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Potential of Food Processing Wastewater Treatment for Reuse

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THIS study aimed to investigate the most effective treatment technique for the wastewater generated from food processing factory to be reused according to Egyptian standards. The discharged wastewater was highly polluted by organic load. As presented by average chemical oxygen demands (COD) value of 4950 mgO_2L^{-1}. Four treatment scenarios were investigated to select the most appropriate module for reuse of wastewater. Chemical coagulation-flocculation followed by adsorption onto granular activated carbon (GAC) achieved 84% of COD removal. The Fenton oxidation followed by adsorption onto GAC achieved COD removal of 91%.The Aerobic treatment followed by adsorption onto GAC reached to 92% COD removals. The quality of treated effluent using the previous modules was far less than the required values stated in Egyptian code for reuse in agriculture (Grade A). Integration of the studied different treatment modules in the form of sedimentation then chemical coagulation-flocculation followed by aerobic treatment then sandwich filter using adsorption/filtration (Sand/GAC/Sand) produced water quality complying with the Egyptian code for reuse in agriculture with COD removal of 99.8%.

Keywords: Food processing wastewater, Reuse, Coagulation, Fenton, Aerobic, Granular activated carbon.

Introduction

Increasing human population and the economic growth, food processing industrial sector plays an important role for food sufficiency of the developing countries like Egypt [1]. Also, compared to other industrial sectors, the food industrial sector uses large volume of water as a raw material and for different purposes like cooling, cleaning, etc. [2, 3]. Food industry wastewater are characterized by different pH levels (highly acidic or alkaline), large amounts of suspended solids, oils and fats, phosphorus, chlorides and organic matters. The characteristics of wastewater generated from food processing industries are biodegradable [2, 4, 5].The tomato industry produces large amount of wastewater during the manufacturing process due to the consumption of large volume of water during the washing of raw material, cleaning machines and sorting. The generated industrial wastewater is characterized by a dark color and bad odor since it is heavily polluted by organics, suspended solids and ground particles [6].

Wastewater treatment and reuse for irrigation in water scarce countries is considered as the best alternative available water resource. Therefore, countries pay great efforts for reusing the treated wastewater [7, 8].

There are several treatment methods for wastewater that produced from food manufacturer's process including physical, chemical, and biological treatment methods. Previous studies reported that coagulation-flocculation treatment reduced 80% of organic load of cheese whey wastewater [9], also removal of 86% of the chemical oxygen demand from

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molasses wastewater [10] and 65% of COD removal from seafood processing industry wastewater [11]**.** Advanced oxidation processes (AOPs) treatment using Fenton's reagent were used to oxidize complex organic constituents that are difficult to degrade biologically into simpler end products, it was applied as efficient treatment for olive oil mill wastewater [12] and removal of up to 90% of chemical oxygen demand of olive oil mill wastewater was reported [13]**.** The biological aerobic and anaerobic treatment methods were reported as a pre-treatment for industrial wastewater discharged from a potato-chips factory and reduction of the organic load was achieved. It was also reported for wastewater treatment of flavor industry and dairy cheese whey industry [1, 14].

Integration of the different treatment processes has the advantage of producing treated water with chemical, physical and biological characteristics complying with the stringent regulatory standards for reuse in agriculture and in some cases reduces the treatment cost [15-18]. In Italy the biological treatment of wastewater was integrated with posterior disinfection (UV irradiation or peracetic acid addition) to produce water with physical, chemical and biological characteristics complying with the limits of agriculture reuse. The produced water quality was better than that produced from conventional biological treatment methods with E.coli content lower than (10 CFU/100 mL) [15]. The integrated treatment module of sequential photocatalytic oxidation-biological treatment was the most effective for pharmaceutical wastewater treatment with 90.5% and 80.8% removals of COD and BOD, respectively. While 46.2% and 46.3% removals of COD and BOD, respectively were obtained by using independent photocatalytic and biological processes. The results indicated that the integration had enhanced the biodegradability of the organic refractory compounds in wastewater [16]. Integration of the treatment by using photo-electro-Fenton as a pre-treatment step followed by biological oxidation processes had transformed recalcitrant compounds in a sanitary landfill leachate into more biodegradable substances (BOD_5/COD = 0.53) which enhanced the microbial activity in the biological oxidation [17]. Integrated simultaneous treatment process by using activated carbon adsorption and ozone treatment followed by biological treatment has shown a synergistic effect in the degradation of Ondansetron in synthetic wastewater with minimum consumption of chemicals and time. The Ondansetron removal percentage was observed to be 90% and the application of biological process reduced the treatment cost. Therefore the integrated treatment system proved to be more economic and efficient than the use of independent treatment processes [18].

Therefore, the aim of this study is to investigate suitable and efficient treatment modules for the wastewater generated from the sauces production factory in order to compliance with the Egyptian code for reuse.

