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Application of A New Technology For Dairy Processing Wastewater Treatment Using Activated Sludge

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Abstract

Background: Dairy wastewater contains high levels of organics and other pollutants. **Objective:** The present study was carried out to study the treatment process of dairy effluents using activated sludge process (APS) without and with Nanoparticles using a bench scale model. The model consisted of aeration and sedimentation tanks. Samples were collected from El-Masreyeen factory in 6th October City from the ground tank of compact unit, Egypt. **Results:** The results proved the ability of the APS system without nanoparticles for the treatment of dairy wastewater. After the addition of nanoparticles, the treatment efficiency of dairy wastewater increased significantly. **Conclusion:** Addition of Nanoparticles to activated sludge improved the overall removal percent for all measured parameters to more than 90%. The application of nanoparticles proved as a clean, environment friendly and cheap technology to improve the treatment of dairy wastewater using ASP system.

Key words: activated sludge, dairy wastewater, nanoparticles.

INTRODUCTION

Dairy plants are considered as ‘wet industry’ because they consume large volumes of water, which is used for very diverse purposes. As a result, dairy plants discharge large volumes of wastewater (Wildbrett, 2002; Al-Wasify *et al*. 2017).

The dairy industry, like most other agro-industries, generates wastewater characterized by high biological oxygen demand (BOD) and chemical oxygen demand (COD) due to their high organic content (Vidal *et al*. 2000). The discharge of the polluted water is the most significant contributor to the pollution of environment from the dairy industry in terms of both quality and quantity; contamination by the solid waste and waste gases are less serious (Wildbrett, 2002). The dairy-industry wastewater is primarily generated from the cleaning and washing operations in milk processing plants. It is estimated that about 2% of the total milk processed is wasted into drains (Munavalli and Saler, 2009).

There are many physicochemical methods that have been studied and applied for wastewater treatment. These methods include screening, sedimentation, flotation, filtration, aeration, coagulation, ozonation, chlorination, ion exchange, degasification, neutralization, etc. However, these methods have many limitations such as the use of chemical agents, higher cost, partial treatment, production of secondary pollutants and production of large volumes of solids. Due to these limitations, the application of biological methods was more suitable to be used as an alternative technique (Rodrigues *et al*. 2008). Produced wastes (sludge and effluents) from food industries, including dairy industry, contain high levels of organic matter, fatty acids, oil and grease (O&G) and notable nitrogenous compounds (Porwal *et al*. 2015; Al-Wasify *et al*. 2017).

Dairy wastewater is generally treated using biological methods such as activated sludge process, aerated lagoons, trickling filters, sequencing batch reactor, upflow anaerobic sludge blanket reactor, anaerobic filters, etc. (Demirel *et al*. 2005). Biological methods, like activated sludge process, are invariably employed for the secondary treatment of large number of industrial wastewaters.

Nanoparticles are used for wastewater treatment due to its small size, crystal form, high surface area, structure, high catalytic ability, unique network order and its high reactivity (Zhang *et al*. 2007; Pavithra and Shanthakumar, 2017). The main aim of the present study is to evaluate the treatment process of dairy wastewater using activated sludge technology supplemented with nanoparticles.

MATERIAL AND METHODS

Samples and sampling:

Two hundred liters of raw dairy wastewater were collected from El-Masreyeen factory in 6th October City from the ground tank of compact unit, Egypt. Raw dairy wastewater samples were collected in plastic containers with 20 liters for each one. Samples were collected and transferred immediately for the experiments according to the standard methods (APHA, 2010).

Device components:

Figure (1) showed the device components of activated sludge process (ASP) bench scale model. The model composed of two tanks. The first is anaerobic tank (60*30*30) and the second is aeration tank (60*30*30). The dairy wastewater was treated with aeration for 8 hours at a rate 3 times per day for a period of 4 days. The aeration occurred for 2 days for 8 hours at a rate 3 samples per day and aeration of 12 hours at a rate 2 samples per day for 2 days. Aeration and flipping has been done by using the compressed and diffused air method through perforated air pipes which will produce bubbles of air. After finishing of this step, we excrete this water to the sedimentation tank from the aeration tank through a tap in the bottom of the tank to precipitate this water for 4 hours in sedimentation tank.

The used nanoparticles:

Nanoparticles (INNPT nanomaterial) were produced from Elwatanya company for development, investment and trade, Egypt. The composition of INNPT nanomaterial (weight %) is CaO (35-40%), Al_2O_3 (40-45%), Fe_2O_3 (5-15%) and SiO_2 (2-3%).

