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Interacting Effects of Operating Parameters on Performance of Step Feed Activated Sludge System

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Abstract. Different types of activated sludge (AS) systems are in use today for treating municipal wastewater and one of them is step feed AS system. The aim of this work is to use activated sludge model No.1 in studying the interacting effects of hydraulic retention time, recirculation ratio and aeration power to volume ratio on performance of step feed AS system considering different influent compositions and influent distribution ratios. To satisfy the study aim, 324 simulations were conducted considering different combinations of the studied parameters. The study results indicated that the performance of step feed AS system treating specific influent composition at specific influent distribution scheme is mainly enhanced by increasing the hydraulic retention time and aeration power to volume ratio rather than the recirculation ratio. They showed that the COD removal percentages of step feed system is based on influent distribution scheme and varies on the range (60.3-93.5) %. In this study, best combinations of design parameters were selected and they are defined as those produce effluent COD less than 100 $mg.l^{-1}$ (according to Iraqi standards) and effluent dissolved oxygen not less than 1 $mg.l^{-1}$.

INTRODUCTION

Biological treatment of wastewater is mostly achieved using activated sludge (AS) system which is composed of an aeration tank followed by a settling tank. In the aeration tank, the wastewater containing organic matter is aerated and biomass is produced. The air is supplied to maintain a minimum concentration of dissolved oxygen (DO) 1-2 $mg.l^{-1}$ [1-3]. The produced biomass is settled in the settling tank. Part of the settled biomass, described as activated sludge, is returned to the head of the aeration tank and the remaining is disposed of as waste sludge. Different types of AS systems are used for municipal wastewater treatment and one of them is step feed AS system. In a step feed system, the influent is discharged through a number of feed points distributed along the length of aeration tank. Full-scale operational data of existing wastewater treatment plants showed that step feed AS system is a reliable and flexible treatment system as compared with a single feed AS systems [4].

The design of AS systems is dependent on a group of design parameters including; (1) sludge retention time (SRT), (2) hydraulic retention time (HRT), (3) recirculation ratio (r), (4) the food to microorganism's ratio (F/M) and (5) volumetric loading rate (the amount of BOD or COD, in kg, applied to the aeration tank volume per day) [1, 5]. While the first three parameters are the basic design and operating parameters, the F/M ratio, and volumetric loading rate provide values that are useful for comparison to historical data and typical observed operating conditions [1]. Generally, for a specific type of AS systems, the values ranges of design criteria were given in the previous studies separately from each other without considering the interacting effect of these criteria on the performance of AS system.

The performance of AS systems can be studied by direct field measurements or by using physical or mathematical models. The most applied mathematical models of AS systems are activated sludge models No.1, 2, 2d, and 3 which were presented by Hence et al. [6]. The aim of this work is to study the performance of step feed AS system considering the interacting effects of HRT and r as well as aeration power to volume of aeration tank ratio (P/V) and influent composition. This shall be done by mathematically simulating the interacting processes that occur in the aeration tank using activated sludge model No.1 (ASM1). The performance of the system shall be measured in terms of COD removal percentage and effluent COD and dissolved oxygen.

The use of ASM1 in studying the performance of AS systems has been considered by many researchers. Bshara [7] used a reduced form of ASM1 to study the effect of P/V ratio on performance of conventional AS system that treats an influent has COD of 400 mg.l-1. Dey et al. [8] applied ASM1 built-in GPX-S software to study the effect of SRT and HRT on performance of completely mixed, conventional and step feed AS systems. They considered the secondary clarifier to have an efficiency of 100% and showed that the treatment efficiency of the considered AS systems increased with SRT and HRT. Sahlstedt et al. [9] compared the performance of step feed and denitrification-nitrification conventional AS systems using GPS-X 5.0 software. They considered two cases of step feed (three steps

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process of 42:32:26% and four steps process of 15:35:30:20%) and compared its performance with that of DN conventional AS systems in terms of air consumption and aeration tank volume. Sijian et al. [10] investigated the performance of anoxic/oxic step feed processes and a modified step feed processes (anaerobic/anoxic/oxic). They kept the DO concentration at 1.2-2 mg.l-1 and influent wastewater distribution ratio at (40/30/30) % at anaerobic/anaoxic/oxic zones and changed SRT and r. Sid et al. [11] applied ASM1 incorporated into GPS-X software to put a strategy for minimizing the energy consumption of a full-scale conventional AS system. Ruogu and Yanqiu [12] compared the performance of conventional (single feed) and step feed AS systems, in removing Ammonium-N and organic compounds, by applying a simplified ASM1 that incorporated six components and five transformation processes. They applied the model to a step feed system that included four inlets, each having a 0.25 influent ratio, and considered one value for both of HRT and recirculation ratio with specific influent composition.

Generally, most of the previous studies conducted on step feed AS systems have investigated the removal efficiency of nutrients such as those conducted by; Ge et al. [13] and Shen et al. [14] who used a pilot plant to investigate the removal efficiency of nutrients under the effect of different influent distribution ratios, Ge et al. [15] who enhanced the removal efficiency of nutrients in an existing wastewater treatment plant by adopting anoxic/oxic step feed process with plastic carriers, and Cao et al.[16] who investigated the removal efficiency of nutrients using a pilot plant that treats low strength municipal sewage with COD and TN values less than 200 and 40mg/l, respectively. From the aforementioned study examples, one can notice that the interaction effect of influent composition, HRT, r, and P/V on the performance of step feed AS system has not been considered in the previous available studies.

METHODOLOGY

Overview on ASM1 Model

ASM1 is a mathematical model that simulates the interaction of thirteen components of sewage by eight reaction processes. It incorporates phenomena such as carbon oxidation, nitrification and denitrification [6]. The thirteen components in ASM1 include fractions of chemical oxygen demand (COD) and total nitrogen (TN) and alkalinity as well as, dissolved oxygen (DO). COD fractions include; inert soluble organic matter (S_I), readily biodegradable substrate (S_S), inert particulate organic matter (X_I), slowly biodegradable substrate (X_S), heterotrophic biomass (X_{BH}), autotrophic biomass, (XBA), and debris from biomass death and lysis (Xp). TN fractions include; nitrate-N (SNO), ammonia-N (S_{NH}), soluble organic-N (S_{ND}), and particulate organic-N (X_{ND}). ASM1 is usually presented in a matrix format called Peterson matrix which can be found in [6].

Application of ASM1 on Step Feed AS System

Aeration tank in AS systems is either considered to be of plug flow or completely mixed reactor. The aeration tank in step feed AS system is usually considered to be of plug flow type [1, 17, 18]. In ASM1, the plug flow system is assumed to be composed of a number of continuous stirred tank reactors in series. Herein, the aeration tank is divided into four equal compartments and the influent is distributed at ratios of α_1, α_2, α_3, and α_4 over aeration tank compartment Nos. 1, 2, 3 and 4, respectively, Fig.1. In this figure; Q_0, Q_r, Q_w, and Q_e are denoting the flowrates of settled sewage, return activated sludge, waste activated sludge, and final effluent, respectively, and $C_{i,ea}$, $C_{i,es}$, and $C_{i,r}$ are denoting the concentrations of component-i in aeration tank effluent, secondary settling tank effluent, and return AS, respectively. The Summation of α_1, α_2, α_3, and α_4 is equal to 100%. The values of α_1, α_2, α_3, and α_4 were varied to study their impact on system performance.