Materials and Methods

The food processing factory under investigation is working in the manufacturing of ketchup, mayonnaise, mustard, and sauces production. The factory produces nearly 700 m^3/day wastewater with high pollution load. The samples were collected from the final end of pipe. Regular monitoring of the volume and characteristics of the wastewater generated from the factory was performed through the collection of composite samples from the effluent during different working days along four months. Characterization for these samples was done in the Reference Laboratory for Wastewater, Holding Company for Water and Wastewater according to the standard methods for examination of water and wastewater by analysis of pH, total dissolved solids (TDS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), settleable solids, oil-grease, total sulfides, total nitrogen (TN) and total phosphorous (TP) [19]**.** Also, different treatment processes were investigated as following:

1- Preliminary treatment via sedimentation was a necessary step in cases of wastewater of appreciable levels of readily settleable suspended solids. Before any type of treatment, the settleable solids in industrial wastewater were allowed to settle by gravity for 30 minutes [20, 21].

2- The Coagulation-Flocculation treatment was conducted using coagulants namely aluminum sulfate octadecahydrate (Alum) with the chemical formula $Al_2(SO_4)_3.18H_2O$ and polyaluminium chloride (PACL) $Al_{13}O_4(OH)_{24}(H_2O)_{12}^{7+}$ at different concentration ranges from 150-300 and 100-200 mg L^{-1}, respectively. The process was conducted for each coagulant using the Jar test apparatus to optimize the coagulant dose, suitable pH, and settling time. The optimum pH was 7 for alum and 8 for PACL. The wastewater was rapid mixed at 160 rpm for 2 minutes than reduced to 25 to 35 rpm slow mixing for 15 to 20 minutes. Finally, allowed to settle for 30 to 45 minutes [22, 23].

3- AOPs using Fenton's reagent was applied using the batch mode Jar test method at optimized conditions of initial pH 3, 1 g L^{-1} ferrous sulfate and 4 mL L^{-1} H_2O_2 and a reaction time 90 minutes. Then, the Fenton treated wastewater was coagulated using slurry of CaO to pH 9.

4- Biological aerobic treatment method was studied for the treatment of effluent. The aerobic activated sludge process was applied using the batch laboratory experiments using two-liter Plexiglas columns after acclimatization and adaptation periods up to 4 weeks. The industrial wastewater was inoculated with activated sludge. MLSS volumes that cover a range of (3– 4 g L^{-1}) were transferred to the different columns to which the industrial wastewater was added. The treatment was conducted at aeration time of 6-8 hours. Dissolved oxygen concentration was adjusted to maintain a minimum concentration of 2 mgO_2 L^{-1}. Characterization of the treated industrial wastewater was carried out after 60 min. settlement [23-25].

5- Sand filtration and granular activated carbon adsorption was applied by using rapid (Sand/GAC) packed columns of different designs that are presented in Figure (1), namely **SSFGAC**, **MLGACS** and **MLSGACS**. These column designs were tested to select the most effective one for polishing of biologically treated and chlorinated water for reuse in agriculture [21, 26-28]. The filtration columns design dimensions are listed in Table (1).

The proposed multistage treatment modules for the discharged wastewater from the factory are presented in Figure (2).

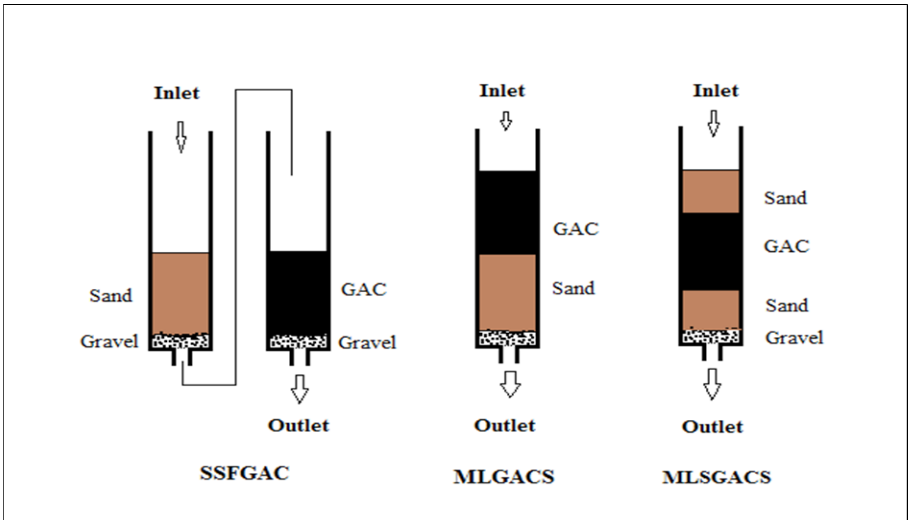

Fig.1. Different designs for multi stage filters.

