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Model-based analysis of the effect of temperature in biological wastewater treatment plants for simultaneous removal of organic matter, nitrogen, and phosphorous

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The effect of temperature on the phosphorous, nitrogen, and organic matter removal in an activated sludge system(ASS) has been assessed in this research. Benchmark Simulation Model No.1 (BSM1-P) with an ASS (ASM3bioP) is used and the temperature is chosen between 10 to 35°C. The kinetic expressions for the maximum growth rate of heterotrophic biomass, autotrophic, and phosphate accumulating organisms and their decay rates are considered. Total ammonia, nitrogen, and phosphorous in the effluent are analysed and when the range of temperature is less than 15°C and greater than 30°C, the effluent quality deviates from the legal requirements.

Keywords: ASM3bioP system, Autotrophic activities, BSM1-P model, Effluent quality, Heterotrophic, Temperature co-efficient

Over the past decades, depleting water resources paid the attention in most of the wastewater treatment plants, which involving complex processes to achieve goals such as maximization of profit and minimization of make span with efficient usage of limited resources available. The rapid increase in emerging pollutants has caused major pollution of the ecosystem and it was perceptible by the swift of modern urbanization and industrialization and their use of natural reserves. Besides, the swift of population is evident to the unmanageable ecology pollution (Water, Air and Soil) conditions. The biota system is infected with several pollutants has become major issues by their bio-accumulation and bio-magnifications in food cycle leads to the dysfunction ecosystem and bio-toxicity. Activated sludge process (ASP) system is the engineering operation for biological wastewater treatment plants and researchers developed diverse types of wastewater treatment systems (WWTS) for biological nutrient removal (BNR). The hydraulic loading and temperature vary significantly in a WWTSdue to di-urinal variations and seasonal events. The composition of the influent wastewater changes because of dilution with storm water or due to the changing load of domestic wastewater. When the flow changes, the composition and characteristics of the wastewater also changes. This impacts the biological processes in the plant, such as the changed concentration of carbon source for denitrification, and it also impacts the physical properties of the particles in the activated sludge with the sudden change in ionic strength and corresponding temperature. Usually, the temperature of influent wastewater is greater than that of the operating temperature of any WWTS due to the inclusion of warm water from residences and small scale industrial operations. In accordance with the geographical area, the mean yearly temperature of wastewater varies. For example, in Latin America, the temperature usually ranges from 3 to 27°C. Whereas in Africa, Asia, and Middle East countries, the temperature goes from 28 to 45°C. The temperature of wastewater is a very crucial parameter as it plays a significant role in the happening of reaction rates and metabolic rates of microbes in the wastewater[1].

Stringent effluent limits must be followed while treating wastewater from municipal and industrial sector irrespective of the ambient and operating temperature. WWTS are facing many complications based on the active biomass for the nitrogen removal (N) in treating industrial and municipal influents. The nitrification rate limits the extent of nitrogen. The nitrification rate is known to be the rate constraint step for N removal. Additionally, phosphorous removal based on uptake of acetate in the anaerobic section is crucial in influencing the amount of ploy accumulating organisms (PAO's) and thus the amount of P removed.

In the literature, the effect of temperature on the kinetic processes in a typical WWTS is not extensively studied, and hence in this paper, this is addressed. The lower temperature has less impact on hydrolysis and fermentation. Short term temperature advancements influence the stoichiometry and the kinetic variables. While long term temperature advancements impact the biomass activity.

Generally, the optimal temperatures for biological operations are in the range of 25 to 35°C. The nitrification process ends when the temperature touches 50°C and at 15°C methane yielding bacteria becomes inert. Moreover, at 5°C, autotrophic nitrifying microbes nearly cease functionally[2]. The effluent quality has proved an optimistic assurance with a temperature range from 10 to 30°C[3]. On investigating the temperature effect on bio-P removal, it was found that the rate of aerobic phosphorus uptake becomes extreme in the range of 15 and 20°C[4]. Despite, the solid retention time (SRT) and settling sludge compositions, with the rise in temperature from 25°C the corresponding nitrogen removal happens simultaneously along with denitrification and nitrification reactions[5].

The flocculants in activated sludge after the settling process is investigated when the temperature varies from 3 to 15°C[6]. Additionally, it is noticed that on temperature rise, the suspended solids (SS) from effluent increases and chemical oxygen demand (COD) removal decreases. An investigation based on the temperature effects by considering the temperature from 9 to 30°C in a tannery wastewater treatment in an SBR to assess the nitrogen removal. Moreover, it is observed that above 20°C the effluent quality meets the effluent regulations[7]. A remarkable increment is observed in the removal of COD and SS by raising the temperature from 15 to 35°C in an up-flow micro aerobic sludge system. When temperature changes from 20 to 8°C, the resultant removal rates of COD and SS are reduced[8,9]. The up-flow anaerobic sludge blanket system is studied by changing the temperature from 6 to 32°C to know the bio-kinetic rates for the treatment of sewage wastewater[10]. Temperature is a foremost element that shows the impact on biomass activity which is important to maintain efficient biological activity. Additionally, physicochemical characteristics like dissolved oxygen, settling velocity change, mixed liquor with respect to change in temperature, which ultimately helps in modeling and prediction of activated sludge system[11]. The rate of biological violations either becomes double or becomes half for every 10 to 15°C of temperature rise. According to Van't Hoff's rule, the biological activity rate doubles with every 10°C rise in the temperature. The results of temperature impact on BNR in various studies are conflicting with each other. Many studies stated that phosphorous removal efficiencies exceed at higher temperatures (20-37°C)[12]. PAO governs the microorganisms at low temperatures (10°C) despite the influence on carbon matter. Moreover, the temperature effect did not confer metabolic advantages to glycogen accumulating organisms above PAOs despite considering aerobic metabolism[13]. In a recent investigation, temperature effects are studied based on the activated sludge model (ASM1) on the BSM1 platform the kinetic parameters. It was noticed that, for temperatures less than 20°C and greater than 30°C, the effluent constraints deviated from the stringent limits[14].

