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Recycling Discharged Treated Wastewater from Dairy Factories for Industrial and Irrigation Purposes

Waleed M. Abood*, Dhafir F. Ali, Firas S. Abass, Baydaa M. Ali

Renewable Energy and Environment Research Center/ Corporation of Research & Industrial Development, Iraq

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Corresponding Author:
Waleed M. Abood
dr.waleedabood@gmail.com

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Abstract

The research aims to assess the input (raw water, RW) and output water (produced water, PW) specifications within the treatment unit of the Abu Ghraib dairy factory. The goal is to ensure that the output water aligns with Iraqi environmental standards outlined in Law 25 of 1967, addressing river water and discharged wastewater, and Law 3 of 2012, pertaining to the reuse of treated water for agricultural irrigation. Analysis of the provided PW samples indicates general adherence to approved specifications for chemical oxygen demand (COD), biological oxygen demand (BOD), acidity (pH), nitrate (NO_3), phosphates (PO_4), total dissolved solids (TDS), total suspended solids (S.S), chloride, and sodium adsorption rate. Effective removal of organic content is observed, with percentages ranging from 92% to 97% for COD and 92% to 97.8% for BOD across all samples. To enhance the treated water quality further, adsorption using activated carbon (AC) was implemented through a batch system involving 800 ml of PW and 2 gm of AC, with a variable time and an equilibrium period of 5 hours. Remarkably, this approach resulted in a 100% removal of both COD and BOD. Sodium absorption rate (SAR) values, before and after adsorption, were 4.7 and 4.86, respectively. In a continuous system using a fixed bed activated at different depths (10, 20, and 30 cm), maintaining a constant flow rate of 15 ml/min and an initial COD concentration of 75 ppm, breakthrough curve time and empty bed contact time increased proportionally with bed depth, showing the impact of this parameter on system performance.

1. Introduction

The discharging of industrial out water and high load domestic waste into the surface water changed the specifications of the water's quality and causes unhealthy drinking water. The expanded urbanization and industrial sectors altered the fresh water's quality and negative impact role in water by extensively increasing the rate of contamination content in the water bodies and resources [1].

The dairy products industry spends a huge volumes of water for its operation processes that generate the amount of output with high load pollution, which if not properly discharged or treated, can cause the serious impact of environmental pollution. The wastewater treatment costs and the limitations of environmental regulations have driven the industry to implement reuse systems. Treated reuse is a significant re-source however its quality must be fitted for reuse [2].

The organic content in untreated water as discharged from production processes differs according to the method and type of products. Usually, in the cheese production process, a high amount of carbohydrates and protein are found in the effluents [3], while in the manufacturing of ghee higher level of lipid is present in the effluent released [1]. The increase of cheese production in the industries gradually raises the dairy wastewater. Dairy industry consumes higher quantity of carbohydrates and proteins for the manufacturing and washing practices, further, dairy wastewater produced from these sectors is composed of higher fixation of nitrogen and other complex organic matter [4]. Basically, the dairy wastewater does not comprise of any highly toxic chemical substances as other industrial effluents. On the other hand, it is basically made up of a mixture of organic compounds such as lactose, whey proteins, nutrients and fats which causes bad odors and makes distress to the encompassing populace during its degradation stage. The flow rate and ingredients of the effluents are not constant and they tend to fluctuate based on the manufacturing and production process. The dairy wastewater is one of the wastewater with high amount of floated and dissolved organic like other food industry effluent. In specific it is characterized by its elevated levels of chemical oxygen demand (COD) and biological oxygen demand (BOD) which becomes a major problem to the water source into which this wastewater is discharged [1, 2]. The characteristics of the dairy effluents depend on the following features such as industrial scale, processing types, type of method, the efficiency of the method, process parameters, type of operation, selection of equipment for cleaning, type of waste discharged and cost required for treatment of wastewater [1, 5, 6]. Dairy industry contributes a major part in the production of a large volumes of industrial wastewater containing high organic load which cannot be eliminated easily [5].

In 2007 around 27.6 million tonnes of milk was delivered to milk-processing plants in Germany. In the dairy industry around 1- 2 m^3 of wastewater is created each day for each tonne of milk during its processing and in the production of a variety of milk products [7].

