Research Article

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Effect of internal and external recycle ratios on the nutrient removal efficiency of anaerobic/anoxic/oxic (VIP) wastewater treatment plant

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Abstract: Due to the disposal of different wastewater into the water bodies, the rate of surface water pollution is increasing. The virginia initiative plant (VIP), one of the most efficient and economical wastewater treatment systems, was assessed. The experiments were carried out by a laboratory-scale VIP system used for this study, with a flow rate of 100 L/day and a solid retention time rate estimated at 10 days. The system works on three different ratios for internal rotation (100, 150, and 200%) and three for external rotation (80, 90, and 100%), and the effective volumes were 20, 40, and 60 L for anaerobic, anoxic, and oxic reactors, respectively. The results showed that the VIP system achieved the best removal efficiency of organic matter represented by COD, phosphorous, and ammonia (86, 94, and 93%, respectively). The impact of internal and external rotation ratios was tested by removing COD, phosphorous, and ammonia. The percentages of internal rotation significantly affect the biological removal of nitrates. The relationship between them is inverse, while the percentages of external rotation significantly impact the biological removal process of phosphorus. The relationship between them is positive, whereas the internal and external rotation percentages did not considerably affect the efficiency of removing both ammonia and COD. According to the research results, internal and external rotation ratios enhanced the removal efficiency of phosphorus and nitrates. The VIP system proved to be an effective method for domestic wastewater treatment with a flow conforming to Iraqi standards for draining wastewater with all organic matter, phosphorous, and nitrogenous compounds to rivers.

Keywords: VIP, biological phosphorous removal, internal rotation, external rotation, returned sludge, biological nutrient removal

1 Introduction

In recent years, the discharge of nutrients into the environment has been controlled to meet new nutrient discharge standards for municipal wastewater treatment systems. Conventional activated sludge systems allowing biological nutrient removal from various anaerobic, anoxic, and oxic reactor combinations are developed. Municipal and industrial discharge of nitrogen and phosphate increases the eutrophication of rivers, causing severe environmental damage; this is especially true when wastewater contains nitrogen, which causes algae and aquatic plants to grow more rapidly in rivers. Stricter regulations have been applied to reduce nitrogen and phosphate discharges to rivers to reduce eutrophication [1–5]. Removal of nitrogenous compounds from wastewater involves two processes: nitrification and denitrification. There are two mechanisms involved in nitrification. Ammonia transforms to nitrite, and then nitrite transforms to nitrate using autotrophic bacteria like Nitrosomonas and Nitrobacter bacteria. Denitrification, generally, includes two processes: heterotrophic and autotrophic [6–8]. External and internal rotation of wastewater in many processes results in high denitrification yields. Several challenges associated with the nitrification process have hindered optimum nitrogen removal. External rotation is generally related to the presence of an external carbon source, and it is necessary for wastewater treatment to achieve high efficiency to reduce nitrogen concentrations. As a result, nitrogen is not effectively removed from wastewater due to problems with the internal and external rotation ratio [9,10]. This study used a modified virginia initiative plant (VIP) advanced treatment process containing anaerobic, anoxic, and oxic reactors to remove nitrogen from domestic wastewater for optimum nitrification. Then, in an anoxic

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reactor, nitrate is converted to N_2 gas by denitrification. The study's primary objectives are (1) studying the efficiency of the performance of the VIP system in removing organic compounds, phosphorous, and nitrogen and (2) studying the effect of both the internal and external rotation ratios on the efficiency of the system.

2 Materials and method

One of the essential things in laboratory work is the design of the size and type of reactors used in the system. The laboratory-scale VIP used in this study is illustrated in Figures 1 and 2. The reactors are made of aluminum with a thickness of 4 mm, and the safety height has been determined (FB of 10 cm) to prevent the reactor contents from overflowing to the outside during the system's operation, whose dimensions are shown in Table 1.

