Enhancing biological removal of nitrogen from wastewater in activated sludge process

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\section*{ABSTRACT}
The removal of total nitrogen from wastewater has become a worldwide emerging concern because the compounds of nitrogen, ammonium, nitrite, also nitrate are toxic to aquatic species and causes eutrophication in natural water environments; although activated sludge technology is old, but until now it is effective in the removal of nitrogen compounds.

To enhance the removal of nitrogen compounds, a modified process including the usage of internal mixed liquor recycling pump (IMLR), with variable rates starting gradually from one to fifth of influent flow. A Pilot plant consists of three tanks, the first and the second tanks are rectangular, and the third is circular with a conical bottom which acts as a final sedimentation tank.

The experiments divided into four phases; phase (1) consists of (A.T), anoxic T. and finally, sedimentation tank with using (IMLLR) rates from (1-4) influent flow, phase (2) as phase (1) but without using (IMLR), phase (3) consists of anoxic tank, (A.T) and final sedimentation tank with using (IMLLLR) rates from (1-5) influent flow, finally phase (4) as phase (3) but without using (IMLLR), the average DO in (A.T) about 2.5mg/l, the temperature ranged from (18 – 21), pH ranged from (6.5 – 8).

Total nitrogen removal was 61.5% in phase one, 27% in phase two, 64.5% in phase three, and 27% in phase four.

- The most effective removal of nitrogen in phase (3), with rate\textsuperscript{QIMLR} = \textsuperscript{2QINF}achieve 64.5% of total nitrogen removal, then in phase (1) with rate \textsuperscript{QIMLR}=\textsuperscript{3QINF}. Achieve 62.39% of total nitrogen removal.

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Introduction

Nitrogen and phosphorus are nutrients that are essential for the growth of the microorganisms in wastewater treatment; thus, some degrees of nutrient elimination occur during all biological treatments, and the resulting cell mass contains about 2 percent phosphorus and 12 percent nitrogen by weight. When a treatment system is engineered to remove nutrients greater than these metabolic amounts, it is called biological nutrient removal (BNR). In essence, BNR is comprised of two processes: biological nitrogen removal and enhanced biological phosphorus removal (EBPR) [1].

Nitrogen compounds are among the most important pollutants in wastewater because of their role in eutrophication, their effect on the oxygen content of receiving waters, and their toxicity to aquatic invertebrate and vertebrate species, including human beings. Wastewater originated from many sources, such as tannery, food processing, fertilizer manufacturing, slaughterhouse and landfill leachate, contains a great amount of nitrogen, which should be treated before being discharged into the surface water body. The biological nitrogen removal (BNR) process is a cheap and the most widely practiced approach for nitrogen control in wastewater treatment. For many years, the traditional biological method for nitrogen removal from wastewater has been the combination of nitrification and denitrification processes. Frequently, space limitations or economic constraints do not allow the capacity of the existing treatment plants, especially for wastewater with a high ammonium load, to be expanded [2].

The deleterious effects of nitrogenous compounds on aquatic environments have long been recognized. Nitrogenous compounds can cause a significant depletion of dissolved oxygen (DO) in receiving waters, exhibit toxicity toward fish, and therefore, decrease the productivity of streams and lakes, and present a public health hazard. Many discharge licenses for wastewater treatment plants are being amended to include the limits on the discharge of different nitrogen compounds in order to protect the receiving water quality. The biological processes of nitrification and denitrification are widely used to satisfy these permit constraints. The method by which ammonia is first converted to nitrite and finally to nitrate is nitrification. Gaseous nitrogen is produced from nitrite and nitrate during denitrification [3].

