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Original Article

Evaluation and Review for an Existing Industrial Wastewater Treatment Plant in El-Horreya Sweets Factory

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Abstract - *The study aims to evaluate the existing industrial wastewater treatment plant of the El-Horriyah sweets factory. The evaluation covers the plant design, the plant construction status and the plant operation performance. The samples are taken from the influent and effluent of each unit from the plant line. From the study results, the appeared design problems are bad choice for treatment units for such wastewater and also the unit's arrangement in the treatment line, large tanks sizing as the unequal design flows are determined, which means that some of the units are over-designed affected the quality performance of the plant and effluent quality due to operation outside the standard design limits, big pumps rates as all pumps' flows are much higher than the plant units design flow also the actual design flow by 10 to 20 times prevents the continuous operation for the plant parts & adding chemicals doses. Also, the chemicals feeding as a powder in one shoot per turn that limited its effect to only 10 minutes after the addition and the diffused air to units without any controlled amount are the operation problems. Some problems appear from construction, especially for the dissolved air flotation unit, bio-filter, pH adjustment, and chemical precipitation units, that affect their efficiencies more than normal for such units. The study changes the chemical feeding to be a continuous solution by dose obtained from jar test at the lab. Also, the control for the pump rates by semi-close delivery valves and operating the plant under skilled supervision raise the effluent quality by 40-50%, but the effluent still does not achieve any limits for disposal or reuse.*

Keywords - *Food industry, Sweets industry, Industrial wastewater treatment, Evaluation of existing plant, Design evaluation, Operation evaluation, Performance evaluation*.

1. Introduction

The sweets industry is one of the main industries around the world that produces various types of candies and other products. These industries continue to grow each year despite economic conditions, employ over 500,000 workers in thousands of factories around the world, and produce about 7 billion pounds (about 3.2 billion kg) of these products each year. In 2008, the global sweets industry was valued at almost $150 billion United States Dollars (USD). In 2009, all of these industries combined reported just over $54 billion USD in sweets product sales around the world, employed more than half a million people and operated more than 7,600 factories around the Globe [1]. Candy sugar is primarily made up of sugar. When sugar (sucrose) is meliorated, it is typically provided as bitsy grains. It is derived from beet and sugar cane. The sugar used in candies manufacture must be of high quality so that the proper texture and structure will be achieved. It's the unique physical and chemical characteristics of sugar that make conformation possible. When sugar is heated, it melts and becomes a workable saccharinity. The saccharinity can be manipulated, rolled, and fashioned. As it cools, the saccharinity becomes thicker and begins to hold its shape. As it cools, the syrup becomes thicker and begins to hold its shape. When the candy is completely cooled, the sugar crystals remain together and form the solid candy sugar [2]. Certain ingredients are added to the candy recipe to aid in production. Water is used to adulterate the sugar and make it workable. During the manufacturing operation the water is steadily boiled off, and the end product has much lower water than what it started with. Another processing ingredient is cream of tartar. This emulsion produces air bubbles that help expand the sugar loaf and make it more stable. Salt also helps to adjust the chemical characteristics of the syrup. Typically, a small amount is used so that it is undetectable in the final product [2]. The sweets market share from the hard-boiled sweets segment will expand from the year 2022 to 2028, driven by their higher popularity among kids. This type of sweets comes in a glossy state and is easy to manufacture. Fruit drops, barley sugars, acid drops, hard gums, butterscotch, toffee, and caramel are some of the most consumed hard-boiled candies. Growing intake to boost blood sugar quickly is another factor influencing product demand [3]. The sweets industry, which includes hard candies, toffies and eclairs, exists in Egypt because sugar is a strong agricultural product that depends on the cultivation of sugar cane and beets. Sugar, water, and glucose are the main products in the sweets industry, and there are secondary products like milk, chocolate, flavouring materials, colors and preservatives [4]. The candies production line passes through three successive stages, as listed in (Figure 1); in each step, a part of the production line is carried out, as shown in the following flow line and details [5].

Fig. 1 Production line stages in the candies factory

The content and quantity of wastewater from the sweets business vary daily and seasonally, which has an unfavorable effect on the disposal process. Biologically degradable sewage comes from the confectionery business. Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) values are both high (BOD) [5]. Quality control is an integral part of all sweets production. The first phase of control begins with tests on the incoming constituents. Prior to use, lab technicians test constituents to ensure they meet company specifications. During production, quality control technicians check the physical aspects of the extruded sweets. A comparison system is generally used. In this system, the recently made product is compared to an established standard. Wastewater generated from different industries constitutes a large number of pollutants, nutrients, and organic solid substances. These pollutants can be biodegradable or, non-biodegradable or inert in the terrain and may hold pathogenic microorganisms [7].

The wastewater when discharged into the environment and any aquatic body, causes pollution or health problems; characteristics of industry wastewater are: [7].

