remaining and removed concentration in complete mix (single cell) hydraulic regime, in anaerobic pond, facultative pond and maturation pond:

- At day 5 the remaining concentrations are 9.11 mg/l, 6.666 mg/l and 7.2222 mg/l, in the meantime, the removed concentrations are 7.288 mg/l, 5.33 mg/l and 5.78 mg/l, respectively.
- At day 10 the remaining concentrations are 6.31 mg/l, 4.61mg/l and 5.00 mg/l, simultaneously, the removed concentrations are 10.092 mg/l, 7.38 mg/l and 8.00 mg/l, respectively.

- At day 15 the remaining concentrations are 4.82 mg/l, 3.529411765 mg/l and 3.823 mg/l, meanwhile, the removed concentration are 11.576 mg/l,8.47 mg/l and 9.18 mg/l, respectively.
- At day 30 the remaining concentrations are 2.83 mg/l, 2.068 mg/l, and 2.241 mg/l, concurrently, the removed concentrations are 13.57 mg/l, 9.93 mg/l and 1.08 mg/l, respectively.
- At day 60 the remaining concentrations are 1.55 mg/l, 1.1320 mg/l and 1.226 mg/l, during this period, the removed concentrations are 14.8528 mg/l. 1.09 mg/l and 1.18 mg/l, respectively.

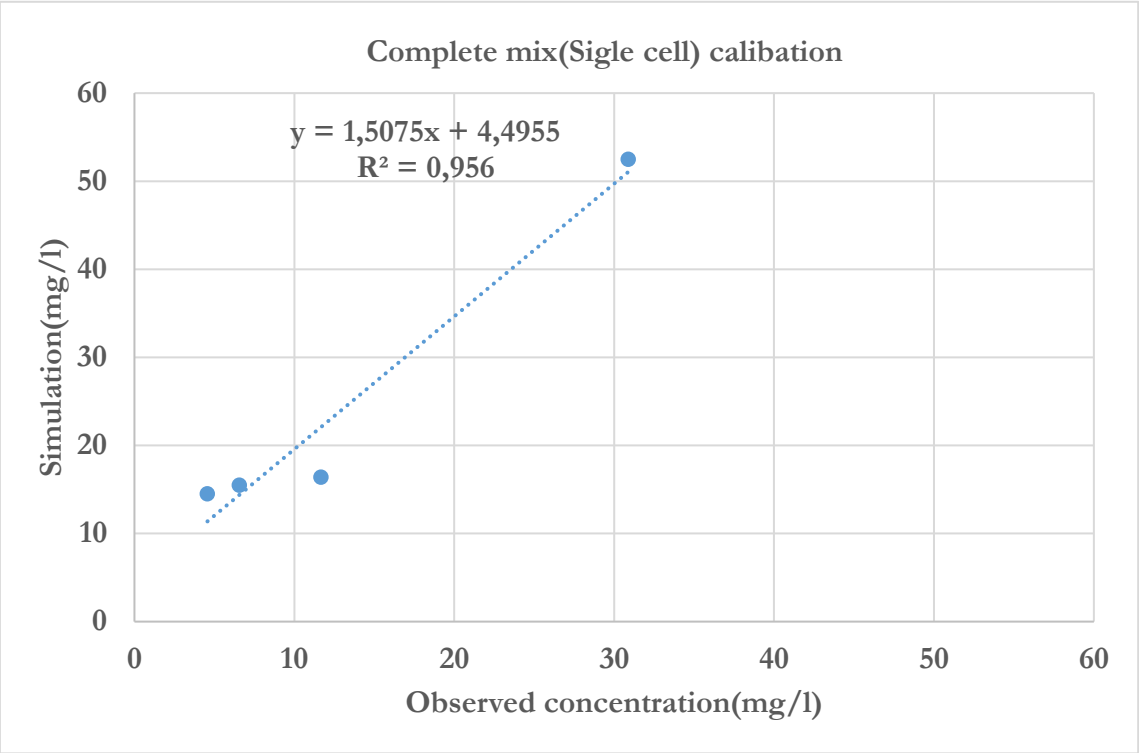


Figure 5: Observed and simulated concentration in complete mix(Single cell)