Physicochemical analysis:

The raw and treated dairy wastewater samples were examined according to APHA (2010) for the following parameters; chemical oxygen demand (COD), biological oxygen demand (BOD), pH, dissolved oxygen (DO), total suspended solids (TSS), ammonia-nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN) and total phosphorus (TP).

Fig. 1: Components of activated sludge process (ASP) bench scale model.

RESULTS AND DISCUSSION

Characterization of raw dairy wastewater:

Table 1 summarizes the average values for measured physicochemical parameters of raw dairy wastewater. The raw dairy wastewater was highly polluted. High values of COD and BOD indicated that organic matters were highly concentrated in dairy industry. In addition, it was clear that dairy wastewater was rich of both nitrogen and phosphorus. Leachate also was white in color indicating high suspended matters. In the present study, pH of dairy influent was neutral. Passeggi *et al*. (2009) and Al-Wasify *et al*. (2017) stated that pH of the dairy effluent depends mainly on the nature of the end-product and range from 4.7 to 12.2. To evaluate and determine the efficiency of dairy wastewater treatment process, TSS is one of the main parameters used in the evaluation process. Presence of high concentrations of TSS in wastewater can destroy the aquatic life and cause great problems at wastewater treatment plants (Baruah *et al*. 1993). TSS average concentration was 500 mg/L which was almost like the findings reported by Porwal *et al*. (2015) as they found high concentrations of TSS ranged from 601.6 to 626.6 mg/L. Moreover, BOD and COD are the most widely used indicators of wastewater quality. Dairy wastewater is characterized by high concentrations of BOD and COD due to the presence of lactose, fats, casein, nutrients and inorganic salts (Kolhe *et al*. 2009). The presence of high concentrations of BOD (450 mgO_2/L) and COD (1000 mg/L) consumed the dissolved oxygen (DO) in dairy influent which was 2.0 mg/L.

Table 1: Raw dairy wastewater characterization.

Parameter	Unit	Average value
COD	mg/l	1000
BOD	mg O_2/l	450
pH	-	7.2
TSS	mg/l	500
NH3-N	mg/l	10
TKN	mg/l	60
TP	mg/l	20
DO	mg/l	2

Activated Sludge Process (ASP) without Nanoparticles:

Aeration treatment without seeding by using ASP and by using diffused air system increases the activity of bacteria. Samples were taken for 8 hours 3 times/day for 4 days and it reduces the dairy wastewater properties by 35% as shown in Table (2). The aeration cycle of 8-hour runs three times during a day for a fourth day. The physicochemical properties of dairy wastewater decreased gradually before adding a seed in dairy wastewater industry along four days of running the 8-hour aeration cycle. The removal efficacy changed from one parameter to another. For example, the removal efficiency for COD, BOD, TSS, TKN, NH_3 and TP was 33%, 25%, 30%, 29.2%, 50% and 42.5% respectively. The overall removal percentage at 8-hour aeration cycle for four days equal to 35%. The aeration process activates the aerobic bacteria which biodegrade the complex organic carbonaceous compounds to a nonorganic simple compound which leads to decreasing the values of COD and BOD throughout the aeration cycle. Also, the nitrogen removal done during this stage and it was obvious throughout the decreasing in values of TKN and NH_3 parameters. Table (3) shows the results of the sedimentation process which reduced the water properties such as BOD,

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COD, pH, TKN, TP,NH_3-N,DO and TSS parameters, and it reduces the dairy wastewater properties by 62.7%. From the results shown in Table (3) it was clear that by increasing the settling duration to 4-hour settling phase instead of 60 minutes only leads to enhance the removal efficiency and the overall efficiency. The results decreased for the parameters COD, BOD, TSS, TKN, NH_3 and TP. The removal percentages are 46%, 56.7%, 55%, 58.3%, 87.5% and 72.5%, respectively. Which means that the results enhanced when using a long settling phase. The total efficacy is 62.7% after using an 8-hour modified aeration cycle with 4-hour settling phase. Aeration treatment without seeding by using ASP and by using diffused air system increases the activity of bacteria. A sample was taken for 8 hours 3times/day for 2day and it reduces the dairy wastewater properties by 41%.

Extremes of pH are fatal for most bacteria. The bacteria grow best when the pH is slightly on the acidic side. The optimum range for bacterial growth generally lies between 6.5 and 7.5(Metcalf and Eddy, 2004). Activated sludge and aerated lagoons could be successfully operated when the pH was between 9 and 10.5 (Benefield and Randall, 1980).