- BOD & COD: Industrial and domestic waste releases oxygen-demanding pollutants into the water. These contaminants appear both from manufactories and creatures from food processing, paper manufacturing, and leather tanning.
- TSS & TDS: TSS is often filtered with the sand carbon filtration method. TDS require chemical treatment, demineralization, or evaporation.
- High Nitrate and Phosphate Levels: Nitrates and phosphates enter wastewater streams through human and animal waste.
- Oil and Grease: In addition to environmental damage, oil and grease can clog the waterways and drainage systems.
- Pathogens: Infectious microorganisms or pathogens are the source of water-borne diseases.

A candy factory in Poland used its wastewater treatment as a photolytic oxidation process as a pretreatment for nano-filtration membrane, and the NF process provided the required quality of treated wastewater that can be reused in industrial applications. The NF process resulted in a total decrease in absorbance, 99% TOC removal, and 98% color removal [8]. A plant for the treatment of wastewater was designed in Egypt, constructed and installed for the continuous treatment of 250 l/d wastewater originating from a sweets factory. The plant consisted of an equalizer, chemical mixing tank, aerator, clarifier, disinfectant tank and sand filter as the main components. The treatment of wastewater by the plant occurred with acceptable efficiency, the relative efficiencies of pollutant removal on industrial scales which were COD (98.6%), BOD (99.17%), TDS (95%) and TSS (95%) [9]. An Anaerobic Membrane Bioreactor (AnMBR) system treating confectionery wastewater was operated in Turkey for 247 days at various organic loading rates; in this study, up to 99% COD removal efficiency was obtained at all OLRs [10]. This paper was made to evaluate the existing plant design, operation and performance to determine the reasons for its effluent not complying with the disposal limits.

2. Existing Plant Components

The plant components illustrated in (Figures 2 and 3) show El-Horreya Factory's existing wastewater treatment plant process flow diagram, starting from the inlet inspection chamber to the effluent disposal of the system that discharges to the city sewerage system. These components are: Inspection Chamber - Flotation Tank - Pump Station - Chemical Sedimentation Tank - Final Sedimentation Tank - pH Adjustment Tank - Sand Filter [6].

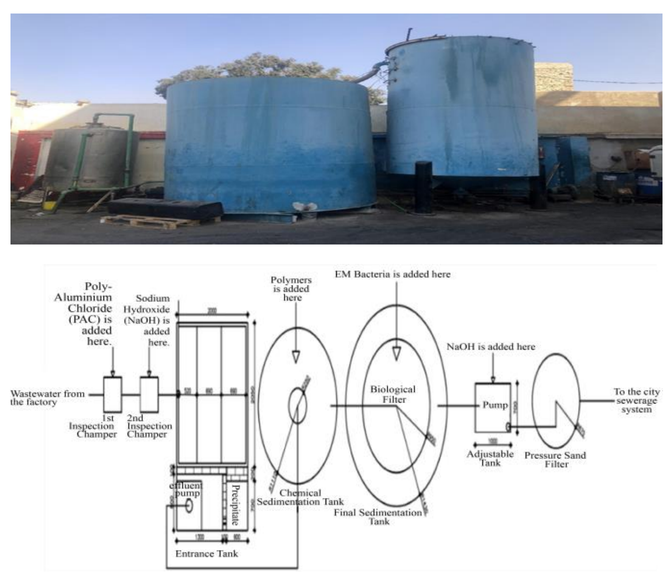

Fig. 2 El-Horreya factory existing wastewater treatment plant process plan

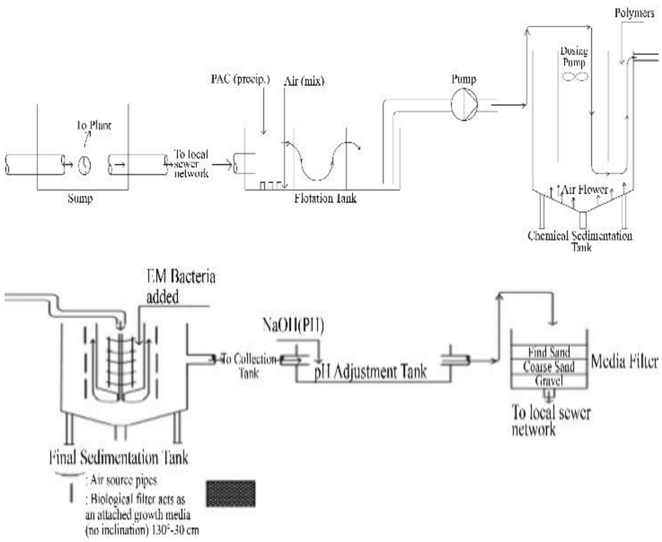

Fig. 3 El-Horreya factory existing wastewater treatment plant process flow diagram