TABLE 1. Dimensions of filtration columns

Design	Description
SSFGAC	Two 45 cm height PVC columns with 5.5 cm internal diameter, the first was packed by 3cm support gravel and 20 cm sand and the second packed by 3cm support gravel and 20cm GAC.
MLGACS	One 45 cm height PVC column with 5.5 cm internal diameter and packed by 3cm support gravel, 20cm sand and 20cm GAC.
MLSGACS	One 45 cm height PVC column with 5.5 cm internal diameter and packed by 3cm support gravel, 10cm sand, 20cm GAC then 10cm sand.

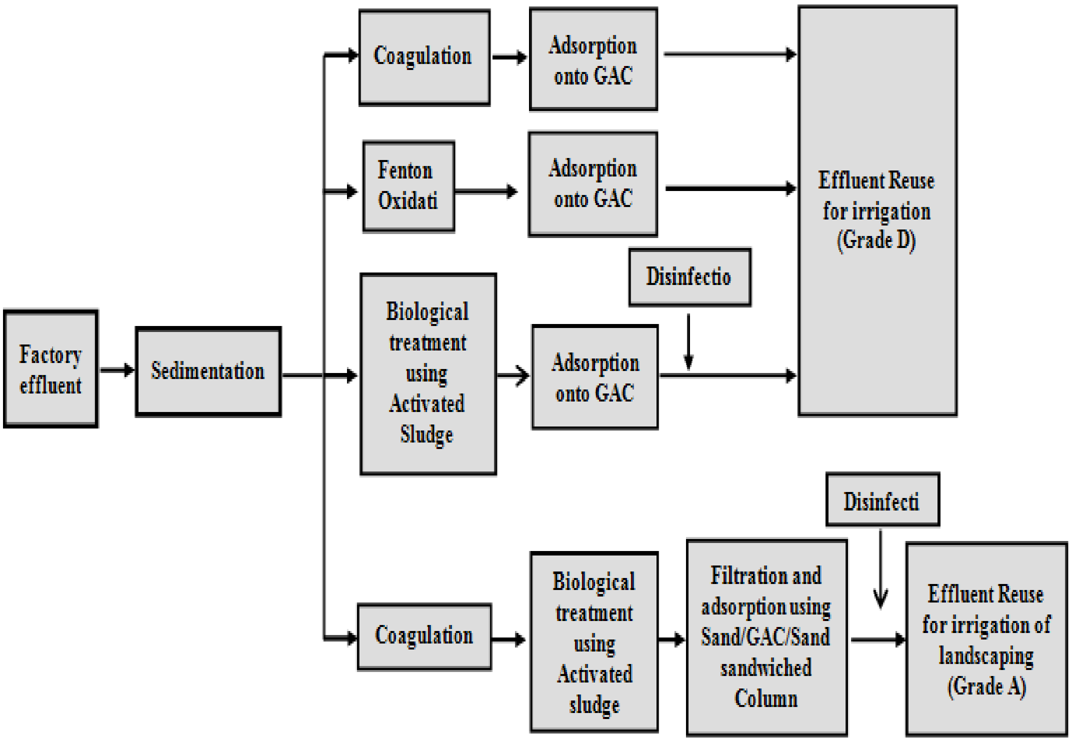

Fig.2. Proposed multistage treatment modules for the factory effluent.

Results and Discussion

Analytical Characterization of wastewater generated from the sauces production factory was performed and the results are listed in Table (2).The physicochemical analysis showed that the organic load of the effluent expressed by COD was ranged from 603 to 4950 mgO_2 L^{-1} with an average of 2457 mgO_2 L^{-1}. The biochemical oxygen demand concentration was ranged from 131 to 3130 mgO_2 L^{-1} with an average of 1447 mgO_2 L^{-1}. The pH in most of working days was highly acidic due to the use of acetic acid in the manufacturing process and the alkaline samples were due to clean in place (CIP) process. It was clear from the results that the average concentration of soluble chemical oxygen demand (CODs) was 1238mgO_2 L^{-1} representing 50.4% of the total COD which indicated that in some cases there was a necessity for additional treatment after the chemical treatment. Also the BOD: COD ratio of average 53% indicated the possibility of application of biological treatment for this effluent. In addition the volume of settleable solids was very high which reached to 58.6 mL L^{-1} because of the presence of product residuals in the effluent; this provides the need for sedimentation step before any treatment.

Preliminary sedimentation step:

The presence of solids in the factory effluent adversely affects the treatment efficiency and cost. This was obvious in the results that are presented in Figure (3) where the raw wastewater was treated through chemical coagulation by using aluminum sulphate before sedimentation and after sedimentation for 30 minutes. The results showed that the application of sedimentation step before coagulation removes about 11% of COD. This result may increase or decrease depending on the amount of readily settleable suspended solids by gravity that present in factory effluent. These results agree with that proved by El-Gohary et al [23] that sedimentation of potato chips factory effluent had reduced COD concentrations up to 48%. Therefore the primary sedimentation step was conducted before any treatment step.

TABLE 2. Physico-chemical characteristic of raw wastewater .