For more than one hundred years and still, it emphasizes that domestic wastewater is the prominent source in addition to agriculture runoff contribution for eutrophication, so that biological sewage treatment by activated sludge process has been utilized to resolve problems associated with the water pollution, such as organic materials, nitrogen and phosphorous. The most widely applied nitrogen removal method in WWTPs is nitrification–denitrification process, where aerobic autotrophic nitrification of NH4+ to NO2- and NO3- is followed by anoxic heterotrophic denitrification of the
oxidized N species to N2. To perform nitrification–denitrification process, the classic bioreactor configuration applied consists of an anoxic tank followed by an aerobic tank (i.e. anoxic/oxic (A/O) process) and a secondary clarifier (Figure 1.A), called the Modified Ludzack-Ettinger (MLE) configuration. Two recirculation flows are used in the MLE configuration: (1) internal recirculation from the aerobic tank to the anoxic tank to supply electron acceptors (NO2- and NO3-) for denitrification and (2) external recirculation from the secondary clarifier to the biological process inflow to maintain a proper sludge concentration and a target biomass retention time. Emerging treatment technologies, such as the anaerobic/anoxic/oxic (A2/O) process and the University of Cape Town (UCT) process, have been proposed and implemented to carry out the conventional nitrification–denitrification process based on modifying the traditional A/O process. Other commonly used nitrification–denitrification-based wastewater treatment technologies include the oxidation ditch (Figure 1.B), which is usually equipped with aerators to provide aeration and circulation and to achieve simultaneous nitrification–denitrification process in the same bioreactor through spatial DO gradient and the sequencing batch reactor (SBR) (Figure 1.C), which creates aerobic and anoxic conditions in the same bioreactor through temporal separation. To design and operate the bioreactors, sludge retention time (SRT) and aeration are the two parameters of key importance. Compared with heterotrophic bacteria, autotrophic nitrifying bacteria (i.e. AOB and NOB) grow slowly; thus, a proper SRT should be considered to maintain those microorganisms in the systems to ensure high nitrification efficiencies and hence better total nitrogen (TN) removal. Aeration is the main treatment in WWTPs performing the conventional nitrification–denitrification process and must be controlled to provide enough oxygen supply for nitrification while avoiding unnecessary energy consumption [4].

The simultaneous nitrification–denitrification (SND) can take place in one single aerobic reactor [5], which is attributed to the presence of heterotrophic denitrifying activity in the anoxic zones of nitrifying sludge flocs (Figure 2). The potential of simultaneous aerobic and anoxic processes is realized by the DO gradients [6], and the performance of the SND process is mainly affected by DO concentration, chemical oxygen demand (COD) concentration and floc size [7]. An optimal C/N ratio to balance the nitrification and the denitrification reactions was reported at 11:1 [8], while the optimal bulk DO concentration was documented at 0.5–1.5 mg/l [9] with an optimum floc size of 80–100 μm. The SND process can also occur in granular and biofilm systems, such as aerobic granular sludge systems [6,10], biological aerated filters, single-packed bed batch reactors [6], membrane bioreactors (MBRs) and membrane-aerated bioreactors (MABRs).
Figure 1. Schematic diagrams of (A) Modified Ludzack-Ettinger configuration; (B) oxidation ditch configuration; and (C) SBR configuration [4].
Materials and methods

Pilot plant location

The experimental work was carried out as shown in Figure 3 at Quhafa wastewater treatment Plant located in Elfayoum Governorate, Egypt.

The plant treats about 120 thousand cubic meters per day; the wastewater in this plant is mainly domestic wastewater in addition to some industrial activity discharge. The plant receives wastewater from different places like Hawara, Demo, Zamloty, Snefer and Fayoum city.

Regional condition

The climate in this region is defined as subtropical with an average temperature of 18°C in winter and 32°C in summer. The physical and chemical characteristics of influent and effluent wastewater in Quhafa WWTP over the entire experimental period are shown in Table 1.

Description of pilot plant and parameters

The influent raw wastewater will be collected after primary treatment (inlets, screens, oil and grease separators and grit chamber) in Quhafa WWTP, and then it will be received to pilot plant by using a submersible pump (about 2 HP) to deliver raw wastewater to an elevated polyethylene tank with a volume of 1000 liters located at the roof of the pilot plant room to feed the model with raw wastewater, as shown in Figure 4; the model consists of

![Figure 2. Schematic diagram of simultaneous nitrification–denitrification in activated sludge flocs [6].](image_url)
Figure 3. Location of pilot plant A: layout of Quhafa WWTP B: location of pilot plant.
three tanks: the first and second tanks are rectangular and the third is circular with conical bottom, description of pilot plant as follows:

Elevated tank: A vertical polyethylene cylindrical tank with a volume of 1000 liters located at the roof of pilot plant to feed the model with raw wastewater, and the Distribution System as follows:

- Main influent pipe of diameter 1 inch with a main control ball valve.
- Delivery pipe of diameter 1 inch with a main control ball valve from first tank to second tank.
- Effluent pipe from second tank to final sedimentation tank.
- Delivery pipe of diameter 1 inch for activated sludge return from final sedimentation tank to first tank.
- Drain pipe of diameter 1 inch from supernatant zone in final sedimentation tank.
- Waste sludge pipe of diameter 1 inch from sludge zone in F.S.T

**First tank**

 Constructed from steel coated with epoxy, the tank furnished with sampling ports 10 cm from the bottom along the effective length equipped with control valves. Dimensions of the Contact tank are shown in Figure 5; Influent distribution system consists of U.P.V.C pipe with a diameter 1 inch at the bottom of the tank and an effluent weir to control hydraulic retention time inside the tank. The tank is equipped with an air compressor (3 HP) with an air distribution system to get a fine air bubble along the length of the tank to control DO concentration to be not less than 2.5 mg/l.

**Second tank**

 Constructed from steel coated with epoxy, the tank has a rectangular shape. As mentioned previously, influent sludge is timely controlled by a pump with 1-inch U.P.V.C pipe at the bottom of the tank and a movable effluent weir at the other side of the tank to control hydraulic retention time inside the tank. The tank is equipped with 3.0 HP air compressors with an air distribution system to get a fine air bubble along the length of the tank to maintain DO concentration of not less than 2.0 mg/l. Dimensions of the tank are shown in Figure 6.

**Third tank is final sedimentation tank**

The third tank is a final sedimentation tank that was constructed from steel coated with epoxy with a circular and conical bottom with 1-inch inlet pipe at the center of the tank from the bottom and an effluent weir at the outer
| Parameter | °C | PH | TN | DO | NH₄ | NO₂ | B.O.D | C.O.D |
|-----------|----|----|----|----|-----|-----|-------|-------|
| Month     | In | Out | In | Out | In | Out | In | Out |
| Jan.      | 18 | 17.5 | 7.6 | 7.5 | 31.50 | 18.7 | 2.4 | 13.4 | 8.50 | 0.1 | ND | 220 | 72 | 395 | 120 |
| Feb.      | 18.7 | 18.7 | 7.4 | 7.3 | 33.15 | 17.80 | 2.1 | 16.4 | 11 | 0.1 | ND | 280 | 68 | 462 | 115 |
| Mar.      | 19.7 | 19.2 | 7.2 | 7 | 32.5 | 19 | 2.6 | 14.5 | 9.1 | 0.1 | 0.1 | 230 | 86 | 376 | 140 |
| Apr.      | 24 | 23 | 7.8 | 7.6 | 30.90 | 14.5 | 3.1 | 13.8 | 8.5 | 0.1 | ND | 346 | 27 | 580 | 55 |
| May       | 28 | 26 | 7.2 | 7.1 | 31.45 | 16.4 | 3.4 | 14.2 | 9.45 | 0.1 | ND | 310 | 22 | 490 | 34 |
| June      | 30.7 | 30.1 | 7.3 | 7.6 | 32.8 | 18.5 | 5.2 | 15.2 | 9.80 | 0.1 | ND | 290 | 36 | 500 | 60 |
| July      | 31.7 | 30.7 | 7.7 | 8 | 33 | 22.5 | 5 | 13.7 | 10.2 | 0.1 | ND | 340 | 26 | 540 | 44 |
| Aug.      | 31.2 | 31 | 7.8 | 8.1 | 27.4 | 31.4 | 4.9 | 15.2 | 15.6 | 0.1 | 0.1 | 280 | 16 | 470 | 26 |
| Sep.      | 30 | 29.6 | 7.7 | 7.8 | 27.6 | 17 | 4.9 | 17.8 | 8.8 | 0.1 | 0.8 | 310 | 32 | 490 | 40 |
| Oct.      | 28.8 | 28.7 | 7.4 | 7.5 | 32.25 | 19.3 | 5.5 | 18.6 | 10.1 | 0.1 | 0.3 | 340 | 25 | 540 | 45 |
| Nov.      | 24.3 | 24.6 | 7.5 | 7.6 | 33.78 | 19.8 | 5.3 | 22.1 | 14.3 | 0.1 | 0.1 | 285 | 26 | 460 | 44 |
| Dec.      | 20.1 | 19.8 | 7.4 | 7.5 | 31.6 | 19.4 | 6.1 | 21.9 | 10.2 | 0.1 | 0.1 | 290 | 14 | 490 | 20 |
| Avg.      | 25.4 | 23.2 | 7.5 | 7.6 | 31.49 | 19.5 | 4.2 | 15.4 | 10.15 | 0.1 | 0.125 | 294 | 37.5 | 482.8 | 62 |
perimeter. Water flows from a sedimentation tank to waste by gravity. Sludge withdrawal from the bottom of the tank is performed with a controlled time pump to the inlet of the first tank. Dimensions of the final sedimentation tank are shown in Figure 7.