Table 1: Design parameters of the system

Type	Size	Time	Height	Width	Length
Reactor	L	Hydraulic retention time (h)	(m)	(m)	(m)
Anaerobic	20	2	0.25	0.2	0.4
Anoxic	40	2	0.3	0.25	0.5
Oxic	60	4	0.4	0.3	0.6

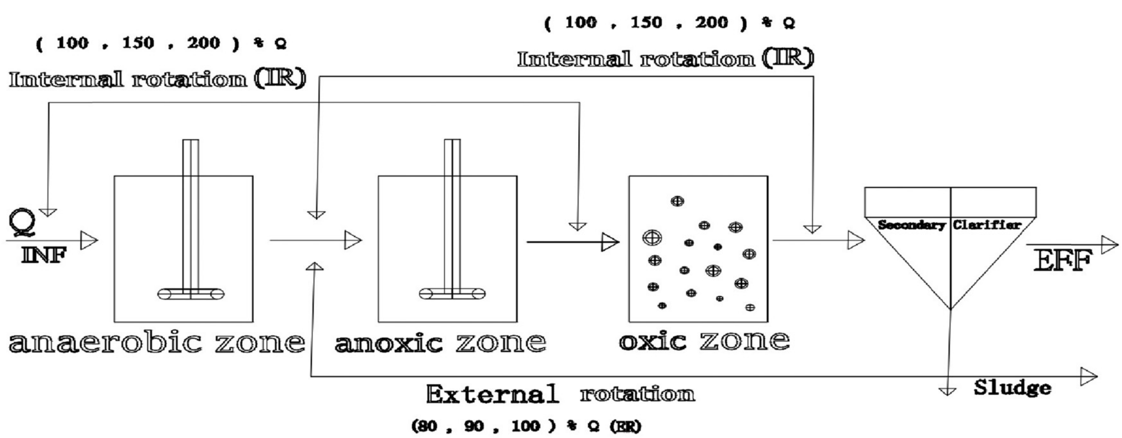

Figure 1: VIP process.

Figure 2: Laboratory model of the VIP system.

The plastic sedimentation tank consisted of a cylindrical basin at the bottom of a minor conical assembly intended to collect sedimentary sludge. To reduce the disturbance caused by water entering the sedimentation tank, the bay has been supplied with a unique inlet made of plastic and rubber for feeding the settlement tank with mixed liquor from the aeration tank. For the rotation system, two types were used: the first is external, in which the activated sludge is returned from the secondary sedimentation tank to the biological reactors. As for the second (internal) system, the mixture is produced from the aerated zone to the anoxic and from the anoxic zone to the oxic zone in biological reactors operating with the VIP system. Three percentages of external rotation sludge have been approved, 80–90–100% of drainage entering the system, and three proportions of the rotation sludge mixture internally are 100, 150, and 200% of the internal discharge. All procedures are expressed in Figures 2 and 3.

The external rotation system, which works to return the sludge from the sedimentation tank to the anoxic reactor, consists of small pumps connected to a flow meter. The flow meter is set to the amount of discharge that must be pumped during the day, making it possible to determine the quantity and proportion of sludge returned from the settling tank to the anoxic reactor. As for the internal rotation system, which is related to biological reactors and works with the VIP system to return the mixture from an oxic reactor to an anoxic reactor and from an anoxic to an anaerobic reactor, this operation is also controlled by pumps and flow meters. The diffuser aeration method was used because it is easier and more efficient than other methods [11]. The anaerobic and anoxic reactor were equipped with mechanical mixer to ensure continuous mixing of mixed liquid suspended solids (MLSS). External rotation ratio returned to anoxic reactor to supply it with sufficient microbial biomass necessary for biological treatment. IR ratio is attributed to the rise in nitrate (NO_3-N) available for nitrification. Both IR and ER are typically expressed as a percentage of the influent wastewater Q. Qr/Q depends on the type of activated sludge system. The mass balance for the variable is shown in below equations:

$$Q_{\text{in}}C_{\text{in}}\text{-}Q_{\text{out}}C + r = \frac{\mathrm{d}(c\cdot v)}{\mathrm{d}t} = v\frac{\mathrm{d}c}{\mathrm{d}t} + c\frac{\mathrm{d}v}{\mathrm{d}t}, \quad (1)$$

$$\frac{\mathrm{d}v}{\mathrm{d}t} = Q_{\text{in}} - Q_{\text{out}}, \quad (2)$$

$$Q_{\text{in}}(C_{\text{in}} - C) + r = v\frac{\mathrm{d}c}{\mathrm{d}t}, \quad (3)$$

$$\frac{Q_{\text{in}}}{v}(C_{\text{in}} - C) + \frac{r}{v} = \frac{\mathrm{d}c}{\mathrm{d}t}, \quad (4)$$

where Q_{in} is the influent flow rate (m^3/day), Q_{out} is the effluent flow rate (m^3/day), C_{in} is the influent concentration (mg/L), C is the effluent concentration (mg/L), r is the rate of reaction (mg/L/day), V is the liquid volume (m^3), t is the time (day), IR is the internal recirculation ratio, and ER is the external recirculation ratio.