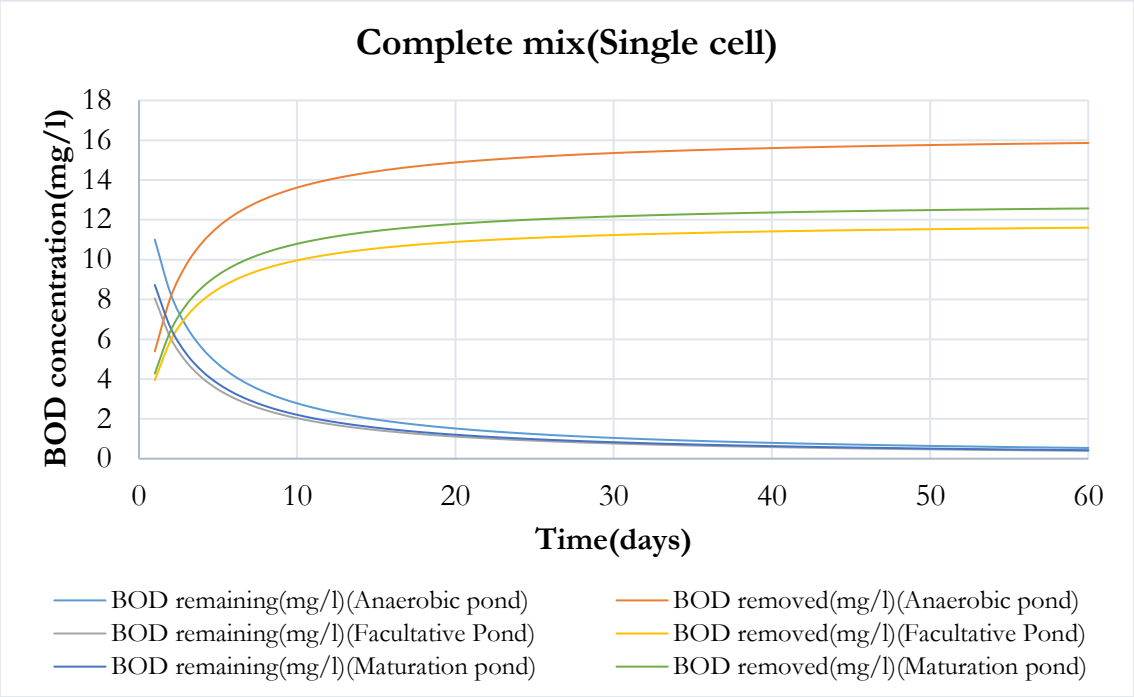


Figure 6: BOD remaining and removal in complete mix(Single cell)

The complete mixed (equal cells in series) model depicts that the RMSE3 concentrations are ranged from 5.849±1.677 mg/l as illustrations in Figure2, when the kinetic reactions are between 0.9-0.16 d^{-1}, RMSE3s are declined between 5.160349 mg/l - 3.33078 mg/l, and the kinetic reactions are greater than 0.16 $d^{-1,}$, the RMSE3s are increasing from 3.33078 mg/l to 8.364738 mg/l, meanwhile, Figure7 depicts that the BOD_5 remaining and removal are fitted in the model of complete mixed (Equal cells in series) with appropriated Coefficient of determination is 0.9865.

Figure8 shows the BOD_5 remaining and removed concentration in complete mixed (equal cells in series) hydraulic regime, in anaerobic pond, facultative pond and maturation pond:

- At day 5 the remaining concentrations are 8.07 mg/l, 5.904 mg/l and 6.40, mg/l meanwhile, the removed concentrations are 2.31 mg/l, 6.1 mg/l and 6.6 mg/l, respectively.
- At day 10 the remaining concentrations are 4.55 mg/l, 3.3286 mg/l and 3.61 mg/l, concurrently, the removed concentrations are 11.85 mg/l, 8.67 mg/l and 9.39 mg/l, respectively.

- At day 15 the remaining concentrations are 2.81 mg/l, 2.057 mg/l and 2.23 mg/l, simultaneously, the removed concentrations are 13.59 mg/l. 9.94 mg/l and 1.08 mg/l, respectively.
- At day 30 the remaining concentrations are 0.93 mg/l, 0.682 mg/l and 0.74 mg/l, during this period, the removed concentrations are 15.47 mg/l, 1.13 mg/l and 1.23 mg/l, respectively.
- At day 60 the remaining concentrations are 0.22 mg/l, 0.1619 mg/l and 0.18, in the meantime, the removed concentrations are 16.18 mg/l. 1.18 mg/l and 1.28 mg/l, respectively.