The water flows from the inspection chamber to the flotation tank through a 2 inches pipe diameter, which is divided into 3 compartments; the first compartment works as an oxidation tank, with a water volume of about 4.51 m^3, an air blower is added here in the first compartment with power 5 hp and working for continuous 30 minutes per hour, and the cycle it repeated every hour. The second compartment works as a flocculation tank with a water volume of about 0.46 m3, and the third compartment works as a chemical flotation tank with a water volume of about 1.144 m^3, Poly-Aluminum Chloride (PAC) is added in the third compartment of the flotation tank by 6 liter/day. The water enters the chemical sedimentation tank by a pump which has a pipe of 2 inches in diameter and 4.40 m in length; the tank consists of a flocculation tank with a gentle mixer inside the chemical sedimentation tank, the depth of the water in the chemical sedimentation tank is 3 m, the water depth in the small settling tank is 2 m. The water volume in the chemical sedimentation tank is 12.56 $m^{3,}$ and the water volume in it is 1.57 m^3; the polymers were added here by 1gm/liter, and the air blower is put in the bottom of the chemical sedimentation tank by power 5hp.

The next unit is the final sedimentation tank with the biological filter inside it. The water enters the biological filter from above through a pipe of 4 inches in diameter and 2.50 m in length with the down flow and then enters the final sedimentation tank from the filter bottom to vertically up flow in the settling tank to the effluent weir, the depth of the water in the final settling tank is 3.15 m. Its volume is 20 m^3, the water depth in the biological filter is 2.5 m, and its volume is 7.5 m^3, Effective Microorganisms Bacteria (EM Bacteria) was added here by 5 liter/day.

The water is transferred to a pH adjustment tank through a pipe of 2 inches in diameter and 3.35 m in length, and the tank dimensions are 3x0.7x4 m; its water depth varies between (0.5 - 2.5) m, and water volume in the tank varies between (1.05 – 5.25) m^3, NAOH is added here by (3 - 4) kg. The water enters the last tank, which is a sand filter with a pipe of 2 inches in diameter and 4.20 in length; the depth of the water in it is 1.90 m, and its volume is 2.86 m^3, the thickness of the fine sand, coarse sand and gravel layers are 30 cm for every layer and from which it exits into the public sewage network through a pipe of 2 inches in diameter and 3.50 m in length.

3. Existing Plant Operation

The sweets factory has 3 working shifts, and the wastewater flow varies between (0.5 – 2.3) m3/hr. The flow of the wastewater has an average flow of 11.63 m3/shift, and the flow has an average flow of 36 m3/day. The wastewater enters through the inspection chamber and passes through the pipes to enter the flotation tank. The tank is divided into 3 parts, and the water passes through the first part, which works as a flotation part with an oxidation part with an air blower to cool the water. The wastewater enters the second part, which collects the scum then wastewater comes out from the bottom through a pipe to enter the third part of the tank. Due to the large area of this part, sedimentation occurs here. Poly-Aluminum Chloride (PAC) is added to it to precipitate relatively large impurities.

The wastewater passes to enter the third part. In this part, there is a perforated sheet that works as a scum detention as the wastewater enters the pump through it to raise the water to the chemical sedimentation tank; the retention time in the Dissolved Air Flotation (DAF) is 2.5 hrs. The chemical sedimentation tank consists of a sedimentation tank with a baffle inside; the water enters first into the baffle so that the water is stirred through the dosing pump, then the water comes out from the baffle to the sedimentation tank, and in this part polymers were added to stick to the impurities and precipitate them in the bottom of the tank. The water is transmitted through a pump to the final sedimentation tank, the retention time in the chemical sedimentation tank is 4.4 hrs. It is a final sedimentation tank with a biological filter inside. The water enters first into the biological filter, then exits to the final sedimentation tank, and the biological filter exists inside to breed and collect bacteria; EM bacteria is added to it to collect bacteria on a biological filter to break down BOD and organics, then the water is transmitted through a pump to the pH adjustment Tank, the retention time in the final sedimentation tank is 5 hrs.

pH Adjustment Tank works as a tank to adjust the degree of acidity and alkalinity so that the water enters with a regular flow. It also helps in adjusting the pH value; then the water is transmitted to enter the sand filter. NaOH is added here to control the pH value, so it must have a pH between (6.5 – 8). The retention time in the pH adjustment tank is (0.4 – 2) hrs. By pump of rate 9 – 27 m3/hr and head 40 – 51 m delivered to the pressure sand filter that its effluent disposed to the city sewerage system. The sand filter consists of 3 layers "Fine sand – Coarse sand – Gravel", the fine sand layer was placed on the top as the first layer, the coarse sand was placed in the middle between the fine sand and the gravel as the second layer, and the gravel was placed in the bottom as the third layer.

4. Experimental Works: The Existing Plant Operation

The study samples were taken from the plant influent and effluent and from the in-between each treatment unit to determine the attitude of each unit and the whole plant and also to determine the problem points that should be solved. Wastewater samples were routinely collected 3 times weekly from the influent after each unit, and at the end of the plant. Then, samples were analyzed to investigate wastewater quality during the study period. In This stage, the existing plant was operated according to the current operation procedure through the flow line of the existing plant to evaluate the applied operation in addition to evaluating the plant units and line designs.