Parameters		Unit	Min	Max	Average.	Ministerial Decree 44/2000 for discharge
pH		-	4.5	12.5	6.27	6-9.5
TSS		mg L^{-1}	175	1250	578	800
TDS		mg L^{-1}	517	2980	1144	-
Settleable solids	10 min.	mL L^{-1}	0.1	120	32.7	8
	30 min.	mL L^{-1}	0.7	160	58.6	15
COD		mgO_2 L^{-1}	603	4950	2457	1100
CODs		mgO_2 L^{-1}	295	2233	1238	-
BOD		mgO_2 L^{-1}	131	3130	1447	600
Total Sulfides		mg L^{-1}	0.5	18	4.55	10
T.N		mg L^{-1}	18.8	58.7	41.37	100
T.P		mg L^{-1}	1.42	4.3	3.04	25
Oil and grease		mg L^{-1}	27	920	277	100

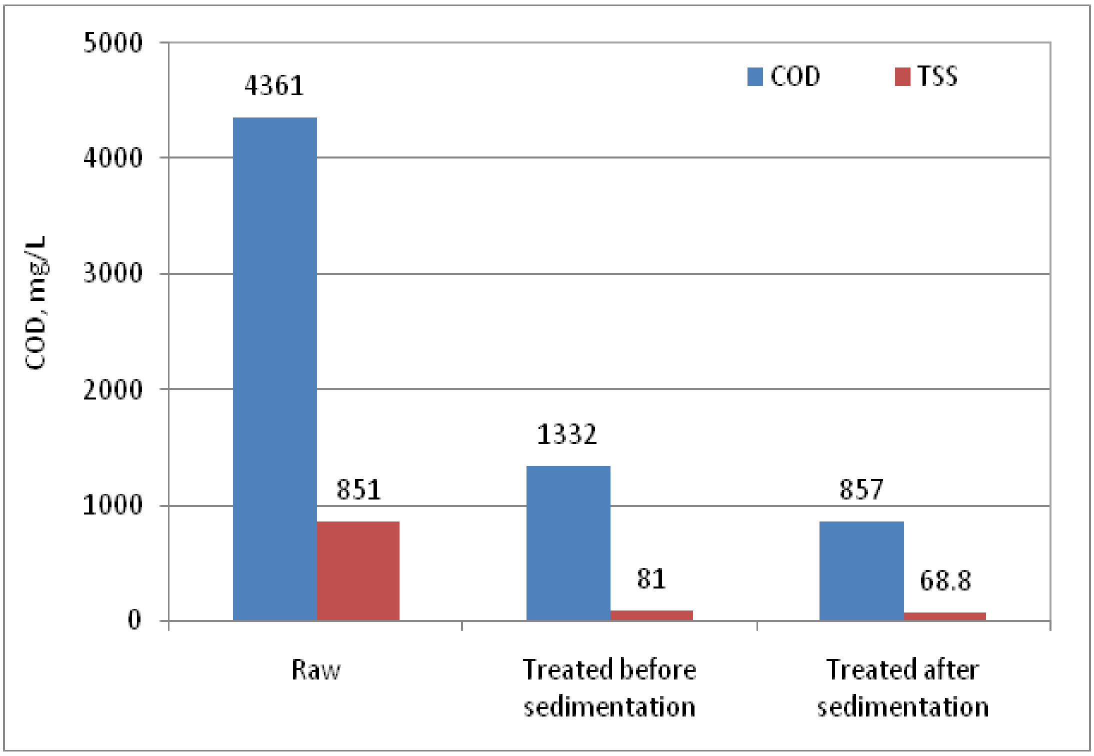

Fig.3. Effect of preliminary sedimentation on the coagulation efficiency.

Comparison between different treatment modules using Alum or PACL as Coagulants followed by adsorption onto GAC

The coagulation followed by settling was studied using Alum or PACL for the contamination reduction in the factory effluent as shown in Figure (4). The doses were ranged from 150-300mg L^{-1} for alum and 100-150 mg L^{-1} for PACL. The coagulation treatment achieved COD removal ranges of 37-72% using Alum and 38-74% using PACL. These results indicate that PACL is more efficient than Alum for removal of organic materials expressed by COD removals which are in agreement with Wong et al [29] who proved that PACL was more efficient than Alum for removing COD and achieved up to 96 % COD removal. As presented in the figure the treated samples need additional polishing through adsorption onto Granular Activated Carbon (GAC) column. The treatment module through coagulation followed by adsorption onto GAC achieved overall removals of 58-84% using Alum and 57-84% using PACL. The effectiveness of adsorption of organic materials by using GAC was found to be in agreement with Ademiluyi et al [30] who stated that the organic matter expressed as chemical oxygen demand (COD) was reduced from an initial value of 378 mgO_2 L^{-1} to 156 mgO_2 L^{-1} by using GAC.