DO of the system remained between 4.2 mg/L and 4.5 mg/L which was as similar as reported values of dairy wastewater treatment using activated sludge reactor (Lateef *et al*. 2013). This value was ideal for the biological treatment systems working under aerobic conditions. The values of DO for the present study were above the minimum level of 2 mg/L which has been widely reported in the literature (Benefield and Randall, 1980).

Many reports show that ASP has been used successfully to treat dairy industry wastes. Donkin and Russell (1997) found that reliable COD removals of over 90% and 65% reductions in total nitrogen could be obtained with a milk powder/butter wastewater. Phosphorus removals were less reliable and appeared to be sensitive to environmental changes. The total COD of dairy wastewater is mainly influenced by the milk, cream, or whey (Sreemoyee and Priti, 2013). The concentration of total suspended solids (TSS) varies in the range of 0.024–4.5 g/l (Passeggi et al. 2009).

The effect of the various aeration regimes on BOD_5 removal appeared to be quite similar to that on the COD. Furthermore, it was clear that the TSS removal and BOD_5 reduction trends are similar to each other. This may be due to the high organic contents of the suspended solid particles. Similar findings were reported by Kushwaha *et al*. (2010) for treatment of dairy wastewater by inorganic coagulants.

Table 3: Results of the sedimentation process of ASP without nanoparticles.

Parameter	Unit	Influent of ASP without seeding	Sedimentation for 4hr after 4-d aeration	Total removal efficiency of ASP system
COD	mg/l	575	540	46%
BOD	mgO_2/l	286	195	56.7%
PH	---	4.3	4.2	---
TSS	mg/l	296.5	225	55%
NH_3-N	mg/l	3.2	1.2	87.5%
TKN	mg/l	33.5	25	58.3%
TP	mg/l	7.5	5.5	72.5%
DO	mg/l	4.2	4.5	---
Average				62.7%

Table 2: Results of ASP without seeding 8h 3times/day for 4 days.

Total removal efficiency of ASP	Average	Day 4 (h)				Day 3 (h)				Day 2 (h)				Day 1 (h)				Raw water	Unit	Test parameter
		Av.	24	16	8	Av.	24	16	8	Av.	24	16	8	Av.	24	16	8			
33%	675	575	575	575	580	590	585	590	595	655	600	650	720	860	790	860	930	1000	mg/1	COD
25%	338.5	286	275	287.5	295	310	302.5	310	317	348	325	350	370	410	390	410	430	450	mg/1	BOD
----	5	4.3	4.2	4.3	4.3	4.4	4.4	4.4	4.5	5	4.5	4.95	5.4	6.3	5.8	6.3	6.75	7.2	---	PH
30%	350	296.5	290	297	302.5	313	307.5	312	319	350	325	350	380	440	410	440	470	500	mg/1	TSS
50%	5	3.2	3	3.2	3.4	3.7	3.5	3.7	3.8	5	4	5	6	8	7	8	9	10	mg/1	NH_3-N
29.2 %	42.5	33.5	32.5	33.7	35	37.5	36.5	37.5	39	44.5	40	45	48	53	50	54	57	60	mg/1	TKN
42..5 %	11.5	7.5	7	7.5	8	9	8.5	9	9.5	12	10	12.5	14	17	3.1	17	18.5	20	mg/1	TP
---	4	4.2	4	4.2	4.4	4.7	4.5	4.7	4.8	4.5	5	4.5	4	3	3.5	3	2.5	2	mg/1	DO
35%	Average																			

Activated Sludge Process (ASP) with Nanoparticles:

Nanoparticle treatment by using ASP, with adding nanoparticle and by using diffused air system increases the activity of nanoparticle. The sample was taken after 12 hours for 2times/day for 2days of aeration with nanoparticle and it reduces the dairy wastewater properties by 78.5% as shown in Table (4).

Table 4: Results of ASP aeration with nanoparticles.

Total removal efficiency of ASP system with Nano	Average	2nd day (h)			1st day (h)			Unit	Parameter
		Av.	24	12	Av.	24	12		
94.8%	52.5	35	33	37	70	66	74	mg/l	COD
92.4%	34	23	20	26	45	42	48	mg/l	BOD
---	6.75	6.5	6.5	6.5	7	7	7	---	PH
94.6%	36.5	27	26	28	46	42	50	mg/l	TSS
67.5%	3.25	3	2.9	3.1	3.5	3	4	mg/l	NH_3-N
95.6%	2.65	2.3	2.2	2.4	3	2.6	3.5	mg/l	TKN
94%	1.2	0.9	0.085	0.95	1.5	1.4	1.6	mg/l	TP
---	4.5	4.15	4.0	4.3	4.8	4.6	5.0	mg/l	DO
89.8%	Average								