Part 1 was divided into two trials:

- The normal existing daily procedure for the factory without modifying the chemical feeding effect.
- The normal existing daily procedure for the factory with modifying chemical feeding effect.

5. Existing Plant Results without Modifying Chemical Feeding Effect

The plant was operated with regular flow as they normally operated in the factory. The operation was made with the normal existing daily procedure for the factory, chemical additives and pump operation schedules. The samples were taken from plant influent and effluent of each unit of the plant components. Based on the operation of the plant, samples were taken cumulatively for the plant on 4 consecutive days.

As the chemicals were added at 9 AM in the morning, then we took 7 samples per day from the following locations:

- Influent of the flotation tank first part from RC tank (9:00 AM).
- Effluent of scum collection chamber second part from RC tank (9:20 AM).
- Influent of the chemical sedimentation tank (9:30 AM).
- Effluent of the chemical sedimentation tank (12:00 PM). All pumps.
- Effluent of the final sedimentation tank (1:30 PM).
- Wastewater Effluent from the pH adjustment tank (1:40 PM).
- Wastewater Effluent from the sand filter. (1:50 PM).

The results are illustrated in (Table 1) and (Figures 4-8) as follows.

Table 1. Results of stage 1 period

Day	Item	Sample Location							Allowable Limit
		1	2	3	4	5	6	7	
20/5/2023	TSS (mg/l)	121	450	383	374	335	329	325	800
	TDS (mg/l)	214	678	665	721	932	1390	1460	2000
	pH	6.9	3.64	3.5	3.4	3.2	3.8	3.8	6-9.5
	BOD (mg/l)	3500	3850	3900	3900	4000	4500	4000	600
	COD (mg/l)	4700	4750	4850	4900	5000	6800	7000	1100
21/5/2023	TSS (mg/l)	187	360	355	360	370	410	430	800
	TDS (mg/l)	199	470	507	675	668	700	690	2000
	pH	6.9	4.5	3.9	3.7	3.7	3.7	4	6-9.5
	BOD (mg/l)	10000	9500	9500	9500	9500	9500	8600	600
	COD (mg/l)	16500	16500	16500	16500	16500	16500	14900	1100
22/5/2023	TSS (mg/l)	231	850	747	469	479	540	525	800
	TDS (mg/l)	202	341	303	387	530	577	575	2000
	pH	5.9	4.7	4.5	3.9	3.4	3.4	3.4	6-9.5
	BOD (mg/l)	3200	9850	9200	9100	9500	9100	9500	600
	COD (mg/l)	4500	16500	15920	16500	15920	16500	15920	1100
23/5/2023	TSS (mg/l)	191	500	590	670	480	493	485	800
	TDS (mg/l)	295	435	395	400	420	430	436	2000
	pH	5.5	4.2	3.9	3.7	3.5	3.4	3.4	6-9.5
	BOD (mg/l)	8500	9500	9850	9500	9600	9800	9500	600
	COD (mg/l)	16500	16500	16500	16500	16500	16500	16500	1100

In all days DO concentrations were zero value in all measured samples.