According to the Plug flow complete mix (single cell) and the complete mixed (equal cells in series) sensitivities analysis. In conclusion, when the models are adjusted and calibrated days are iterated by 5 days' time, the BOD_5 remaining are decreased while BOD_5 removed concentrations are increasing.

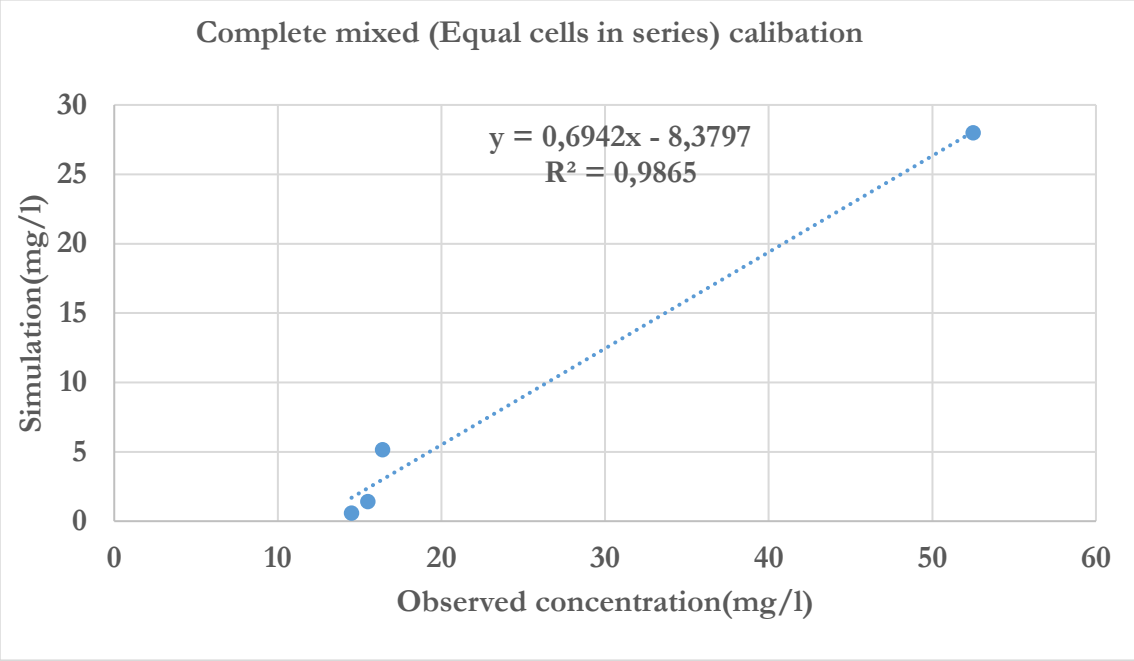


Figure 7: Observed and simulated concentration in complete mixed (equal cells in series)

