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Effect of Internal Recycle Ratio on the Nutrient Removal Efficiency Using Enhanced Bardenpho Process

Masood M. Hazzaa *, **Waleed M. Alabdraba**
Department of Environmental Engineering, College of Engineering, Tikrit University, Tikrit, Iraq.

Keywords:
Bardenpho; COD; Internal recycle ratios; PO4; Total nitrogen.

Highlights:

- *The removal efficiency for TN and PO4 increased with increasing IR ratios from 0% to 200%, then decreased when the IR ratio increased to 300%.*
- *The maximum removal efficiencies for TN and PO4 were (92.86%) and (86.67%), respectively.*

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Corresponding author:
Masood M. Hazzaa
Department of Environmental Engineering, College of Engineering, Tikrit University, Tikrit, Iraq.

Abstract: An appropriate recycling ratio can be determined to support the needed conditions for optimization operation in wastewater treatment. This study aims to address the impact of the Internal Recycle Ratio (IR) on Nutrient removal efficiency using an enhanced Bardenpho process. The reactors (Anaerobic, First Anoxic, First Aerobic, Second Anoxic, Second Aerobic) were constructed with a secondary settling tank to settle the biomass before discharge to accomplish significant nitrogen and phosphorus removal. After oxidizing in the second aeration chamber, the nitrate was recycled into the first anoxic chamber (IR1), first aerobic chamber (IR2), and second anoxic chamber (IR3). In that order, the internal recycle ratios of 0%, 100%, 200%, and 300% were shown to impact the biological removal of nitrogen and phosphorus using the Bardenpho process in the pilot-size plant. Input COD, TN, and PO4 values in raw synthetic wastewater of 413 mg/L, 35 mg/L, and 15 mg/L, respectively, were used to operate each IR. The IR of (200%) and IR1 attended maximum TN and PO4 removal efficiency of (92.86%) and (86.67%), respectively. IR of (0%) attended its maximum TN and PO4 removal efficiency at (51.4%) and (46.7%) respectively.

تأثير نسبة إعادة التدوير الداخلية على كفاءة إزالة العناصر الغذائية باستخدام عملية باردينفو المحسنة

مسعود محسن هزاع، وليد محمد شيت العبدربه
قسم هندسة البيئة/ كلية الهندسة / جامعة تكريت / تكريت - العراق.

الخلاصة
يمكن تحديد نسبة الارجاع المثلى لتدعيم الظروف اللازمة لعملية تحسين معالجة مياه المطروحات. ان الهدف من هذه الدراسة هو ايجاد تأثير نسبة الارجاع الداخلية (IR) على كفاءة ازالة المغذيات باستخدام نظام Bardenpho. تم تصنيع المفاعلات (لاهوائي، قليل الاوكسجين الاول، هوائي اول، قليل الاوكسجين الثاني، وهوائي ثاني) مع حوض ترسيب نهائي لترسيب الكتلة البيولوجية قبل طرحها لاتمام ازالة مركبات النتروجين والفسور بشكل فعال. بعد حصول عملية الاكسدة في حوض التهوية الثاني، يتم الارجاع الى حوض قليل الاوكسجين الاول (IR1)، حوض التهوية الاول (IR2)، والى حوض قليل الاوكسجين الثاني (IR2). في هذا البحث تم ايجاد تأثير نسب الارجاع الداخلية (٠٪، ١٠٠٪، ٢٠٠٪ و ٣٠٠٪) على كفاءة ازالة مركبات النتروجين والفسفور باستخدام وحدة مختبرية تعمل بنظام Bardenpho. اذ كانت تراكيز COD، TN و PO_4 في المياه المصنعة الخام هي (٤١٣، ٣٥ و ١٥ ملغم/لتر) على التوالي. بينت النتائج انه عند نسبة الارجاع الداخلية ٢٠٠٪ و عند حالة IR1 تعطي اعلى نسبة ازالة بلغت ٩٢,٨٦٪ و ٨٦,٦٧٪ لكل من TN و PO_4 على التوالي. في حين كانت نسبة الارجاع الداخلية ٠٪ اعطت اقل نسبة إزالة لها لكل من TN و PO_4 والتي بلغت ٥١,٤٪ و ٤٦,٧٪ على التوالي.

الكلمات الدالة: باردينفو، COD، نسب إعادة التدوير الداخلية، PO4، النيتروجين الكلي.