3 Experimental conditions

The wastewater in this study was collected from the discharge point of the maintenance hole in Wasit City, south of Iraq. As shown in Table 2, the main sewage characteristics of the constituents used in this study were compared

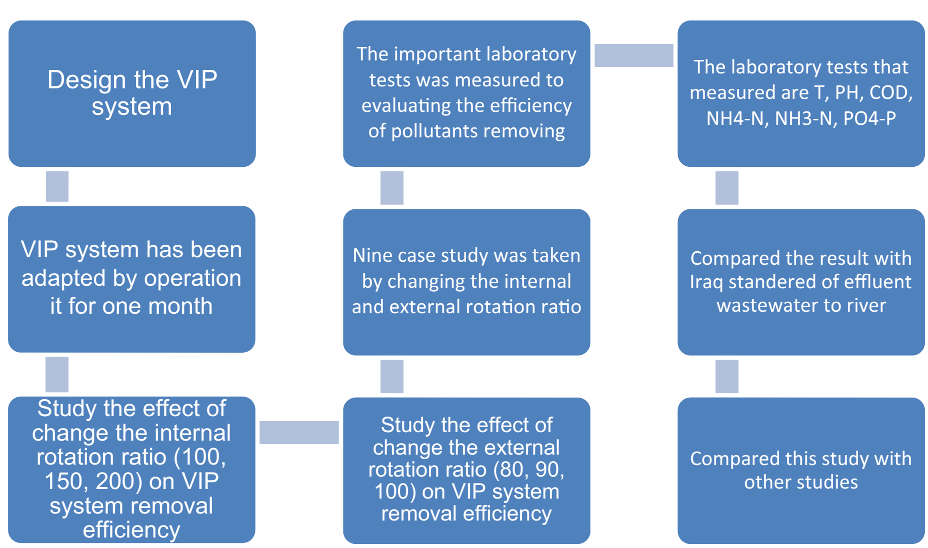

Figure 3: Flowchart of the process of this study.

Table 2: Wasit sewage properties compared with a domestic sewage universal concentration

Pollutants (mg/L)	Mean value of raw wastewater (mg/L)	Concentration of international sewage [12]		
		Low	Medium	High
BOD	200	110	190	350
COD	420	250	430	800
Ammonia	28	12	25	45
TN	45	20	40	70
TP	6	4	7	14
TSS	265	120	210	400
TDS	450	270	500	860

with the universal concentration of domestic wastewater. It is evident from parameters such as biological oxygen demand (BOD), chemical oxygen demand (COD), total phosphorus (TP), and total suspended solids (TSS) that the wastewater of Wasit City is of medium strength. During this study, DO concentrations were kept high at three mg/L in the oxic tank to provide the oxygen necessary for biological treatment.

3.1 Reactor startup and operation

VIP operates on a three-cycle external rotation ratio during the startup phase. For each of the three internal rotation ratios, the work continues for 1 year to provide sufficient time to accumulate it in each case after taking samples. The VIP system operated 24 h per day, and the examinations were performed 5 days per week to ensure that the biological treatment system was optimal.

4 Result and discussion

Removal of nitrogenous compounds (nitrates).

Figure 4 shows that the relationship between the internal rotation rate and the concentration of nitrates in the outflow water is reversed. The reason for this is the increase in the amount of nitrates available for the denitrification process due to the rise in the volume of the nitrate-rich liquid mixture circulated from the aerobic reactor to the anoxic reactor that combines with a water rich in organic matter to maintain the optimum condition for the growth of non-autotrophic bacteria heterotrophs that denitrify and use nitrates as an electron acceptor instead of oxygen.