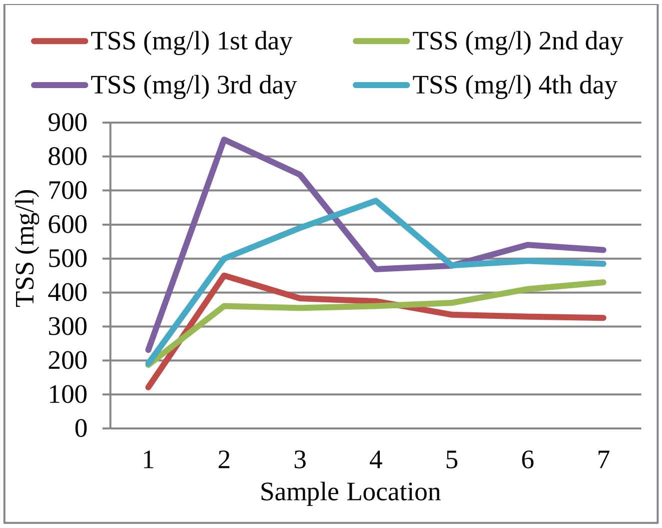

Fig. 4 Suspended Solids (TSS) through the plant

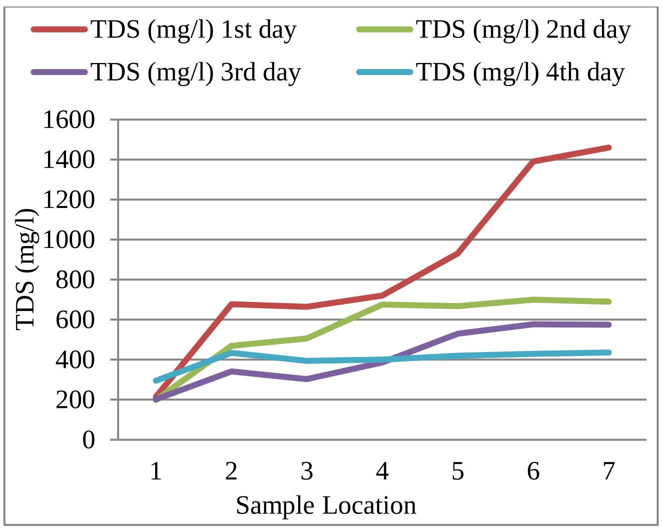

Fig. 5 Total Dissolved Solids (TDS) through the plant

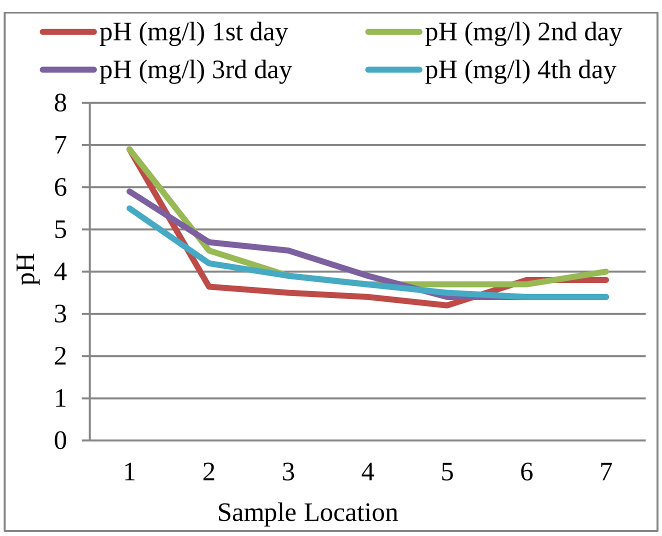

Fig. 6 pH through the plant

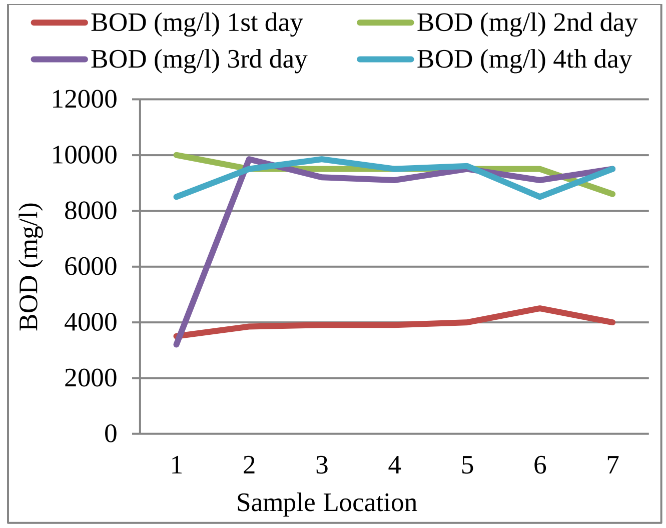

Fig. 7 BOD through the plant

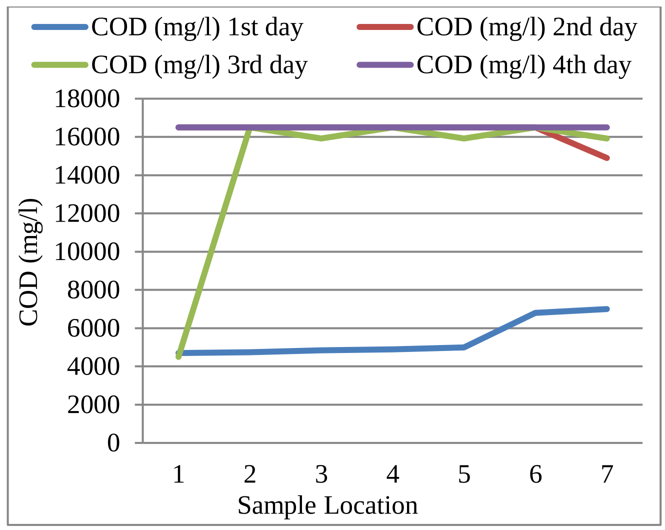

Fig. 8 COD through the plant

6. Discussion of Existing Plant without Modifying Chemical Feeding Effect

TSS in the 4 days were measured by low ppm values as it achieved law limits, but because of adding poly-aluminum chloride as powder one shot at the beginning of the first shift. TSS values increased in the second tank by 48-73%, then in the other tanks, the values continued to decrease, but they were still larger than influent values by 10-63%.