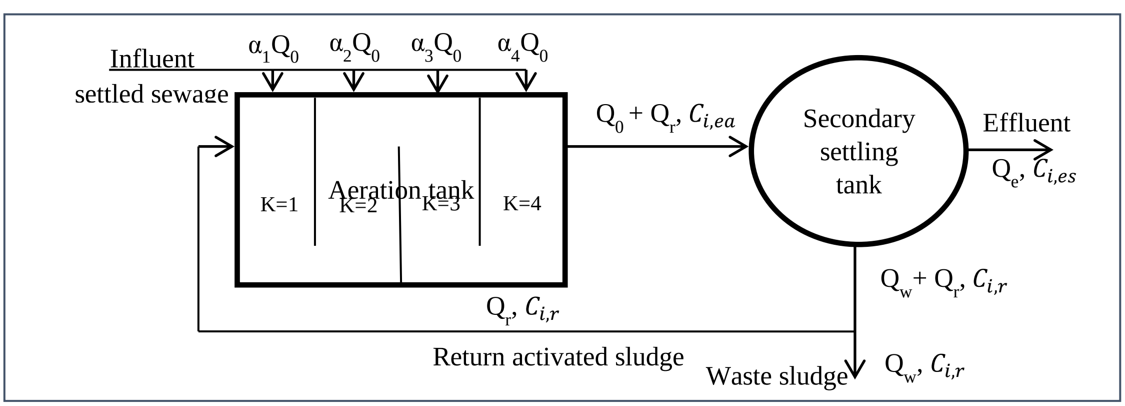


FIGURE 1. Influent distribution over the four compartments of aeration tank

Basic Equations

The basic equations of the ASM1 model are those describing the temporal variation of each of the thirteen components. These equations are based on mass balance principle and have the following general form [6];

$$dC_i/dt = f(C_i) \quad (1)$$

where;

C_i = concentration of component-i (S_I, S_S, X_I, X_S, X_{BH}, X_{BA}, X_P, S_O, S_{NO}, S_{NH}, S_{ND}, X_{ND}, or alkalinity), ML^{-3}.

f (C_i) = time-dependent function defined as;

$$f(C_i) = MB_{C_i} + R_{C_i} \quad (2)$$

where MB_{C_i} and R_{C_i} are the mass balance and reaction terms for component-i. The reaction term of component-i includes all the interacting processes that affect its concentration and they are obtained from Peterson matrix [6]. Whereas, the mass balance term represents the time rate of component-i concentration change due to mass inflow/outflow to/from the reactor. For step feed system, the definitions of mass balance terms for component-i, excluding the dissolved oxygen, and for compartment Nos. 1, 2, 3 and 4 ($MB_{C_{i,1}}, MB_{C_{i,2}}, MB_{C_{i,3}}\, and\, MB_{C_{i,4}}$) are;

$$MB_{C_{i,1}} = (\propto_1 Q_0\, C_{i,0} + Q_r C_{i,r} - (\propto_1 Q_0 + Q_r)C_{i,1})/V_{a1} \quad (3)$$

$$MB_{C_{i,2}} = \left[[(\propto_1 Q_0 + Q_r)\, C_{i,1} + \propto_2 Q_0\, C_{i,0}] - [(\propto_1 + \propto_2)Q_0 + Q_r]\, C_{i,2}\right]/V_{a2} \quad (4)$$

$$MB_{C_{i,3}} = \left[[(\propto_1 + \propto_2)Q_0 + Q_r]\, C_{i,2} + \propto_3 Q_0\, C_{i,0} - [(\propto_1 + \propto_2 + \propto_3)Q_0 + Q_r]\, C_{i,3}\right]/V_{a3} \quad (5)$$

$$MB_{C_{i,4}} = \left[[(\propto_1 + \propto_2 + \propto_3)Q_0 + Q_r]\, C_{i,3} + \propto_4 Q_0\, C_{i,0} - [(\propto_1 + \propto_2 + \propto_3 + \propto_4)Q_0 + Q_r]\, C_{i,4}\right]/V_{a4} \quad (6)$$

For dissolved oxygen, the definitions of mass balance terms for compartment Nos. 1, 2, 3, and 4 ($MB_{S_{O,1}}, MB_{S_{O,2}}, MB_{S_{O,3}}\, and\, MB_{S_{O,4}}$) are;

$$MB_{S_{O,1}} = \left[\propto_1 Q_0\, S_{O,0} + Q_r S_{O,r} - (\propto_1 Q_0 + Q_r)S_{O,1}\right]/V_{a1} + K_L a\left(S_O sat - S_{O,1}\right) \quad (7)$$

$$MB_{S_{O,2}} = \left[[(\propto_1 Q_0 + Q_r)\, S_{O,1} + \propto_2 Q_0\, S_{O,0}] - [(\propto_1 + \propto_2)Q_0 + Q_r]\, S_{O,2}\right]/V_{a2} + K_L a\left(S_O sat - S_{O,2}\right) \quad (8)$$

$$MB_{S_{O,3}} = \left[[(\propto_1 + \propto_2)Q_0 + Q_r]\, S_{O,2} + \propto_3 Q_0\, S_{O,0} - [(\propto_1 + \propto_2 + \propto_3)Q_0 + Q_r]\, S_{O,3}\right]/V_{a3} + K_L a\left(S_O sat - S_{O,3}\right) \quad (9)$$

$$MB_{S_{O,4}} = \left[[(\propto_1 + \propto_2 + \propto_3)Q_0 + Q_r]\, S_{O,3} + \propto_4 Q_0\, S_{O,0} - [(\propto_1 + \propto_2 + \propto_3 + \propto_4)Q_0 + Q_r]\, S_{O,4}\right]/V_{a4} + K_L a\left(S_O sat - S_{O,4}\right) \quad (10)$$

where;

Q_0 = Flow rates of settled sewage, L^3T^{-1}.

$C_{i,0}$ = influent concentration of component-i, ML^{-3}.

$C_{i,r}$ = concentration of component-i in the return AS, ML^{-3}.

$C_{i,1}, C_{i,2}, C_{i,3}\ and\ C_{i,4}$ = Component-i concentration in compartment Nos.1, 2, 3, and 4, respectively, ML^{-3}.

$S_{O,0}$ = influent DO concentration, ML^{-3}.

$S_{O,1}$, $S_{O,2}$, $S_{O,3}$ and $S_{O,4}$ = DO concentration in compartment Nos.1, 2, 3, and 4, respectively, ML^{-3}.

$S_{O,r}$ = DO concentration in return AS, ML^{-3}.

$K_L a$ = oxygen volumetric mass transfer coefficient, T^{-1}.

$S_O sat$ = oxygen concentration at saturation, ML^{-3}.

V_{a1}, V_{a2}, V_{a3}, and V_{a4}= volumes of aeration compartment Nos.1 to 4, respectively, L^3.

$MB_{C_{i,1}}$ and $MB_{C_{i,k}}$= mass balance terms for component-i in compartment Nos.1 and k, respectively.

$MB_{S_{O,1}}$ and $MB_{S_{O,k}}$= mass balance terms for dissolved oxygen in compartment Nos.1 and k, respectively.

The last term in Eqs.7 through 10 represents the rate of oxygen supply to the aeration tank. In this term; $K_L a$ and $S_O sat$ values are dependent on air supply method and wastewater characteristics as will be shown in the next section. It is important to mention here that inert and particulate suspended organic matter in the wastewater influent becomes enmeshed in the AS and they are removed from the system via the sludge wastage [6]. Thus their concentrations in the return AS are considered to be zero.

Oxygen Volumetric Mass Transfer Coefficient and Saturation Concentration

The rate of oxygen transfer from the gas phase to the liquid phase by an aeration system is usually represented by the coefficient, K_La. The value of this coefficient is determined based on aeration system type. For surface aeration system, K_La in min^{-1} is determined as [19]:

$$K_L a = 2.75 \times 10^{-3}(P/V) \quad (11)$$

where P/V is the power input per aeration tank volume, W.m^{-3}.

The saturation concentration of oxygen in fresh water is mainly dependent on water temperature and partial pressure of the oxygen in contact with the water. It is expressed as;

$$S_O sat = 14.628 - 0.4118T + 0.0098T^2 - 0.0002T^3 + 1E - 06T^4 \quad (12)$$

where; $S_O$sat is saturation concentration of dissolved oxygen, mg.l^{-1}, and T is the water temperature, $°C$. The $S_O$sat value obtained from Eq. 12 is usually corrected using β factor to include the impact of salinity and particulate constituents on oxygen solubility in water. β factor is defined as [2];

$$\beta = \frac{(S_O sat)_{wastewater}}{(S_O sat)_{cleanwater}} \quad (13)$$

And it can be obtained as [20];

$$\beta = 1.57 \times 10^{-6} \times TDS \quad (14)$$

where TDS is total dissolved solids concentration in mg.l^{-1}. Generally, β values range from 0.7 to 0.98 with a typical value of 0.95 for wastewater [2].