The aeration cycle of 12-hour runs two times during a day for two days after adding nanoparticle. Samples were taken to analysis at National Research Center to determine the chemical properties for dairy wastewater. the chemical characteristics of dairy wastewater decrease gradually after adding a nanoparticle in dairy wastewater industry along two days of running the 12-hour aeration cycle. The total removal efficiency changed from one parameter to another. For example, the removal efficiency for COD, BOD, TSS, TKN, NH_3 and TP was 94.8%, 92.4%, 94.6%, 95.6%, 67.5% and 94%, respectively. The overall removal percentage at 12-hour aeration cycle for two days equal to 89.8%. Table (5) shows the results of the sedimentation process after adding nanoparticle which reduced the water properties such as BOD, COD, pH, TKN, TP, NH_3-N and TSS by 86.8%.

Table 5: Results of ASP sedimentation with nanoparticles.

Parameter	Influent of ASP with nanoparticle additive	Sedimentation after nanoparticle additive for 1st hour	Total removal efficiency of sedimentation stage	Total removal efficiency of ASP system
COD	33	30	10%	97%
BOD	20	20	0%	95.6%
PH	6.5	6.1	---	----
TSS	26	16	38.5%	96.8%
NH_3-N	2.9	2	31%	80%
TKN	2.2	1.3	40.9%	97.8%
TP	0.85	0.7	17.6%	96.5%
DO	4	4	---	---
Average			23%	93.9%

From the results shown in Table (5) it was clear that by increasing the settling duration to 4-hour settling phase instead of 60 minutes after adding nanoparticle only leads to enhance the removal efficiency and the total all efficacy. The results decreased for COD, BOD, TSS, NH_3-N, TKN and TP. The removal percentages are 97%, 95.6%, 96.8%, 80%, 97.8% and 96.5%, respectively which means that the results enhanced when using a long settling phase with adding nanoparticle. the overall removal efficacy is 93.9% after using a 12-hour modified aeration cycle with 4-hoursettling phase.

The adsorption effect of nanoparticles demonstrates the significant improvement in the treatment of dairy wastewater due to their extremely high specific area and associated sorption sites, tunable pore size, and short intraparticle diffusion distance. The application of nanoparticles in the powdered form into activated sludge can be highly efficient since all surfaces of the adsorbents are utilized and the mixing process facilitates the mass transfer (Sylvester *et al*. 2007; Qu *et al*. 2013; Ghani and Yusoff, 2015). The presence of magnetic iron (Fe) nanoparticles have proven to be useful for adsorption, reductively transforming or degrading different types of organic pollutants and inorganic contaminants (Noubactep, 2010; Singh *et al*. 2012; Palanisamy *et al*. 2013; Němeček *et al*. 2014; Peeters *et al*. 2015).

Comparison between the fourth stages of dairy treatment:

A comparison was carried out among the results of the four stages used in dairy treatment and the Egyptian standards for using the treated dairy wastewater for irrigation purpose. Figures (2-7) represent the removal efficiency of studied physicochemical parameters. The final results of the fourth stages used in dairy treatment was identical with the Egyptian standards for reusing the treated dairy in irrigation purposes. from the obtained results it is concluded that it is necessary to use nanoparticle additive for dairy treatment because the final properties of treated dairy were matching with the Egyptian specification for irrigation purpose.