Typically, in the global context, the average room temperatures vary with respect to local atmospheric and environmental conditions. The rise in temperature is mostly because of the varying in sudden change in seasonal weather around the world. This work focuses with an aim to signify the temperature effects on phosphorous, nitrogen, and organic matter removal in a BSM1-P platform of an ASP (ASM3bioP).

Experimental section

Mathematical model of the WWTS

Activated sludge models (ASM1, ASM2, ASM2d, ASM3) are internationally recognized, models. In this work, the activated sludge model (ASM3bioP)[15] for biological processes in seven reactor systems with a non-reactive double exponential settling velocity model for the secondary clarifier[16] is considered. The model involves seventeen state variables and twenty-three biological processes in the ASM3bioP and no reactions in the sedimentation zone. The corresponding kinetic expressions for all state variables and stoichiometric parameters are given in the supplementary information. The effluent quality (EQ) required to meet stringent regulations are given in Table 1.

Table 1 — Limits for effluent concentration

Variable	Value
TN	< 18 gN/m^3
COD	< 100 $gCOD/m^3$
NH	< 4 gN/m^3
TSS	< 30 gSS/m^3
BOD_5	< 10 $gBOD/m^3$
TP	< 2 gP/m^3

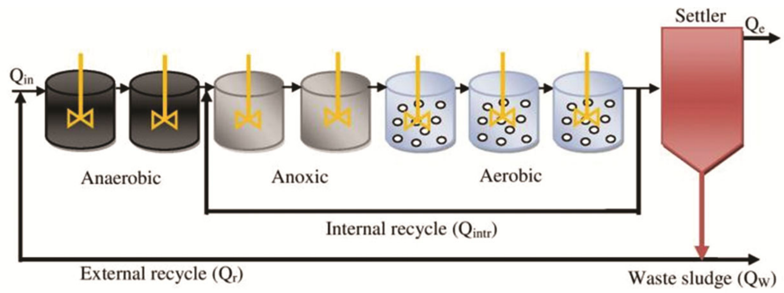

Fig 1 — BSM1-P plant layout

Table 2 — WWTS plant physical configurations

Bioreactor-1(Anaerobic), volume (m^3)	1000
Bioreactor-2(Anaerobic), volume (m^3)	1000
Bioreactor-3(Anoxic), volume (m^3)	1000
Bioreactor-4(Anoxic), volume (m^3)	1000
Bioreactor-5 (Anaerobic), volume (m^3)	1333
Bioreactor-6 (Anaerobic), volume (m^3)	1333
Bioreactor-7 (Anaerobic), volume (m^3)	1333
Depth of the Secondary clarifier (m)	4
Area of the Secondary clarifier (m^2)	1500
Volume of the Secondary clarifier (m^3)	6000
K_La_5 (mass transfer coefficient in reactor 5)	240
K_La_6(mass transfer coefficient in reactor 6)	240
K_La_7(mass transfer coefficient in reactor 7)	252
System variables	
Q_{intr} (m^3/d)	34500
Q_r (m^3/d)	18446
Q_w (m^3/d)	385

Plant treatment structure and composition

The plant layout includes 7 bioreactors (anaerobic-anoxic-oxic in series) and a secondary clarifier as shown in Fig. 1. Here, Q_o represents the influent flow, Q_{intr} represents the internal recycle, and Q_r represents the recycling of external sludge. Q_{intr} carries the wastewater which has enoughconcentration of nitrite to the anoxic tank in order to enhance the denitrification and in order PAO to have an electron acceptor while Q_r supplies the bulk sludge to the 1st anaerobic reactor in WWTP. Besides, $Q_{w,}$ which is waste sludge is taken away constantly from the bottom of the secondary settler. The flow from the 7th reactor goes to the 6th feed layer of the secondary settler which consists of 10-layers[16]. The ASM1 models interchanged with ASM2d for analyzing the removal of P[17]. To remove both N and P, the model of ASM3bioP has 17 variables without taking into account both fermentation and decay. ASM3bioP model denotes the compositions and features of influent wastewater that varies from ASM2d influent data[18]. Here the anaerobic reactor is implemented to yield PAO's that play a key role to remove P. Denitrification step includes the bacteria that use nitrate as an electron acceptor to convert nitrates into dinitrogen. This process happens continuously in the two successive anoxic reactors. Due to nitrification, the ammonium is generated from the corresponding process i.e., converted to nitrite. Hence, both anoxic and aerobic tanks recognize PAO's growth by consuming poly hydroxyl alkanoates (PHA) with the storage of S_{PO4} and convert to X_{PP}. Table 2 represents the physical contributions of plant layout.

Influent data

The influent data and composition are modified from the ASM2d wastewater data[18]. The basic difference is that S_A(fermentation products) and S_F (readily biodegradable substrate) are integrated as S_S in ASM3bioP, and there are no metal precipitation reactions[19].

Processes and State Variables

ASM3bioP process coupled with heterotrophic, autotrophic, and hydrolysis is modelled to relate with the ASM3 model. In addition, biological phosphorus removal is added as documented in the literature[15]. ASM3 has 13 variables by default and an additional 4 new state variables are added from ASM2d. Table 3 shows the bio-P included variables with average influent concentration and units.

Plant evaluation indices

Study state simulations are executed to assure that performance analysis is carried out under the same operating parameters and are compared. Index of plant performance evaluation plays a crucial role to predict the nutrients as well as the quality of the effluent for both combined P and N removal in the benchmark simulation framework of WWTS (BSM1-P). The performance index initially developed for BSM1 for N removal is extended to P[15,20,21]. The extended form of the effluent quality index (EQI) with P, is