Concentration of Particulate Constituents in Return AS

In most of the previous studies conducted on applications of ASM1, the concept of ideal settling tank was applied [6, 21, 22], i.e., the concentration of any particulate constituent (X_I, X_S, X_{BH}, X_{BA}, X_P, or X_{ND}) in the effluent of secondary settling tank is assumed to be zero. In other words, all particulate constituents shall be removed by settling in the secondary settling tank. In this study, the effect of secondary settling tank efficiency on AS system performance is included as described below.

If C_i is the concentration of a particulate constituent, then, applying conservation of mass principle around the settling tank, see Fig. 1, gives;

$$C_{i,r} = \left[(Q_0 + Q_r)C_{i,ea} - Q_e C_{i,es} \right] / (Q_r + Q_w) \quad (15)$$

where;
$C_{i,ea}$ = particulate solids concentration in the effluent of aeration tank, ML^{-3}.
$C_{i,es}$ = particulate solids concentration in the effluent of secondary settling tank, ML^{-3}.
Q_0, Q_r, Q_{wa} and $C_{i,r}$ = as defined before.

The concentration of any particulate solids in the effluent of secondary settling tank ($C_{i,es}$) is calculated as [23];

$$C_{i,es} = 0.001[-180.6 + 4C_{i,ea} + 135.6(Q_0(1+r)/24A) + h(90.2 - 62.5\, Q_0(1+r)/24A)] \quad (16)$$

where; h is the side water depth in secondary settling tank, m, and A is surface area of secondary settling tank, m^2.

COD Removal Percentage

The performance of step feed AS system shall be measured in terms of effluent COD and dissolved oxygen and percent of COD removal which is defined as;

$$\%COD_{removal} = (COD_{in} - COD_{ef})/COD_{in} \times 100 \quad (17)$$

Solution of ASM1 Model Equations

The application of ASM1 model on step feed AS system resulted in 13 simultaneous ordinary differential equations. These equations were solved numerically using fourth order Runge-Kutta numerical integration method. The algorithm of this method is described in [24]. For solving the final equations set, a computer program has been developed using Matlab R2015a.

Data of ASM1 Application

All the ASM1 applications were conducted using influent flow rate of 2710 m^3/hr. and three cases of influent sewage composition; low, medium and high strength. The characteristics of these cases are:

1. Case-1: Low strength sewage of COD_{in} and TN_{in} equal to 240 and 18 mg.l^{-1}, respectively.
2. Case-2: Medium strength sewage of COD_{in} and TN_{in} equal to 510 and 47 mg.l^{-1}, respectively.
3. Case-3: High strength sewage of COD_{in} and TN_{in} equal to 800 and 70 mg.l^{-1}, respectively.

The concentrations of influent COD and TN fractions that represent 11 components of ASM1 were specified using the values presented in Tables 1 and 2, respectively. The obtained concentrations for the three influent composition cases are shown in Table 3.

TABLE 1. Common fractions of COD [25, 26]

Component	S_S	X_S	X_{BH}	X_{BA}	S_I	X_I	X_P
Fraction (%)	35	35	15	0	5	10	0

TABLE 2. Common fractions of TN in wastewater [27]

Component	S_{NH}	S_{NO}	S_{ND}	X_{ND}
Fraction (%)	66	0	2	32

TABLE 3. Concentrations of influent COD and TN fractions

Influent Case No.	Concentration (mg.l^{-1})										
	S_I	S_S	X_I	X_S	X_{BH}	X_{BA}	X_P	S_{NO}	S_{NH}	S_{ND}	X_{ND}
1	12	84	24	84	36	0	0	0	11.88	0.36	5.76
2	25.5	178.5	51	178.5	76.5	0	0	0	31.02	0.94	15.04
3	40	280	80	280	120	0	0	0	46.2	1.4	22.4

Stoichiometric and kinetic parameters are required to solve the basic equations of ASM1. The values of these parameters were specified to be the most applied values [cited in 6]. The temperature and TDS of treated sewage were specified to be 27 °C and 6200 mg.l^{-1}, respectively. These values represent the maximum records of temperature and TDS of primarily settled sewage in Hamdan Sewage Treatment Plant, Basra city, south of Iraq. The aeration tank volume (V) and flow rates of return AS (Q_r)and waste AS (Q_W) were calculated using Eqs. 19, 20 and 21, respectively, as;

$$V = HRT \times Q_O \tag{19}$$

$$Q_r = r \times Q_0 \tag{20}$$

$$Q_W = V/SRT \tag{21}$$

The adopting of Eqs.19-21 requires the specification of design parameters HRT, SRT and r. The values of these parameters were obtained from the literature and they are reviewed in Table 4. In this study the interacting effect of operating parameters on the performance of step feed AS system was studied considering three HRT values (3, 6 and 7.2 hr.), three r values (20, 50 and 75%) and SRT of 10 days.

TABLE 4. Review of HRT, SRT and r values for step feed AS system

HRT (hrs.)	SRT (days)	r (%)	Ref. No.
4.8-7.2	4-14	20-50	[5]
3.0-5.0	3-15	25-75	[1]
3.0-5.0	5-15	25-75	[2]

The aeration tank is assumed to be provided with surface aeration system. The applied values of aeration power to volume ratio were; 65, 40, 25 and 10 W.m^{-3}. These values were chosen from the range of P/V values specified by Munz and Roberts [19]. The performance of step feed system was studied considering the effect of influent distribution scheme (IDS) besides the influent composition, HRT, r, and P/V. Three IDSs were considered with the influent distribution ratios presented in Table 5.

TABLE 5. Influent distribution ratios.

IDS No.	Influent distribution ratios (%)			
	α_1	α_2	α_3	α_4
1	25	25	25	25
2	50	0	50	0
3	40	30	20	10

RESULTS AND DISCUSSION

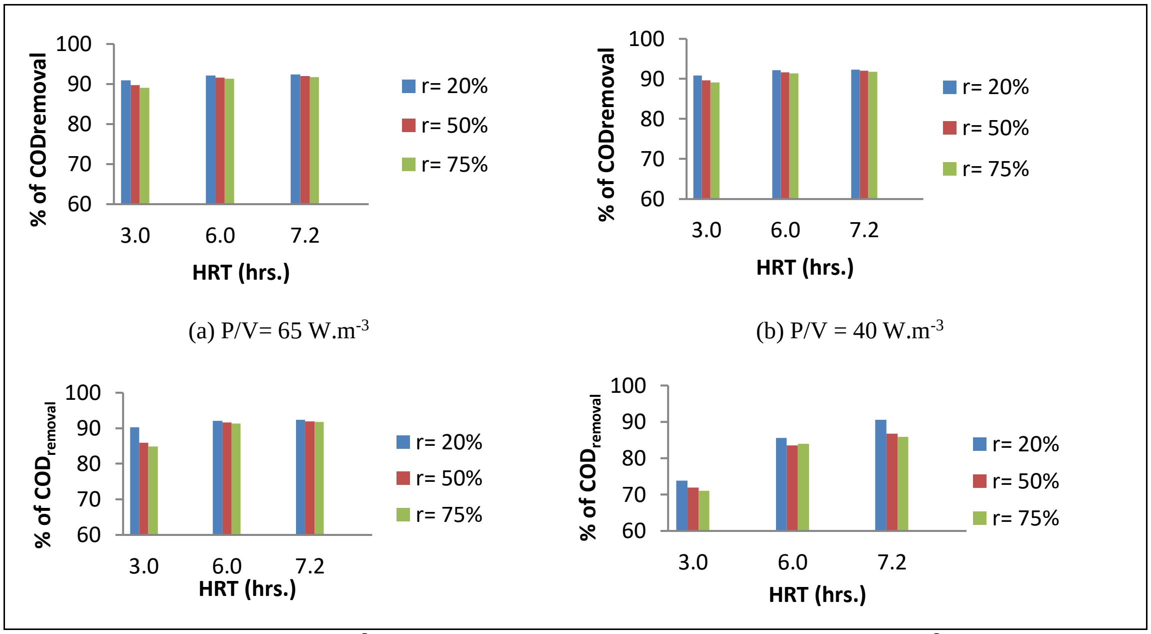
Complete application results of ASM1 on step feed AS system includes the time dependent concentration values of the 13 ASM1components. These values were obtained for each of the four aeration tank compartments. However, since the performance of step feed AS system would be assessed based on effluent COD and dissolved oxygen and percent of COD removal, thus, the presented results shall be focused on these issues. To study the system performance, 324 runs (3 IDSs × 3 values of HRT × 3 values of r × 3 cases of sewage composition × 4 values of P/V) have been implemented using the aforementioned data.