1.INTRODUCTION

Aquatic toxicity and eutrophication are caused by nutrient discharge into the aquatic environment [1]. For example, microbial development increases the required biological oxygen and decreases the dissolved oxygen concentrations in the aquatic environment, which the ammonia compound will be harmful to fish and other aquatic life. This extremely harms aquatic life because it produces dead zones in the water due to a lack of dissolved oxygen [2]. Consuming contaminated drinking water can result in serious health problems for anyone exposed to nitrate for both short- and long-term periods. Short-term exposure to contaminated drinking water can result in methemoglobinemia, or "blue baby syndrome," in newborns [3, 4]. This may result in an unsustainable rapid population expansion that kills algae. Bacterial action causes these algae to break down, thus lowering the dissolved oxygen that is essential to the water's health [5, 6]. Nowadays, nitrogen and phosphorus must be removed from wastewater entering rivers. A surplus of nitrogenous and phosphorus-containing wastewater released into streams can promote the growth of weeds and algae. Therefore, an additional treatment is needed to remove phosphate or nitrogenous materials. By changing the sludge system naturally and without using chemicals, a biological treatment is one way to remove the nutrients that nitrogen and phosphorus contain from treated wastewater [7]. Because there are no chemicals required, this process is also more economical. The carbon and energy needed to extract the nitrogen and phosphorus are found in the organic component of the sludge. The primary type of nitrogen in the original wastewater is ammonia. The sludge has to mature to the point where full nitrification occurs, and ammonia nitrogen is transformed into nitrates and nitrites, which happens only in the aerobic zone. Due to the lack of dissolved oxygen, the bacteria employ the organic carbon molecules as hydrogen donors to convert the nitrates to nitrogen gas when they reach the anoxic zone. Following this step, the nitrogen will be moved to the atmosphere. In the last zone, the effluent is aerated to increase the dissolved oxygen content and stop more denitrification [8, 9]. Phosphorus removal is accomplished through a step-feed procedure that treats wastewater influent in at least one aerobic zone. Once more, this passes through a minimum of one anoxic zone. After that, raw water and some of the anoxic zone's effluent are transferred to an anaerobic zone. Anaerobic zones send their influence to anoxic zones, which subsequently transfer it to aerobic zones downstream [10]. Among wastewater treatment facilities, the Bardenpho method has frequently been employed to remove biological nutrients. One important aspect influencing the improvement of biological nutrient removal in mixed liquor is its internal recycling. This research presented the outcomes of removing nutrients from various internal recycle ratios and suggested a key operational parameter adjustment for laboratory settings. A study on the treatment of actual municipal wastewater used a modified five-stage Bardenpho process on a pilot scale with a 10 m^3/day capacity. The steady-state removal efficiencies of (COD), (TKN), (NH_4^+-N), (PO_4^{3-}-P), suspended solids (SS), and volatile suspended solids (VSS) were 87.5%, 86.12%, 93.14%, 89.9%, 88.8%, and 94.4 percent, respectively [11]. Furthermore, Yasouj's sanitary wastewater was treated using a modified 5-stage Bardenpho pilot plant tthat was created and ran for a year. The plant was designed to remove nitrogen and phosphorus. During the pilot plant's operation, the optimal values for the parameters hydraulic retention time, solid retention time, recycling sludge rate, and recycle flow rate were determined. The trial results indicated that the removal efficiencies of TN, TP, BOD, and COD were roughly 73%, 90%, 93%, and 75%, respectively. The highest amount of TP removed was 85% [12, 13]. A study of effecting various hydraulic retention times (HRT) and nitrate recycle ratios (R) was assessed. High removal efficiencies were achieved for (COD), (TN), (TP), and ammonium, which were approximately 98.20%, 92.54%, 94.70%, and 96.50%, respectively. At HRT of 2, 4, 6, 2.67, and 1.07 hours, the anaerobic, first anoxic, first aerobic, second anoxic, and second aerobic compartments demonstrated the best performance, respectively. This led to a 15.74-hour total HRT and a 2-nitrate recycle ratio [14]. The viability of a three-stage method (anaerobic, anoxic, and moving bed biofilm reactor, or MBBR) for removing organic matter and nutrients from secondary WWTP effluents at different nitrate recycle ratios (R) and hydraulic retention times (HRT) was investigated. Under ideal circumstances (HR Total = 12.8 hr. and R = 1.5), significant reductions in chemical oxygen demand (%COD removal), %TN removal, and %TP removal of 95.5%, 96.2%, and 94.70% were attained. Increasing the HRT up to 1.5 h and internal recycling increased %TN removal [15]. An investigation into the simultaneous biological removal of phosphorus and nitrogen in a vertical bioreactor was occurred. The total phosphorus (TP) content of the synthetic wastewater employed in this investigation was 32.6 mg/L, and the total nitrogen (TN) content was 272 mg/L, of which 45 mg/L was ammonia-nitrogen (NH_3-N). Over 350 days of continuous operation were spent running the bioreactor at constant flow rates, temperatures, and pH levels of 240 (L/day), 22–24 (°C), and 7–7.5, respectively. The findings demonstrated that an as-yet-unclassified microbial species' main process was simultaneous nitrification-denitrification-BPR. The values of TP and TN in the effluent were 2.7± 0.4 mg/L and 4.3± 1.2 mg/L, respectively [16]. Another study included treating municipal wastewater by an anaerobic-multistage anaerobic/oxic (A-MAO) process. The average removal efficiencies for COD, NH_4-N, TN, and TP were 91.81%, 96.26%, 83.73%, and 94.49%, respectively [17]. The up-flow anaerobic sludge blanket (UASB) modified Bardenpho process was used to treat Municipal solid waste incinerator (MSWI) leachate. The results indicated that it was possible to recirculate the settling tank effluent to dilute the leachate, which significantly impacted the effectiveness of the bio-treatment process. The treatment method attained removal efficiencies of COD and NH_4^+ -N of 97.5-99.5% and 99.3-99.7%, respectively. A TN removal efficiency of 97.7-98.7% was achieved by modifying the primary anoxic tank's operating parameters, including adding an organic carbon supply [18]. On the other hand, the influence of external recycle on nitrogen removal was studied. IR ratios of 0, 4, and 6 were operated at various concentrations of COD and TN. The results showed that the TN removal efficiency was 90.7% at an IR ratio of 6 [19]. Moving Bed Biofilm Reactor was used to remove phosphorus and nitrogen from wastewater. The results showed that the average TN removal efficiency of 82% was achieved, and 76.79% was the average phosphorus removal efficiency [20]. The impact of HRT on organic and nutrient removal was investigated. The result indicated removal efficiencies of 97% and 68% to 80% at 6 h HRT for COD and TN, respectively [21]. In this research, the effect of the internal recycle ratio (0%, 100%, 200%, and 300%) was found at a total hydraulic retention time (17.5, 13.5, and 9.5 hours) when the internal recycle was made from the second aeration basin to first anoxic basin (IR1), the second aeration basin to the first aeration basin (IR2), and from the second aeration basin to the second anoxic basin (IR3), respectively.

