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# Nitrification of activated sludge effluent in low depth nitrifying trickling filter (LDNTF)

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## ABSTRACT

Nitrogen in treatment plants effluent causing problems such as oxygen depletion, toxic impacts on aquatic organisms, eutrophication, and negative impacts on public health. The aim of present study was to determine the performance of integrated system activated sludge/nitrifying trickling filter to improve nitrification in the wastewater treatment plant of Isfahan. In this applied experimental study, an integrated activated sludge (AS) process (in full scale) was used with a trickling filter (TF) (in semi-industrial scale). The diameter and height of TF were 1.8 m and 3 m of steel, respectively. The volume of polypropylene media was 8 $m^3$ and surface area of 240 $m^2/m^3$. The hydraulic loading rate during the startup period was 2.4 $m^3/h$ which was raised to 7.2 $m^3/h$ in the operation period. Flow rate, $BOD_5$, COD, pH, TKN, $N\text{-}NH_3$, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, alkalinity and temperature were measured weekly according to standard methods during the operation period. The effect of filter depth on nitrification was studied in 3.6, 4.2, 5.4 and 6 m and HRT of 3.6 m/h. The samples were analyzed by SPSS. The results showed that the best hydraulic and ammonia loading rate achieved here were 3.6-4.2 m/h and 2-2.5 g $N/m^2d$, respectively. The AS/TF system efficiency were 86 % COD removal, 94 % BOD5 removal, 70 % turbidity removal, 94.4 % TSS removal, 55.5-75.5 % TKN removal and 85 % nitrification, respectively. The highest efficiency to reduce of wastewater pollution and nitrification was occurred in depth 4.5 m. Integration of the activated sludge and trickling filter processes, especially in old wastewater treatment plants is a good way to reduce the amounts of nitrogen in treatment plants effluent.



## 1. Introduction

As freshwater systems provide multiple environmental services such as supplying drinking water and irrigation, assimilating wastes through biotic/abiotic cycling, and supporting numerous species; water resource protection is critical and essential (Jackson et al. 2001; Naiman et al. 2000). Linkages between aquatic systems and terrestrial (Meyer et al. 1988) create a critical condition in freshwater systems that result from population growth and land use modifications. Estimates indicate that 60 % of the world will reside in urban areas by 2030, with the effect of increasing water demand creating larger volumes of wastewater in populous areas ( Postel et al. 1996).

Nutrient content is a characteristic of WWTP effluent that often impacts receiving water bodies. Although one may assume that WWTPs are regulated (i.e. requiring a discharge permit) and therefore without a significant impact in pollutant loads, this is not necessarily true for nutrients (Hager et al. 1992; Andersen et al. 2004; Gibson et al. 2007).

Unfortunately, at present time, the wastewater treatment plants that are often used as activated sludge process for several reasons including overloaded, absence of suitable operation due to low qualification of operators or shortage of investment costs; cannot remove nutrients and high concentrations of these compounds can be seen in the effluent treatment plant (Sudol et al. 2014). In order to reduce these pollutants; developing of treatment methods and selecting of the best management techniques is necessary.

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During recent years, biofilm processes with attached growth have been under special attention for biological treatment of municipal and industrial wastewater due to the low investment and operation costs, needless to return sludge system, simplicity of the operation, and high removal of nutrients (Wang et al. 2006; Yang et al. 2013). But in these systems there are also issues of high hydraulic losses, short circuiting problem, clogging and the need for periodic backwashing. That's why the idea development of designing integrated systems that have the benefit of the both suspended growth and attached growth system (Lee et al. 2006; Grady et al. 2012).

The use of trickling filter (TF) for upgrading the WWTPs is due to low operating costs and ease of operation (Aguilera et al. 2000). Application of plastic medium trickling filter systems for nitrification, with or without concurrent organic matter removal, has received considerable attention since the late 1960 (Huang et al. 1989).

Use of a TF system for nitrification of secondary effluent reduces capital cost because there is no need for final clarifiers (Almstrand et al. 2011).