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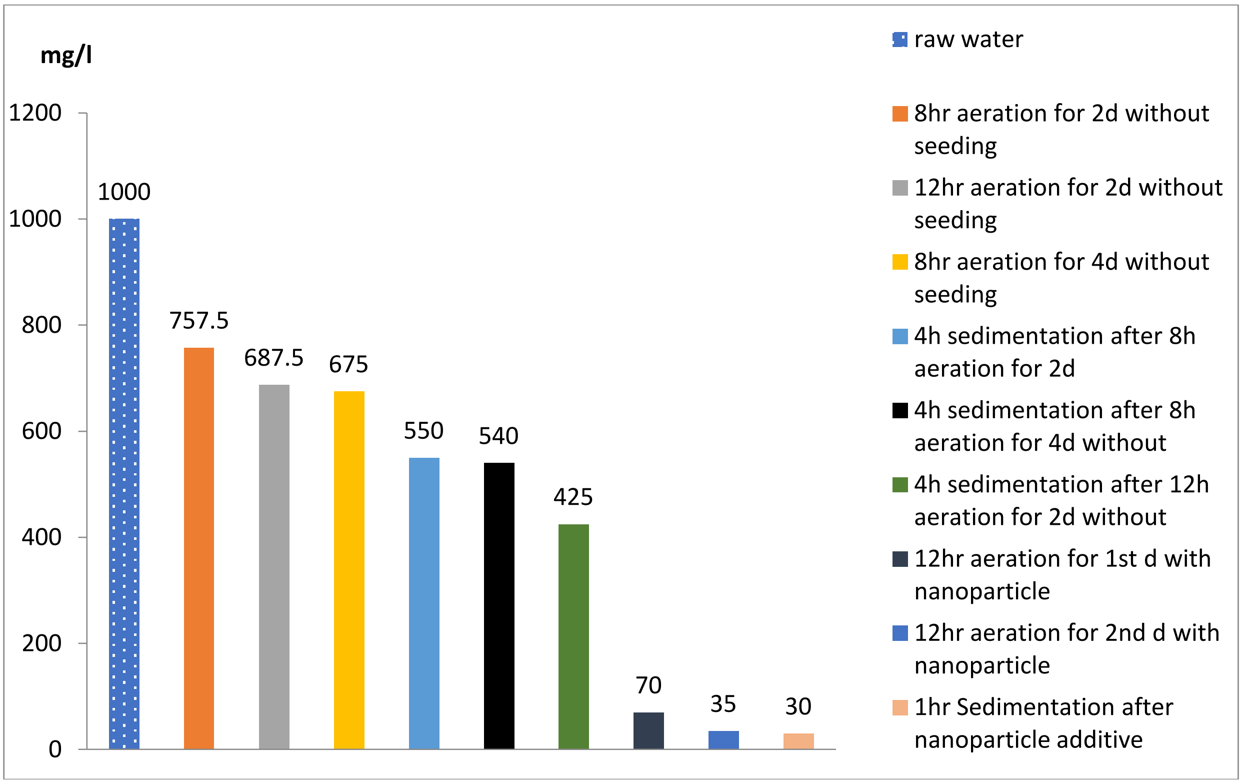

Fig. 2: Removal of pollutants during four stages for COD.

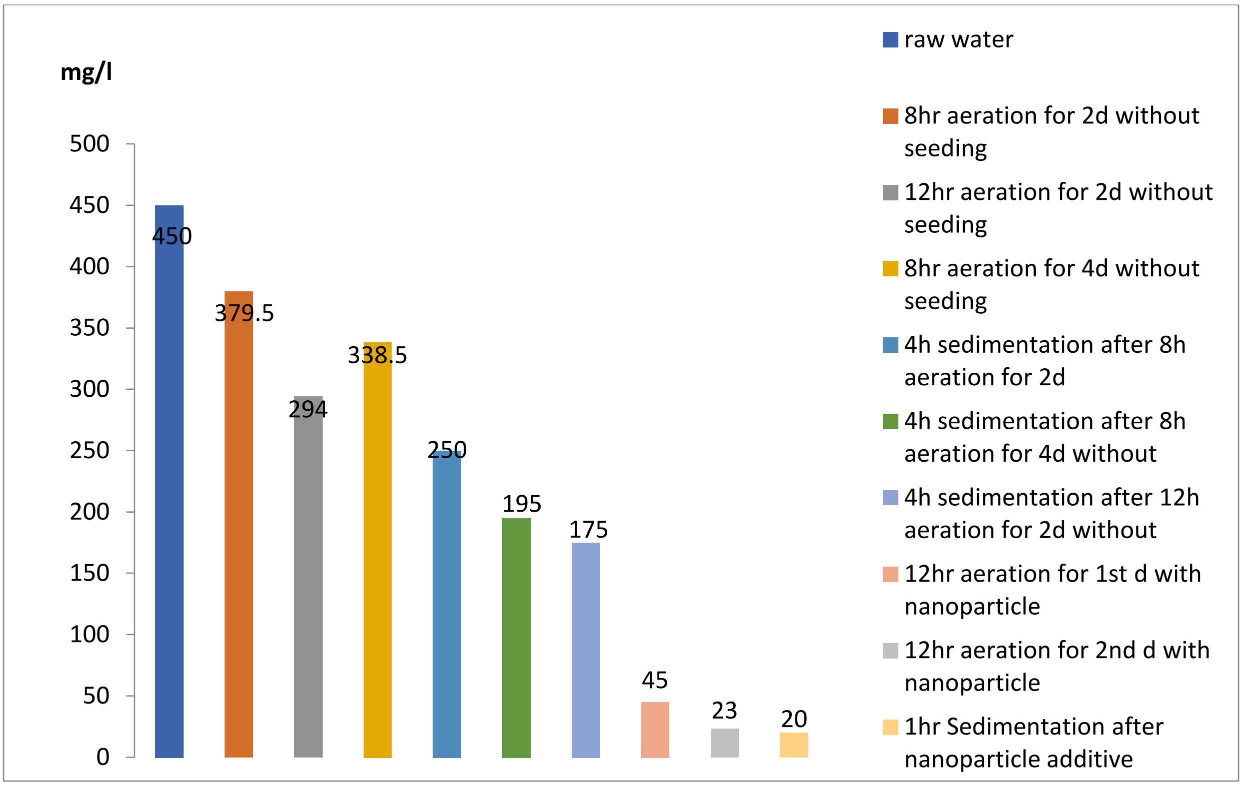

Fig. 3: Removal of pollutants during four stages for BOD.