Table 3 — State variables of ASM3bio P

Compounds	Symbol	Units	Average influent composition
Dissolved oxygen	S_O	$g(COD)m^{-3}$	0
Readily biodegradable organic substrate	S_S	$g(COD)m^{-3}$	90.34
Inert soluble organic	S_I	$g(COD)m^{-3}$	30
Ammonia+ Nitrogen	S_{nh}	$g(N)m^{-3}$	39.40
Nitrate and nitrite	S_{NO}	$g(N)m^{-3}$	0
Dinitrogen	S_{N2}	$g(N)m^{-3}$	0
Primarily orthophosphates	S_{PO4}	$g(P)m^{-3}$	8.864
Alkalinity	S_{alk}	$mol(HCO3)m^{-3}$	7.001
Inert Particulate	X_I	$g(COD)m^{-3}$	51.20
Slowly biodegradable substrates	X_S	$g(COD)m^{-3}$	202.34
Heterotrophic Organisms	X_H	$g(COD)m^{-3}$	28.17
Cell internal storage	X_{STO}	$g(COD)m^{-3}$	0
Phosphate accumulating organisms	X_{PAO}	$g(COD)m^{-3}$	0
Polyphosphate	X_{PP}	$g(P)m^{-3}$	0
Primarily polyhydroxyalkanoates	X_{PHA}	$g(P)m^{-3}$	0
Nitrifying Organisms	X_A	$g(COD)m^{-3}$	0
Suspended solids	X_{TSS}	$g(SS)m^{-3}$	215.51
Flow	Q_{in}	m^3/day	18446

$$EQ = \frac{1}{100(t_f - t_0)} \int_{t_0}^{t_f} HU_{(t)}\, Q_{e(t)} dt \quad \ldots (1)$$

$$HU_{(t)} = HU_{TSS(t)} + HU_{COD(t)} + HU_{BOD(t)} + HU_{TKN(t)} + HU_{NO_3(t)} + HU_{P_{tot}(t)} \quad \ldots (2)$$

The t_o and t_f in Eq.(1) are the beginning and final times for calculating the EQ. Where HU_t signifies mean pollution load which considers every element in the composition viz. total suspended solids (TSS), biological oxygen demand (BOD_5), COD, total kjeldahl nitrogen (TKN), Nitrate (NO), ammonia (S_{nh}), total nitrogen (TN), and total phosphorus (TP). Thus the related HU_t is estimated in Eq.(3). The elaboration of estimating EQ by the reference of Q_e represents the effluent quality.

Primarily, EQ is basically quantified by TN, S_{NH}, COD, TSS, TP, and BOD_5 compositions

$$HU_t = \beta_t T_t \quad \ldots (3)$$

Where β_t (g^{-1}) are weighting factors ascribe every component of the pollution and are considered as:

$$\beta_{TSS} = \beta_{BOD5} = 2, \beta_{COD} = 1, \beta_{TKN} = 30, \beta_{NO} = 10, \beta_{P_{tot}} = 100.$$

The concentrations of different components (T_t) were assessed based on Eq.(4)-(10).

$$T_{COD} = S_S + S_I + X_I + X_S + X_H + X_{PAO} + X_{PHA} + X_A \quad \ldots (4)$$

$$T_{BOD} = 0.25\left(S_S + (1 - f_{S_I})X_S + (1 - f_{XI_H})X_H + (1 - f_{XI_P})(X_{PAO} + X_{PHA}) + (1 - f_{XI_A})X_A\right) \quad \ldots (5)$$

$$T_{TKN} = S_{NH} + i_{N,S_S}S_S + i_{N,S_I}S_I + i_{N,X_I}X_I + i_{N,X_S}X_S + i_{N,BM}(X_H + X_{PAO} + X_A) \ldots (6)$$

$$T_{N_{tot}} = T_{TKN} + T_{NO_3} \quad \ldots (7)$$

$$T_{NO_3} = S_{NO_3} \quad \ldots (8)$$

$$T_{P_{tot}} = S_{PO_4} + i_{P,S_I}S_I + i_{P,X_I}X_I + i_{P,X_S}X_S + i_{P,BM}(X_H + X_{PAO} + X_A) + X_{PP} \quad \ldots (9)$$

Modelling approach

The analysis of kinetic and stoichiometry parameters is considered to be a key role for optimizing the WWTP in terms of modelling, design, and enhancing the improvement of WWTP biologically. These parameters are highly dependent on the temperature and the sensitivity of biomass. In this study, the ASM3bioP model is executed in Matlab/Simulink environment[15]. The ASM3bioP model comprises 17 state variables that are related to the stoichiometric and kinetic variables to perform all twenty-three processes relating to anaerobic, anoxic, and aerobic decay of autotrophs and heterotrophs, growth of autotroph sand heterotrophs, hydrolysis, ammonification, and phosphorous uptake. The corresponding stoichiometric parameters matrix and process rate equations were obtained. The kinetic and stoichiometric parameters affected by temperature are evaluated at different temperatures, and are given below[20,21].

$$\theta_T = \theta_{T_{ref}}.\exp\left(\left(ln\left(\frac{\theta_{T_{ref}}}{z}\right)/5\right).\left(T - T_{ref}\right)\right) \ldots (10)$$

Where θ_T the parameter value of temperature at T, $\theta_{T_{ref}}$ is the measure of the parameter at a reference temperature T_{ref} and z is the temperature co-efficient. A reference temperature of 20°C is considered[15] and the variables are analysed within the range of 10-35°C by changing the temperature values. The kinetic parameters selected to investigate the effect of temperature coefficients (TC) are given below:

i) Maximum heterotrophic growth rate(μ_{mH})
ii) Maximum autotrophic growth rate(μ_{mA})
iii) Heterotrophic decay rate(b_H)
iv) Autotrophic decay rate (b_A)
v) Maximum growth rate of X_{PAO}(mu_{PAO})
vi) Endogenous respiration rate of X_{PAO} (b_{PAO})

Results and Discussion

Effect of temperature co-efficient on effluent quality

From the literature, it was observed that the kinetic parameters significantly affect the effluent quality. It is noted from Eq.(10) that the kinetic parameters strongly rely on the measure of temperature co-efficient 'z'.Thus, it is imperative to assess the impact of TC in detail. The range of 'z' chosen for kinetic parameters are given below:

i μ_{mH}, 0.8 <z< 8
ii μ_{mA}, 0.6<z< 2
iii b_H,0.05 <z< 1
iv b_A,0.14 <z< 0.3
v mu_{PAO},0.7 <z< 2
vi b_{PAO}, 0.08<z< 0.6

By varying 'z' in these ranges and temperature between 15 – 35°C, simultaneously carried out to understand the effect of this change on the kinetic parameters like μ_{mH}, μ_{mA}, b_H, b_A, mu_{PAO}, and b_{PAO}. The corresponding graphs of μ_{mH} and μ_{mA} are shown in Fig. 2(a), Fig. 2(b), and other kinetic parameters are represented in the supplementary (SF1 to SF3) data. It is observed that the kinetic parameters have shown the highest values between 15–25°C and then observed decaying until 35°C and 10°C.The kinetic parameters are computed for the associating temperature co-efficient using Eq.(10) and the EQ is observed for individual values. Table 4 represents the effluent quality having both state and composite variables when the temperature coefficient is varied between 0.8–8 when the maximum heterotrophic growth rate is determined at 25°C. Similarly, the effect of other kinetic parameters is studied and the corresponding results are given in the supplementary data.