Figure 5 shows that the relationship is also inverse between the concentration of nitrates in the outflow water and the rate of external rotation; that is, the concentration of nitrates decreases with the increase in the external rotation rate. This phenomenon is attributed to the fact that the process of external rotation brings more active biomass to the test system than the previous one. These objects are considered the central element in the treatment system. They can feed back on the nutrients (organic, nitrogenous, and phosphorous compounds) at a rate greater than primary microorganisms in the experimental system [13].

4.1 Removal of phosphorous compounds

From Figure 6, the phosphorus removal efficiency increases with an increase in the internal rotation rate. This phenomenon is attributed to the increase in the amount of nitrate (NO_3-N) available for the denitrification process that occurs

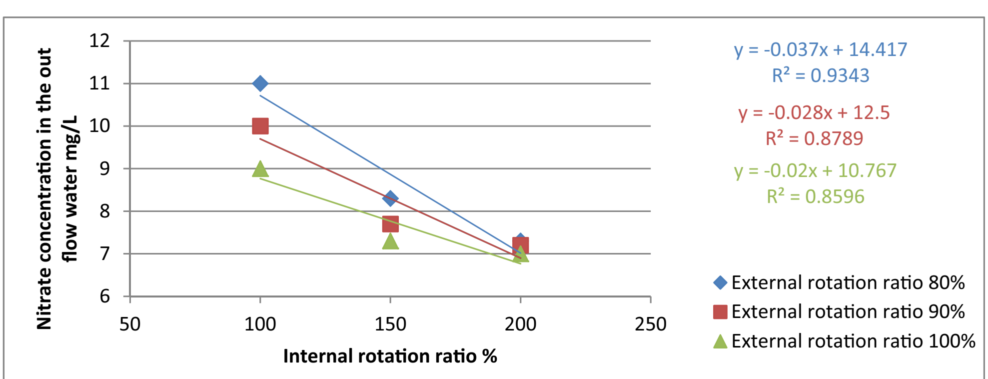

Figure 4: The relationship between internal rotation and nitrate concentration in the outflow water.

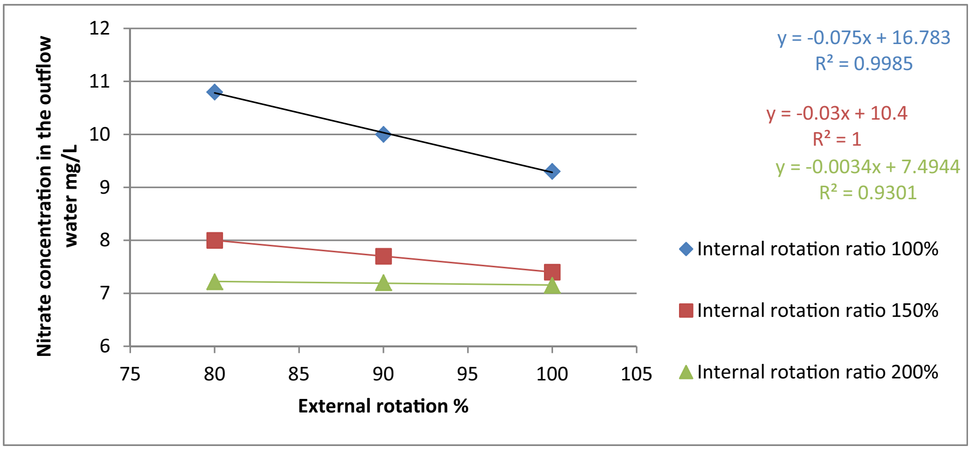

Figure 5: The relationship between external rotation and nitrate concentration in the outflow water.