The treated wastewater using (PACL followed by adsorption onto GAC) was of average residuals, 410 $mgO_2L^{-1}$for COD, 171 mgO_2 $L^{-1}$for BOD and 9.25 mg L^{-1} for TSS which was better than treated using Alum followed by adsorption onto GAC with average residuals of 437 mgO_2 L^{-1} for COD, 198 mgO_2 L^{-1} for BOD and 11.8 mg L^{-1} for TSS. The treated wastewater was suitable for irrigation reuse according to Egyptian Code 501/2015(Grade D).

Multistage treatment module using advanced oxidation using Fenton's reagent followed by adsorption onto GAC

This treatability study was carried out via chemical oxidation using Fenton's reagent at the optimized conditions. The characteristics of the effluent from advanced oxidation process are presented in Figure (5) with 85.5, 80.5 and 64% removals for COD, BOD, and TSS, respectively. The removal percent of COD is agreeing with that stated by Pala et al [31] who reported that Fenton oxidation of a baker's yeast industry effluent reached to 88% COD removal and is higher than the COD removal of 56.6 % that reported by Amaral-Silva et al [32] for the Fenton oxidation of winery industrial wastewater. To enhance the treated water quality for irrigation reuse, subsequent adsorption onto GAC column was applied to the Fenton effluent. The data which are shown in this figure represent a recommended multistage treatment module. The overall removal efficiencies using this multistage treatment module reached to 91, 93.5 and 92% for the COD, BOD and TSS, respectively. These removal efficiencies are better than those produced using coagulation followed by adsorption onto GAC. The effluent of this multistage treatment module is characterized by residual values of 74 mgO_2 L^{-1} BOD and 20mg L^{-1} TSS which is suitable for reuse in irrigation according to Egyptian Code 501/2015 (Grade D).

Multistage treatment module using Aerobic treatment followed by adsorption onto GAC

Commonly, biological treatment is suitable for the degradation of soluble biodegradable organic matters which are hardly removed by coagulation. The activated sludge, one of the most promising treatment methods was applied for the treatment of the final effluent after acclimatization and adaptation periods up to 4 weeks. The results of aerobic treatment for the Factory effluent after 6 hours aeration and 30 minutes settling are shown in Figure (6) that representing of 85.6%, 89% and 69 % removals for COD, BOD and TSS respectively. These results agree with that reported by El-Gohary et al [23] who proved that the aerobic treatment using the activated sludge for potato chips manufacture effluent achieved BOD removal of 91.4%. The treatment module using aerobic treatment followed by adsorption onto GAC achieved removal efficiency of 92, 96.2 and 94.6 % for COD, BOD and TSS, respectively. This treatment module achieved higher removal efficiencies with lower cost than either the chemical coagulation-GAC adsorption or the advanced oxidation-GAC adsorption treatment modules. The treated wastewater quality was adequate for irrigation reuse according to Egyptian Code 501/2015 (Grade D).

In order to produce treated water with quality adequate for reuse in agriculture or landscape irrigation (Grade A), this module was developed by applying the chemical treatment before the biological treatment step. The aeration time was increased from 6 to 8 hours and the GAC adsorption system was developed through the application of Sand/GAC/Sand sandwich column for Filtration/Adsorption as illustrated in the following section.

