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DEVELOPING AND UPGRADING CONVENTIONAL AERATION WWTP USING STEP-FEED TECHNIQUE

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الملخص العربي :

توسعت أعمال إمدادات المياه في مصر في السنوات القليلة الماضية بشكل كبير، ولكن على النقيض، لم تتوسع معالجة مياه الصرف الصحي كما توسعت أعمال إمدادات المياه، حيث معظم المناطق الريفية في مصر ليس لديها مرافق معالجة الصرف الصحي مقارنة بالمناطق الحضرية، وهذا النقص في المرافق يتسبب بمشاكل كبيرة لمصر على المستويات الاقتصادية والبيئية والفردية، خاصة لأن النمو السكاني في مصر سريع للغاية.

لإيجاد حل لهذه المشكلة وبسرعة، بدلاً من إنشاء محطات معالجة مياه صرف صحي جديدة في كل قرية، يمكن أن تعمل محطات المعالجة في المدن كمحطات معالجة مركزية للمناطق المحيطة، مما يزيد من الحاجة إلى تحسين قدرات محطات المعالجة القائمة، ويمكن القيام بذلك بإحدى الطريقتين؛ إما التوسع الأفقي عن طريق بناء وحدات جديدة أو التوسع الرأسي عن طريق إعادة تأهيل وتحديث الوحدات القائمة.

التوسع الأفقي يستهلك وقت كبير ومكلف للغاية بسبب ارتفاع أسعار الأراضي وخاصة في المناطق الزراعية، هذا يقودنا إلى البديل الاخر وهو التوسع الرأسي وذلك باستخدام نفس الوحدات القائمة لأن العمر الافتراضي للمنشآت المدنية كبير جدًا ويتراوح من 3 إلى 4 مرات العمر الافتراضي للمهمات الميكانيكية.

يتم عمل التوسع الرأسي باستخدام نفس المنشآت المدنية من خلال تطبيق التقنيات العلمية الجديدة لتحويل نظام المعالجة من الحمأة النشطة التقليدية إلى تقنية أخرى.

طبقت دراستنا إحدى تقنيات التطوير وهي نظام التغذية المرحلية إلى جانب النظام التقليدي لزيادة طاقة المحطة وبأقل تكلفة ممكنة، تم إجراء الدراسة على جهاز معملي أقيم في محطة معالجة صرف صحي البركة بالقاهرة، ونتج عن هذه التجربة أن هذا النظام (التغذية المرحلية) يستطيع زيادة الطاقة الاستيعابية للمحطة التي تعمل بالنظام التقليدي بنسبة 300٪ مع الحفاظ على تحقيق الكفاءة المطلوبة.

ABSTRACT:

In Egypt, water supply works has expanded dramatically in the last few years. Sewage treatment, on the other hand, did not expanded as the water supply works did. Most of the rural areas in Egypt do not have sewage treatment facilities compared to the urban areas. The lack of these facilities is causing significant problems for Egypt at the economic,

environmental and individual levels. Specially, because the population growth in Egypt is very rapid.

In order to solve this problem fast, instead of constructing new wastewater treatment plants (WWTPs) in each village. The treatment plants of the cities can work as central sewage treatment plants for the surrounding areas, that raises the need to upgrade the capacities of the existing treatment plants, and it can be done by either two ways; horizontal expansion by building new units or vertical expansion by rehabilitating and upgrading the existing ones.

The horizontal expansion is time consuming and very expensive due to the rising land prices specially in agricultural zones. This leads to vertical expansion instead because the civil work life times is very large and it is 3 to 4 time the life time of the mechanical equipment.

Vertical expansion will be done using the same civil work by applying the new scientific techniques developments to convert the conventional technique into another technique.

Our study applied one of these development techniques (Step-feed) beside the conventional technique to increase the plant capacity technically and with minimum cost. The study was done on a lab-scale pilot erected in ALBERKA WWTP, Cairo and resulted that the step-feed achieved increase in the capacity by 300% with the same efficiency.

KEY WORDS

Wastewater treatment, Activated Sludge, CAS, Step-feed, WWTP, Development, Upgrading, Rehabilitation.

INTRODUCTION

Wastewater treatment is the process of removing pollutants from wastewater to make it harmless and suitable to be reused or discharged back into the environment.

It’s formed by a number of activities including bathing, washing, using the toilet, and rainwater runoff. Wastewater is full of contaminants including bacteria, chemicals and other toxins. Its treatment aims at reducing the contaminants to acceptable levels to make the water safe for discharge back into the environment **[1]**.

The basic function of wastewater treatment is to speed up the natural processes by which water is purified. The treatment procedure of wastewater depends on the type of wastewater to be treated and the application in which the treated wastewater will be used in, when it is about domestic wastewater; the constituents is mainly suspended solids and organic matter either in the suspended or the dissolved state **[1]**.