**Description phases for pilot plant**

The whole experiment executed in this study was divided into four major phases of a constant retention time with the usage of an IMLR pump in two phases (phase one and phase three). All phases, in each, were operated at the same hydraulic retention time, the same velocity, under the same conditions, and the same feed wastewater to investigate the effect on the removal nitrogen efficiency of the different phases.

**Phase (1)**

In the first phase as shown in Figure 8, the sequence of the process consists of an aeration tank followed by an anoxic tank and then a final sedimentation tank; in this phase, the system provided with internal mixed liquor recycle pump which is located at the effluent of the second tank with rate ranged from $Q_{IMLR} = (1–4) Q_{INF}$.

**Phase (2)**

In the second phase as shown in Figure 9, the sequence of the process consists of an aeration tank followed by an anoxic tank and then a final sedimentation tank, without using internal mixed liquor recycle pump, and this case is the same as most the wastewater treatment plant.

**Phase (3)**

In the third phase of the experiment observing as shown in Figure 10 the sequence of process consists of an anoxic tank followed by an aeration tank and then to a final sedimentation tank, in this phase the system provided with internal mixed liquor recycle pump, which is located at the effluent of the second tank with a rate ranged from $Q_{IMLR} = (1–5) Q_{INF}$. 

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*Figure 4. Schematic diagram of pilot plant.*
Figure 5. First tank.
Figure 6. Second tank.
Figure 7. Final sedimentation tank.
Phase (4)

In the fourth phase of the experiment observing as shown in Figure 11, the sequence of the process consists of an anoxic tank followed by an aeration tank and then to a final sedimentation tank, without using internal mixed liquor recycle pump and this case as the same as most of wastewater treatment plant.

**Anoxic Tank, Aeration Tank and Final Sedimentation Tank**

**Plant operation and observed parameters**

The pilot plant was operating at wastewater influent continuous flow rates. It is planned to work continuously for 24 hours a day under the realistic condition of operation, such as sunlight and fluctuation in flow capacity and characteristics; aeration was provided with pressurized air passing through the air probes in nitrification/aerobic tank to make sure that there are enough DO levels of nitrification in aeration tank and controlled with a minimum of 2.5 mg/l and terminal to be approximately zero and a maximum of 0.5 mg/l in the anoxic tank.

**Samples collection**

The influent and effluent samples were collected from raw line and treated line plus samples from a specific location through the process. DO and pH was also measured using portable instruments for processes, as well as nitrogen removal efficiency evaluation; the samples were collected from the pilot plant twice per week along with the experimental work of this pilot plant. The analysis of the samples was conducted in HBRC laboratory according to American standard methods for examination of wastewater as follows:

**Temperature, pH and DO**

Temperature, pH and DO were measured at the site of pilot plant by multi-parameter analyzer Horriba.

**Total nitrogen**

TN was measured at HBRC laboratory using Millipore (Elix) UV-Milli-Q Advantage A 10 System.

**Result and discussion**

The operating variables rate of the IMLR process were studied in a pilot plant technique to determine the optimum conditions of the economical rate of IMLR pump in the process to achieve maximum removal efficiency.