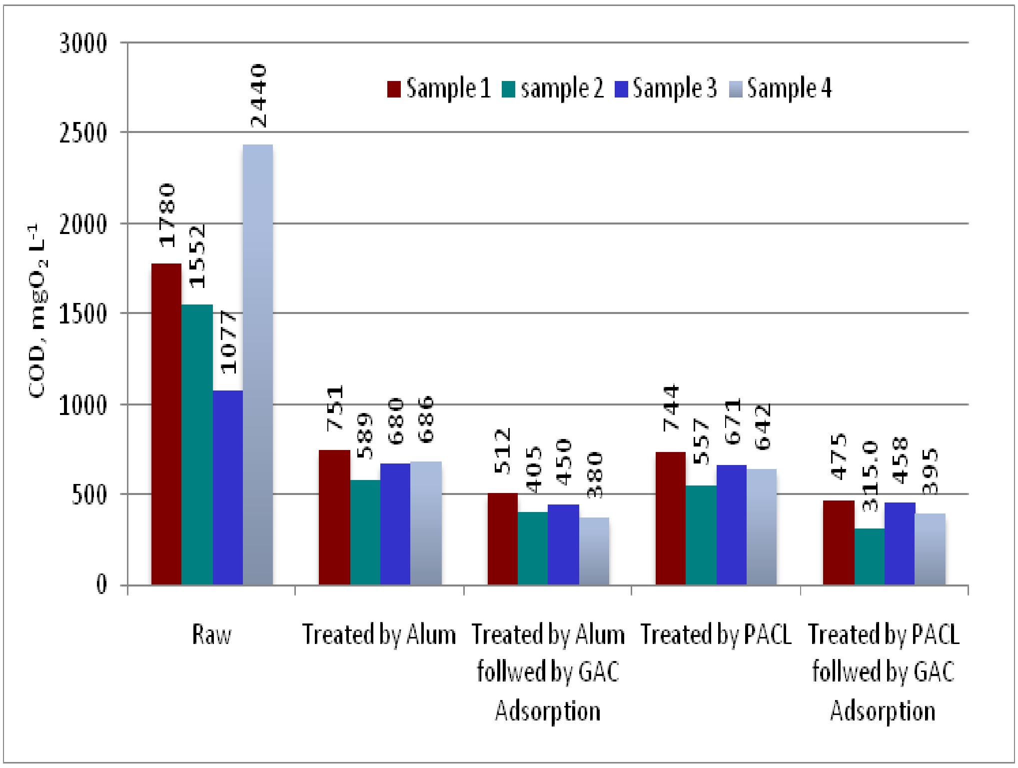

Fig.4. Comparison between different treatment modules using Alum or PACl as Coagulants followed by adsorption on GAC.

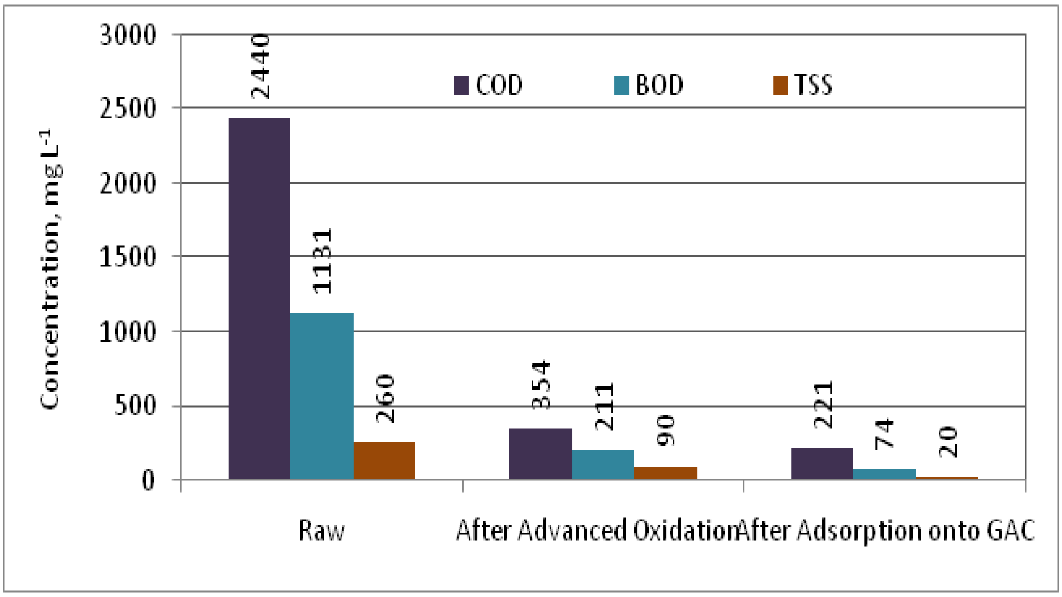

Fig.5. Removal of pollution indicators using advanced oxidation followed by adsorption on GAC.

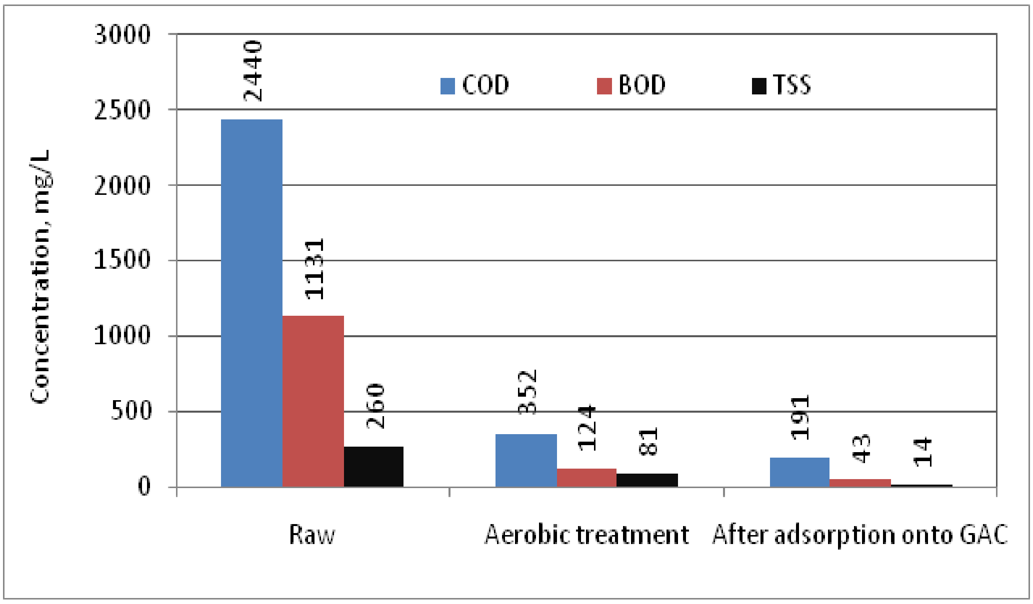

Fig.6. Multistage treatment module using Aerobic followed by adsorption on GAC.