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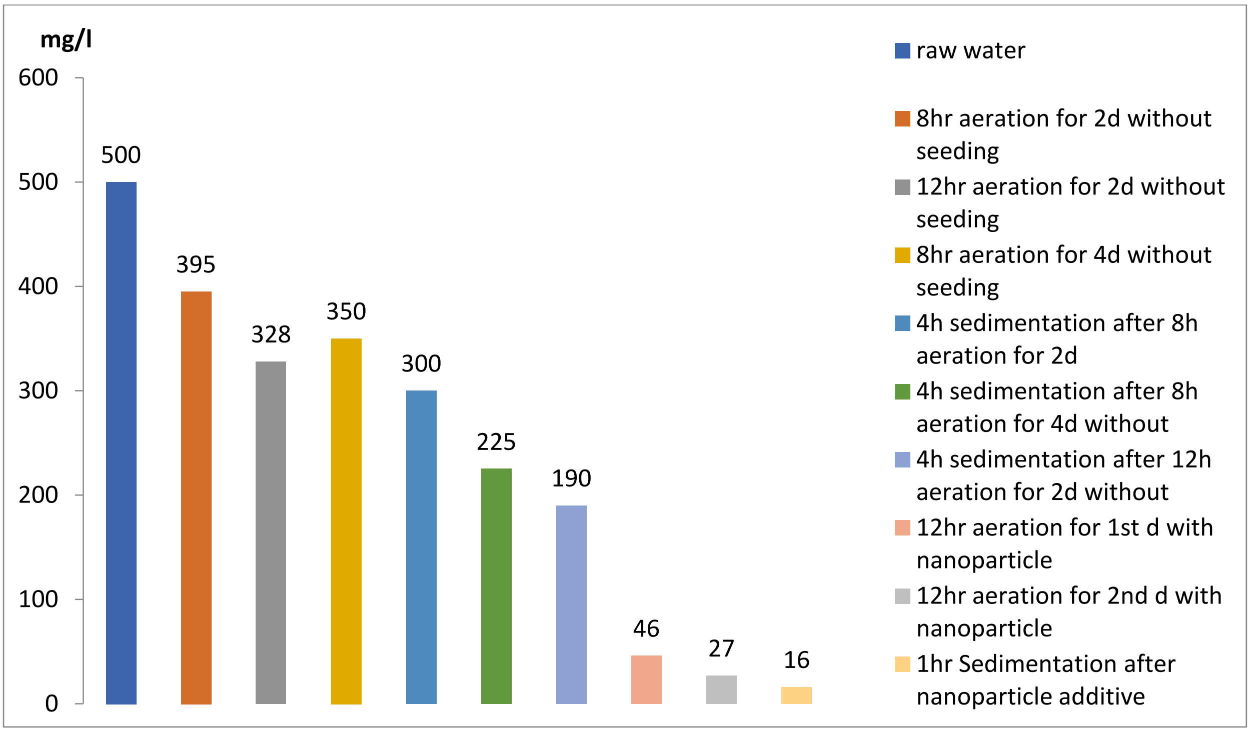

Fig. 4: Removal of pollutants during four stages for TSS.