Percent of COD Removal

Figures 2-4 show the results of COD removal percentages for IDS No.1 and influent composition cases 1-3, respectively. These results are presented versus HRT at different r and P/V values. From these figures, it can be shown that:

1. For Case-1 of influent composition, Fig. 2 shows that;
   a. COD removal percentages at P/V values of 40 and 65 $W.m^{-3}$ are approximately equal. Thus, there is no need to apply P/V greater than 40 $W.m^{-3}$ if the treated sewage is of low strength.
   b. At P/V values of 40 and 65 $W.m^{-3}$, COD removal percentages increase slightly with HRT. However, when P/V equals $10W.m^{-3}$, the impact of HRT is significant. Thus for high aeration power, one can apply lower HRT values and hence save the cost of aeration tank construction.
   c. The impact of r on percentages of COD removal is insignificant at P/V equals 65 W.m-3.
2. For Case-2 of influent composition, Fig. 3 shows that;
   d. The impact of P/V on COD removal percentage is more than that of Case-1 of influent composition, especially at P/V values of 10, 25, and 40 W.m-3. This result is reasonable since the influent composition of Case-2 has a higher COD value than that of Case-1 and thus more aeration power is required.
   e. The percentages of COD removal are lower than their corresponding percentages at Case-1 of influent composition. For example, at r, HRT, and P/V of 75%, 3hrs, and 10W.m-3, respectively, the percentages of COD removal were 71.1 and 63.6 % for Case-1 and Case-2, respectively. That is because as the influent COD increases, the soluble substrate inflows to compartment No.4 of the aeration tank increases which may not be completely biodegraded before it reaches the tank outlet.
3. For Case-3 of influent composition, Fig. 4 shows that;
   f. Both P/V and HRT have significant effects on COD removal percentages, where, COD removal increases with the increase of HRT and P/V.
   g. The COD removal percentages are less than their corresponding values of Cases-1 and 2.

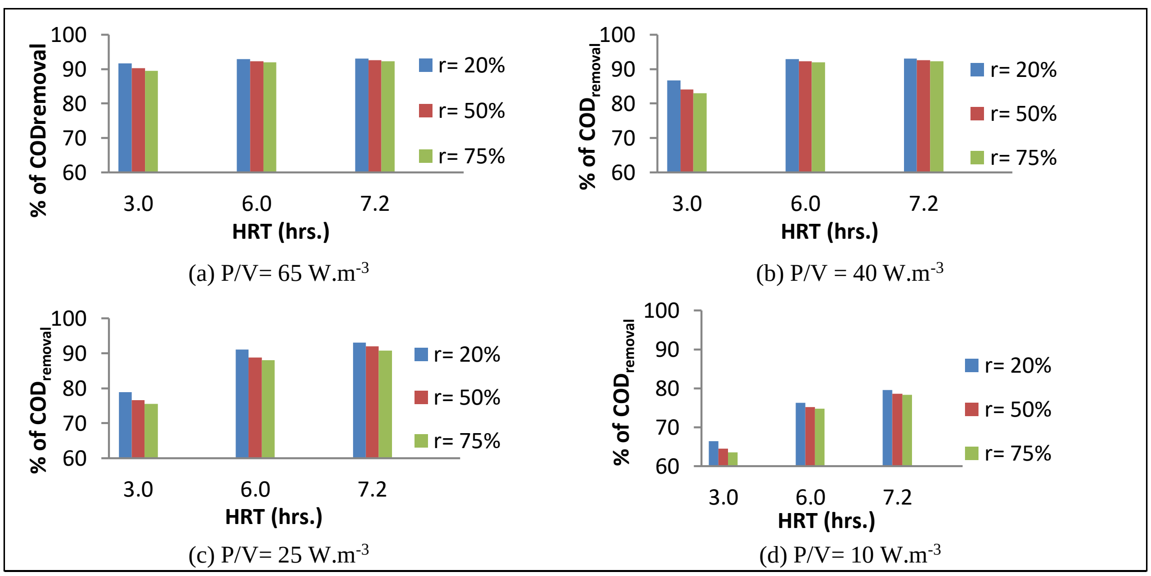
Figures 5-6 and 7-9 show the percentages of COD removal versus HRT at different r and P/V values for IDS Nos.2 and 3, respectively. From these figures, it can be noticed that IDS No.2 and 3 results are very close and the impacts of both P/V and HRT on COD removal percentage are the same as those of IDS No.1.



(a) P/V= 65 W.m^{-3} (b) P/V = 40 W.m^{-3}

(c) P/V= 25 W.m^{-3} (d) P/V= 10 W.m^{-3}

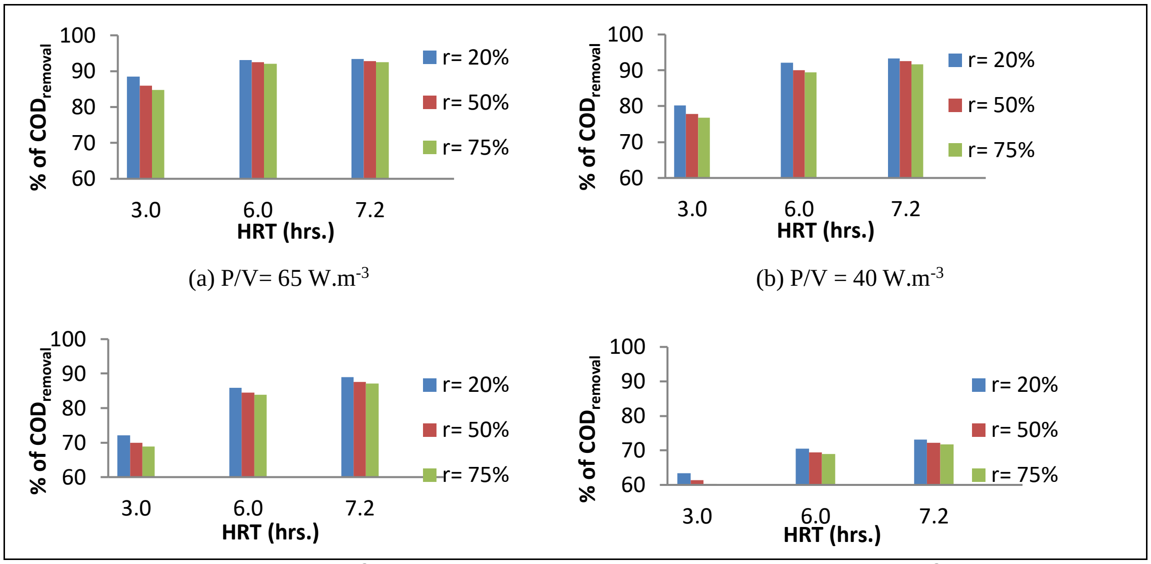
FIGURE 2. COD removal percentage versus HRT for IDS No.1 and Case-1 of influent composition