Phase (1): In this work, the unit was operated with a continuous flow rate of raw wastewater with a different rate of IMLR pump average ambient
Figure 8. Phase 1 Schematic Diagram QIMLR = (1–4) QINF (Aeration Tank, Anoxic Tank and Final Sedimentation Tank).
Figure 9. Phase 2 Schematic Diagram (NO IMLR) (Aeration Tank, Anoxic Tank & Final Sedimentation Tank).
**Figure 10.** Phase 3 Schematic Diagram $Q_{IMLR} = (1-5) Q_{INF}$. (Anoxic Tank, Aeration Tanks and Final Sedimentation Tank).
**Figure 11.** Phase 4 Schematic Diagram (No IMLR).
Figure 12. Overall Efficiency of (TN) Phase (1) QIMLR = (1–4) QINF.
Table 2. Influent and effluent of (TN and NH4) Phase (1) QIMLR = (1–4) QINF.

| DATE      | INFLUENT | EFFLUENT | DATE      | INFLUENT | EFFLUENT |
|-----------|----------|----------|-----------|----------|----------|
| 11/11/2018| 25.2     | 14.55    | 11/27/2018| 31.32    | 11.74    |
| 12/11/2018| 28.4     | 16.2     | 12/28/2018| 32.18    | 11.7     |
| 18/11/2018| 28.96    | 16.8     | 11/29/2018| 35.4     | 13.6     |
| 19/11/2018| 29.82    | 17.1     | 12/1/2018  | 32.89    | 12.56    |
| AVERAGE   | 28.095   | 16.1625  | AVERAGE   | 32.9475  | 12.4     |

Q = 1Q

| DATE      | INFLUENT | EFFLUENT | DATE      | INFLUENT | EFFLUENT |
|-----------|----------|----------|-----------|----------|----------|
| 11/11/2018| 11.7     | 6.7      | 27/11/2018| 14.56    | 5.43     |
| 12/11/2018| 13.2     | 7.54     | 28/11/2018| 14.46    | 5.1      |
| 18/11/2018| 13.1     | 7.65     | 29/11/2018| 16.46    | 6.3      |
| 19/11/2018| 13.86    | 8        | 1/12/2019 | 15.3     | 5.87     |
| AVERAGE   | 12.965   | 7.4725   | AVERAGE   | 15.195   | 5.675    |

Q = 3Q

| DATE      | INFLUENT | EFFLUENT | DATE      | INFLUENT | EFFLUENT |
|-----------|----------|----------|-----------|----------|----------|
| 11/21/2018| 30.86    | 12.68    | 11/28/2018| 32.18    | 24.5     |
| 12/22/2018| 27.1     | 11.65    | 11/29/2018| 35.4     | 26.2     |
| 11/25/2018| 29.81    | 13.45    | 12/1/2018  | 32.89    | 24.17    |
| 11/26/2018| 29.9     | 13.8     | 12/4/2018  | 30.14    | 23.5     |
| AVERAGE   | 29.4175  | 12.895   | AVERAGE   | 32.6525  | 24.5925  |

Q = 2Q

| DATE      | INFLUENT | EFFLUENT | DATE      | INFLUENT | EFFLUENT |
|-----------|----------|----------|-----------|----------|----------|
| 11/21/2018| 13.89    | 5.96     | 11/28/2018| 14.46    | 10.78    |
| 12/22/2018| 12.21    | 5.35     | 11/29/2018| 16.46    | 12.1     |
| 11/25/2018| 14.05    | 6.35     | 12/1/2018  | 15.3     | 11.3     |
| 11/26/2018| 13.35    | 6.25     | 12/4/2018  | 13.84    | 10.66    |
| AVERAGE   | 13.375   | 5.9775   | AVERAGE   | 15.015   | 11.21    |

Q = 4Q
temperature of 21°C. The pilot plant was operated in this phase for about 16 weeks.

**Total nitrogen and ammonium ions removal during phase (1)**

From Figures (11, 12) and from Table 2, overall removal efficiencies of TN or ammonium ions, it can be seen that the removal efficiency increases when increasing rate of return recirculation pump gradually from QIMLR = 1 QINF up to QIMLR = 3 QINF. And efficiency was 42%, 56% and, 61.5% respectively, but when the rate increase is equal to four times of influent rates, the removal efficiency decreases to 25%.