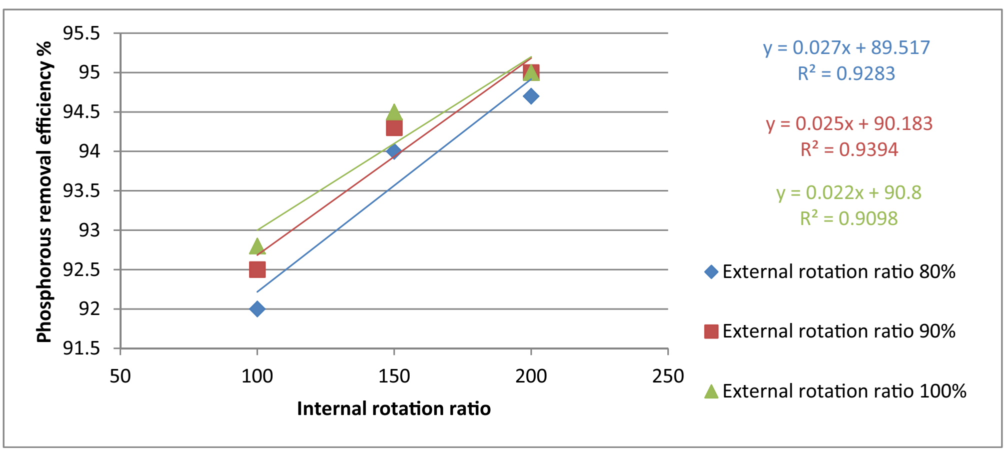

Figure 6: The relation between internal rotation ratio and phosphorous removal efficiency %.

by the PAOs bacteria due to the increase in the volume of the nitrate-rich liquid mixture rotation which combines with the flow of water rich in PAOs bacteria to increase the growth rate of the PAOs bacteria and their absorption of phosphorus in the anoxic reactor by using nitrate as an electron acceptor instead of oxygen, and then increase the

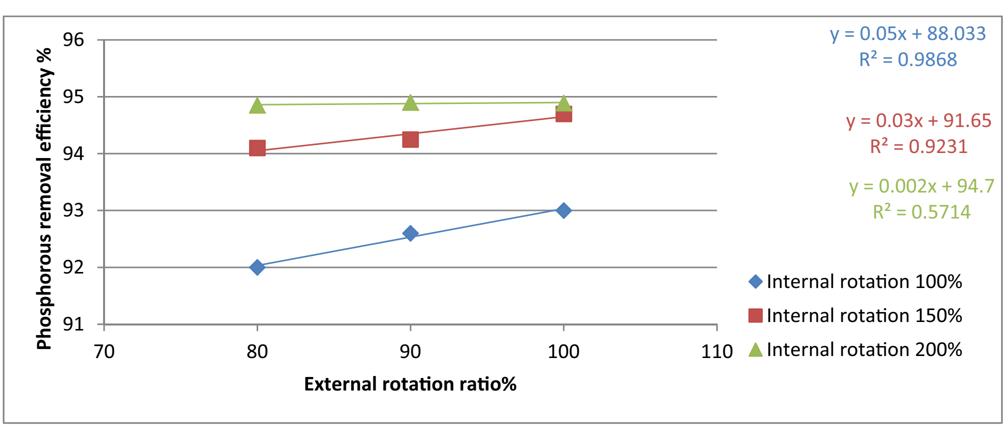

Figure 7: The relation between external rotation ratio and phosphorous removal efficiency %.

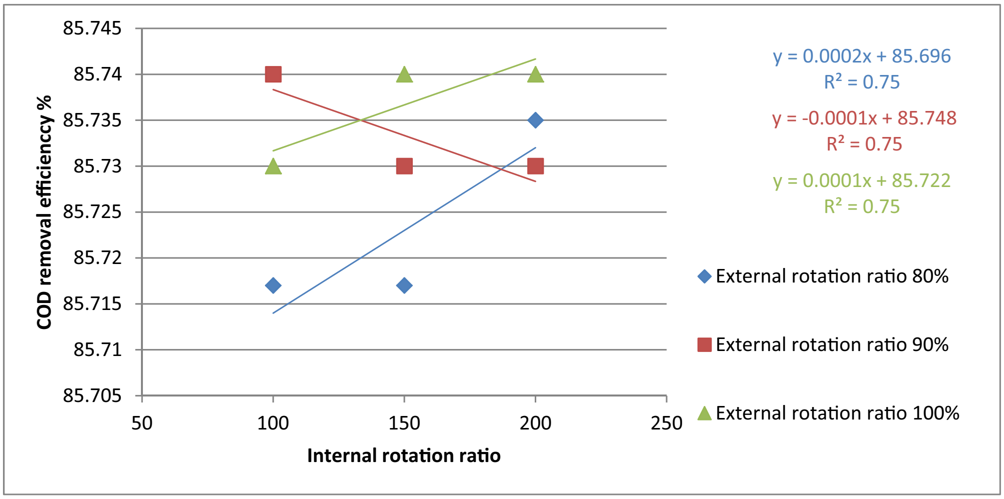

Figure 8: The relation between internal rotation ratio and COD removal efficiency %.

rate of acetate absorption by PAOs bacteria and form polyhydroxyalkanes, and increase the rate of phosphorus release in the anaerobic reactor, and then increase phosphorus removal efficiency in the anoxic and oxic reactors.