(a) P/V= 65 W.m^{-3} (b) P/V = 40 W.m^{-3}

(c) P/V= 25 W.m^{-3} (d) P/V= 10 W.m^{-3}

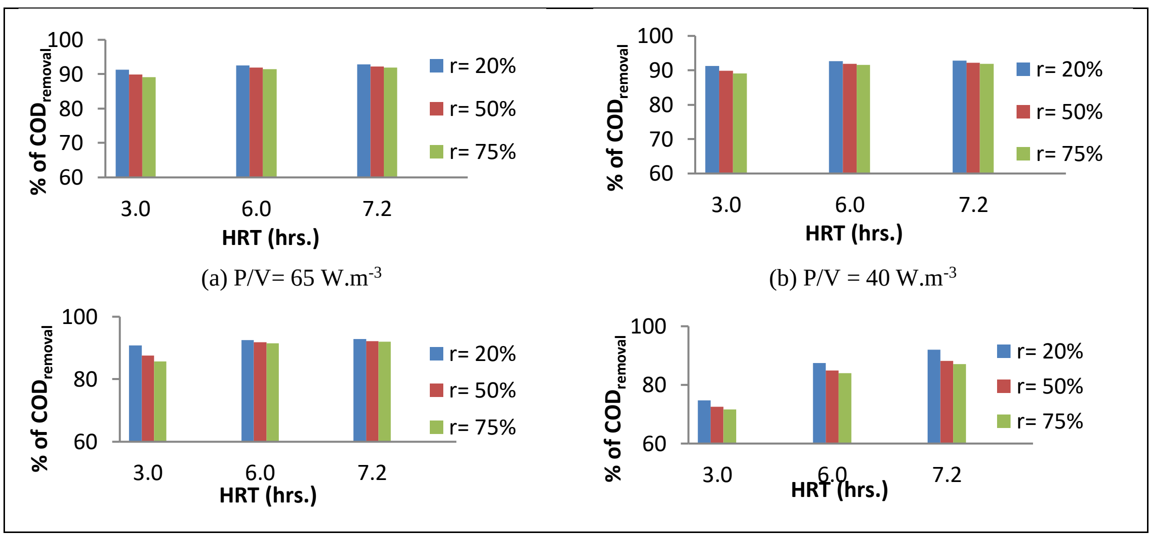
FIGURE 3. COD removal percentage versus for IDS No.1 and Case-2 of influent composition.



(a) P/V= 65 W.m^{-3} (b) P/V = 40 W.m^{-3}

(c) P/V= 25 W.m^{-3} (d) P/V= 10 W.m^{-3}

FIGURE 4. COD removal percentage versus HRT for IDS No.1 and Case-3 of influent composition.



(a) P/V= 65 W.m^{-3} (b) P/V = 40 W.m^{-3}

(c) P/V= 25 W.m^{-3} (d) P/V= 10 W.m^{-3}

FIGURE 5. COD removal percentage versus HRT for IDS No.2 and Case-1 of influent composition.

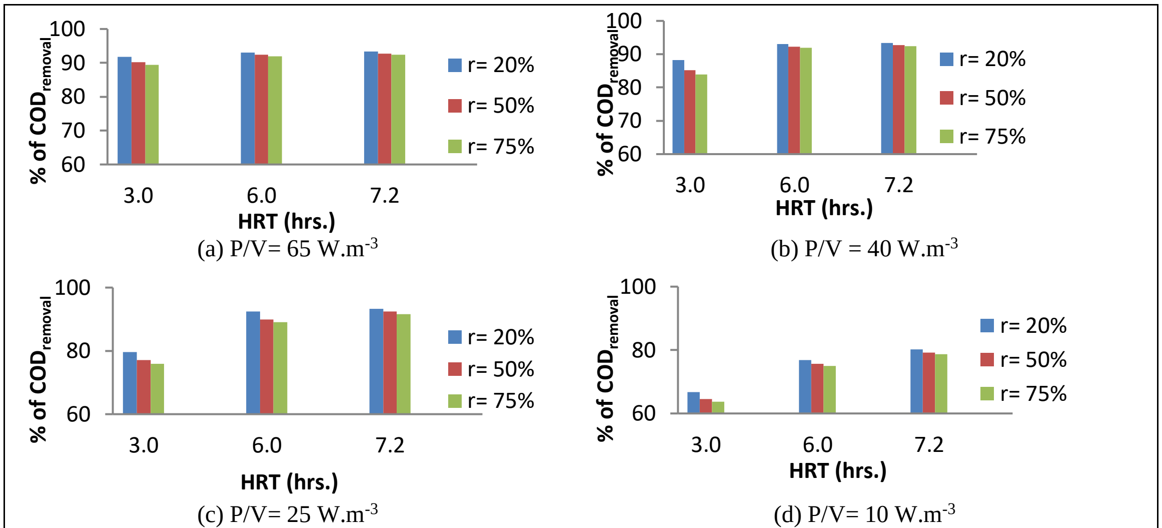


FIGURE 6. COD removal percentage versus HRT for IDS No.2 and Case-2 of influent composition.

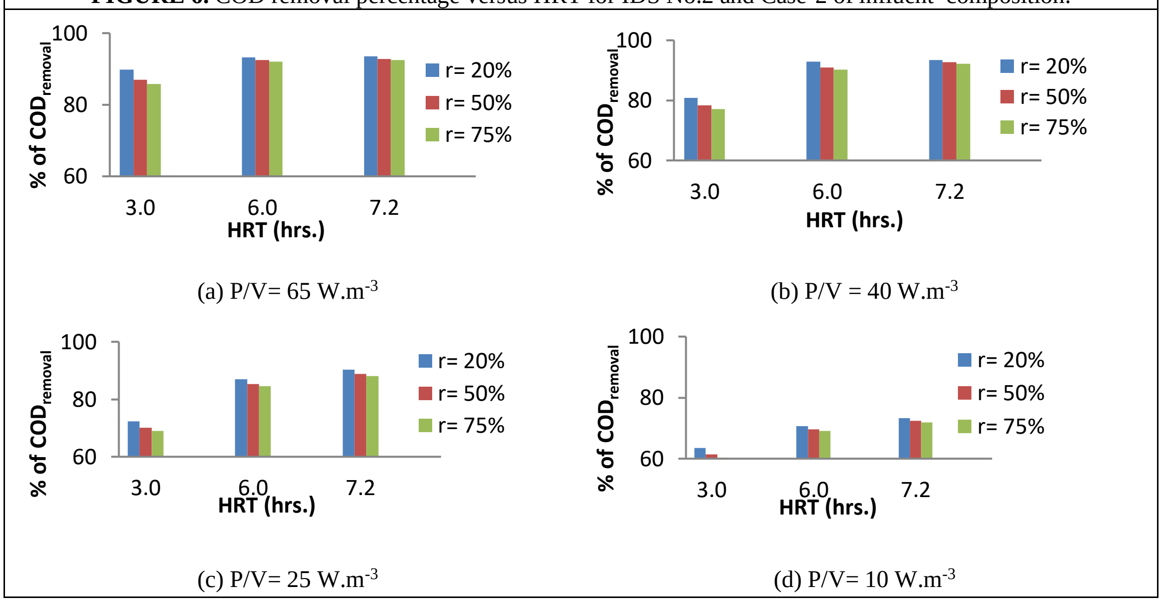


FIGURE 7: COD removal percentage versus HRT for IDS No.2 and Case-3 of influent composition.

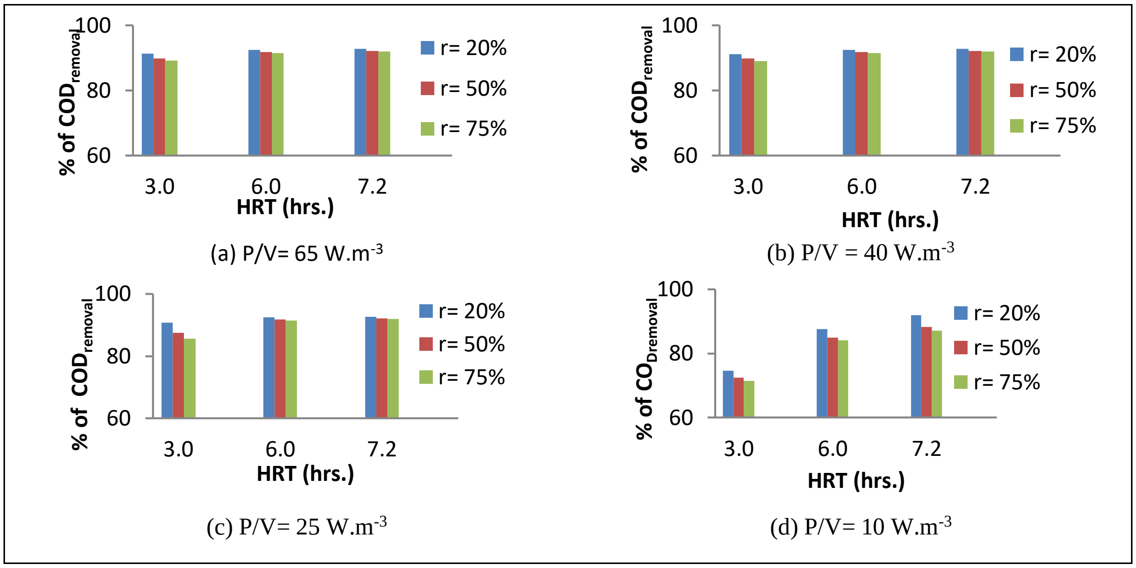


FIGURE 8. COD removal percentage versus HRT for IDS No.3 and Case-1 of influent composition.