Dairy influent treatment is considered one of priority options in production process. Treatment systems are divided into 3 categories: primary, secondary, or tertiary, depending on their design, operation, and application [8]. In primary treatment systems, physical operations remove floatable and settleable solids. In secondary treatment systems, biological and chemical processes remove most of the organic matter in the waste water. In tertiary treatment systems, additional processes remove constituents not taken out by secondary treatment [6, 9].

Wastewater is reused as irrigation source in many ways [10]. It can be used as reclaimed water as treated water which is defined as "water that has received at least secondary treatment and basic disinfection and is reused after flowing out of a domestic wastewater treatment facility" [11] or non-treated (raw wastewater) and it can be applied directly to crops or indirectly after discharge and dilution with water from rivers or reservoirs. Sometimes reuse is part of a planned project, but most of the time -and particularly in developing countries- it just happens. In industrialized countries water reuse is part of a strategy to protect water bodies and to reduce wastewater treatment costs. It is usually performed only after high ecological standards of wastewater treatment have been achieved, and as a consequence reclaimed water has a low organic matter and nutrient content. In contrast, in developing countries reuse is frequently a spontaneous response to a shortage of water and job opportunities. It is generally practiced with "poor quality" water (even raw wastewater) [12].There are various water quality standards by different organizations. The US Regional Salinity Laboratory and Food and Agriculture Organization (FAO) have given the quality of irrigation water [13].

The aim of research is evaluation of characteristics of input and output waste water treatment unit and capability of treated water to match with recommended specification of irrigation water by evaluation of total dissolved solid TDS, electrical conductivity EC, chemical oxygen demand COD, biological oxygen demand BOD, nitrate NO3, phosphates PO, total suspended solid TSS, Chloride and sodium adsorption rate where bench scale unit of filtration and activated carbon is assembly for tertiary treatment for treated water to enhance produced water quality.

2. Experimental Procedure

2.1. Waste Water

Samples of raw water RW and produced water PW were sampled and tested which were done by environment department of factory to determine acidity pH, chemical oxygen demand COD, biological oxygen demand BOD, total dissolved solid TDS, suspended solid SS, phosphate PO_4,nitrate NO_3 and Chloride Cl^- of influent and effluent of Abu Graib dairy factory/ general company of food stuff/ Iraqi ministry of industry and minerals as Table (2) shows recommended standard methods of testing, where treatment unit with capacity of 240 M^3/hour which consist of different processes as balance tank, polyelectrolyte addition tank, air flotation tank, aeration tank1, clarifier tank 1, aeration tank 2, clarifier tank 2, recycled activated sludge unit and final storage tank with chlorination addition. Sodium adsorption rate SAR had been calculated for effluent stream and recycled water as a result of sodium, magnesium and potassium concentration by testing with Atomic absorption spectrophotometer AAS type according to equation (1) [14]. Where SAR is dimensionless and Na, Ca and Mg at mg/l(ppm).

$$SAR = \sqrt{\frac{Na}{\frac{Ca+Mg}{2}}} \qquad (1)$$

2.2. Filtration and Adsorption Unit

Bench scale unit was applied to retreatment of effluent of dairy factory treatment unit as tertiary treatment for improving the waste water quality where the this bench scale unit consist of treated waste water plastic storage tank of 10 litre with submerge pump and polypropylene filter package 5 micrometer, plastic feed tank of 10 litter and fixed bed granular activated carbon column with 0.5 m length and 0.5 inch diameter. Activated carbon AC was supplied locally with surface area911m^2g^{-1}, particle size (0.05-0.075)cm, bulk density711 kg/m^3 [15].

2.3. Laboratory Experiments

2.3.1. Batch Adsorption Experiment

Batch experiment of adsorption shown in Figure (1) was carried out by adding 2 g of activated carbon AC to 800 ml waste water in baker of 1 litre where the mixing at 250 rpm in room temperature using magnetic stirrer, the sampling at interval time (15, 30, 60,120, 180 and 240) min after filtration were achieved to assessment COD, BOD.