Phase (2): In this phase, the unit was operated with a continuous flow rate of raw wastewater with an average ambient temperature of 20°C. The pilot plant was operated at this stage for about 2 weeks.

**Total nitrogen and ammonium ions removal during phase (2)**

The target of this phase was to record the removal efficiency of nitrogen in a normal case of the process without using an internal mixed liquor pump, and then we can compare with the same sequence of the process with the use of internal mixed liquor recycle pump with different rates.

From Figures (13, 14) overall removal efficiencies of TN or ammonium ions, it can be seen that the removal efficiency was in an average of 27.7%.

Phase (3): In this phase, the unit was operated with a continuous flow rate of raw wastewater with a different rate of IMLR pump average ambient temperature of 17°C. The pilot plant was operated at this stage for about 16 weeks.

**Total nitrogen and ammonium ions removal during phase (3)**

The target of this stage was to obtain the maximum removal efficiency of nitrogen by using different rats of IMLR pump ranging from QIMLR = (1–5) QINF

| Table 3. Influent and effluent of (TN & NH4) Phase 2 – NO IMLR. |
|-------------------|-------------------|-------------------|
| **TN**            | **INFLUENT**      | **EFFLUENT**      |
| DATE              | 2/4/2019          | 34.4              | 24.6              | 28.488             |
|                   | 3/4/2019          | 30.96             | 22.8              | 26.357             |
|                   | 9/4/2019          | 29.6              | 20.9              | 29.392             |
|                   | 10/4/2019         | 35.8              | 26.25             | 26.676             |
| **AVERAGE**       | 32.69             | 23.6375           | 27.72821          |
| **NH4**           | **INFLUENT**      | **EFFLUENT**      |
| DATE              | 2/4/2019          | 16.01             | 11.5              | 28.17              |
|                   | 3/4/2019          | 15.79             | 11.7              | 25.902             |
|                   | 9/4/2019          | 13.6              | 9.86              | 27.5               |
|                   | 10/4/2019         | 16.66             | 12.1              | 27.371             |
| **AVERAGE**       | 15.515            | 11.29             | 27.23583          |
Table 4. Influent and effluent of (TN and NH4) Phase 3 QIMLR = (1–5) QINF.

Q = 1Q

| DATE       | INFLUENT | EFFLUENT | %     | DATE       | INFLUENT | EFFLUENT | %     |
|------------|----------|----------|-------|------------|----------|----------|-------|
| 13-3-2019  | 34.6     | 21       | 40.8  | 13-3-2019  | 16       | 9.25     | 42.2  |
| 14-3-2019  | 33.4     | 19       | 43.4  | 14-3-2019  | 15.35    | 8.8      | 42.7  |
| 19-3-2019  | 23.9     | 13       | 43.9  | 19-3-2019  | 11.2     | 6.3      | 43.8  |
| 20-3-2019  | 35.8     | 22       | 39.7  | 20-3-2019  | 16.66    | 10       | 40    |
| AVERAGE    | 31.9     | 19       | 41.9  | AVERAGE    | 14.803   | 8.5875   | 42.1  |

Q = 2Q

| DATE       | INFLUENT | EFFLUENT | %     | DATE       | INFLUENT | EFFLUENT | %     |
|------------|----------|----------|-------|------------|----------|----------|-------|
| 26/2/2019  | 32.3     | 12       | 62.8  | 26/2/2019  | 15.03    | 5.5      | 63.4  |
| 27/2/2019  | 26.8     | 9        | 66.4  | 27/2/2019  | 12.45    | 4.3      | 65.5  |
| 6/3/2019   | 37.2     | 12       | 67.1  | 6/3/2019   | 17.3     | 5.58     | 67.7  |
| 7/3/2019   | 34.3     | 13       | 61.8  | 7/3/2019   | 15.95    | 6.21     | 61.1  |
| AVERAGE    | 32.7     | 12       | 64.5  | AVERAGE    | 15.183   | 5.3975   | 64.4  |