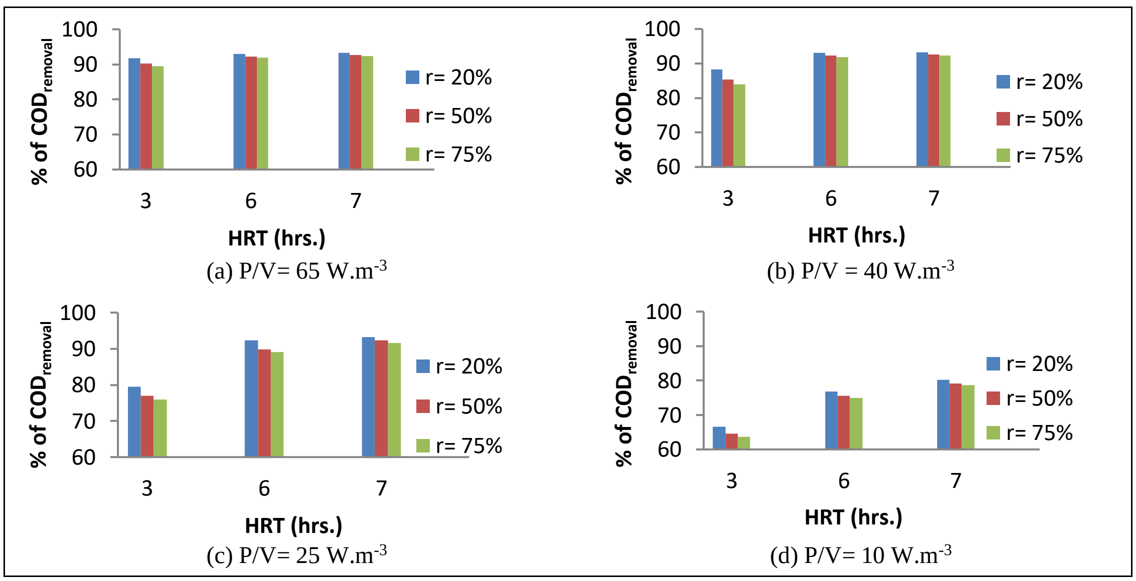


FIGURE 9. COD removal percentage versus HRT for IDS No.3 and Case-2 of influent composition.

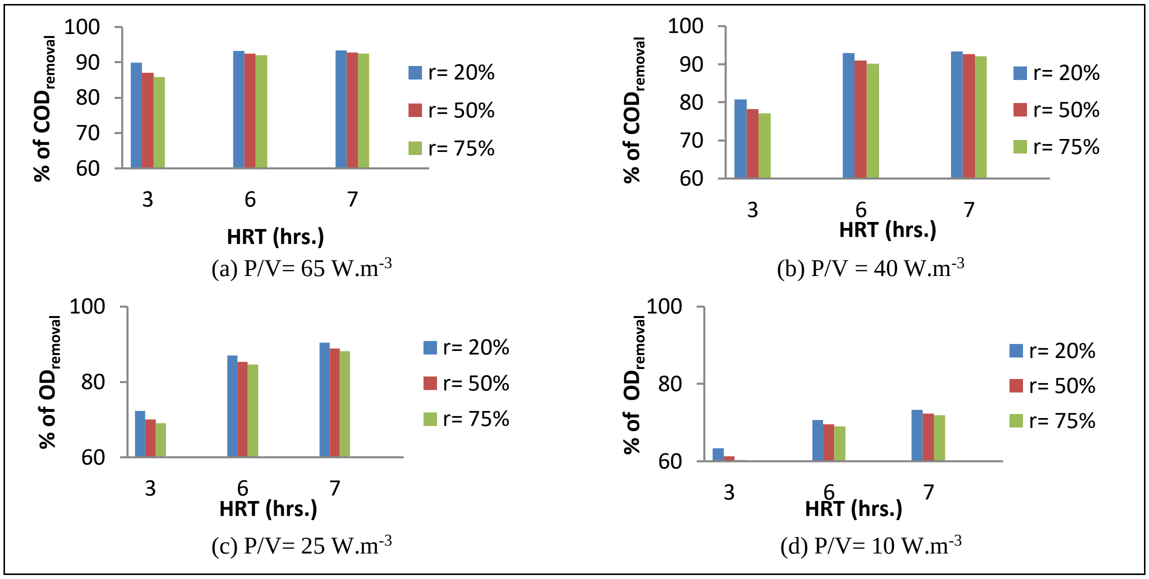
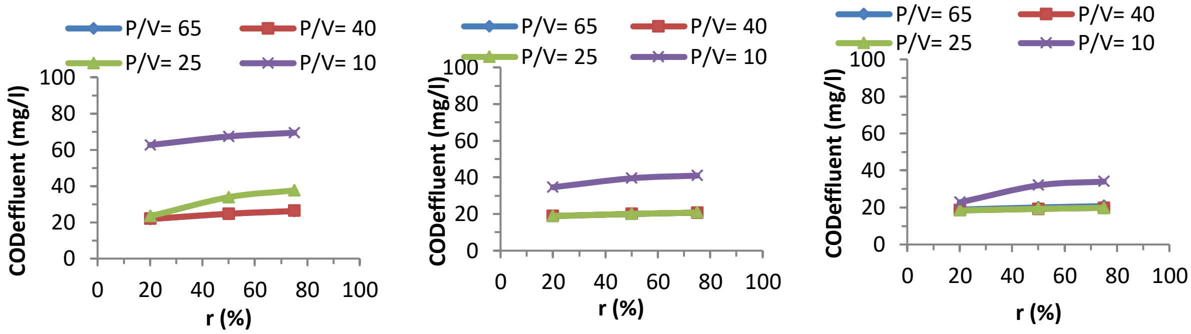


FIGURE 10. COD removal percentage versus HRT for IDS No.3 and Case-3 of influent composition.

Effluent COD and Dissolved Oxygen

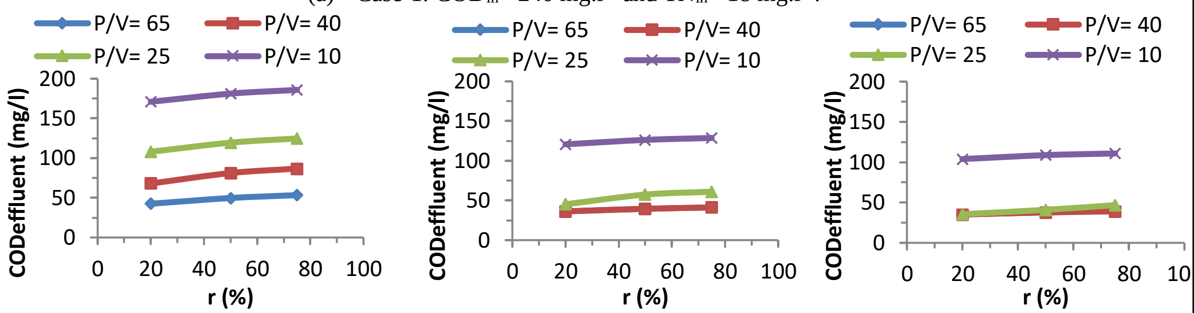
The results of effluent COD versus r at different P/V and HRT values and influent compositions for IDS Nos.1, 2 and 3 showed that for r values vary on the range (20-75) %, the effect of r on effluent COD is insignificant as compared with those of HRT and P/V. Where, the increase of both the last parameters can decrease the effluent COD. Example of these results are presented in Fig. 11 for IDS No.1.