Figure (1): Batch experiment at contact time.

2.3.2. Fixed Bed Adsorption Experiment

Continuous fixed bed activated carbon runs Figure (2) were achieved at bed depth (10, 20, and 30) cm with constant flow rate 15 ml/min as recommended value [16] and waste water characteristics. The waste water was pumped from storage tank towards filter then to feed tank where the waste water was regulated to stream down to fixed bed column through activated carbon bed which fixed by mesh layer up and bottom of bed. Sampling of drain was done at interval time (15, 30, 60, 120, 180, 240, 300, and 360) min to assessment COD and BOD.

Figure (2): Filtration and carbon fixed bed column of treatment.

2.3.3. Experimental Tests Methods

Water tests were done according to standard methods as shown below:

- COD test: titration method ASTM D1252-06 2011.
- BOD test: Dissolved oxygen meter method ASTM D888-12-2012.
- pH test: pH meter ASTM D 1293-1999.
- $NO3^{-1}$ test: Optical method UV spectrophotometer ASTM D3867-09-2005.
- $PO4^{-3}$ test: Optical method UV spectrophotometer ASTM D6501-15-2015.
- TDS test: TDS meter ASTM D5907 -13-2013.
- SS test: weight method ASTM D5907-10-2011.
- Cl^{-1} test: titration methods ASTM D512-12-2012.
- Na, Ca, Mg tests: Atomic absorption spectrophotometer ASTM D3561-11-2011.

3. Results and Discussion

3.1. Assessment of Raw and Produced Water for Treatment Unit

Table (1) shows specifications of influent (raw water RW) and effluent (produced water PW) during testing monthly of dairy factory's treatment unit of as a primary and secondary treatment.

Table (1): Characteristics of raw water produced water of treatment unit.

Samples	COD ppm		BOD ppm		pH		NO_3^- ppm		PO_4ppm		TDSppm		S.S ppm		Cl^{-1} ppm	
item	RW	PW	RW	PW	RW	PW	RW	PW	RW	PW	RW	PW	RW	PW	RW	PW
S1 21/1/2022	370	30	217	17	6.8	7.5	25	7.5	5	2	1260	1185	250	65	240	28
S 2 24/4/2022	1550	40	1200	25	7.1	8.4	20	4	4	2	1300	950	250	50	230	136
S 3 21/5/2022	380	25	217	16	6.5	8	16	4	4	1.5	1265	1100	125	53	270	25
S 4 21/6/2022	300	30	210	20	6.85	7.75	21	14.3	10	4	1300	1045	180	40	220	41
Standard Value*		100		40		6.5-9		50		3	-	------		60		600

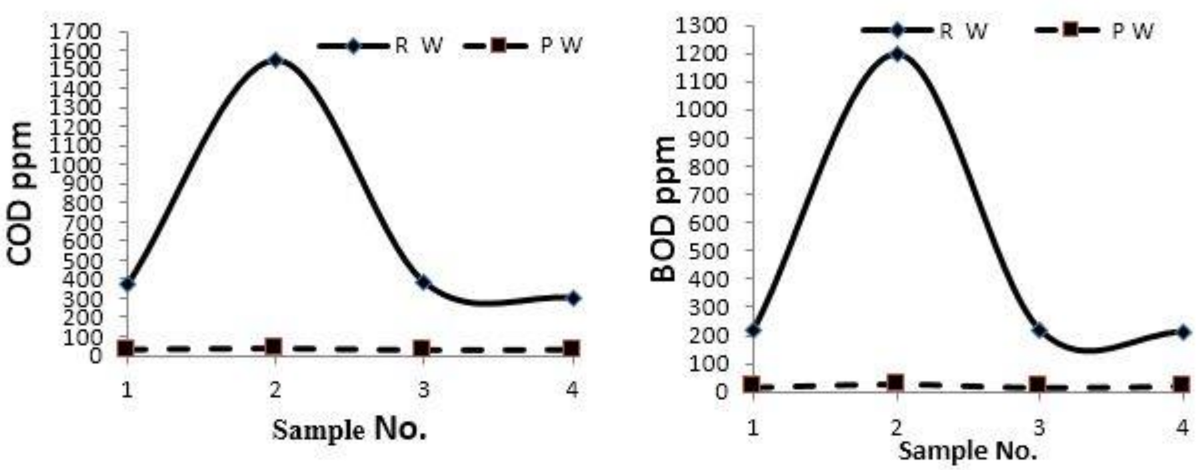
*Standard value according to Iraqi law No.25 /1967 of recommended discharging of treated water to rivers, lakes and marshes.