Q = 3Q

| DATE       | INFLUENT | EFFLUENT | %     | DATE       | INFLUENT | EFFLUENT | %     |
|------------|----------|----------|-------|------------|----------|----------|-------|
| 12/2/2019  | 31.1     | 22       | 29.2  | 12/2/2019  | 14.45    | 10.2     | 29.4  |
| 13/2/2019  | 30.8     | 21       | 31.2  | 13/2/2019  | 14.29    | 9.9      | 30.7  |
| 20/2/2019  | 31.7     | 22       | 30.5  | 20/2/2019  | 14.73    | 10.2     | 30.8  |
| 21/2/2019  | 35.3     | 24       | 31.5  | 21/2/2019  | 16.4     | 11.3     | 31.1  |
| AVERAGE    | 32.2     | 22       | 30.6  | AVERAGE    | 14.968   | 10.4     | 30.5  |

Q = 4Q

| DATE       | INFLUENT | EFFLUENT | %     | DATE       | INFLUENT | EFFLUENT | %     |
|------------|----------|----------|-------|------------|----------|----------|-------|
| 2/1/2019   | 29.6     | 23       | 22.9  | 2/1/2019   | 13.76    | 10.4     | 24.4  |
| 3/1/2019   | 30.3     | 24       | 22.1  | 3/1/2019   | 14.1     | 11.03    | 21.8  |
| 9/1/2019   | 30.8     | 23       | 23.9  | 9/1/2019   | 12.51    | 9.4      | 24.9  |
| 10/1/2019  | 31.1     | 23       | 25.4  | 10/1/2019  | 10.8     | 8.1      | 25    |
| AVERAGE    | 30.4     | 23       | 23.6  | AVERAGE    | 12.793   | 9.7325   | 24    |

Q = 5Q

| DATE       | INFLUENT | EFFLUENT | %     | DATE       | INFLUENT | EFFLUENT | %     |
|------------|----------|----------|-------|------------|----------|----------|-------|
| 18-12-2018 | 32.1     | 28       | 13.4  | 18-12-2018 | 14.96    | 13       | 13.1  |
| 19-12-2018 | 31.9     | 27       | 14.5  | 19-12-2018 | 14.87    | 12.3     | 17.3  |
| 25-12-2018 | 31.1     | 26       | 15.4  | 25-12-2018 | 14.28    | 12.3     | 13.9  |
| 26-12-2018 | 29.1     | 26       | 9.97  | 26-12-2018 | 13.22    | 11.7     | 11.5  |
| AVERAGE    | 31.1     | 27       | 13.3  | AVERAGE    | 14.333   | 12.325   | 13.9  |

From Figures (15, 16) overall removal efficiencies of TN and ammonium ions, it can be seen that the removal efficiency increases when increasing rate of return recirculation pump gradually from QIMLR = 1 QINF up to QIMLR = 2 QINF. And efficiency was 42% and 64.5% respectively, but when the rate increases is equal to two, three, four or five times of influent flow, the removal efficiency decreases to 30%, 25% and, 15%, respectively.
Figure 13. Overall Efficiency of (NH4) Phase (1) QIMLR = (1–4) QINF.
Figure 14. Removal Efficiency of TN Phase 2 (NO IMLR).
Figure 15. Removal Efficiency of NH4 Phase 2 (NO IMLR).
Figure 16. Overall Efficiency of TN.
Figure 17. Overall Efficiency of NH4.
Figure 18. Removal Efficiency of TN Phase 4 (No IMLR).
Phase (4): In this phase, the unit was operated with a continuous flow rate of raw wastewater with an average ambient temperature of 19.5°C. The pilot plant was operated in this stage for about 2 weeks.

**Total nitrogen and ammonium ions removal during phase (4)**

The target of this phase was to record the removal efficiency of nitrogen in a normal case of the process without using internal mixed liquor pump, and then we can compare with the same sequence of the process with the use of internal mixed liquor recycle pump with different rates.

From Figures (17, 18) Table 5, overall removal efficiencies of TN or ammonium ions, it can be seen that the removal efficiency was in an average of 26%.

**Conclusion**

Using internal mixed liquor recycle pump in biological phase in activated sludge process, like RAS pump, return activated sludge from final sedimentation tank to the influent tank of biological phase, so when using recycling pump to be returned flow (water and sludge) to the system, this flow is rich in microbial activated and adapted nitrification/denitrification bacteria, which is mixed again with the raw wastewater and takes its time to complete nitrification/denitrification in special conditions of DO in aeration tank not less than 2.5 mg/l, DO equal or less than 0.5 mg/l in an anoxic tank, temperature about 20°C and more with an average PH ranged from 6.5 up to 8 in our pilot plant.