Multistage treatment module using chemical coagulation followed by biological treatment; for landscape irrigation:

For reuse in landscape irrigation according to Egyptian code for reuse (Grade A), other set of samples were collected from the factory effluent with averages, COD of 4039 mg L^{-1}, BOD of 2453 mg L^{-1}, TSS of 1068 mg L^{-1} and Turbidity of 687 NTU. Multistage treatment module was applied through sedimentation followed by chemical coagulation using 200 mg L^{-1} PACL and settling for 30 minutes. Then the effluent from the coagulation process was treated using the aerobic activated sludge treatment. By using the aerobic treatment for 8 hours aeration and 30 minutes settling time, the removals achieved for COD, BOD and TSS were reached to 98.73%, 99.1% and 84%, respectively. Accordingly, analysis of the coagulation treatment effluent and the aerobic treatment effluent was carried out and the results are depicted in Table (3). By comparing these results of aerobic treatment with the results that are presented in Figure (6) it was clear that in addition to the increased aeration time, the application of the chemical coagulation using PACL reduced the organic load that entered the aeration system which in turn enhanced the removal efficiency of the aerobic treatment system.

The biologically treated wastewater was disinfected using calcium hypochlorite solution then subsequent filtration and adsorption through the use of different designs for rapid Sand/GAC packed columns namely **SSFGAC**, **MLGACS** and **MLSGACS** were tested to select the most effective one. The multilayer Sand/GAC/Sand sandwich column achieved the best removal efficiencies for COD, BOD, TSS and Turbidity as indicated in Figure (7). It was applied efficiently for the chlorinated effluent of the biologically treated wastewater and produced water quality that is in agreement with Egyptian Code 501/2015(Grade A) and is adequate for reuse in landscape irrigation [27, 28 and 34]. The removal efficiencies results that are presented in Figure (7) are agreeing with those reported by Jianan-Li et al [27] proved that the removal of COD reached to 65.8% by using 20 cm GAC sandwich filter.

Finally, the selected treatment module was sedimentation, chemical coagulation-flocculation **followed by a**erobic treatment then filtration (Sand/GAC/Sand). Treated wastewater was complying with the Egyptian code 501/2015for reuse in agriculture (Grade A) .The average removal efficiency of COD, BOD, Turbidity and TSS were 99.8, 99.8, 99.9, 99.7%, respectively (Table 4).

TABLE 3. Multistage treatment module using chemical coagulation followed by biological treatment.

Parameters	unit	Raw	Chemical coagulation effluent	Aerobic treatment Effluent	% Removal
Turbidity	**NTU**	687	110	18	83.6
COD	**mgO_2 L^{-1}**	4039	1587	20	98.73
BOD	**mgO_2 L^{-1}**	2453	895	8	99.1
TSS	**mg L^{-1}**	1068	108	17	84

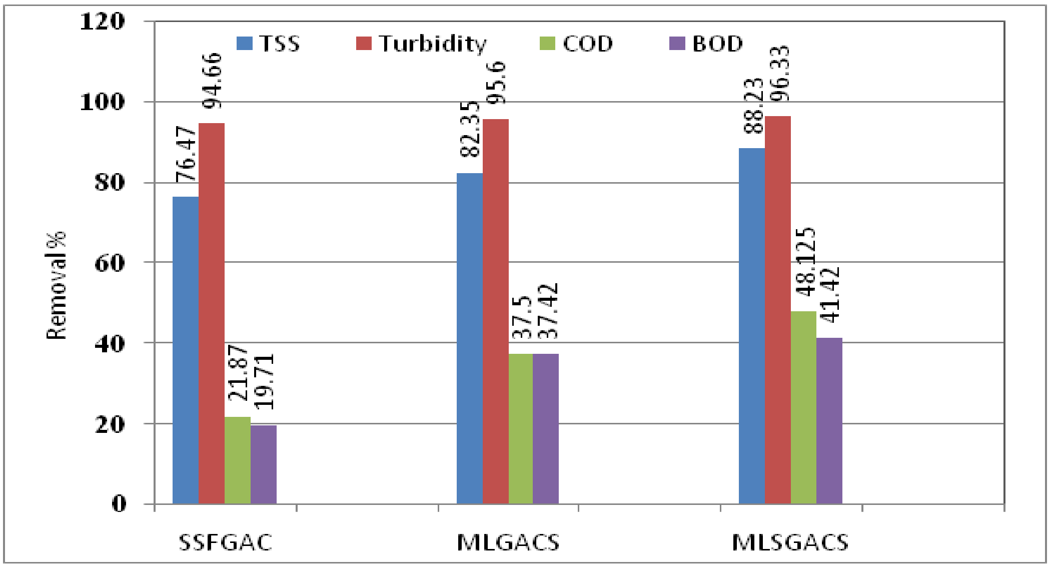

Fig.7. Comparison between removal efficiency for different designs of Filtration column.