Figures (3 a-h) show the water test's results of RW and PW for COD, BOD, pH, $NO3^{-1}$, $PO4^{-3}$, TDS, SS and Cl^{-1} respectively. Where Figures (3a, b) show acceptable COD and BOD for PW even there high value for S2 RW

(1550 and 1200) ppm respectively due increasing in dairy production during April when fasting month (Ramadan) but still the value of PW results were in range of recommended values less 100 ppm for COD and 40 ppm for BOD with good matching with limitation of law 25/1967, BOD/COD ratio where (0.58,0.77,0.57andd 0.7) for RW and (0.57m 0.625, 0.64 and 0.66) for PW of S1, S2,S3and S4 respectively which refers to acceptable option of biological treatment for this type of waste water[17]. The recorded results show removal efficiency (92, 97, 93 and 9)% for COD and (92, 97.8, 92 and 90) % for BOD of all samples respectively.

$$\boldsymbol{Removal\% = \frac{Ci-Cf}{Ci} 100} \qquad (2)$$

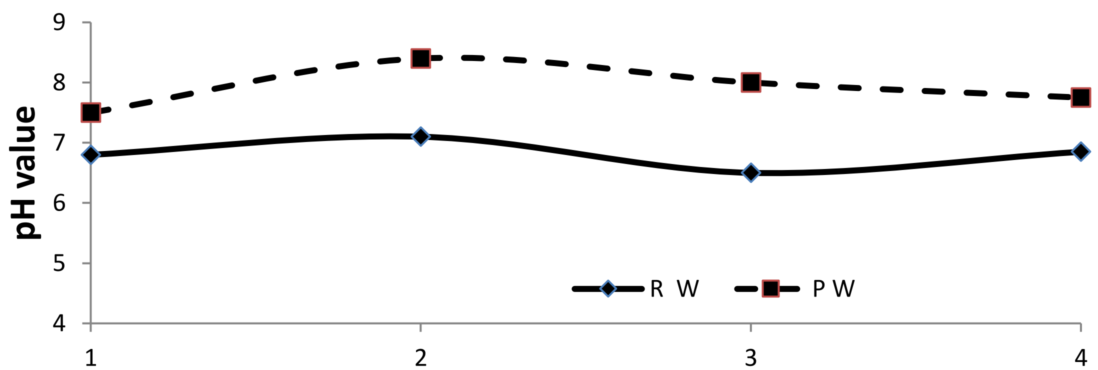
Where Ci is initial concentration of RW for BOD or COD and Cf final concentration of PW of BOD or COD (mg/l).



(a) **(b)**

Figure (3): (a): COD and (b): BOD tests for raw water (RW) and produced water (PW).

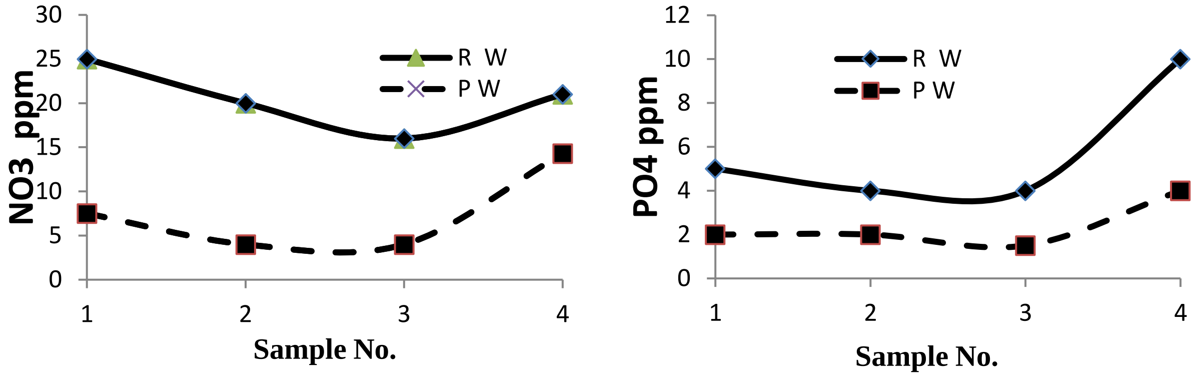
pH values of PW for all samples shown in Figure (3c) illustrates acceptable value of limited pH value (6.5-9) where no addition of any material the cause over rang of recommended values according to limitation of Iraqi law No.25/1967.