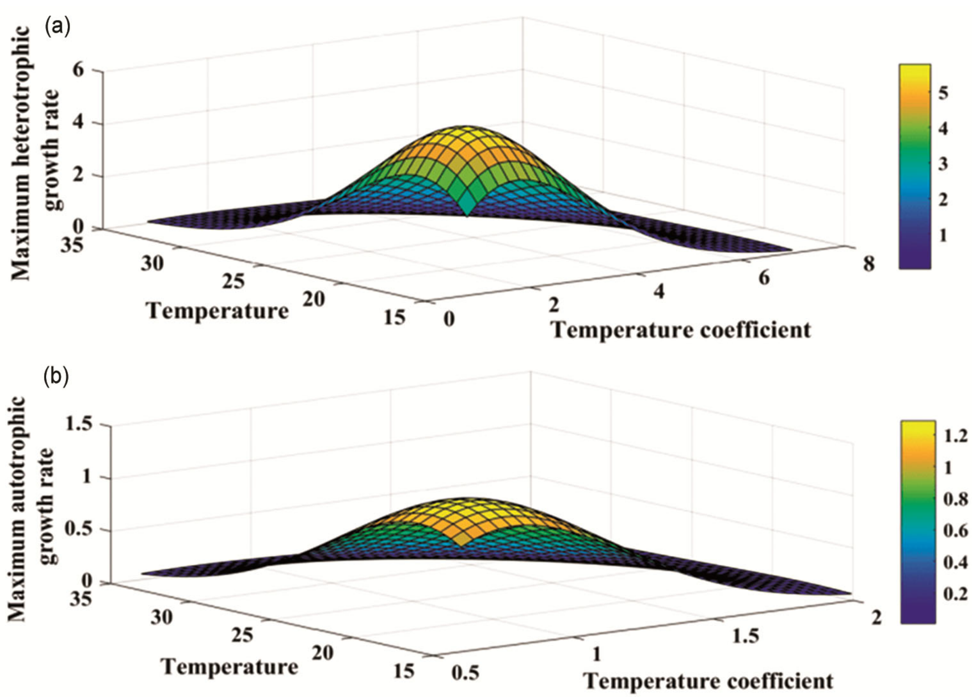

Fig 2 — Effect of temperature and temperature co-efficient on (a)μ_{mH} and (b)μ_{mA}

Table 4 — Effect of $z$on EQ when μ_{mH} is evaluated at 25°C

Tem co-eff →	0.8	1	1.5	2	3	4	5	6	7	8
Variables ↓	State variables									
S_O	1.99	1.99	1.98	1.9799	1.989	1.9894	1.977	1.9747	1.9592	1.94
S_S	0.13	0.13	0.135	0.1345	0.1339	0.1334	0.133	0.133	0.1328	0.131
S_I	30	30	30	30	30	30	30	30	30	30
S_{nh}	0.36	0.36	0.372	0.3765	0.36931	0.3711	0.3781	0.3728	0.3756	0.378
S_{NO}	9.71	9.7	9.68	9.6896	9.6859	9.7084	9.7383	9.737	9.75	9.78
S_{N2}	35.76	35.76	35.81	35.81	35.82	35.79	35.768	35.79	35.8004	35.82
S_{PO4}	5.006	5.05	5.2	5.285	5.41	5.49	5.5577	5.6133	5.6557	5.68
S_{alk}	3.57	3.57	3.57	3.5697	3.56	3.56	3.5619	3.56	3.55	3.37
X_I	6.48	6.45	6.42	6.5103	6.45	6.544	6.541	6.48	6.499	6.52
X_S	0.087	0.08	0.08643	0.0863	0.08616	0.08737	0.087	0.087123	0.08721	0.08727
X_H	3.12	3.141	3.2	3.228	3.25	3.3347	3.3529	3.344	3.35	3.36
X_{STO}	0.0033	0.00433	0.00708	0.01032	0.01816	0.02812	0.0391	0.050988	0.06426	0.06722
X_{PAO}	2.9	2.85	2.8	2.77	2.728	2.7043	2.67	2.6735	2.6696	2.692
X_{PP}	0.35	0.35	0.346	0.342	0.3369	0.33384	0.3292	0.3296	0.32878	0.3299
X_{PHA}	0.1	0.0999	0.0958	0.0934	0.09037	0.08428	0.0873	0.0863	0.08535	0.0851
X_A	0.39	0.394	0.39	0.3916	0.3934	0.3946	0.3946	0.396	0.39514	0.3945
X_{TSS}	12.2	12.24	12.23	12.26	12.27	12.136	12.136	12.158	12.1464	12.131
Composite variables										
TKN	1.32	1.31	1.32	1.326	1.31	1.32	1.33	1.323	1.33	1.33
TN	11.03	11.02	11	11.016	11.002	11.033	11.06	11.0614	11.08	11.085
TP	5.52	5.56	5.7	5.78	5.9067	5.98	6.0426	6.098	6.13	6.16
COD	43.23	43.16	43.14	43.21	43.14	43.29	43.26	43.2	43.2	43.2
BOD5	1.36	1.35	1.35	1.35	1.34	1.36	1.35	1.3552	1.35	1.35
EQI	15969.0	15961.1	15826.5	15728.8	15753.7	15792.8	15800.9	15725.2	15747.6	15849.2

From these values, the following are the observations.