TABLE 4. Physico-chemical characteristic of the selected multistage treatment module.

Parameters / Sample No.	Unit	Final Effluent*	Overall Removal %	Egyptian Code 501/2015 (Grade A)
pH	-	7.05	-	-
TSS	mg L^{-1}	3	99.7	**10**
Turbidity	NTU	0.65	99.9	**5**
COD	mgO_2 L^{-1}	8.5	99.8	-
BOD	mgO_2 L^{-1}	4.22	99.8	**10**
T.N	mg L^{-1}	4.6	89.7	-
T.P	mg L^{-1}	0.33	92	-
Oil and grease	mg L^{-1}	1.4	99.7	-
Fecal Coliform	Coliform / 100 mL	< 1.8	-	**100**
Intestinal Nematodes	Nematode / Liter	0	-	**1**

**Average of 4 treatment runs*

Economic Feasibility study

Feasibility study was conducted by estimating the capital expenditure (CAPEX) and operational expenditure (OPEX) for the recommended multistage treatment system for reuse in irrigation of landscape (grade A). The capital expenditure is the construction cost of the multistage wastewater treatment plant including the civil construction, mechanical equipment, electrical connections, piping, tanks and any other fixed assets required to produce acceptable treated wastewater quality and quantity which calculated to be about 1538 USD per one cubic meter of plant capacity. The operational expenditure is the operational cost of the treatment system including the cost of chemicals, electricity, adsorbent thermal regeneration, maintenance, replacements and operators salaries [35, 36]. In Egypt the drinking water tariff for industrial consumption is 0.55 USD /m^3 (0.28 USD /m^3 and 0.27 USD /m^3 for the cost of wastewater discharge into public sewage network) [37]. Therefore, the implementation of the proposed multistage treatment system is economically feasible and saves about 37% of the total water consumption cost.

Conclusion

The selection of the appropriate treatment method depends on the wastewater characteristics. The treatment module which produces (Grade D) treated water with characteristics suitable for reuse in irrigation or discharge into the public sewerage networks are including sedimentation followed by (coagulation, Fenton oxidation or aerobic treatment) then polishing through adsorption onto GAC column. While for wastewater reuse in agriculture or landscape irrigation, another integrated and economically feasible multistage treatment module consisting of sedimentation, coagulation using PACL, aerobic treatment, disinfection and finally (MLSGACS) column was used to produce (Grade A) treated water with average concentrations of 8.5 $mgO_2\ L^{-1}$ for COD, 4.22 $mgO_2\ L^{-1}$ for BOD and 3 $mg\ L^{-1}$ for TSS which are the best results obtained. The produced water quality using these modules was complying with the Egyptian code 501/2015 for reuse. Therefore the irrigation reuse of treated food industry wastewater can meet part of the water demand.

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إمكانيه معالجه مياه الصرف الصناعى الغذائى لإعاده الإستخدام

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هدفت هذه الدراسة إلى البحث عن تقنيه المعالجة الأكثر كفاءه لمياه الصرف الناتج من مصنع لإنتاج المواد الغذائيه لإعادة استخدامها وفقا للمعايير المصرية. وجد ان مياه صرف المصنع ملوثه بنسب عاليه من الحمل العضوي حيث أن الأكسجين الكيميائى المستهلك وصل الى ٤٩٥٠ مجم أكسجين/لتر. تم التحقيق في أربعة سيناريوهات للمعالجه لتحديد أنسب وحدة لإعادة الاستخدام. إستخدام وحدة المعالجة المكونه من التخثر والتلبد متبوعه بالإمتزاز على سطح الكربون المنشط الحبيبي حققت 84٪ إزالة كليه معبرا عنها بالأكسجين الكيميائى المستهلك. الأكسدة بالفنتون متبوعه بالإمتزاز على سطح الكربون المنشط الحبيبي حققت إزالة كليه ممثله بالأكسجين الكيميائى المستهلك تصل إلى ٩١ ٪. المعالجه الهوائيه متبوعه بالإمتزاز على سطح الكربون المنشط الحبيبي حققت إزالة كليه ممثله بالأكسجين الكيميائى المستهلك تصل إلى ٩٢ ٪. كانت جودة مياه الصرف المعالج باستخدام الوحدات السابقة أقل بكثير من القيم المطلوبة الواردة في الكود المصري لإعادة الإستخدام في الزراعة (درجه أ). دمج وحدات المعالجه المختلفه المدروسه فى صوره الترسيب ثم التخثر والتلبد الكيميائى متبوعه بالمعالجه الهوائيه ثم الامتزاز والترشيح بإستخدام الفلتر المكون من رمل/كربون منشط حبيبى/رمل أنتج نوعية المياه التي تتوافق مع الكود المصري لإعادة الاستخدام في الزراعة و حقق إزاله كليه ٩٩,٨ ٪ من الاكسجين الكيميائى المستهلك.