Nourmohammadi et al., have reported the reduction of ammonia concentration at treatment plant of north of Tehran from 26.8 mg/l to 0.29 mg/l in an integrated process of trickling filter and activated sludge (Nourmohammadi et al. 2013). In the removal of inert organic fraction from municipal wastewater using the integrated activated sludge and trickling filter system showed that the integrated process can remove refractory organics two times higher in compared to single process (Sadeghi et al. 2014). Hannah et al., have also reported the removal of



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organics by using the activated sludge and trickling filter processes (Hannah et al. 1988). Chung et al. (2007), have done the removal of nitrogen in hybrid biofilm reactors/suspended growth. Daigger et al. (1993), founded that in compound process of trickling filter/activated sludge, nitrification occurs when loading of trickling filter is about 1kg BOD/m$^3$d.

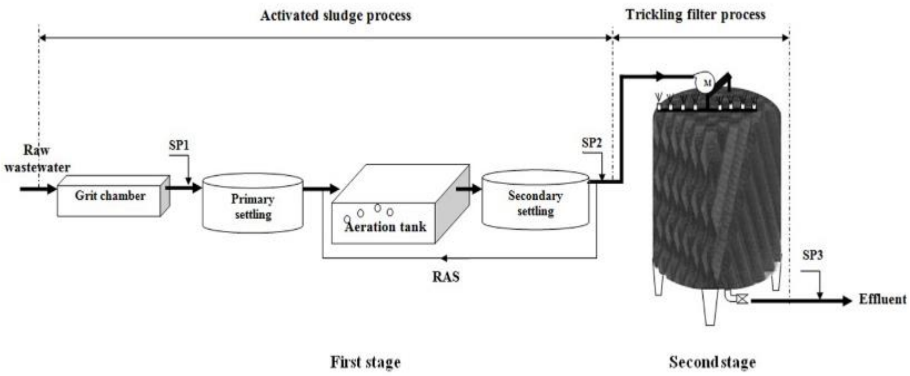
In Iran, many wastewater treatment plants discharge secondary effluent to the receiving waters without nutrient removal. There is growing interest in using methods to improve quality of the secondary effluent as organic materials, clearness, and nutrients.

This study examines the feasibility of using a XF (X-Flow) plastic media TF system with low depth for nitrification of activated sludge effluent. The aim of this work was nitrification of activated sludge effluent in the low depth nitrifying trickling filter.

## 2. Materials and methods

### 2.1. Bioreactor configuration

Considering a part of the experimental work was done on the AS process and was conducted in full scale, hence we tried to apply changes mostly on the second process (NTF) to examine and observe the reaction of the integrated process. Therefore, one TF tank in the semi-industrial scale was constructed using a 2.5 mm thickness steel sheet with two epoxy layers for avoiding the corrosion. Diameter and depth of NTF tank were 180 cm and 300 cm, respectively. Subtracting the depth of the flow distributor and pier media supporting system, there was an effective volume of 5.787 m$^3$ in the TF tank (it is volume of applied media). Polypropylene XF media with a surface area of 240 m$^2$/m$^3$ was used as the biomass support material. The TF tank was coupled with an activated sludge process (Fig. 1).




(a)

(b)

**Fig. 1.** Schematic of integrated activated sludge/nitrifying trickling filter (AS/NTF) process (a) and 2 HX-media (b).

Final effluent from the activated sludge in full scale, that was applied to treat a large region in Isfahan, was used as TF influent by tow installed pumps (1+1) on a channel between the clarifier basins and the chlorination unit (Fig. 2).

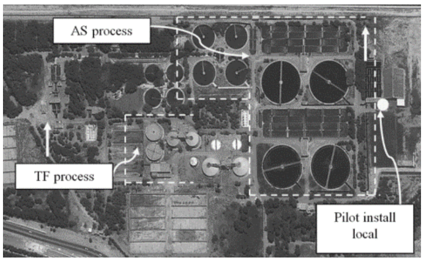



**Fig. 2.** A plan view from the wastewater treatment plant of Isfahan.

Flow rate was monitored by using a Rotameter for liquids with sp.gr. 1.0. Inlet flow to the TF tank was sprinkled on surface of the media by tow rotary arms equipped with 9 nozzles on each one and a rotor coupled to a gear box with 2.5 rpm in head of the tank. Hydraulic capacity minimum of the pilot in during the start-up phase was 3.6 m$^3$/h. The pilot was operated about 3 months until set-up completed (i.e. fluctuations of control parameters in the pilot received below ±5 % in set-up period). Total surface of circle and square grooves applied in order to aeration in the TF tank was 0.0314-0.22 m$^2$ (Fig. 3).