Sample No.

Figure (3 c): pH values for raw water RW and produced water.

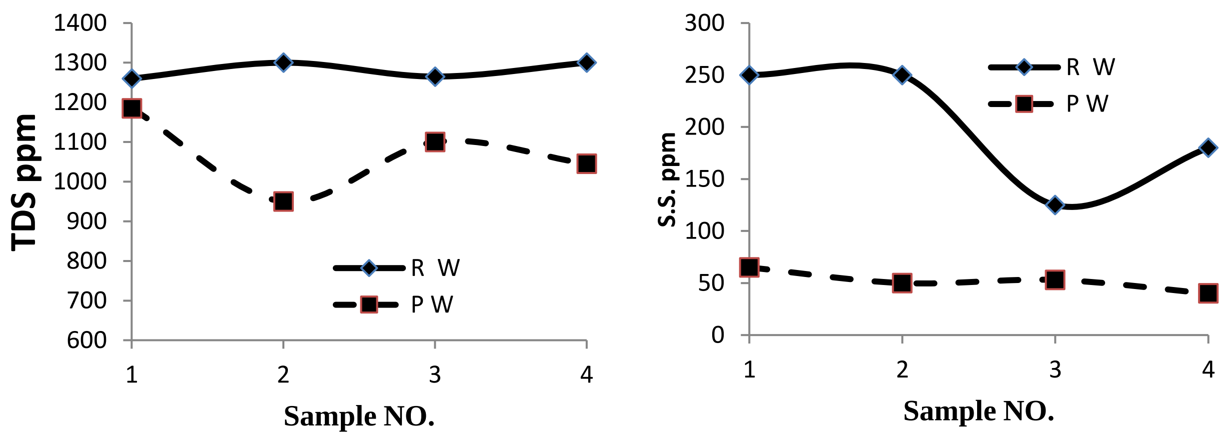
For Nitrate $NO3^{-1}$ and Phosphate $PO4^{-3}$ as nutrients as shown in Figures (3d & e) where all results are involved into the recommended concentration 50 ppm for $NO3^{-1}$and 3 for $PO4^{-3}$ of law 25/1967 even there are values out of range slightly for phosphate of S3 and S4.



(d) (e)

Figure (3 d-e): $NO3^{-1}$ and $PO4^{-3}$ tests for raw water RW and produced water.

TDS values shown in Figure (3f) illustrates a slight decrease in RW (1260, 1300, 1265, and 1300) ppm and PW (1185, 950, 1100, and 1045) ppm for S1, S2, S3, and S4 respectively which are ranged with recommended characteristics of dairy effluent waste water[18], while concentrations of total suspended solid S.S at Figure (3g) show less than 60 ppm except for S1 was 65 ppm which is considered near to the acceptable value according to law 25/1967 as discharged treated water.



(f) (g)

Figure (3 f-g): TDS and S.S tests for raw water RW and produced water.

Chlorides Cl^{-1} values are 240ppm, 230ppm, 270ppm, and 220 ppm for RW and 28ppm, 136ppm, 25ppm, and 41ppm for PW as shown in Figure (3h), where both results are under limitation of law 25/1967 which refers to 600 ppm as standard value of discharging.