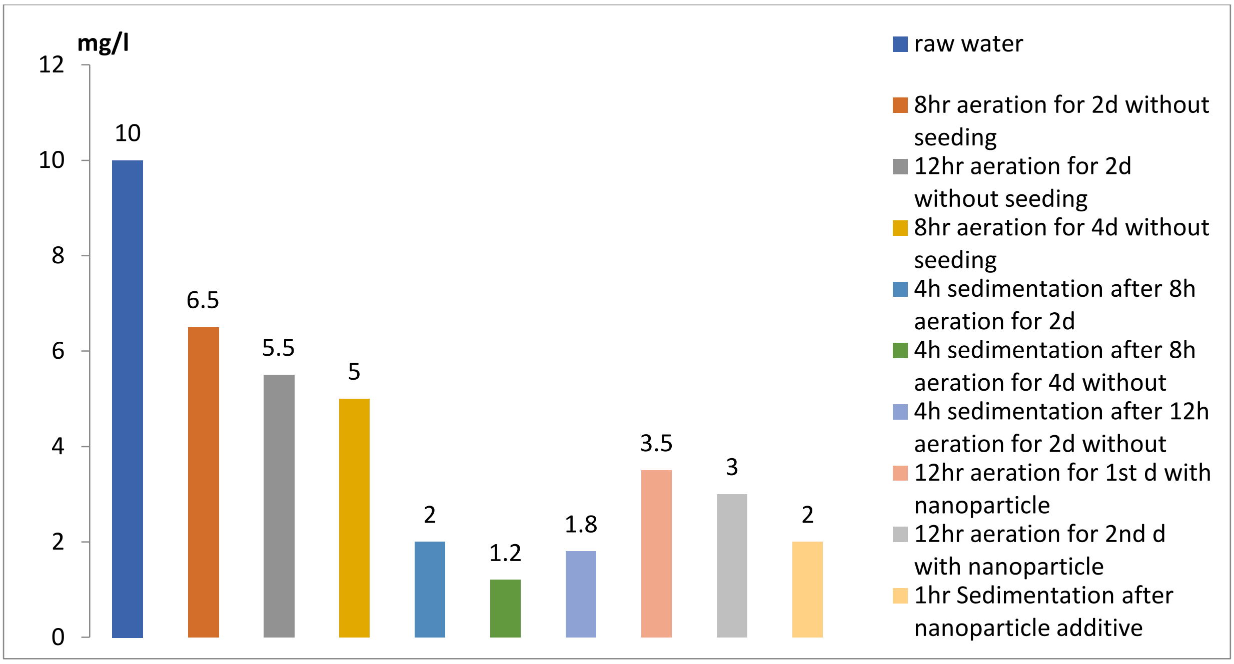

Fig. 5: Removal of pollutants during four stages for NH_3-N.

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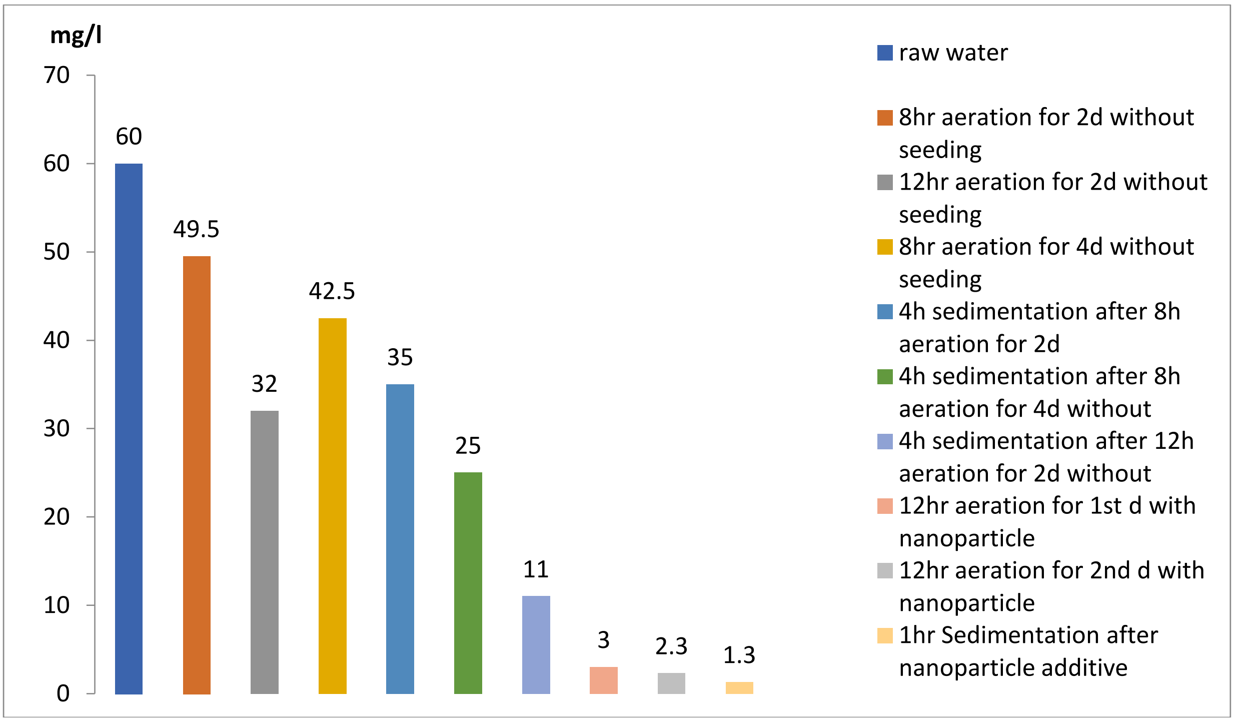

Fig. 6: Removal of pollutants during four stages for TKN.