Hydraulic Loading Rate (HLR) of the pilot in this study was 2.4-7.2 m/h in operation period (Fig. 4). Flow rate, $BOD_5$, COD, $N\text{-}NH_3$, $N\text{-}NO_2$, $N\text{-}NO_3^-$, Total Kjeldahl Nitrogen (TKN), Total Suspended Solids (TSS), alkalinity, pH and temperature were measured according to standard methods daily during the set-up and weekly during the operation period.

## 3. Results and discussion

Effluent from secondary treatment of wastewater (AS process) with hydraulic capacity of 2.4, 3.12, 3.6, 4.2, 5.4, 6 and 7.2 m/h were loaded on the NTF in separate stages and controlling parameters were measured during the operation periods. Changes occurred in the concentration of organic carbon compounds in various hydraulic loading rates is given in Table 1.



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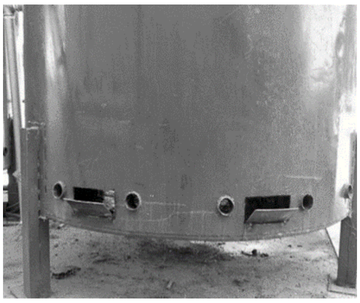

**Fig. 3.** Circle and square grooves applied in order to aeration in the NTF tank.

**Fig. 4.** Rotary sprinkle system on the pilot head.

**Table 1.** Average values of organic carbon compounds in AS/NTF system.

| **HLR (m/h)** | **2.4** | **3.12** | **3.6** | **4.2** | **5.4** | **6** | **7.2** |
|---|---|---|---|---|---|---|---|
| $COD_{raw}$ (mg/L) | 365±76.02 | 385±61.94 | 460±11.13 | 447±22.0 | 485±15.0 | 530±32.78 | 565±60.0 |
| $BOD_{5raw}$ (mg/L) | 220±46.63 | 244±24.78 | 218±37.04 | 230±20.29 | 262±19.07 | 251±31.04 | 265±8.88 |
| $COD_{AS\text{-}outlet}$ (mg/L) | 184±67 | 187.2±41.3 | 263.3±91.52 | 208.7±7.93 | 216±6.0 | 259±61.0 | 204±41.57 |
| $BOD_{5AS\text{-}outlet}$ (mg/L) | 113±7.0 | 101±6.0 | 72±2.0 | 82±0.71 | 80±2.82 | 140±5.65 | 87±9.89 |
| $COD_{NTF\text{-}outlet}$ (mg/L) | 131±61.05 | 100.8±24.4 | 62±9.16 | 78±6.0 | 90±18.0 | 113±11.26 | 134±3.11 |
| $BOD_{5NTF\text{-}outlet}$ (mg/L) | 82±6.0 | 41±5.0 | 15±2.0 | 18±3.0 | 18±2.0 | 50±5.65 | 70±2.82 |

In the present study, usefulness of an integrated system of the activated sludge/nitrifying trickling filter was investigated to upgrade the nitrification level. Fig. 5 shows the removal efficiency of organic materials versus the HLR in the NTF and the AS/NTF.

Study indicated that the average of numbers related to organic carbon compounds (COD and $BOD_5$) in activated sludge effluent exceeds the minimum necessary to be. The reason of this is the full-scale usage of activated sludge system and considering overload capacity of the wastewater treatment plant due to population growth, the wastewater provided by the system does not meet the standards of secondary treatment. The high concentration of organics (as $BOD_5$ and COD) in the inlet of NTF was one of the main nitrification limits in this study.

It can be concluded that the HLR within the range of 3.6 to 5.4 m/h, are the best conditions in which the removal efficiency of 86 % for COD and 94 % for $BOD_5$ have been achieved. Meanwhile, the maximum removal of TSS and nitrification was obtained in 4.2 m/h hydraulic load.

Aguilera et al. (1999) ascertained the concentration of COD and $BOD_5$ that are supposed to pass the nitrification stage should be respectively lower than 60 mg/L and 20 mg/L (Parker et al. 1986). However, in this study the average concentration of these parameters at the NTF inlet have been respectively 216 mg/L and 96.5 mg/L. Moreover high concentrations of TSS entering the NTF through the outlet current of the activated sludge have been highly effective on role of this process in nitrification.