Low ppm values measured TDS in the 4 days, but because of the presence of organic matter and dissolved metals, the values increased from the influent to reach the maximum values in the effluent, but it also still achieved the law limits. pH values in the influent were between 5 to 7, but because of adding poly-aluminum chloride as powder one shot and also because of the non-existence of a pH adjustment tank to adjust pH before exiting the last tank, it continued to decrease until its effluents by values between 3-4.

BOD and COD values influents low ppm values and effluents with large ppm values by 12-72% because of the unequal design flows of the biological tank, which means that it is are over design that affects the quality performance of the plant and also they put in the biological tank a lamella that has no effect on the BOD and COD values and also the EM-Bacteria were added as one shot in the first shift.

In general, the discussion of the effluent analysis results before modification showed that the effluent quality doesn't comply with reuse limits or the city sewerage system disposal limits. The effluent mainly contained very high BOD & COD values with highly acidic corrosive floe, as the removal efficiency in all the parameters has negative values. TSS, TDS, BOD, and COD removal efficiency are very bad.

The results of the effluent analysis showed that the effluent quality doesn't comply with reuse limits or the city sewerage system disposal limits; this was achieved with the high consumption of chemical additives and the washing water for filters. The effluent mainly contained high BOD and COD values with highly acidic corrosive flow.

Several comments on the plant operation procedure appeared on the top of the failure reasons for all measured parameters as follows:

- The applied methodology for chemical addition that depends on putting all the required amounts of chemical powder per shift as one shot at (9:00) AM in the first shift and repeated for the second and third shifts after one hour of the shift starting that reduces the chemical effect along the shift period and makes it only an instant effect which makes its effect negligible for the treatment needs. The plant design flow is not equal for all units, even if there is no recirculation noticed in the system.
- All the units' designed volumes do not meet both international design criteria or the Egyptian code design limits. Therefore, their performance does not achieve what is designed for it.
- Moreover, all pumps' flows are much higher than the plant units' design flow. Also, the actual design flow of 10 to 20 times prevents the continuous operation of the plant parts.
- According to the design review for the units with their existing sizes, the unequal design flows were determined, which means that some of the units are over-designed, affecting the quality performance of the plant and effluent quality due to operation outside the standard design limits.
- The Reinforcement Concrete (RC) tank is used to separate brick walls corroded by wastewater effect. There is also no isolation for the inside walls and bottom of the tank, with some edge cracks in the weirs.
- All the metallic tanks are rusted, with some corrosion from the inside, some rust from the outside, and some leakage points at welding points.

7. Modifying Chemical Feeding Effect Results on the Existing Plant

There are a lot of problems in the operation procedure that could be one of the reasons that affect the plant failure; a little bit of modification was made for the chemical feeding system to make it a continuous dose instead of a sudden shot dose using solution chemical instead of powder that controlled by a dosing valve to ensure its continuity, the second modification was controlling pump delivery by partially closing the valve to make it in continuous work. A trial of operation was made after this modification, and the results were illustrated in (Table 2) & (Figures 9 - 14) as follows: -

Table 2. Results stage 1 after modifying both chemical feeding and pump flows

Day	Item	Sample Location							Allowable Limit
		1	2	3	4	5	6	7	
Day 1	TSS mg/l	410	340	320	320	300	290	270	800
	TDS mg/l	570	520	490	490	460	430	410	2000
	pH	3.5	2.5	2.3	2	6	6.5	6.5	6-9.5
	BOD mg/l	4000	3850	3620	3000	2980	2800	2600	600
	COD (mg/l)	5600	5500	5300	5000	4600	4200	4000	1100
	DO (mg/l)	2	4	5	5	6	5	3	10
Day 2	TSS (mg/l)	630	600	550	520	480	470	450	800
	TDS (mg/l)	770	725	685	610	585	560	520	2000
	pH	4	3.1	2.5	2	6	7	7	6-9.5
	BOD (mg/l)	5850	5670	5480	5000	4710	4500	4200	600
	COD (mg/l)	6700	6540	6400	6320	6000	5700	5400	1100
	DO (mg/l)	3	5	4	5	6	6	3	10