2.MATERIALS AND METHODS

2.1.Pilot Plant and Operation

Five main components of the pilot scale plant were used in this investigation: Anaerobic, 1st Anoxic, 1st Aerobic, 2nd Anoxic, and 2nd Aerobic. The pilot scale's total operational capacity shown in Fig. 1 was (36.4, 29.2, and 19.8) L for run1, run2, and run3, respectively. All reactors were constructed of plastic material. Air diffusers were placed at the bottom of the aeration tanks to give the required oxygen and ensure proper mixing of the contents. Additionally, the anaerobic tanks were furnished with mixers that completely mixed the contents of the tanks. Following these tanks, there was a plastic sedimentation basin with a cone-shaped base and a cylindrical top that had a hole in it for a small pump to be installed to return some of the settled sludge to the anaerobic basin to keep the concentration of living mass at a certain level. The synthetic wastewater was supplied to the Lab scale with a flow rate (Q) of 50 Liter/day. In the first run, the Anaerobic, 1st Anoxic, 1st Aerobic, 2nd Anoxic, and 2nd Aerobic hydraulic retention times (HRT) were 2, 4, 6, 4, and 1.5 hr, respectively, making a total HRT of (17.5) hr. For the second run, the HRTs were 1.5, 3, 5, 3, and 1 hr, respectively, making a total HRT of (13.5) hr, and in the third run, HRTs were 1, 2, 4, 2, 0.5 hr, respectively, making a total HRT of (9.5) hr. The process required wasting a suitable quantity of MLSS daily, with a mean cell residence time (MCRT) of 15 days. Several experiments were carried out in the laboratories of the Department of Environmental Engineering at Tikrit University, and the standard methods for examining water and sewage were adopted to examine the samples. The UVD-3000 spectrophotometer was used to determine the concentration of nitrogen and phosphorus compounds. The HACH DRB200 device was also used for the COD test. At this stage, the activated sludge was prepared, and the laboratory unit was operated. This activated sludge was acclimatized by bringing a sample of seeds from the Tikrit wastewater treatment plant. This sludge was placed in two laboratory tanks with a capacity of 10 liters each. These laboratory tanks were used to acclimate the microorganisms and to increase their numbers. Three runs comprised the experimental phase, with each run concentrating on changing the location of IR (IR1, IR2, and IR3) with each run changing the recycle ratio IR and total hydraulic retention time.

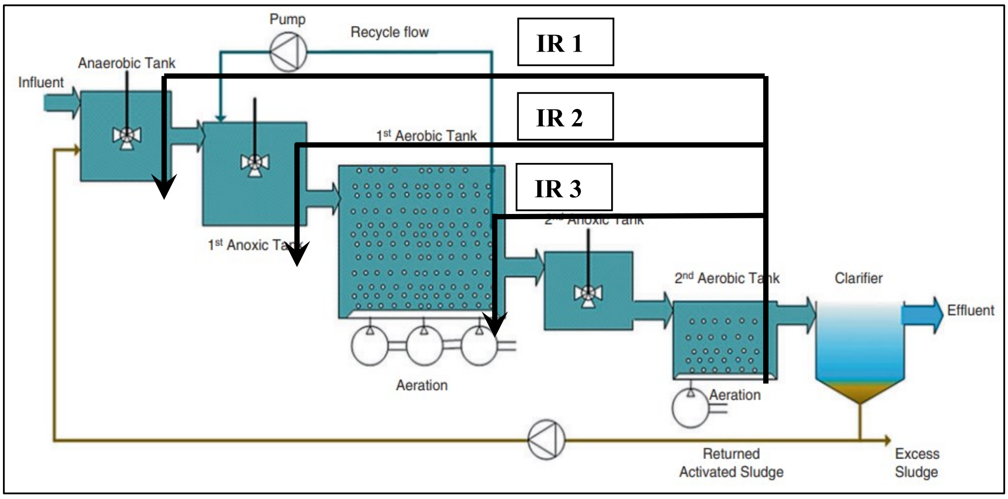

Fig. 1 The Pilot Scale's Total Operational Capacity.

2.2.Influent Synthetic Wastewater Characteristics

Table 1 lists the influent wastewater's composition. The laboratory system was operated using a continuous operation system. The tanks were fed by gravity using a small tank with a capacity of 15 liters. The fed wastewater was delivered to the tanks using a plastic pipe through which the drainage was passed, and it was operated by a unique valve. In order to keep the pressure steady, the system set so that the feed water reaches the tank with a capacity of (15) liters from a larger tank with a capacity of (200) liters. This tank was placed at a level higher than the water level in the small tank, as the water can be transferred from the large tank to the small tank using a plastic tube ending with a valve. A cutoff that stops the drain from the 15-liter tank when the water level in it reaches a certain limit. Wastewater characterization results are shown in Table 2.

Table 1 Composition of Synthetic Wastewater [22].

#	Component	Concentration (mg/L)
1	Ammonium chloride (NH4CL)	85
2	Starch (C6H10O5)	100
3	Urea (CO(NH2)2)	5
4	Sucrose (C12H22O11)	75
5	Magnesium chloride (MgCl2.7H2O)	75
6	Sodium chloride (NaCl)	70
7	Potassium dihydrogen phosphate (KH2PO4)	65
8	Calcium chloride (CaCl2.2H2O)	35
9	Iron Sulphate (FeSO4.7H2O)	1.7
10	Zinc sulphate (MnSO4.H2O)	1.7
11	Manganese sulphate (MnSO4.H2O)	1.1
12	Yeast extract	0.86
13	Copper sulphate (CuSo4.5H2O)	0.86
14	Milk (mL/L)	15

Table 2 Characteristics of Synthetic Wastewater.

#	Component	Unit	Concentration
1	COD	mg/L	413±10
2	TN	mg/L	35±5
3	NO3-N	mg/L	2
4	PO4	mg/L	15±2
5	pH		7-7.5
6	Temperature	°C	17-25

3.RESULTS AND DISCUSSION

3.1.Relationship between pH of Raw Wastewater and Treated Wastewater

The pH is one of the important factors influencing the progress of biological treatment. This factor rising or falling below certain values leads to a shock that paralyzes the work of microorganisms, thereby decreasing the efficiency of removing pollutants as well as deteriorating the sedimentation properties of the sludge [23]. Fig. 2 shows a higher pH value for treated water than in raw water [24]. The high pH values in treated water are due to the generation of carbon dioxide gas resulting from the oxidation of organic materials inside the aeration basins. As in Eq. (1), the dissolution of this gas in the treated water leads to an increase in the basic capacity due to the generation of carbonate ions. As shown in Eq. (2) and (3) [25], these ions work to equalize the pH values towards the limit of 8.2, regardless of the nature of raw water, acidic or basic [26].

$$organics + O_2 \xrightarrow{biodegradable} CO_2 + H_2O + Newcells + Other\ products \quad (1)$$

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^- \quad (2)$$

$$CO_2 + OH \longleftrightarrow HCO_3^- \longleftrightarrow H^+ + CO_3^{-2} \quad (3)$$