- For all temperatures, μ_{mH} extensively affects the total phosphorous (TP) and EQ as represented in bold letters in Table 4.
- μ_{mA} impacts on BOD, TN, TP, TSS, and EQ.
- The maximum growth rate of X_{PAO} also influences TN, TP, $S_{PO4,}$ and EQ
- b_H impacts COD, TP, S_{PO4}, S_O, S_{NO}, and EQ.
- b_A effects mostly TN, TP, S_O, S_{nh}, and EQ
- The maximum decay rate of X_{PAO} also influences TN, TP, S_O, and EQ.

The resultant variations in effluent quality and concentrations of $\mu_{mH}, and\ \mu_{mA}$ at various temperatures are depicted in Figs. 3 and 4. For different temperatures, at 15°C, the EQ and TP are decreasing but at other higher temperature points (23 to 30°C) the EQ and TP are increasing by varying the TC from 0.8 – 8, and the corresponding graphs are depicted in Fig. 3(a) and 3(b). Effect of μ_{mA} at different temperatures by varying TC (0.6 to 2) and the corresponding nutrient removals are depicted in Fig. 4(a), 4(b), 4(c), and 4(d). On seeing the graphs, at 15°C, the EQ, ammonia, and TN shows higher removal rate at initial stages but as TC increases the corresponding removal rate is also improved. For other higher temperature measures (23 to 30°C) there removal rate is initially low but as there is a rise in TC the removal rate decreased. In TP, at 15°C the removal rate is much less than other temperature measures (23 to 30°C). EQ is directly proportional to the nutrient removal rate. So, if the rate of nutrient (C, N, and P) removal rate increases, then the EQ is also increases. Effect of z on EQ when μ_{Ma} is determined at 25°C is tabulated in the supplementary data S6.

Further, corresponding decay rates (b_H, and b_A) are also tabulated in supplementary data. The effect of temperature coefficient for different compositions at various temperatures are depicted in Figs 5 and 6. Effect of b_H at different temperatures by varying TC (0.05 to 1) and the corresponding nutrient removals are depicted in Fig. 5(a), 5(b), 5(c) and 5(d). On seeing the graphs, at 15°C, the EQ, ammonia, and TN show a higher removal rate at initial stages but as TC increases the corresponding nutrient removal is improved. For other higher temperature measures (23, and 25°C) the removal capacity is initially low but as there is a rise in TC the nutrient removal is increased. On the other hand, at 28 and 30°C show lower nutrient removal rate is noticed on comparing with other temperatures. Effect of 'z' on EQ when b_H and b_A are determined at 25°C tabulated in the supplementary data S5 and S7.

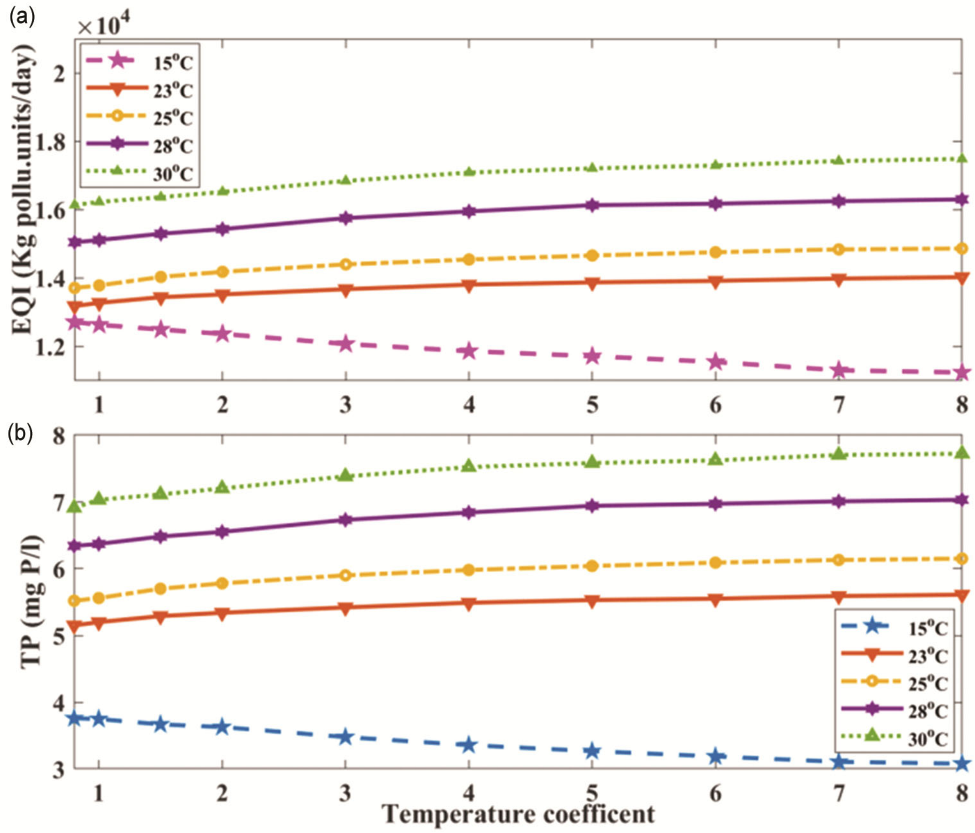

Fig 3 — Effect of μ_{mH} at different temperatures on (a) EQI and (b) Total phosphorus