Table 2 shows that the average concentration of TSS entering NTF is 109 mg/L which may be led to reduce of nitrification rate occurred in the study (with average concentration of 15.8 mg/L nitrate formed in NTF effluent) (Fig. 6).

**Table 2.** Average concentration and the removal efficiency of TSS in NTF and AS/NTF in different loading rates.

| **HLR m/h** | **2.4** | **3.12** | **3.6** | **4.2** | **5.4** | **6** | **7.2** |
|---|---|---|---|---|---|---|---|
| $TSS_{raw}$ (mg/L) | 178±36.91 | 183±37.33 | 170±5.0 | 178±30.61 | 220±32.78 | 308±48.28 | 311±25.06 |
| $TSS_{AS\text{-}outlet}$ (mg/L) | 70±28.47 | 118±6.63 | 102.7±64.29 | 96±19.69 | 112±24.0 | 140±15.10 | 125±30.02 |
| $TSS_{NTF\text{-}outlet}$ (mg/L) | 64±31.15 | 30±5.29 | 29±5.0 | 10±4.0 | 22±5.29 | 62±8.71 | 33±13.0 |
| NTF. Eff. (%) | 8.5 | 74.5 | 72 | 89.6 | 80 | 55.7 | 73.6 |
| Overall Eff. (%) | 64.04 | 83.61 | 82.94 | 94.38 | 90 | 79.87 | 89.39 |

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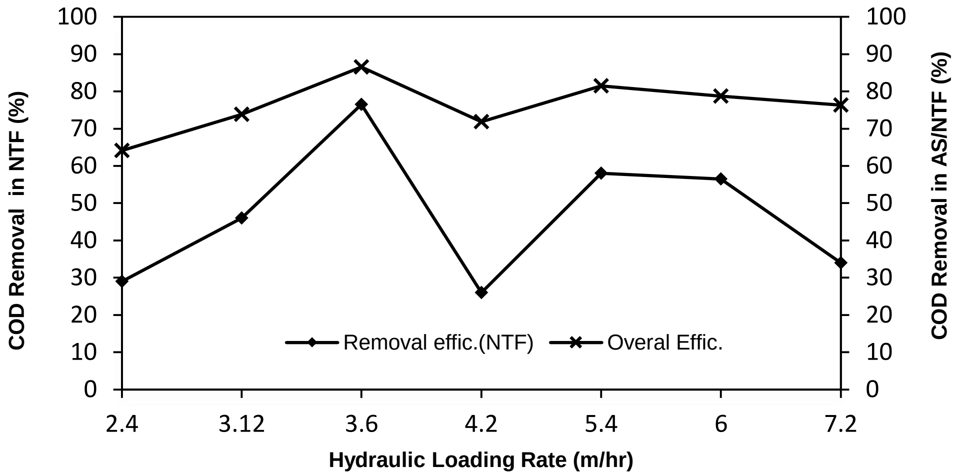
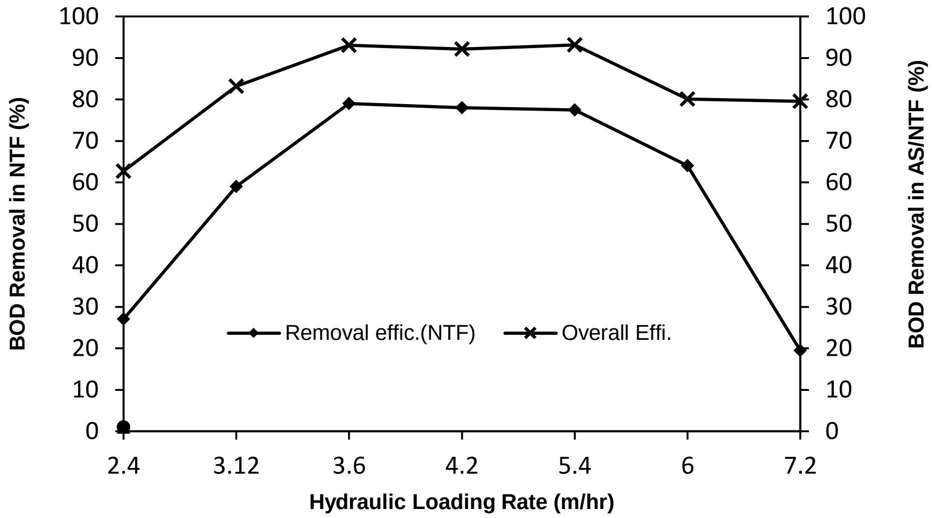



(a)




(b)

**Fig. 5.** Removal efficiency of organic compounds in NTF and AS/NTF Versus HLR, (a) COD and (b) $BOD_5$.

The occurred nitrification rate (actual nitrification) and the expected rate (based on alkalinity consumption) in different hydraulic loads are shown in Fig. 6.