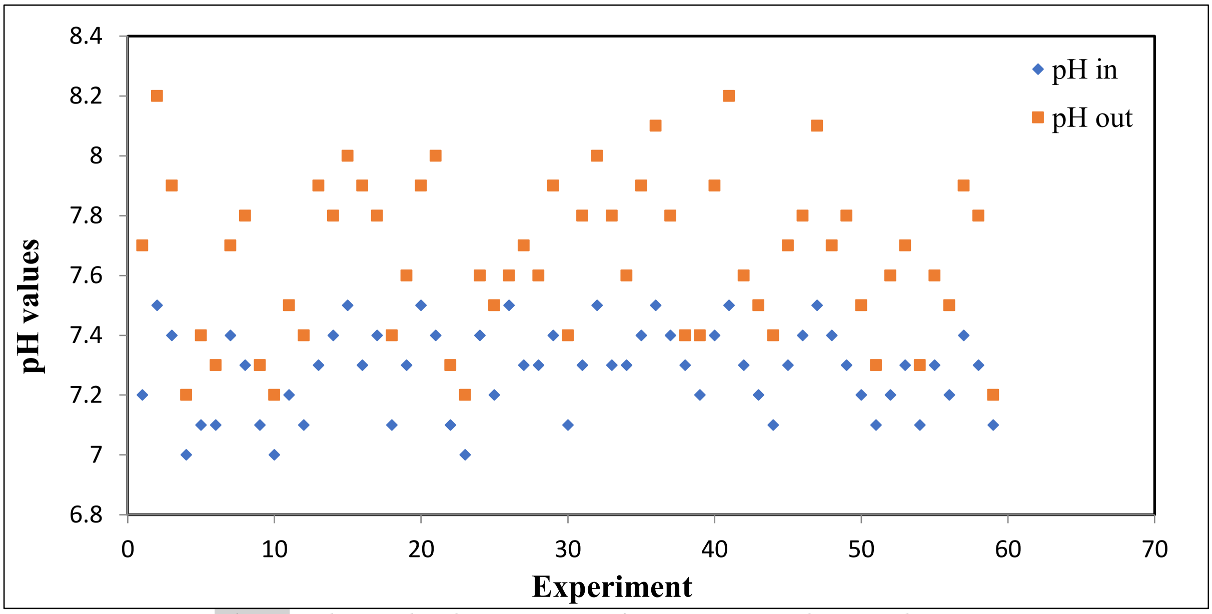

Fig. 2 Relationship between PH of Raw Water and Treated Water.

3.2.Effect of IR on System Efficiency

Eq. (4) was used to compute the mean removal efficiencies for the three major measurements of performance (COD, TN, and PO_4). It is clear that extremely high clearance levels were achieved under all circumstances, demonstrating that the synthetic wastewater is successfully treated.

$$effecincy = \frac{C_{in} - C_{out}}{C_{in}} * 100\% \quad (4)$$

3.3.Effect of IR on Removal Efficiency at 17.5 hr HRT_{total}

In terms of how the IR affected the elimination of COD, there was a moderate improvement when the recycling rate increased. That is, the variation in the percentage of COD elimination was small for any minor adjustment in Q [27]. Fig. 3 shows the effect of the IR ratio on COD, TN, and PO_4 removal at IR1 and 17.5hr total hydraulic retention time. Nonetheless, as the IR ratio increased from 0% to 200%, the TN removal demonstrated a distinct, if little, trend in improvement. The increased enhancement of nitrogen removal may be due to biomass acclimation, but in a BNR system, where nitrification takes place in the last zone, it also makes sense that an increase in the IR ratio would supply the denitrification reactor with more nitrates, which would enhance nitrogen removal overall [28]. This kind of optimization method appears to have a practical limit in this study, too, as no additional improvement was noted at the greatest IR ratio. At a 200% internal recycle ratio and IR1, nitrogen removal was more than 92.86%. Concerning PO4, it seems to be at its best when the IR ratio is raised from 0% to 200%. That is, already at (200%) and IR1, over (86.67%) of the PO4 was being removed. These results showed that the removal efficiency increases with an increase in the internal recycle ratio to a certain extent, after which it begins to decrease [29, 30]. Fig. 4 shows the effect of the IR ratio on COD, TN, and PO_4 removal at IR2 and 17.5hr total hydraulic retention time. The results indicated that the removal efficiency of COD increased slightly with increasing IR, while the TN and PO_4 removal efficiencies increased clearly with an increase in IR ratio.

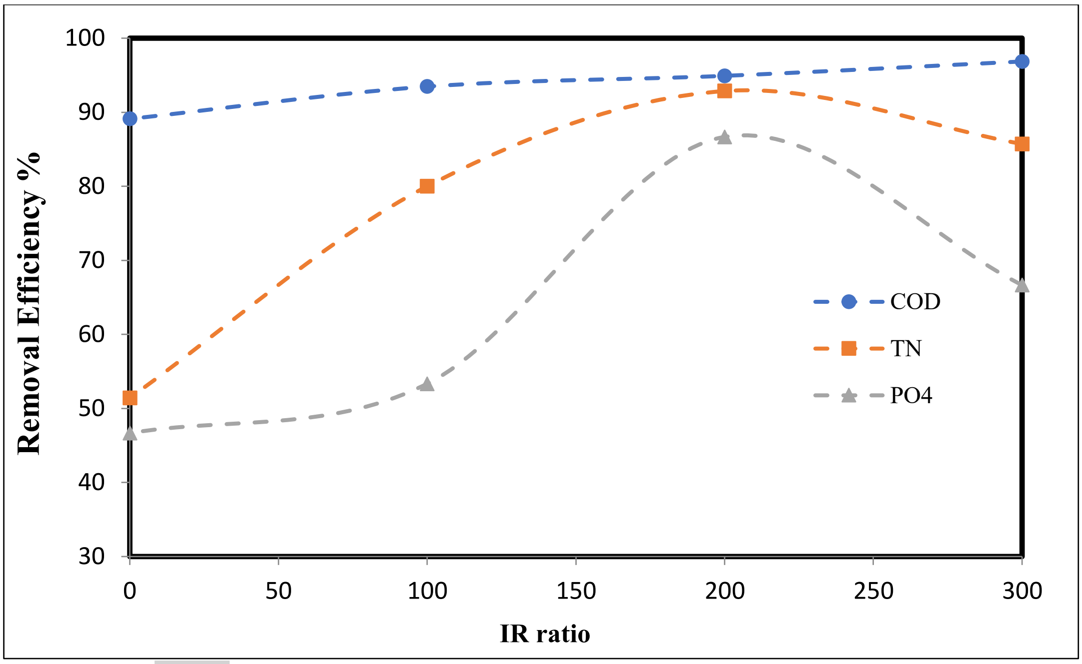

Fig. 3 Effect of IR on Removal Efficiency at IR1 and HRT= 17.5 h.