From Figure 7, the efficiency of phosphorus removal increases with the increase in the percentage of external rotation. This phenomenon is attributed to the fact that the external rotation process brings more active biomass than its predecessor to the experimental system, and these organisms are the main components of the treatment system. They can feed again on nutrients (organic, nitrogenous, and phosphorous compounds) at a greater rate than previously existing microorganisms. This indicates that by increasing the percentage of external rotation, the rate of nitrification increases and that the ideal ratios for RAS are 80–100% [14–16]. So, we conclude from the above relationships that the phosphorus removal efficiency increases with an increase in the external rotation ratio.

4.2 Removal of organic compounds represented by COD

The effect of varying the internal and external rotation ratios on the efficiency of the COD was studied. It is noted from Figures 8 and 9 that the COD removal efficiency is not affected by an increase or decrease in both the internal and external recycling ratios, and the differences are not apparent due to the convergence of COD removal efficiencies.

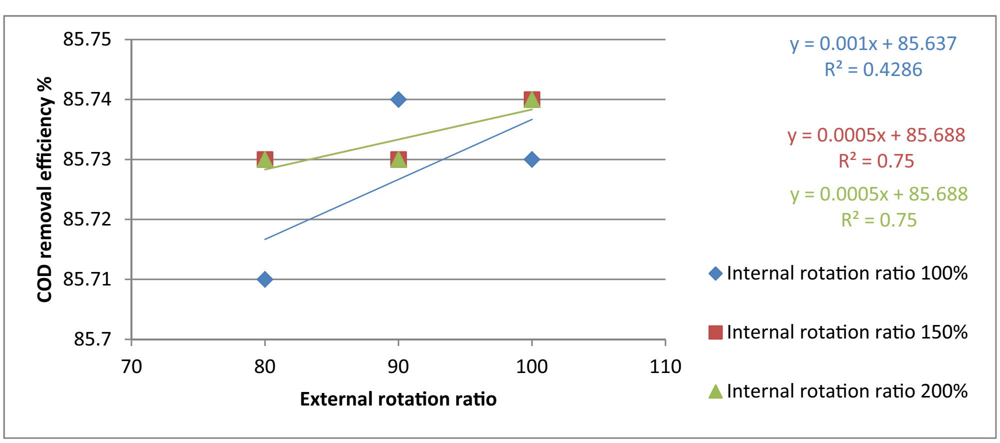

Figure 9: The relation between external rotation ratio and COD removal efficiency %.

Table 3: Result of the VIP system

Case	Pollutant	Influent (mg/L)	Anaerobic	Anoxic	Oxic	Effluent
ER 80%	COD	251.4	147.5	71.8	52.1	35.42
IR	PO_4-P	1.324	17.58	11.5	0.13	0.1
100%	NH_4-N	27.4	21.6	11.5	2.1	2.076
	NO_3-N	0.804	0.1	0.32	10.8	10.81
ER 80%	COD	266	151.1	64	51.2	37.2
IR	PO_4-P	1.356	17.62	4.1	0.1	0.077
150%	NH_4-N	31	21.5	9.6	2.2	2.42
	NO_3-N	1.026	0.12	0.9	8.1	8.13
ER 80%	COD	242	152.3	61.2	51.9	34.12
IR	PO_4-P	1.722	17.8	0.6	0.91	0.087
200%	NH_4-N	30	22.19	5.9	2.22	2.34
	NO_3-N	0.87	0.13	2	7.4	7.41
ER 90%	COD	263	122	69.1	51.8	36.05
IR	PO_4-P	1.476	15.35	1.3	0.12	0.1
100%	NH_4-N	27.4	17.7	11.4	1.9	2.11
	NO_3-N	0.876	0.131	0.4	10.1	10.15
ER 90%	COD	267	123	64.1	52	37.45
IR	PO_4-P	1.722	15.8	0.8	0.1	0.091
150%	NH_4-N	28.8	18.4	7.6	2.2	2.29
	NO_3-N	0.898	0.11	1.1	7.8	7.82
ER 90%	COD	268.4	127.3	60.9	51.9	37.65
IR	PO_4-P	1.796	15.8	0.3	0.089	0.086
200%	NH_4-N	27.8	17.9	6	2.18	2.24
	NO_3-N	0.86	0.2	2	7.4	7.416
ER 100%	COD	267	105.1	67.8	52.2	37.45
IR	PO_4-P	1.534	13.3	1.1	0.12	0.1
100%	NH_4-N	27.4	16.8	10.98	2.14	2.11
	NO_3-N	0.858	0.19	0.35	9.45	9.45
ER 100%	COD	255.6	110.2	62.9	51.85	35.05
IR	PO_4-P	1.746	13.5	0.69	0.092	0.091
150%	NH_4-N	29	17.2	9.1	2.21	2.33
	NO_3-N	0.894	0.1	1.1	7.3	7.316
ER 100%	COD	264	11.3	61	51.95	36.27
IR	PO_4-P	1.796	13.6	0.1	0.08	0.083
200%	NH_4-N	29.2	16.4	7	2.23	2.34
	NO_3-N	0.868	0.18	2.05	6.92	7