From the experiment, we find that, in case of an increasing rate of internal mixed liquor recycle pump in phase (1) (aeration tank, anoxic tank and F.S.T), the efficiency increases gradually until QIMLR = 3QINF, but in the case of flow rate to 4QINF, we find the total account of anaerobic bacteria is lower and DO
is higher due to the suction of the flow settling tank, no sucking only sludge, but mixing of sludge (containing anaerobic bacteria) and amount of water with high content of dissolved oxygen and high aerobic bacteria, so that the total count of anaerobic bacteria became very low due to dilution and increase in DO, and hence, the efficiency decreases.

However, in phase (3) (anoxic tank, aeration tank, and F.S.T), from the experiment, we find that the efficiency increases gradually until QIMLR = 2QINF, and maximum efficiency is achieved due to increase in the anaerobic bacteria content in the anoxic tank and decrease in the oxygen content in an anoxic tank; the bacteria will react or use the ammonia and nitrate as food in the absence of oxygen, which improves the efficiency removal for nitrogen (ammonia and nitrate), but when increasing QIMLR = (3–5) QINF, the efficiency decreases due to dilution and total account of anaerobic bacteria is lower.

Compared between phase (1) and phase (3), from the experiment, we found the maximum effeminacy achieve in-phase (3), (anoxic, aeration, and F.S.T), due to the recycling from the second tank (aeration tank), in which the nitrifying bacteria such as Nitrosomonas and Nitrobacter are using carbon dioxide or inorganic carbon as their carbon source for the synthesis of cellular material, return to first tank (anoxic tank), which have denitrifying bacteria that use nitrite ions and nitrate ions in the absence of oxygen, for growth and reproduction; the gases were formed and released by denitrifying bacteria as escaping bubbles.

Referring to regulation law (law 48 year 1982, Egypt law), the characteristics limits of effluent are shown in Table 6.

The effluent from experimental for TN and NH4 as follows:

- **In phase 1** (A.T, Anoxic T. & F.S.T), in case of QIMLR = 3QINF, influent of TN and NH4 are 32.94 and 15.195 mg/l, respectively, and the effluent

| Date       | Influent TN | Effluent TN | Date       | Influent NH4 | Effluent NH4 |
|------------|-------------|-------------|------------|--------------|--------------|
| 26-3-2019  | 33.2        | 23.5        | 26-3-2019  | 15.44        | 11.15        |
| 27-3-2019  | 32.52       | 23.65       | 27-3-2019  | 15.129       | 11.1         |
| 28-3-2019  | 33.49       | 25.5        | 28-3-2019  | 15.6         | 11.95        |
| 29-3-2019  | 30.14       | 22.95       | 29-3-2019  | 14.05        | 11.01        |
| **AVERAGE**| **32.3375** | **23.9**    | **AVERAGE**| **15.05475** | **11.3025**  |

**Table 5.** Influent and effluent of (TN and NH4) Phase 4 No IMLR.
are 12.4 and 5.675 mg/l, respectively, with removal efficiency of 62.39%.

- **In phase 3** (Anoxic T., A.T & F.S.T), in case of QIMLR = 2QINF, influent of TN and NH4 are 32.7 and 15.183 mg/l, respectively, and the effluent are 12 and 5.39 mg/l, respectively, with removal efficiency of 64.5%.

From the previous discussion and the results of experimental works, the resultant of this works as follows:

- **QIMLR = 3QINF. Achieve Total Nitrogen Removal Efficiency 62.39% In Aeration Tank Followed by Anoxic Tank and Finally Sedimentation Tank Process.**
- **QIMLR = 2QINF. Achieve Total Nitrogen Removal Efficiency 64.5% In Anoxic Tank Followed by Aeration Tank and Finally Sedimentation Tank Process.**

**Disclosure statement**

So the most effective removal of nitrogen occurs in case of process anoxic tank followed by aeration tank and finally sedimentation tank which achieve 64.5% of total nitrogen removal with using QIMLR=2QINF.

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