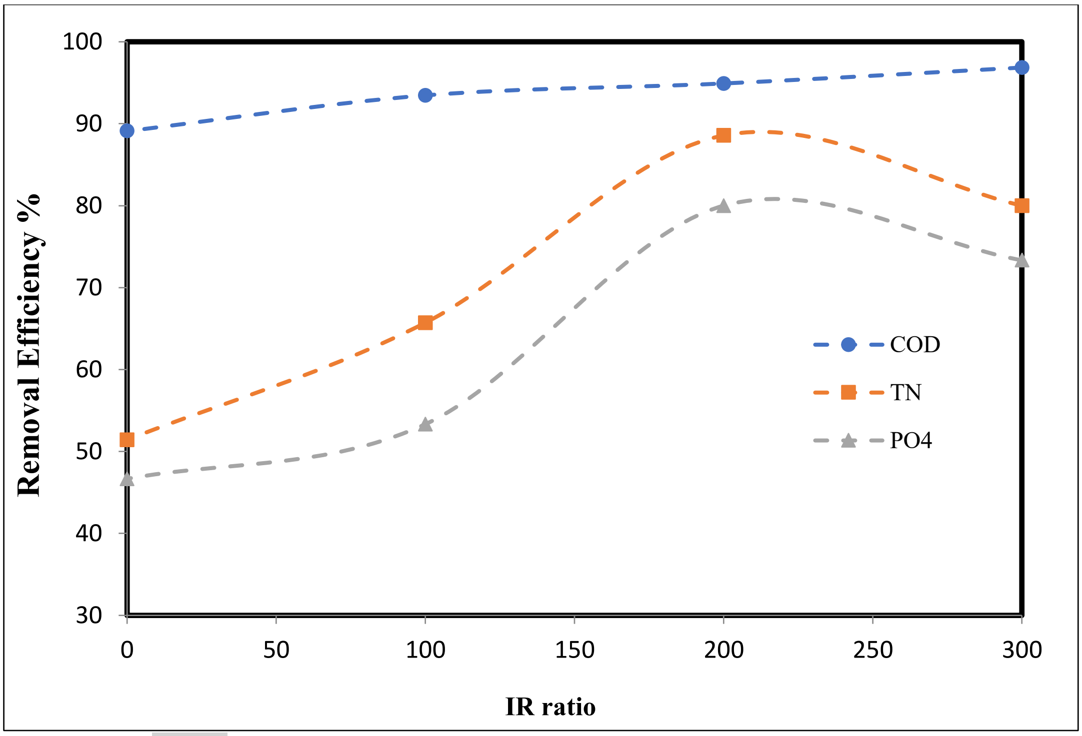

Fig. 4 Effect of IR on Removal Efficiency at IR2 and HRT= 17.5 h.

From Fig. 4 above, the maximum COD, TN, and PO_4 removal efficiencies were 96.85% at IR 300%, 88.57% at IR 200%, and 80% at IR 200%, respectively. The effect of IR on removal efficiency at IR3 and 17.5hr HRT_{total} is represented in Fig. 5. The data showed that the COD removal efficiency increased from 89.1% at 0% IR to 96.13% at 300% IR ratio.

3.4.Effect of IR on Removal Efficiency at 13.5 h HRT_{total}

In terms of how the IR affected the elimination of COD, there was a moderate improvement when the recycling rate increased. That is, the variation in the percentage of COD elimination was small for any minor adjustment in Q. Fig. 6 shows the effect of the IR ratio on COD removal at (IR1, IR2, and IR3) and 13.5hr total hydraulic retention time.

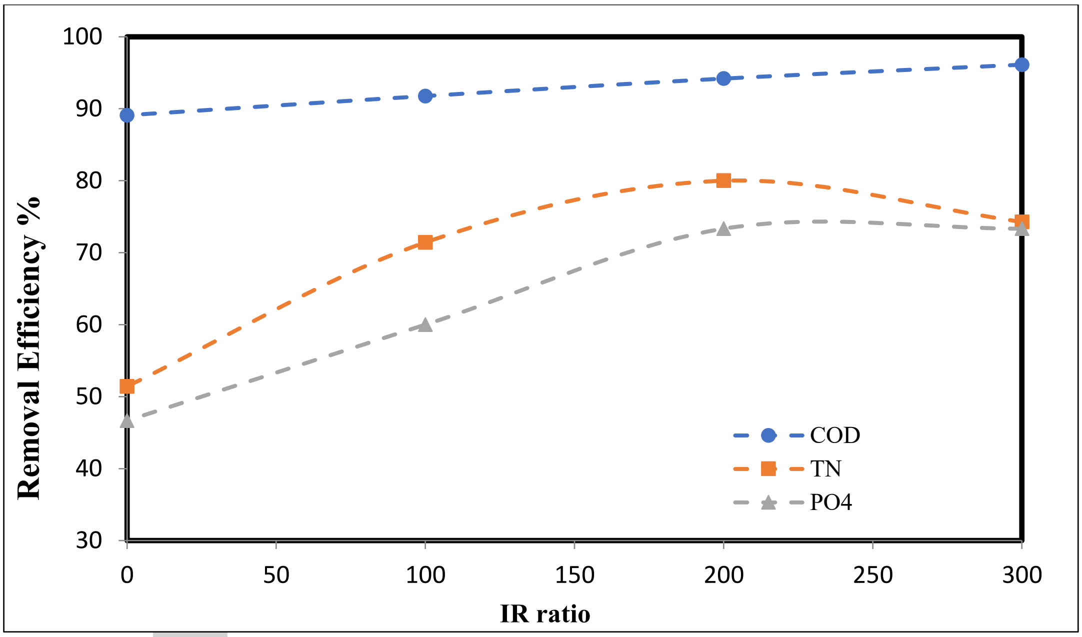

Fig. 5 Effect of IR on Removal Efficiency at IR3 and HRT= 17.5 h.