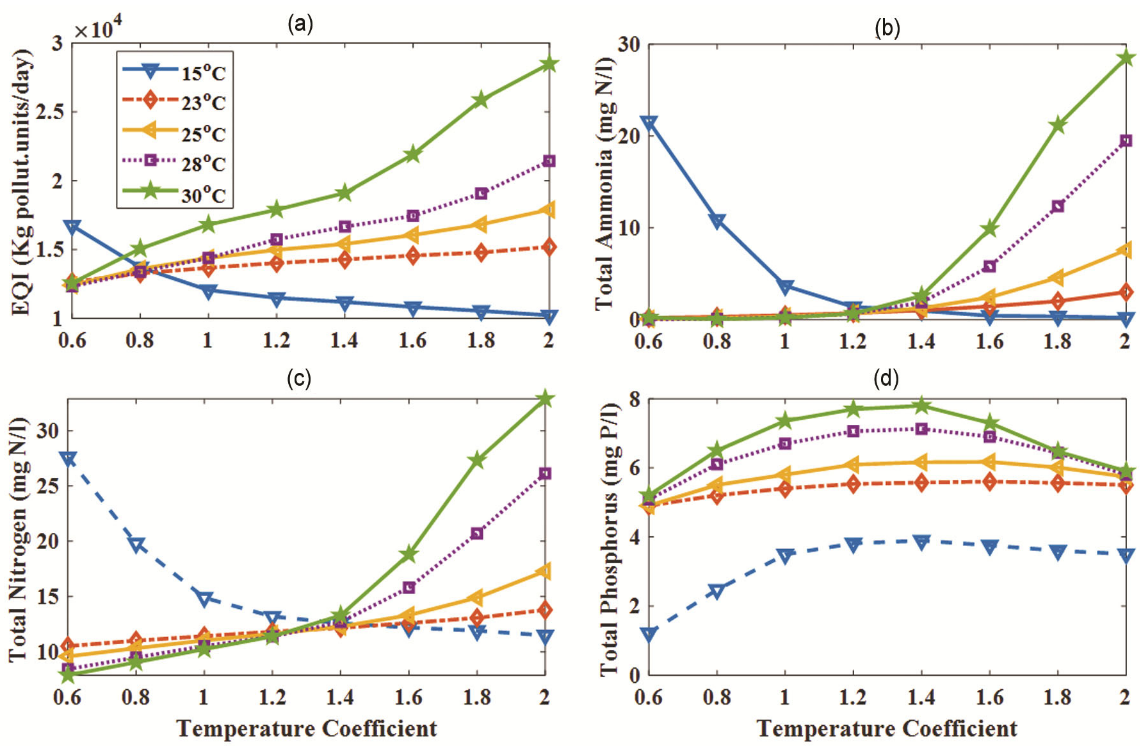

Fig 4 — Effect of μ_{mA} at different temperatures on (a) EQI Ammonia and (b) Ammonia (c) Total nitrogen and (d) Total phosphorus

Effect of b_A at different temperatures by varying TC (0.14 to 0.3) and the corresponding nutrient removals are depicted in Fig. 6(a)A, 6(b), 6(c), and 6(d). On seeing the graphs of TP and ammonia, at 15°C the TN and ammonia increasing linearly with respect to TC. But remaining temperature measures TN, and ammonia is achieved better removal rate and independent on TC. By observing the graphs Fig. 6(a), and 6(c) reported that at 30°C, TN and ammonia achieved a better removal rate. Moreover, TP and EQ are enhanced in the case of lower temperatures and worsened at higher temperatures.

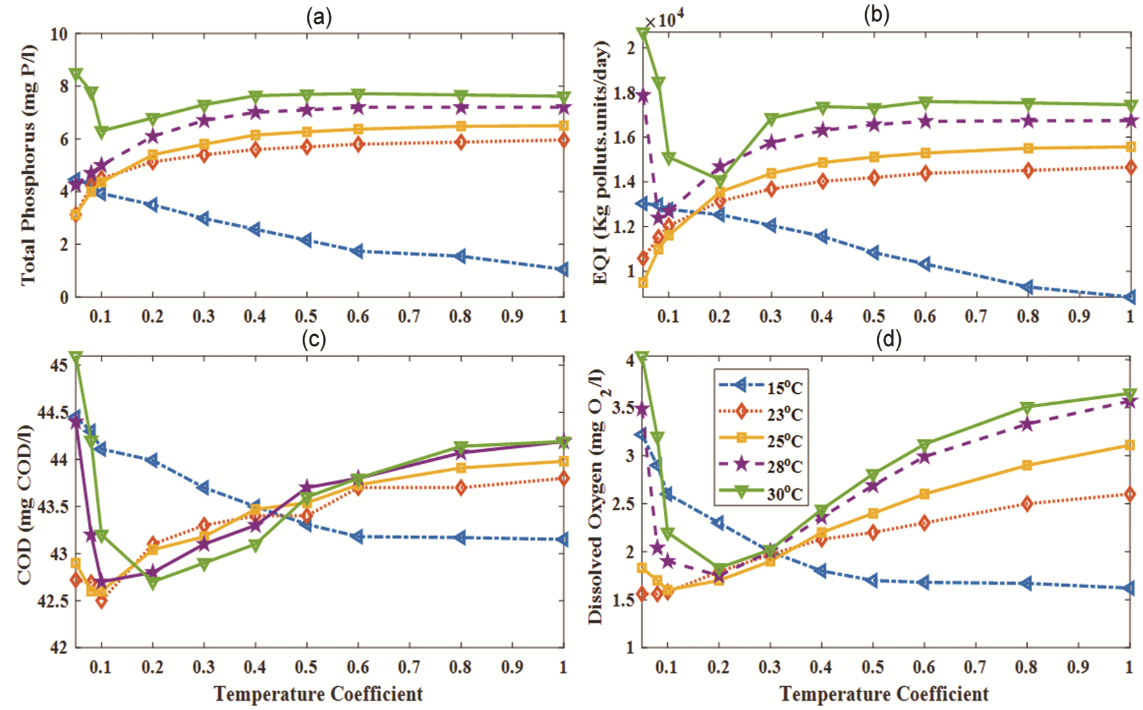

Fig 5 — Effect of b_H at temperatures on (a) Total phosphorus, (b) EQI Total phosphorus (c) COD and (d) Dissolved oxygen