Alkalinity reduction rate in the NTF effluent and the percentage of ammonia removal along with pH reduction rate compared to different hydraulic loads is shown in Table 3.

**Table 3.** Percentage of reduction in alkalinity, ammonia and pH in NTF effluent and changes in the concentration of added nitrate versus various hydraulic loads.

| HLR m/h | 2.4 | 3.12 | 3.6 | 4.2 | 5.4 | 6 | 7.2 |
|---|---|---|---|---|---|---|---|
| Alkalinity reduction (%) | 36.8 | 42 | 54.55 | 42.86 | 45.45 | 33.33 | 36.38 |
| Ammonia reduction (%) | 55.5 | 47.11 | 75.56 | 69.21 | 61.55 | 61.26 | 58.06 |
| pH reduction (%) | 2 | 0.63 | 0.9 | 2.26 | 3.65 | 0.4 | 0.8 |
| Added nitrate concentration (mg/L) | 16.3 | 14.54 | 15.65 | 16.13 | 17.77 | 17.12 | 13.02 |

Considering that the highest percentage of alkalinity reduction for the NTF reactor happened to be in the hydraulic load of 3.6 m/h, also given the acceptance of 7.14 mg/L $CaCO_3$ alkalinity consumption per 1 mg ammonia nitrogen nitrified. The theoretical rate of nitrogen nitrified in this hydraulic load is obtained nearly at 22.41 mg N/l. Nevertheless, in this hydraulic load the actual amount of ammonia removal has been the maximum and equal to 28.53 mg/L $N\text{-}NH_3$. Hence using this method, the actual amount of nitrified nitrogen with 27 % deviation from its theoretical amount represents a fair balance. In addition, the significant reduction of pH in hydraulic loading range of 3.6-5.4 m/h proves the significant rate of nitrification. On the other hand, ammonia removal efficiency started in low amount 55.5 % at the hydraulic load of 2.4 m/h and increased to 75.56 % in hydraulic load of 3.6 m/h however from this point onwards despite the increase in hydraulic load the efficiency has been decreased. The reason of this could be that as hydraulic load gets higher in the system, the amount of inlet ammonia to the media will be increased as well and it leads to more nitrification. Moreover, in low hydraulic loading the media hydraulic wetting low and consequently the dearth of available



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ammonia leads to less nitrification. The efficiency obtained in this study for the ammonia removal is similar to the work done by G. Aguilera Soriano et al (Aguilera et al. 1999b) on an integrated AS/TF system for C and N removal in which they were able to achieve the 50-70 % of the removal efficiency.

This efficiency rate is low compared to 82 % ammonia removal observed in a study done by Bernard et al (Bernard et al. 1998) in which a form of third type of nitrification (TF filled with a different plastic Sessil) was implemented with external loading of ammonia 1.12 g N-$NH_3$/$m^2$.d. However, with increase in ammonia loading rate and growth of the biofilm on the media, effective area of media is reduced and acts as a limiting factor in nitrification process and is likely lead to a slight reduction in ammonia removal efficiency. Nevertheless, if increase in ammonia loading rate is due to increase in flow rate passed through the filter (increase in the HLR), in practice leads to increase in shear forces on the media as well as reduction of biofilm containing nitrifiers and consequently less nitrification will occur.

As it can be seen, in the range of hydraulic loads 3.6 and 4.2 m/h, curves are closer to each other and it indicates the better balance of process in this range. The higher nitrification efficiency achieved in this research compared to similar studies perhaps is due to more ammonia loading (2-2.5 g N-$NH_3$/$m^2$d).

The nitrification rate occurred in the NTF at different temperatures of wastewater is shown in Fig. 7. The temperature measurements showed that in the coldest days (December) the average temperature of wastewater is not less than 16 °C, while the highest temperature average of wastewater has been 26.5 °C which is registered in July has been equal to 26.5 °C. The nitrification rate in cold seasons compared to the best condition of this process (nitrification at 22 °C) shows the 57.5 % reduction ratio.