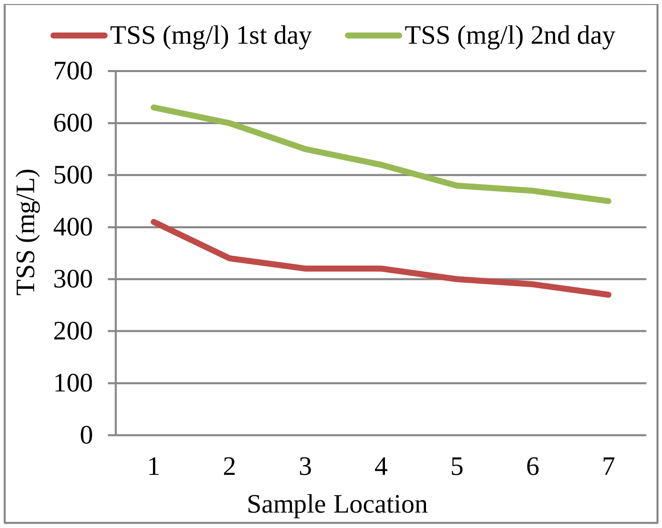

Fig. 9 Modified TSS through the plant

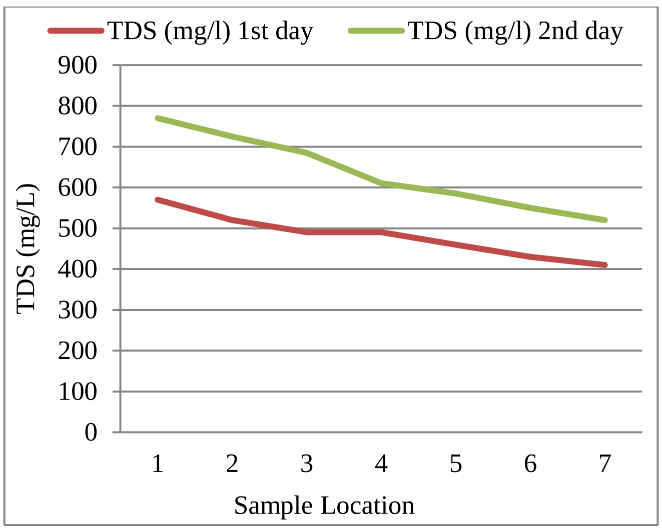

Fig. 10 Modified TDS through the plant

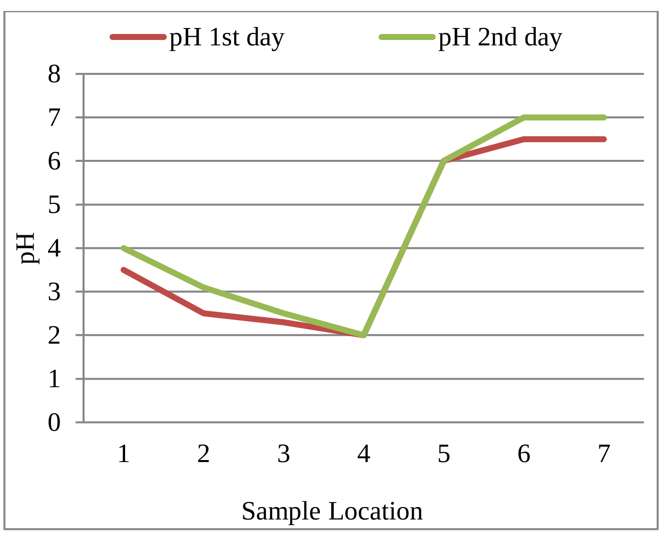

Fig. 11 Modified pH through the plant

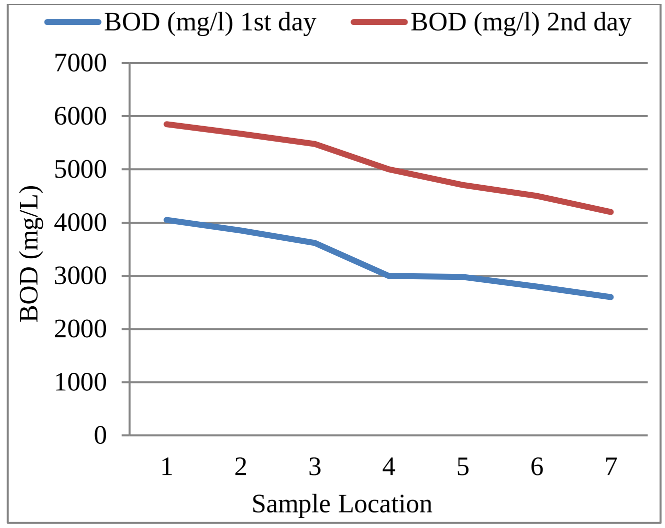

Fig. 12 Modified BOD through the plant

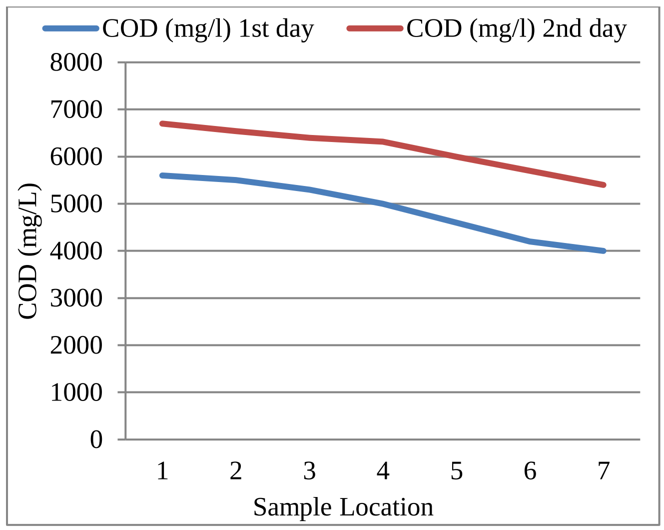

Fig. 13 Modified COD through the plant

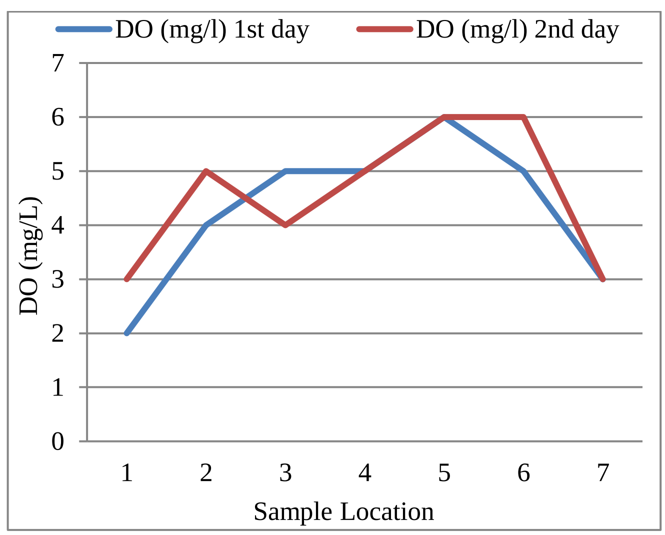

Fig. 14 Modified Dissolved Oxygen (DO) through the plant

Table 3. Discussion table after modifying chemical feeding effect on the existing plant

Parameter	Effluent Values (mg/l)	Influent Values (mg/l)	Allow able Limits	Removal efficiency (%)
TSS	270	630	800	57.14
TDS	410	770	2000	46.75
BOD	2600	5850	600	55.55
COD	4000	6700	1100	40.30

8. Discussion of Modifying Chemical Feeding Effect on the Existing Plant

TSS and TDS in the 2 days had large values in the influent, and it continued to decrease until it reached the effluent by a low value as it in all conditions achieved law limits because of adding ferric chloride in solution instead of powder and with continuous dose. pH values in the influent were between 3 to 4. However, because of adding ferric chloride solution in the flotation tank instead of powder and with continuous dose, it continued to decrease until it reached the minimum in the biological tank. However, after that, it began to increase because of adding NaOH solution in the pH adjustment tank to adjust pH before exiting the last tank. It continued to increase until it effluents by values between 6.5 - 7. BOD and COD had large ppm values in the influent.

They continued to decrease until it reached the minimum values in its effluent as it had a slight improvement because of adding EM-Bacteria in a continuous dose. DO values were low in the influent and effluent due to non-adding the air dose, but they increased in the chemical sedimentation and biological tank due to the addition of the air dose. In general, the discussion of the effluent analysis results after modification showed that the removal efficiency after modifying the chemical feeding effect on the existing plant has a slight improvement in TSS, TDS, BOD and COD, but it has also not achieved the disposal law limits. The operation development by the mentioned procedure increases the plant efficiency by about 40 - 50%, as illustrated in (Table 3), but we still cannot achieve the required limits.

9. Conclusion and Recommendations