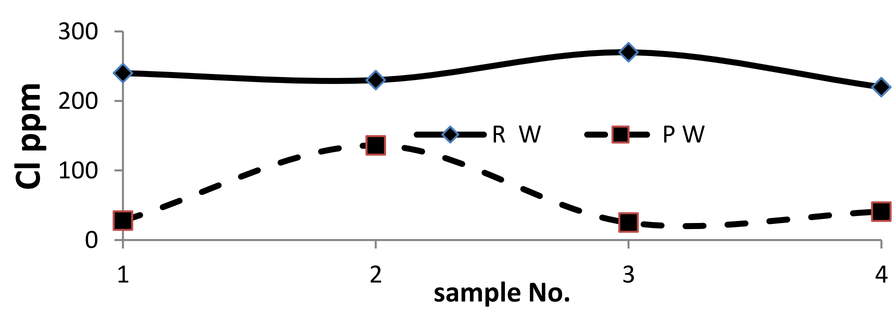


Figure (3h): Chloride Cl^{-1} test for raw water RW and produced water.

Validity of produced water PW for irrigation purpose according to Iraqi law No. 3/2012 of national limitations of using treated water in agricultural irrigation, table (2) shows some of recommended tests value for acceptance the treated water as irrigation source.

Table (2): Limitation of treated water quality for agricultural irrigation Iraqi law 3/2012.

Test item	Units	Treated water after secondary treatment	Treated water after tertiary treatment
COD	ppm	100	40
BOD	ppm	40	10
pH		6-8	6-8
TDS	ppm	2500	3500
SS	ppm	40	10
NO_3^{-1}	ppm	50	50
PO_4^{-3}	ppm	25	12
Sodium Na	ppm	250	230
Calcium Ca	ppm	450	400
Magnesium mg	ppm	80	60
Sodium adsorption rate SAR		6-9	<6

The recorded results at table (1) for PW show good fitting with limitation of law 3/2012 table (4) except S.S values for S1, S2, and S3 which refers to provide filtration process.

3.2. Adsorption Experiments

For more improving the quality of reusing treated water according to Iraqi law 3/2012, sample S5 was supplied for application of tertiary treatment.

Characteristics of supplied sample S5 RW were COD 75 ppm, BOD 30 ppm, pH 7.2, $NO3^{-1}$ 45ppm, $PO4^{-3}$ 3 ppm, TDS 850 ppm, SS 55 ppm, Na 200 ppm, Ca 60 ppm and Mg 25ppm where SAR according to equation (1) equal to 4.7 which in range of law 3/2012 and matching with previous works [13].

3.3. Adsorption at Batch System

Figure (4) shows value of COD of S5 at batch process at different time until equilibrium after 5 hour contact time where results show 100% removal and all samples were filtrate to improve 100% S.S removal where table (3) shows other tests after equilibrium which show good fitting with limitation of Iraqi law 3/2012 and recommended limitation in world [19] [20].

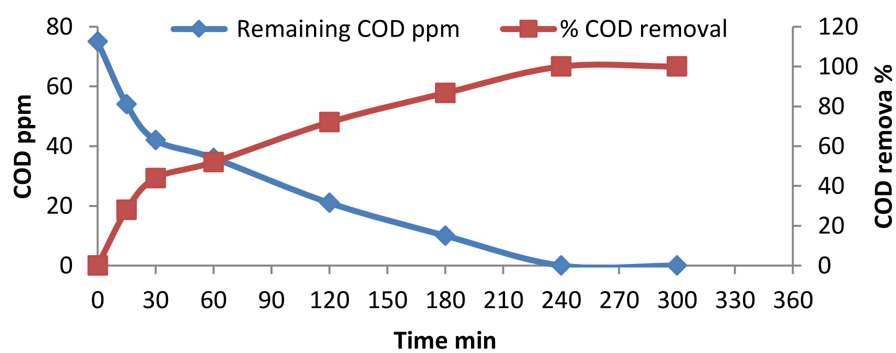


Figure (4): Effect of contact time during COD removal at initial concentration 75 ppm, 2 gm activated carbon and speed 250 rpm at room temperature.