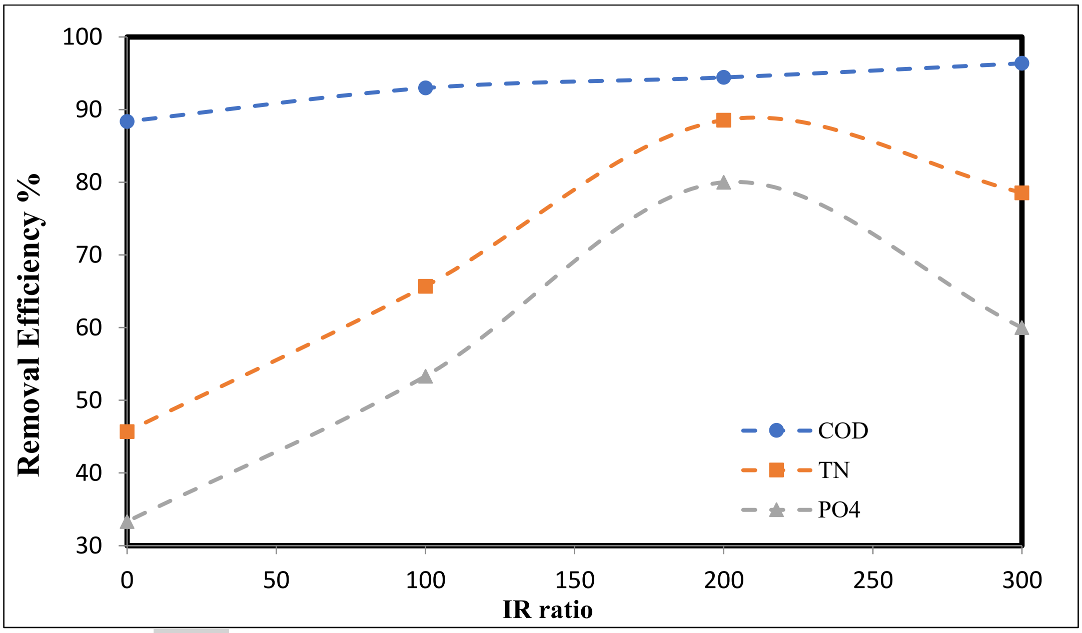

Fig. 6 Effect of IR on Removal Efficiency at IR1 and HRT= 13.5 h.

However, the TN removal showed a clear, if small, trend in improvement as the IR ratio increased from 0% to 200%. As no additional improvement was seen at the greatest IR ratio in this study, it appeared that this kind of optimization method had a practical limit. More than 88.57% of the nitrogen was eliminated at the internal recycling ratio (200%) and IR1 [24]. Regarding PO4, the optimization was observed when the IR ratio was raised from 0% to 200%. This means that more than 80.0% of the PO4 was eliminated at (200%) and IR1. These results showed that the removal efficiency increased with increasing the internal recycle ratio to a certain extent, after which it decreased. These results are consistent with [7, 6, 12, 13]. Figure 7 shows the effect of the IR ratio on COD, TN, and PO_4 removal at IR2 and 13.5hr total hydraulic retention time. The results indicated that the removal efficiency of COD increased slightly with increasing IR, while the TN and PO_4 removal efficiencies were increased clearly with increasing IR. These results showed that the maximum COD, TN, and PO_4 removal efficiencies were 96.4% at IR 300%, 81.4% at IR 200%, and 66.67% at IR 200%, respectively. The effect of IR on removal efficiency at IR3 and 13.5hr HRT_{total} is presented in Fig. 8. The data showed that the COD removal efficiency increased from 88.37% at 0% IR to 95.64% at 300% IR. Also, the results indicated the highest removal efficiencies of 74.28% and 66.67% at 200% IR ratio for TN and PO_4, respectively.

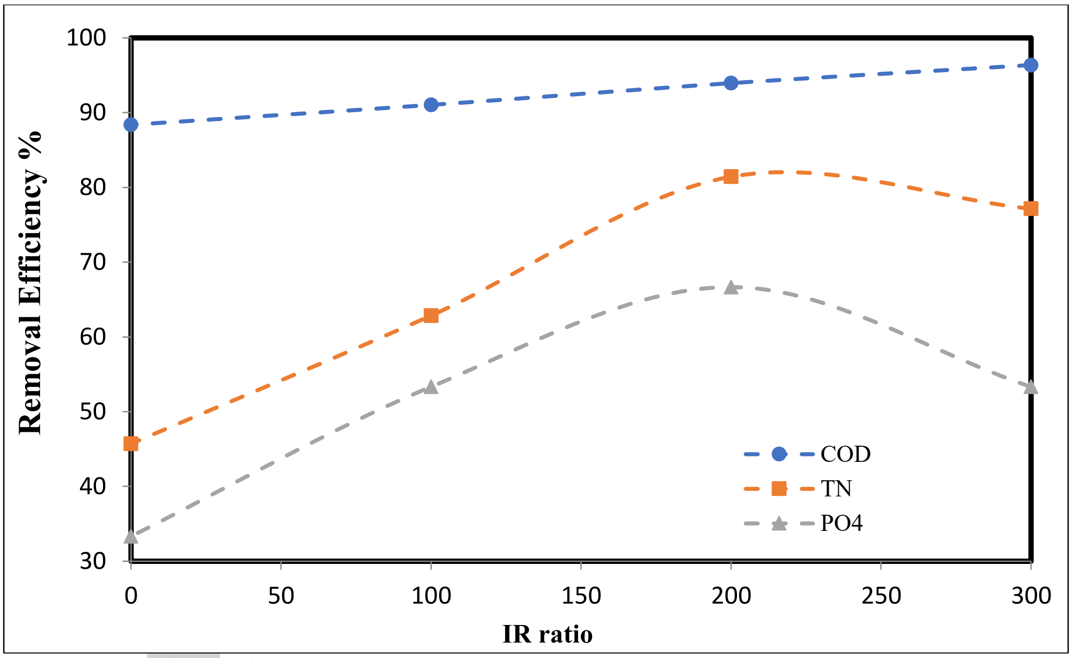

Fig. 7 Effect of IR on Removal Efficiency at IR2 and HRT= 13.5 h.