In general, the existing plant has several problems that affect its performance and effluent efficiency. The study found design problems due to a huge increase in unit sizing and pump rates that affect all the unit criteria that reflect on the effluent efficiency. The study showed the bad status of the existing units also affected the effluent quality. The main problem faced by the plant performance was the operation procedure, especially the methodology of chemical addition as one shot per turn, the pumping operation procedure with the on-off sequence that affected shock loads on the delivery receiving tanks. The study concluded that there is a possibility of improving the existing plant performance by changing the operation procedure.

The modifications that should be made to achieve the right operation procedure could be as follows:

- The chemical feeding should made by solutions added by continuous dosing along the turn period.
- The pump's rating should be controlled to achieve continuous operation by partially closing the pump delivery valve to minimize the pump delivery rate to the design flow rate.
- Rehabilitate and isolate unit walls and bottoms to prevent any leakage and entering corroded materials into the flow.
- Change the sand media of the filter and wash it at least once per day.
- Review all sedimentation units and uniform sludge dewatering from it to be at least once per 4 hours.

In the second part, To overcome the performance problems of the existing plant, two trials will be made to try to improve the existing plant performance with minimal modifications, as the study will be applied on a similar lab scale units simulate the existing plant for the factory, including all physical, biological and chemical units. The pilot operation was made in two trials:-

1st Trial: Operation without chemicals. The first trial depends on the stopping of all chemical additives and operates all air and water pumps continuously.

2nd Trial: Adding chemicals to increase the plant performance. As the second trial puts on the first trial modification, the chemical additives are continuous solutions with the same existing dose distributed during the plant's operation period. In the third part, Modifications will be applied to the existing plant using the existing units, especially the concrete one, with as minimum changes as possible, as new chemical additives and doses that resulted from the second part.

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