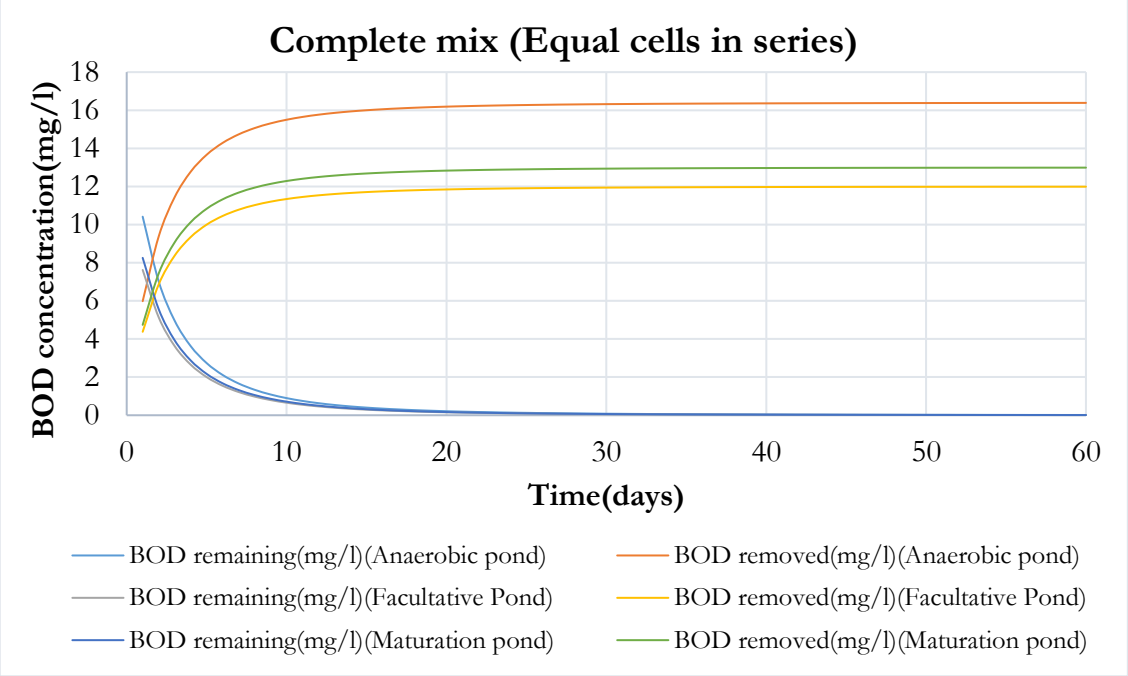


Figure 8: BOD remaining and removal in complete mixed (equal cells in series)

CONCLUSION

In conclusion, the study found that the kinetic reaction value is 0.49 d^{-1} as optimized value among of 3 hydraulic regimes in the model, , therefore, the coefficient of determination (R^2) of plug flow, complete mix (single cell) and complete mixed (equal cells in series) are 0.99, 0.95 and 0.98, respectively, they are fitted to the model between the observed and simulated concentration. The efficiency of waste stabilization pond in anaerobic pond (68.78%), facultative pond (77.14%) and maturation pond (75.24%). Hence, the concentration of BOD_5 in the hydraulic regime system, it is accepted to discharge to environment, it means that the waste stabilization pond is able to treat waste water and it would be good for communities in terms of environmental prevention and sustainable water and environmental health.

Acknowledgement

Authors would like to acknowledge the Global Environment Facility (GEF) Small Grants Programme, UNDP for financial support, Department of Environmental Engineering, Department of Mechanical Engineering, Faculty of Engineering, National University of Laos that support the use of all equipment for experiments and experience

shares knowledge with team.

REFERENCES

Adibe, E. D. T. N., & Ugwuanyi, E. D. S. E. (2019). Study, Analysis and Design of a Waste Stabilization Pond (WSP) for Institute of Management and Technology (IMT) Enugu Community.

Alavi, J., Ansari, S. J. W. S., & Technology. (2022). Kinetic models evaluation for chemical organic matter removal prediction in a full-scale primary facultative pond treating municipal wastewater. *85*(6), 1720-1735.

Ammary, B. Y., Al-Samrraie, L. a. A. J. I. J. o. E., & Management, W. (2014). Evaluation and comparison of methods used for the determination of BOD first-order model coefficients. *13*(4), 362-375.

Gitta Agnes, P., Sunarsih, S., & Susilo, H. J. A. S. L. (2017). Numerical Solution of 2-D Pollutant Distribution Model Based on Advection-Diffusion Mechanism in Waste Stabilization Ponds.

Islami, M. N., Sunarsih, S., & Tjahjana, R. H. (2022). *Stability Analysis of Biological Wastewater Treatment in Facultative Stabilization Ponds: Mathematical Model.* Paper presented at the Soedirman International Conference on Mathematics and Applied Sciences (SICOMAS 2021).

Khusravi, R., Khodadadi, M., Gholizadeh, A., Mehrizi, E. A., Shahriary, T., & Shahnia, A. J. E. J. o. E. B. (2013). BOD5 removal kinetics and wastewater flow pattern of stabilization pond system in Birjand. *3*(2), 430-436.

Mazumder, D., & Bhaduri, S. J. J. O. T. I. C. S. (2020). Simplistic approach for evaluating the BOD rate constants. *97*(9 A), 1399-1405.

Mekaoussi, H., Heddam, S., Bouslimanni, N., Kim, S., & Zounemat-Kermani, M. J. H. (2023). Predicting biochemical oxygen demand in wastewater treatment plant using advance extreme learning machine optimized by Bat algorithm. *9*(11).