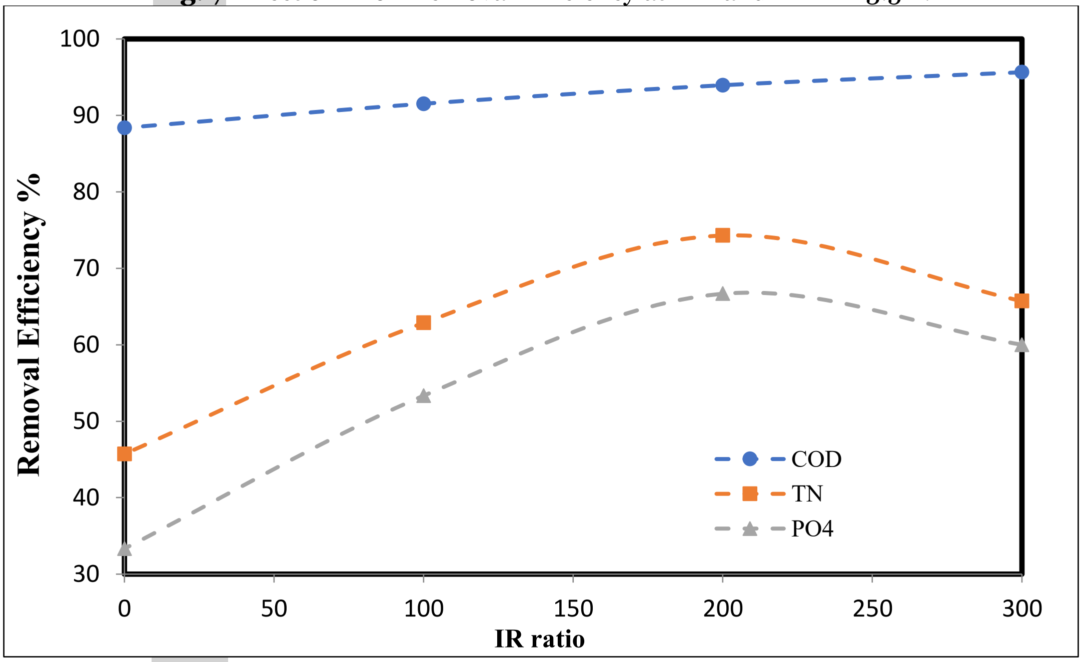

Fig. 8 Effect of IR on Removal Efficiency at IR3 and HRT= 13.5 h.

3.5.Effect of IR on Removal Efficiency at 9.5 h HRT_{total}

In terms of how the IR affected the elimination of COD, there was a moderate improvement when the recycling rate increased. The variation in the percentage of COD elimination was small for any minor adjustment in Q. Figure 9 shows the effect of the IR ratio on COD removal at (IR1, IR2, and IR3) and 9.5 hr total hydraulic retention time [23]. Nonetheless, the results showed that as the IR ratio climbed from 0% to 200%, the TN removal demonstrated a distinct, if little, trend in improvement. It is possible that increased improvement in nitrogen removal [14]. As no additional improvement was seen at the greatest IR ratio in this study, it appeared that this kind of optimization method had a practical limit. Essentially, at 200%, more than 81.43% of the nitrogen was eliminated at the internal recycling ratio (200%) and IR1 [22], [25]. Regarding PO4, it seemed to be at its best when the IR ratio raised from 0% to 200%. Hence, the highest removal efficiency was 63.33% when the IR ratio was 200%. The removal efficiency increased with increasing the internal recycle ratio to a certain extent, after which it decreased [7, 6]. Figure 10 shows the influence of IR on removal efficiency at IR2 and 9.5 hr HRT_{total}. The results showed that the removal efficiency of COD increased slightly with increasing IR, while the TN and PO_4 removal efficiencies increased clearly with increasing IR.

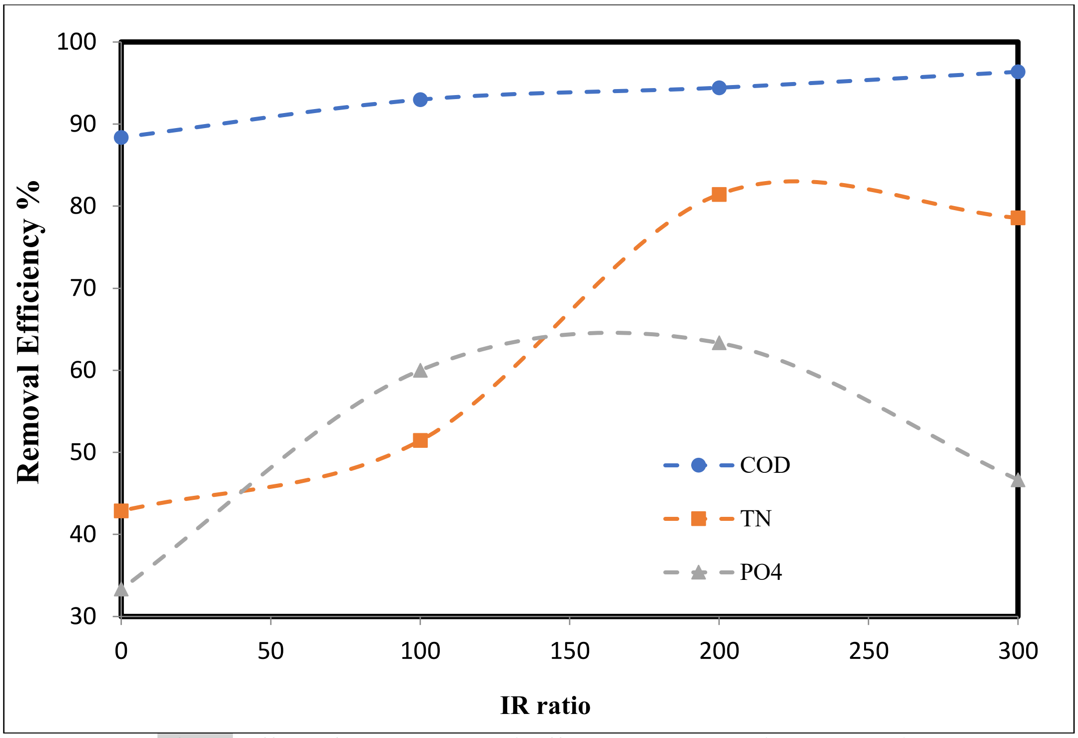

Fig. 9 Effect of IR on Removal Efficiency at IR1 and HRT= 9.5 h.