The effluent concentration results of dissolved oxygen (S_O) versus r at different P/V and HRT values showed that for all IDSs, the effluent S_O increases mainly with the increase of HRT. Also, they showed that the effluent S_O of IDS No.2 > effluent S_O of IDS No.3> effluent S_O of IDS No.1. For example, at influent composition of Case-2, HRT of 3 hrs., r of 75% and P/V of 65 W.m^{-3}, the effluent S_O equals to 0.87 mg.l^{-1}, 1.78 mg.l^{-1} and 1.59 mg.l^{-1} for IDS No.1, 2 and 3, respectively. That is because the influent distribution ratios of compartment No.4 are 25%, 0%, and 10% for IDS No.1, 2 and 3, respectively. Thus, compartment No.4 of IDS No.2 has the minimum oxygen demand and subsequently the maximum effluent S_O. An example of effluent S_O results is presented in Fig. 12 for IDS No.1.



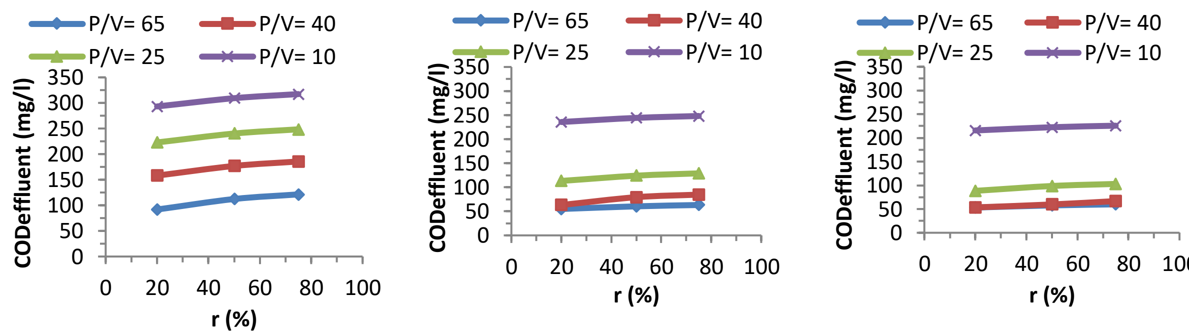
1) HRT= 3.0 hrs 2) HRT= 6.0 hrs 3) HRT= 7.2 hrs

(a) Case-1: COD_{in}= 240 mg.l^{-1} and TN_{in}= 18 mg.l^{-1}.



1) HRT= 3.0 hrs 2) HRT= 6.0 hrs 3) HRT= 7.2 hrs

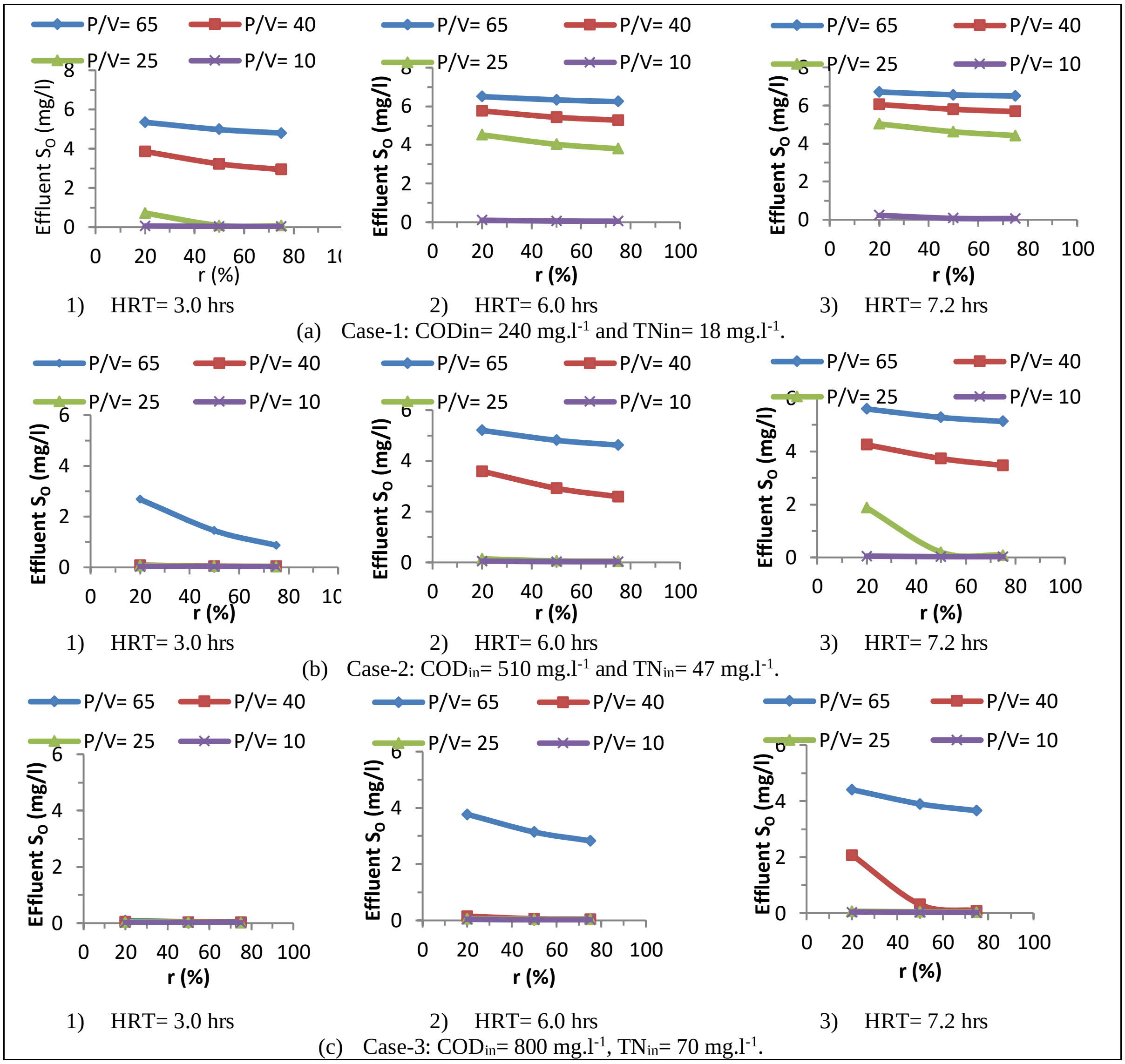
(b) Case-2: COD_{in}= 510 mg.l^{-1}, TN_{in}= 47 mg.l^{-1}.



1) HRT= 3.0 hrs 2) HRT= 6.0 hrs 3) HRT= 7.2 hrs

(c) **Case-3: COD_{in}= 800 mg.l^{-1}, TN_{in}= 70 mg.l^{-1}.**

FIGURE 11. Effluent COD versus r at different P/V and HRT values and influent compositions for IDS No.1.



1) HRT= 3.0 hrs 2) HRT= 6.0 hrs 3) HRT= 7.2 hrs

(a) Case-1: CODin= 240 mg.l^{-1} and TNin= 18 mg.l^{-1}.

1) HRT= 3.0 hrs 2) HRT= 6.0 hrs 3) HRT= 7.2 hrs

(b) Case-2: COD_{in}= 510 mg.l^{-1} and TN_{in}= 47 mg.l^{-1}.

1) HRT= 3.0 hrs 2) HRT= 6.0 hrs 3) HRT= 7.2 hrs

(c) Case-3: COD_{in}= 800 mg.l^{-1}, TN_{in}= 70 mg.l^{-1}.

FIGURE 12. Effluent S_O versus r at different P/V and HRT values and influent compositions for IDS No.1.