All nutrient removal and organic matter percentage at each reactor are mentioned in Table 3, which express the effect of internal rotation ratio and external rotation ratio nutrient removal and COD in the VIP system

4.3 Efficiency of the VIP system in removing nitrates

The VIP is one of the most essential biological treatment systems due to low operation cost, reduces sludge production, and is excellent in wastewater treatment nutrients and COD removal. Setup includes an anaerobic/anoxic/oxic treatment sequence for removing phosphorus, nitrification, denitrification, and organic carbon. It has the best removal efficiency of organic matter represented by COD, phosphorous, and nitrogen in ammonia form (85.7, 93.5, and 92.4%), respectively, while meeting the outflow water

Table 4: Study results were compared with Iraqi determinants of wastewater discharge to rivers [16,17]

Number	Test	Iraq determinants	Study result
1	BOD5	40	7
2	COD	100	35
3	TSS	60	2
4	PO_4-P	3	0.3
5	NO_3-N	11.2	6.5
6	PH	6–9.5	7.8

Table 5: Comparison of removal efficiency of the present research with other anaerobic, anoxic, and oxic studies

Reference	Year	Removal efficiency (%)		
		COD	Ammonia	TP
Zhang et al. [18]	2016	81.25	80.30	96.61
Zheng et al. [19]	2021	88.7	77.1	93
Li et al. [20]	2022	91.57	80.20	92.68
This study	2023	85.7	92.4	93.5

of Iraqi standards for draining waste water with all organic and phosphorous compounds and nitrogen to river, as shown in Table 4.

4.4 Comparison with other anaerobic, anoxic, and oxic studies

A comparison was made for the efficient removal of the present research with that of other anaerobic, anoxic, and oxic biological removal processes, as shown in Table 5. Based on the results of this study, the efficiency removal of COD was near to that in the study by Wang et al. [18,19], while it was far from that in the study by Li et al. [20]. In the present study, the efficiency removal of TP was near to that in previous literature [19,20], while it was far from that in the study by Li et al. [20]. There was a significant difference in ammonia removal efficiency between this study and the studies shown in Table 5.

5 Conclusion

1. When the internal rotation ratio increases from 100 to 150%, nitrate removal efficiency is increased by four times as much as by increasing the percentage from 150 to 200%. The relationship between nitrate removal and the internal recycling rate becomes insignificant when the internal rotation ratio increases by more than 150%.
2. It was found that the relationship between the efficiency of phosphorous removal and both the internal and external rotation ratios is linear, with a correlation coefficient greater than 0.75.
3. The relationship between the efficiency of removing ammonia and COD with both internal and external circulation ratios is not significant, and the efficiency of ammonia removal or COD is not significantly affected by an increase or decrease in both the internal and external rotation percentages.
4. The experimental VIP system achieved a rate of material removal efficiency of organics represented by COD and phosphorous represented by phosphates and ammonia of 85.7, 93.5, and 92.4%, respectively, with the outflow water meeting Iraqi standards for draining wastewater with all organic and phosphorous compounds and nitrogen to rivers.

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Data availability statement: Most datasets generated and analyzed in this study are in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

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