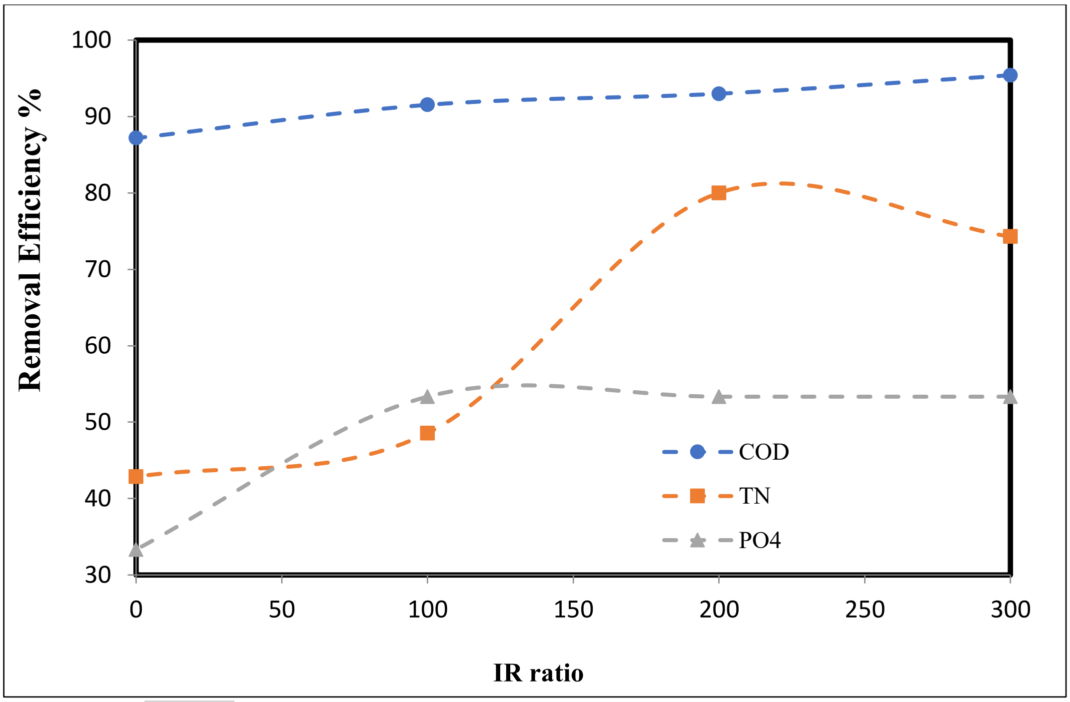

Fig. 10 Effect of IR on Removal Efficiency at IR2 and HRT= 9.5 h.

These results showed that the maximum COD, TN, and PO_4 removal efficiencies were 95.4% at IR 300%, 80.0% at IR 200%, and 53.33% at IR 200%, respectively. The relationship between the IR ratio and removal efficiency of COD, TN, and PO_4 is shown in Fig. 11. The variation in the percentage of COD elimination was small for any minor adjustment in the IR ratio. The data showed that the COD removal efficiency increased from 87.16% at 0% IR to 94.91% at 300% IR. Also, the results indicated the highest removal efficiencies of 62.86% and 60.0% at 200% IR ratio for TN and PO_4, respectively.

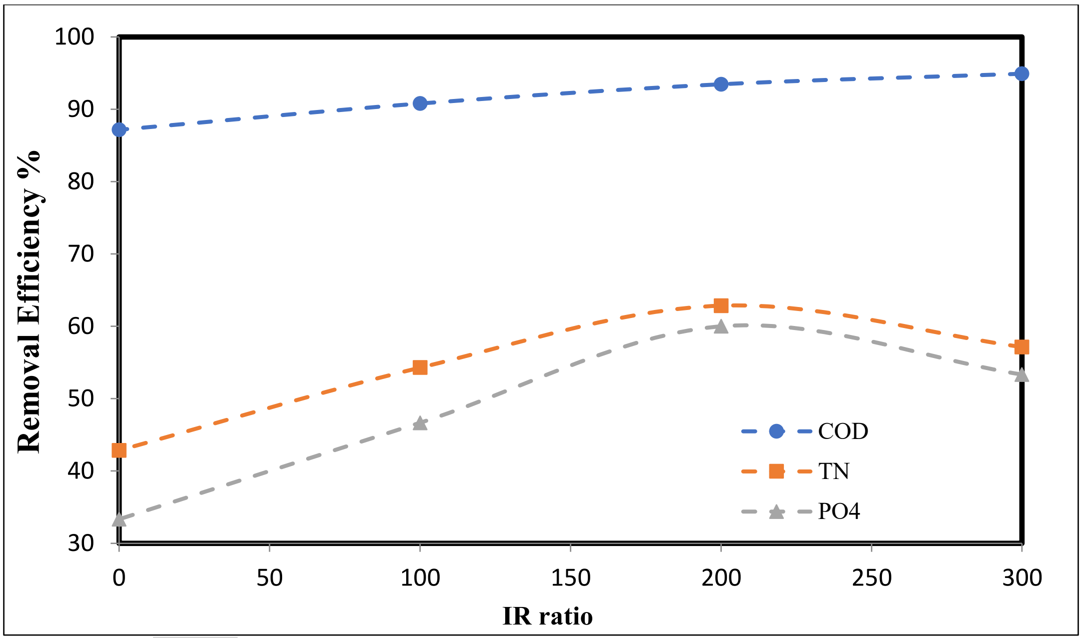

Fig. 11 Effect of IR on Removal Efficiency at IR3 and HRT= 9.5 h.

4.CONCLUSIONS

This research evaluated the COD, TN, and PO4 performance associated with a Bardenpho process treating synthetic wastewater with the IR ratio increased from (0% to 300%). The results showed that very high removal levels were obtained for all three performance parameters. There appeared to be no appreciable improvement concerning the influence of the IR ratio on COD removal. However, there was a moderate increase in TN and PO4 removal as the IR increased from (0% to 200%) and IR1 then decreased at (300%) IR ratio. Thus, the optimum IR ratio for this research would be around (200%) with maximum removal efficiencies of 92.86% and 86.67% for TN and PO_4, respectively. Further investigations may be carried out for future work to express the validity of a proposed study with other types of pollutants and other parameters such as temperature.

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