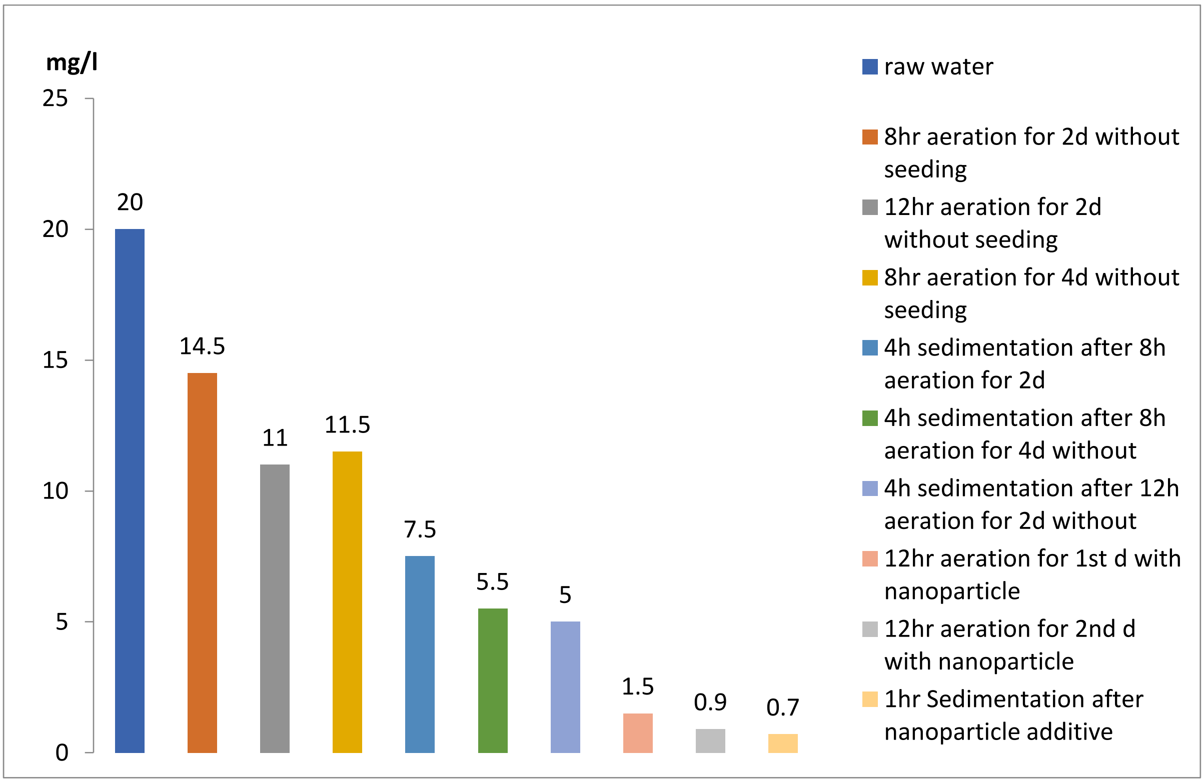

Fig. 7: Removal of pollutants during four stages for TP.

Conclusions:

Based on the experimental program executed in this research, the following conclusions had been reached:

- The raw dairy wastewater sample has low properties.
- Aeration tank reduces the water properties such as COD, BOD, and TSS by 33 % because COD fraction test which is experimented in the dairy wastewater water showed that the dissolved material was 80 %, suspended material was 30 %.
- These prove that it is important to use aeration tank.
- Using biological treatment by ASP with Nanoparticle additive and using air blower to increase the activity of Nanoparticle for 12 hours reduces the water properties 85.5%.
- Biological treatment in ASP tank is depending on Nanoparticle additive which reduces the value of COD, BOD.
- A comparison was made between the results of the two stages used in industrial wastewater treatment and the Egyptian standards for the treated dairy processing drainage in sewer system.

- The results of the two stages used in industrial wastewater treatment were identical with the Egyptian standards for reusing the treated dairy wastewater in irrigation purposes.
- From the obtained results it is concluded that it is necessary to use Nanoparticle additive to dairy wastewater because the final properties of dairy wastewater treated were matching with the Egyptian specification for final treatment.

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