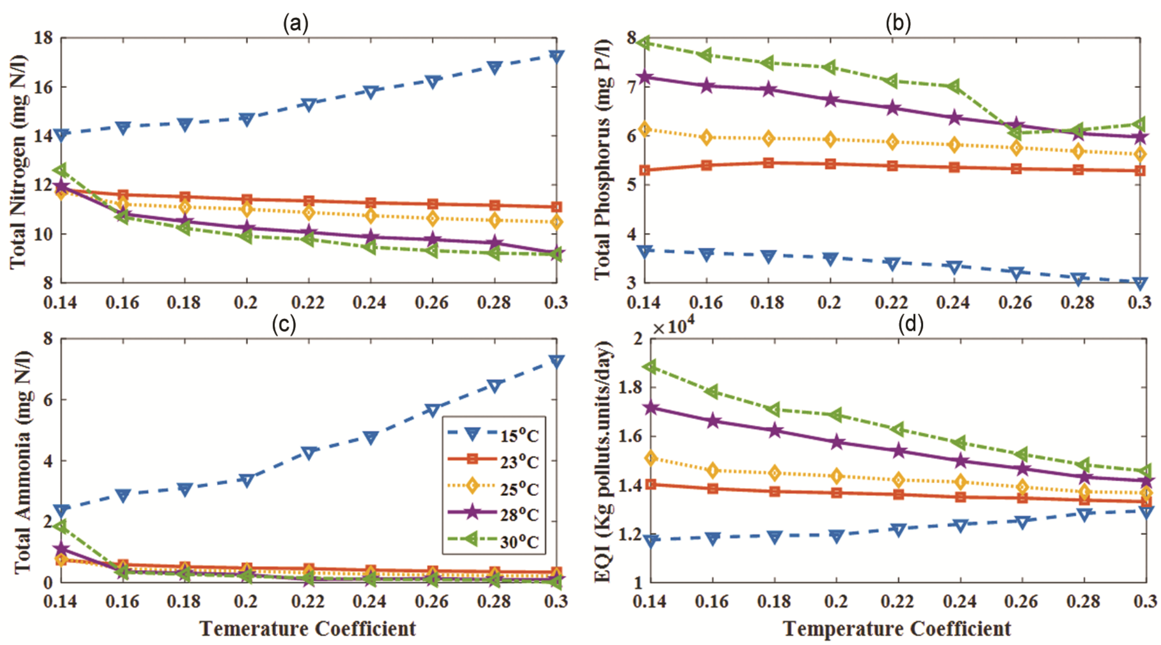

Fig 6 — Effect of b_A at temperatures on (a) Total Nitrogen, (b) Total phosphorus (c) Ammonia and (d) EQI

Maximum decay and growth rate of X_{PAO} of resultant variations of effluent quality and concentrations at various temperatures are depicted in the in Figs. 7 and 8. Effect of mu_{PAO} at different temperatures by varying TC (0.7 to 2), and the corresponding nutrient removals are depicted in Figs 7(a), 7(b), and 7(c). From Fig.7(a) and 7(b) it was noticed that at 15°C the EQ and TP are initially showing improved removal rate, as TC increases the removal rate decreases. Furthermore, at higher temperatures, the removal rate shows a parabolic path with respect to TC. On the other hand, TN is enhanced in the case of higher temperatures and worsened at lower temperatures.

Effect of b_{PAO} at different temperatures by varying TC (0.08 to 6) and the corresponding nutrient removals are depicted in Fig. 8(a), 8(b), 8(c), and 8(d). It was noticed that at 15°C the EQ and TP are initially showing improved removal rate, as TC increases the removal rate decreases. At higher temperatures, it is observed that the EQ and TP are initially showing a lower removal rate. As TC increases the TP and effluent quality is improved. In the DO, the consumption is decreased as TC increases at lower temperature measures, and in higher cases, the consumption DO is increased on increasing TC. On the other hand, TN is enhanced in the case of higher temperatures and worsened at lower temperatures. Effect of z on EQ when mu_{PAO} and $b_{PAO}$are determined ati25°Ctabulated in the supplementary data S8, and S9.

The impact ofμ_{mH} on the quality of the effluent with varying temperature co-efficient is depicted in Fig.3. μ_{mH} is highly dependent on how the wastewater is treated and hence a huge range of deviated results are noticed in the publications. Moreover, they are related to the structure of the reactor where the growth of biomass is happening. Additionally, it is noticed that the TP increases with the rise of temperature co-efficient and eventually leads to a rise in EQ.

The effect of μ_{mA}on the quality of effluent with different temperature coefficients are depicted in Fig. 4. It impacts mainly S_{nh}, TN, TP, and EQI. Here the Kinetic parameter μ_{mA} play a key role to regulate the SRT at which the nitrifying bacterium is terminated. Generally, nitrification is carried out as a single-stage process, and it is relevant to the usage of μ_{mA} related to the removal of nitrogen-ammonia in the design. The effect b_H on the quality of effluent with different temperature coefficients is depicted in Fig. 5. As the temperature increases, the corresponding state and composite variables also increases. The b_H effects almost all state and composite variables namely COD, TP, S_O, and EQ. It is crucial to investigate b_Ho wing to its enormous impact on the estimated cell area for a particular SRT. Figure 6 depicts the effect of b_A in the quality of effluent with different temperature coefficients. The b_A rate effects mostly in TN, TP, S_{nh}, and EQ. Biomass activity is terminated because of a critical effect on the ASP in a stable process. Aerobic and anoxic endogenous respiration causes the biomass loss and requirements of energy not used for growth.

The effect of mu_{PAO} in the effluent quality and concentrationsof resultant variations of various temperatures are depicted in the supplementary data. The mu_{PAO} rate effects mostly TN, TP, and EQ. In the anaerobic section, PAO's incorporate fermentation products into storage products inside the cells with the discharge of P from stored Poly-P. In the aerobic section, energy is formed by the oxidation of storage products, and hence Poly-P storage inside the cell increases. The biomass activity rises owing to the growth of Polyhydroxybutyrate (PHB) composition as it falls with a rise in poly-p. All this leads to the decay of orthophosphate with a decrease in temperature and hence it influences on lower production of Poly-P.

The effect of b_{PAO} in the effluent quality and concentrations of resultant variations of various temperatures are depicted in the supplementary data. The b_{PAO} rate effect mostly in TN, TP, S_O, and EQ. Aerobic and anoxic lysis of internal poly-phosphates takes care of the fact that cell internal poly-phosphates decay together with the biomass. Hence, the determination of decay rates inhabits a key role in the microbial process. Overall, the following observations are made.