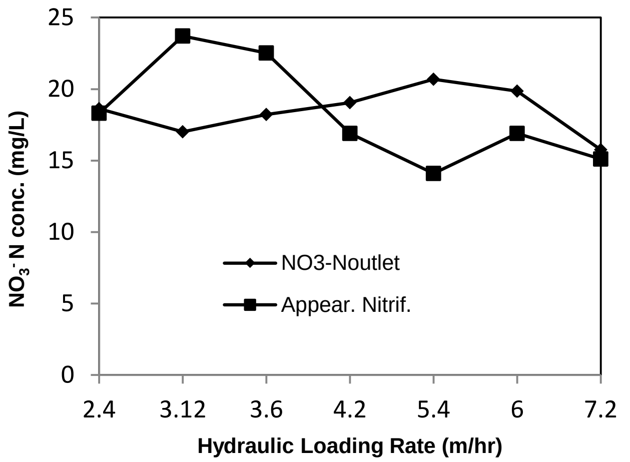


**Fig. 6.** Changes in the occurred nitrification rate in comparison to the expected rate versus hydraulic load rate.

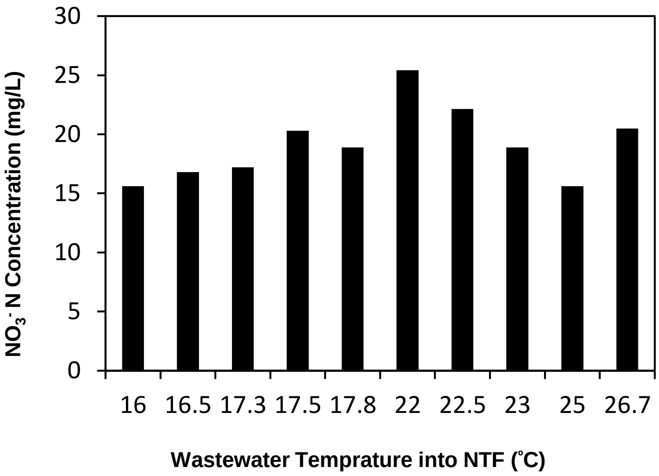


**Fig. 7.** The nitrification rate occurred in NTF versus wastewater temperature (HLR=3.6 m/h).

The evaluation of TKN/COD and $BOD_5$/COD in NTF effluent is one of the most important parameters in this process. If the process could reduce these ratios, it can be concluded that the quality of effluent has been improved.

In Table 4, it is shown that the highest reduction of $(TKN/COD)_{out}$ and $(BOD_5/COD)_{out}$ has occurred in the hydraulic load of 4.2 m/hr.

**Table 4.** The ratio of TKN/COD and $BOD_5$/COD in NTF effluent.

| HLR m/h | 2.4 | 3.12 | 3.6 | 4.2 | 5.4 | 6 | 7.2 |
|---|---|---|---|---|---|---|---|
| $(TKN/COD)_{out}$ | 0.21 | 0.23 | 0.26 | 0.17 | 0.25 | 0.25 | 0.29 |
| $(BOD_5/COD)_{out}$ | 0.62 | 0.41 | 0.24 | 0.20 | 0.23 | 0.44 | 0.52 |

## 4. Conclusion

In general, the laboratory experiments involving analysis of various parameters in the integrated process of activated sludge/trickling filter (AS/NTF) included the following results:

- The best hydraulic and ammonia loading rate achieved here were 3.6-4.2 m/h and 2-2.5 g N/$m^2$. d, respectively.
- The AS/NTF system efficiency based on the research conditions has been equal to 86 % COD removal, 94 % $BOD_5$ removal, 70 % turbidity removal, 94.4 % TSS removal, 55.5-75.5 % TKN removal and 85 % nitrification, respectively.
- The nitrification rate in the depth of 3 m was not enough to reach an acceptable level of nitrified nitrogen in NTF effluent.
- Integration of activated sludge and trickling filter processes, especially in old wastewater treatment plants in which equipment depreciation and removal efficiency reduction of pollution parameters happen due to overload of individual process is a way to fix the problem and is able to withstand the hydraulic pressure and organic loading exerted to it.

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