Selection of Best Operating Parameters

The obtained values of effluent COD at all IDSs, were checked by comparing them with the maximum permissible limit of Iraqi standards for effluent COD (effluent COD≤100 mg.l^{-1}). The results of effluent COD satisfaction checking versus IDS, P/V, HRT and COD_{in} are given in Table 6. At IDS No.1, as an example, Fig.11 shows that when influent COD equals 240 mg.l^{-1} and at all r, P/V and HRT values, the maximum value of effluent COD was 70 mg.l^{-1} which is less than that permissible by the Iraqi standards. Then, these conditions are indicated by "+" in Table 6. While, when the influent COD equals 510 mg.l^{-1} and HRT equals 6 hrs, the effluent COD reached a value of 128.7 mg.l^{-1} at P/V equals 10 W.m^{-3} which exceeds the MPL of effluent COD and then this condition is indicated by "-".

To check whether the oxygen supply of each scheme can produce an effluent S_O not less than 1mg.l^{-1}, the obtained values of effluent S_O were examined whether they are greater or less than 1mg.l^{-1}. The checking results are presented in Table 7. From this table, it can be shown that the problem of inadequate air supply appeared mainly when HRT and P/V values are low and r is high, especially, during Case-3 of influent composition which has the highest COD value and thus the maximum DO requirement.

The best combinations of operating parameters for the step feed AS system were selected by statistical analysis of positive satisfaction checking results of effluent COD and S_O as presented in Tables 6 and 7, respectively. The statistical analysis results are shown in Fig. 13 in terms of satisfaction percent (percentage of positive satisfaction cases). If the satisfaction percentage of both the effluent COD and S_O are 100% (the effluent COD and DO are satisfying the recommended standards), then, the corresponding design parameters are considered to be the best combination. Based on this concept, the selected best combinations of design parameters for step feed ASP of IDS No.1, 2 or 3 are;

(a) P/V= 65 $W.m^{-3}$, r= 20% and HRT= 6 hrs.

(b) P/V= 40 $W.m^{-3}$, r= 20% and HRT= 7.2 hrs.

TABLE 6. Checking results of effluent COD satisfaction with the Iraqi standards

IDS No.	HRT (hr.)	P/V ($W.m^{-3}$)	Satisfaction of effluent COD at indicated COD_{in}		
			240mg. l^{-1}	510mg. l^{-1}	800mg. l^{-1}
1	3	65	+	+	-
		40	+	+	-
		25	+	-	-
		10	+	-	-
	6	65	+	+	+
		40	+	+	+
		25	+	+	-
		10	+	-	-
	7.2	65	+	+	+
		40	+	+	+
		25	+	+	-
		10	+	-	-
2	3	65	+	+	-
		40	+	+	-
		25	+	-	-
		10	+	-	-
	6	65	+	+	+
		40	+	+	+
		25	+	+	-
		10	+	-	-
	7.2	65	+	+	+
		40	+	+	+
		25	+	+	+
		10	+	-	-
3	3	65	+	+	-
		40	+	+	-
		25	+	-	-
		10	+	-	-
	6	65	+	+	+
		40	+	+	+
		25	+	+	-
		10	+	-	-
	7.2	65	+	+	+
		40	+	+	+
		25	+	+	+
		10	+	-	-

TABLE 7. Checking results of effluent S_O satisfaction

IDS No.	HRT (hr.)	P/V ($W.m^{-3}$)	Satisfaction of effluent S_O at indicated COD_{in} and r values								
			240mg.l^{-1}			510mg. l^{-1}			800mg. l^{-1}		
			20%	50%	75%	20%	50%	75%	20%	50%	75%
1	3	65	+	+	+	+	+	+	-	-	-
		40	+	+	+	-	-	-	-	-	-
		25	-	-	-	-	-	-	-	-	-
		10	-	-	-	-	-	-	-	-	-
	6	65	+	+	+	+	+	+	+	+	+
		40	+	+	+	+	+	+	-	-	-
		25	+	+	+	-	-	-	-	-	-
		10	-	-	-	-	-	-	-	-	-
	7.2	65	+	+	+	+	+	+	+	+	+
		40	+	+	+	+	+	+	+	-	-
		25	+	+	+	+	-	-	-	-	-
		10	-	-	-	-	-	-	-	-	-
2	3	65	+	+	+	+	+	+	-	-	-
		40	+	+	+	-	-	-	-	-	-
		25	+	-	-	-	-	-	-	-	-
		10	-	-	-	-	-	-	-	-	-
	6	65	+	+	+	+	+	+	+	+	+
		40	+	+	+	+	+	+	-	-	-
		25	+	+	+	-	-	-	-	-	-
		10	-	-	-	-	-	-	-	-	-
	7.2	65	+	+	+	+	+	+	+	+	+
		40	+	+	+	+	+	+	+	-	-
		25	+	+	+	+	-	-	-	-	-
		10	-	-	-	-	-	-	-	-	-
3	3	65	+	+	+	+	+	+	-	-	-
		40	+	+	+	-	-	-	-	-	-
		25	+	-	-	-	-	-	-	-	-
		10	-	-	-	-	-	-	-	-	-
	6	65	+	+	+	+	+	+	+	+	+
		40	+	+	+	+	+	+	-	-	-
		25	+	+	+	-	-	-	-	-	-
		10	-	-	-	-	-	-	-	-	-
	7.2	65	+	+	+	+	+	+	+	+	+
		40	+	+	+	+	+	+	+	+	-
		25	+	+	+	+	-	-	-	-	-
		10	-	-	-	-	-	-	-	-	-

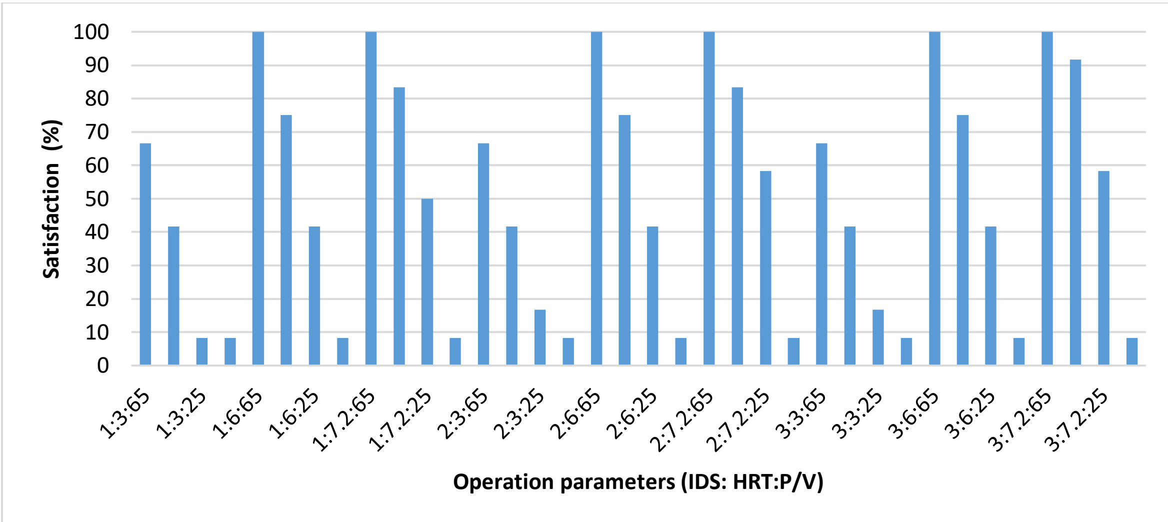


FIGURE 13. Statistical analysis results of satisfaction percentage for different combinations of operating parameters

CONCLUSIONS

Based on application results of ASM1 on step feed AS system, the followings are concluded;

a. The impact of P/V and HRT on COD removal percentage is significant at medium to high strength influent sewage, where the COD removal percentage increases with the increase of P/V and HRT.
b. The impact of r on percentages of COD removal is insignificant at high P/V and low strength sewage.
c. The percentages of COD removal vary in the ranges (60.3-93.5) %.
d. The best combinations of design parameters for step feed AS system of IDS No.1, 2 or 3 are;
e. P/V= 65 $W.m^{-3}$, r= 20% and HRT= 6 hrs.
f. P/V= 40 $W.m^{-3}$, r= 20% and HRT= 7.2 hrs.

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