- On considering 10 and 35°C as the lower and upper-temperature ranges, at both the temperatures, it is observed that the simulation is stopped when stoichiometric parameters are reached beyond their limit.
- b_{PAO} is estimated with multiple temperature changes within the range of 10 - 30°C, and finally, it is observed that the appropriate temperature ranges to get the simulation results is 15 – 28°C.
- Generally, in phosphorous removal, it is noticed that at very low temperatures (5 to 10°C), a higher sludge age is needed because of a decrease in the rate of the kinetic process.

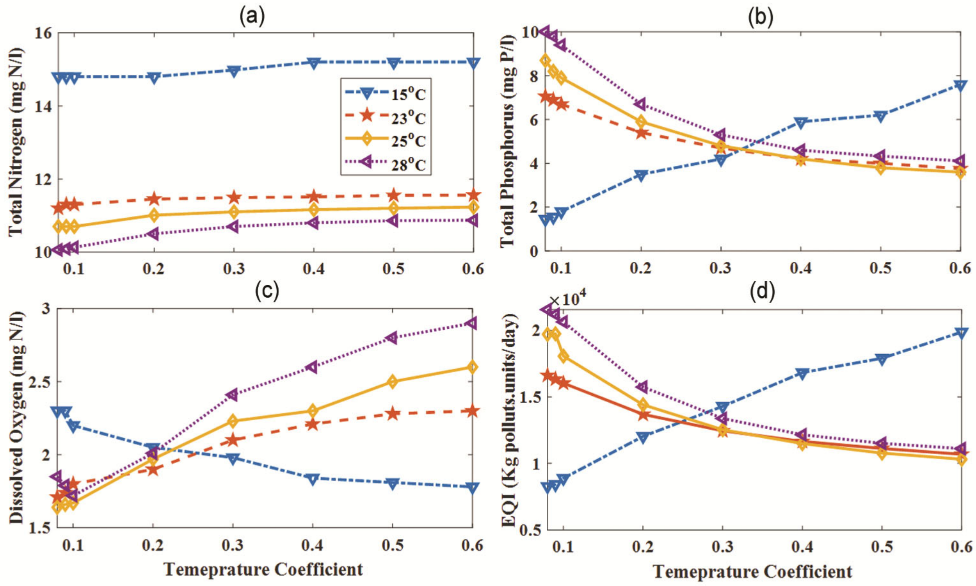

Fig 8 — Effect of b_{PAO} at different temperatures (a) Total Nitrogen, (b) Total phosphorus and (c) Dissolved oxygen and (d) EQI

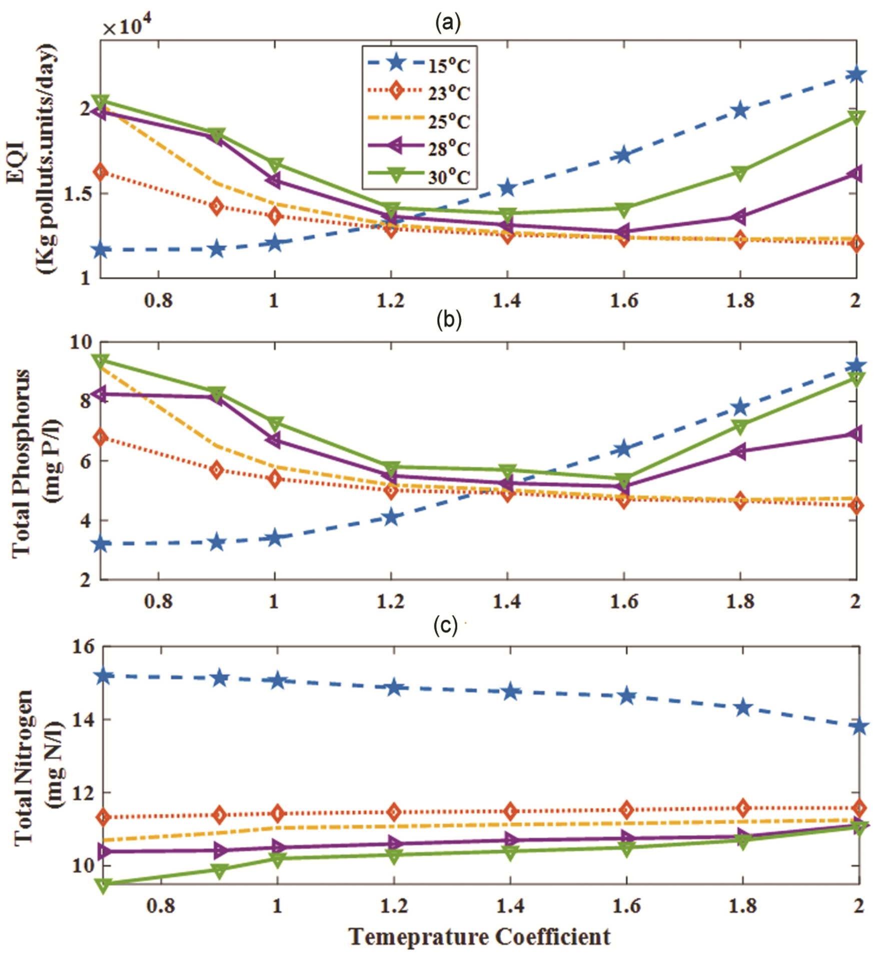

Fig 7 — Effect of mu_{PAO} at different temperatures (a) EQI, (b) Total phosphorus, and (c) Total Nitrogen

- At (>10^{o}C), the anaerobic metabolism of Glycogen Accumulating Organisms (GAO's), the anaerobic glycogen hydrolysis is completed and hence limiting the substrate uptake rate leading to the growth of the GAO's. With weather differences or geological a real differences, when the temperature (>25°C) is observed, the PAO's are at a lower level than GAO's production.

Conclusion

A model-based analysis is studied to evaluate the effluent compositions with varying kinetic parameters accessed from varying temperature coefficients in the temperatures range from 10 to 35°C. With the increase in temperature, the EQ is increasing. A considerable violation in EQ is observed with the variation in kinetic parameters when the temperature is <15°C and >30°C. For Phosphorous removal, at 5 to 10°C, a higher sludge age is needed because of a decrease in the reaction rate. Hence, it is necessary to implement a control strategy to bring the effluent within the legal limits as prescribed by the regulatory bodies.

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