Ogarekpe, N., Ibiang, I., & Onyekweredike, K. (2012). An empirical regression model for the prediction of the Biochemical Oxygen Demand in waste stabilization ponds with Nappe flow regime.

Oke, I., Ismail, A., Lukman, S., Foghi, P., Adeosun, O., Amele, S., & Bolorunduro, A. J. I. J. o. S. (2016). An improved solution of first order kinetics for biochemical oxygen demand. *18*(3), 739-752.

Pattnaik, B. S., Pattanayak, A. S., Udgata, S. K., Panda, A. K. J. C., & Systems, I. (2021). Machine learning based soft sensor model for BOD estimation using intelligence at edge. *7*(2), 961-976.

Shekarabi, F. H. J. I. J. o. E. S. (2023). Numerical simulations of stochastic biochemical oxygen demand equations via RBF method. *80*(3), 769-776.

Siharath, P., Sonemanivong, C., Thammathevo, K., Vilaychaleun, S., Mallik, B. B., Khounpaserth, P., . . . Mathematics, C. (2023). Arsenic and Copper Contaminant Transport Modelling In Xaysomboun Province, LAO PDR. *4*(3), 17-30. doi:https://doi.org/10.15864/jmscm.2101

Siharath, P., Tongnamavong, V., Vilaychaleun, S., Thammathevo, K., Kannitha, S., Sonemanivong, C., . . . Leuanglith, Y. J. J. I. M. I. (2024). Waste stabilization pond design for wastewater treatment at Huakhua village, Xaysettha district, vientiane capital. *3*(01), 9-19. doi:https://doi.org/10.58471/esaprom.v3i01.3841

Siharath, P., Vilaychaleun, S., Thammathevo, K., Sonemanivong, C., Kannitha, S., Nhaovarath, P., & Keokhamphui, K. J. J. o. W. S. (2023). Water Quality Assessment in Hong Xeng Channel, Vientiane Capital. *2*(6), 833-841. doi:https://doi.org/10.58344/jws.v2i6.318

Siharath, P., Vilaychaleun, S., Thammathevo, K., Sonemanivong, C., Kannitha, S., Phommakone, B., . . . Art. (2023). Lead and Zinc Groundwater Contaminant Transport Modelling Using MT3DMS in Xaysomboun Province, Lao PDR. *1*(2), 208-228. doi:https://doi.org/10.58578/ajstea.v1i2.1934

Siharath, P., Xayyamunh, K., Vilaychaleun, S., Thammathevo, K., Sonemanivong, C., Kannitha, S., . . . Phommakone, B. J. A. J. o. N. S. (2023). Wastewater Treatment using The Photosynthetic Bacteria at Parksarp Village, Xaythany District, Vientiane Capital. *2*(4), 223-234. doi:https://doi.org/10.55927/ajns.v2i4.5563

Siwiec, T., Kiedrynska, L., Abramowicz, K., Rewicka, A., & Nowak, P. J. A. o. W. U. o. L. S.-S. L. R. (2011). BOD measuring and modelling methods-review. *43*(2).

Sunarsih, S. (2018). *Facultative Stabilization Pond: Measuring Biological Oxygen Demand using Mathematical Approaches*. Paper presented at the E3S Web of Conferences.

Sunarsih, S., Dwi P, S., & Sutrisno, S. J. A. J. o. E. R. e.-I.-p.-I.-V.-., Issue-11, pp-01-05. (2021). Mathematical Model of Biological Oxygen Demand in Facultative Wastewater Stabilization Pond Based on Two-Dimensional Advection-Dispersion Model.

Sunarsih, S., Sasongko, D. P., Sutrisno, S., Putri, G. A., & Hadiyanto, H. J. E. E. R. (2021). Analysis of wastewater facultative pond using advection-diffusion model based on explicit finite difference method. *26*(3).

Sunarsih, S., SUTRISNO, S. J. A. I. S., TECHNOLOGY, & SYSTEMS, E. (2020). Parameter estimation on two-dimenional advection-dispersion model of biological oxygen demand in facultative waster water stabilization pond: case study at Sewon waster water treatment facility. *5*(3), 11-15.

Von Sperling, M. (2007). *Waste stabilisation ponds*: IWA publishing.

Von Sperling, M., Verbyla, M. E., & Oliveira, S. M. (2020). *Assessment of treatment plant performance and water quality data: a guide for students, researchers and practitioners*: IWA publishing.