Table (3): Tests of treated water S5 before and after adsorption at batch system with AC.

sample	COD ppm	BOD ppm	pH	TDS ppm	NO_3^{-1} Ppm	PO_4^{-3} ppm	SS ppm	Na ppm	Ca Ppm	Mg ppm	SAR
S5 before adsorption	75	30	7.2	850	45	3	55	200	60	25	4.7
S5 after 5 hr adsorption	nil	nil	7.8	715	35	2	nil	192	56	23	4.86

3.4. Adsorption at Continuous System

Effect of bed depth BD during adsorption with continues process at AC fixed bed as shown in table (4),% COD removal was estimated.

Table (4): Adsorption results of S5 during continues process at different bed depth.

Time min	Bed depth B D 10 cm			Bed depth B D 20 cm			Bed depth B D 30 cm		
	Remaining COD (Ct) ppm	% removal	Ct/Ci	Remaining COD (Ct) ppm	% removal	Ct/Ci	Remaining COD (Ct) ppm	% removal	Ct/Ci
0	0	100	0	0	100	0	0	100	0
15	0	100	0	0	100	0	0	100	0
30	0	100	0	0	100	0	0	100	0
60	15	80	0.2	0	100	0	0	100	0
120	36	52	0.48	10	86.67	0.133	0	100	0
180	58	22.67	0.773	20	73.33	0.267	10	86.67	0.133
240	72	4	0.96	34	54.67	0.453	18	76	0.24
300	74	1.33	0.987	56	25.3	0.747	35	53.33	0.467
360	74	1.33	0.987	68	9.3	0.907	50	33.33	0.667
420	75	0	1	72	4	0.96	63	16	0.84

Figure (5) shows curves of relation between time and Ct/Ci to explain break through curve which represent (Ct/Co=0.1) where break through curve time show increasing with value (40, 90 and 150) min approximately and empty bed contact time EBCT as shown in equation (3) where increasing of EBCT values (49, 98 and 147) sec with increasing bed depth (10, 20 and 30) cm at constant flow rate (15)ml/min due to increasing bed depth will lead to increasing mass of AC and provide more adsorption site that available for COD removal which matching with conclusions of previous works [15].

$$EBCT = \frac{Vb}{Q} \quad (3)$$

Where: Vb is bed volume cm^3, equals to $(\text{column radius})^2 \times 3.14 \times$ bed depth, and Q is flow rate (ml/min).

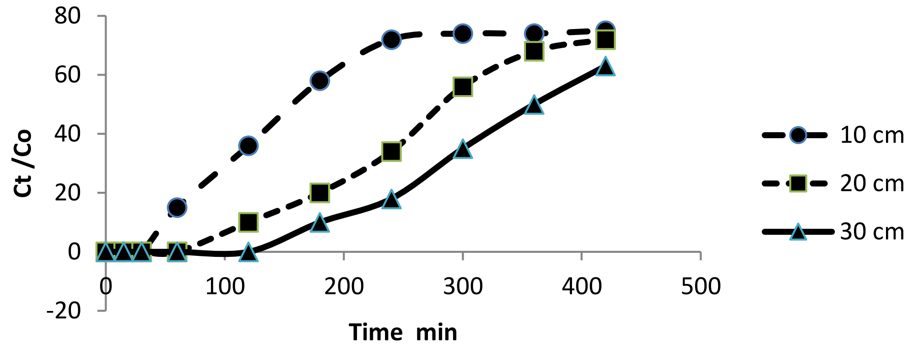


Figure (5): Breakthrough curves for COD removal of S5 at different bed depth in fixed bed AC column.

4. Conclusions

All effluent samples of produced water PW S1, S2, S3, and S4 from dairy factory treatment plant are fitted approximately with limitations of discharged water according to Iraqi law 25/1967 and reusing treated water as irrigation source according to Iraqi law 3/2012 with removal efficiency > 90 for COD and BOD and accepted values for pH, $NO3^{-1}$, $PO4^{-3}$, TDS, SS and Cl^{-1}respectively. Tertiary treatment in batch system by adsorption with activated carbon for improving quality of treated water with 100% removal for both COD and BOD with acceptable SAR value (4.7 and 4.86) before and after adsorption respectively. Adsorption in continuous system using fixed bed column at different bed depth, where break through point and empty bed contact time increase with increasing of bed depth.

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