CONVENTIONAL ACTIVATED SLUDGE SYSTEM

Conventional Activated Sludge (CAS) System is a commonly used system, the first step of a CAS system is the aeration tank, where the wastewater is mixed with air to activate micro-organisms. While digesting the wastewater, the organisms collide with each other, forming larger particles called flocs, which have a larger capacity to degrade the biological components of the wastewater **[2]**.

The aeration basin is followed by a secondary clarifier or settling tank. During this step, micro-organisms with their adsorbed organic material settle.

Water from the clarifier is transported to installations for disinfection and final discharge or to other tertiary treatment units for further purification.

The surplus micro-organisms can easily be channeled to any of sludge treatment solutions.

Another part of the micro-organisms is fed back into the aeration tank in order to keep the load of micro-organisms at a sufficient level for the biological degrading processes to continue **[2]**.

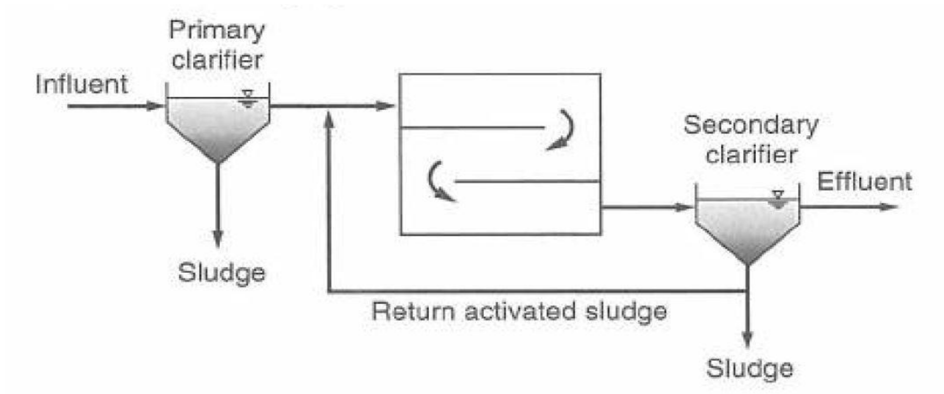

Figure (1) Conventional Activated Sludge

STEP-FEED SYSTEM

Step feed is a modification of the conventional plug flow process in which the settled wastewater is introduced at 3 to 4 feed points in the aeration tank to equalize the F/M ratio, thus lowering peak oxygen demand. Generally, three or more parallel channels are used. Flexibility of operation is one of the important features of this process because the apportionment of the wastewater feed can be changed to suit operating conditions. The concentrations of MLSS may be as high as 5000 to 9000 mg/L in the first pass, with lower concentrations in subsequent passes as more influent feed is added. The step feed process has the capability of carrying a higher solids inventory, and, thus, a higher SRT for the same volume as a conventional plug flow process **[2]**.

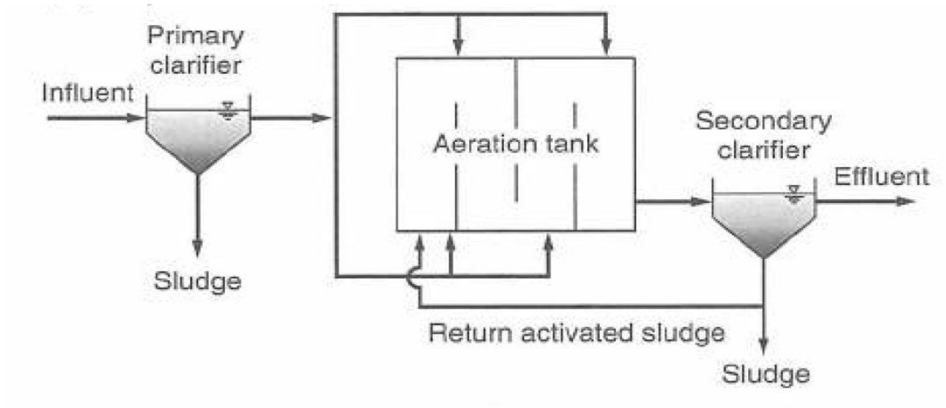

Figure (2) Step Feed

MATERIALS AND METHODS

The Study was conducted in order to determine the most appropriate technique from both a technical and a financial point of view to upgrade conventional aeration units in wastewater treatment plants with minimum civil works as much as possible.

To achieve that, a lab experiment applied on a lab scale pilot has been made, this study took place at ALBERKA WWTP, and a primary treated wastewater (After the primary sedimentation tanks) has been used for the lab experiment.

Analysis of samples were conducted in the laboratory of the ALBERKA WWTP.

PILOT DESCRIPTION

The Pilot was made from acrylic glass and it consisted of 2 streams that work in parallel, each stream has the same volume and same dimensions.

The following is an illustration for the wastewater path through the pilot:

- Wastewater is fed into the pilot system from a tank used to store primary treated wastewater.
- The wastewater moves through pipes to a channel prior to aeration tanks of each stream
- The flow is adjusted to 200 liter/day (50 liter/day for each stream) through valves at the entrance of the channel
- The tanks dimensions were designed on the average design criteria
- The wastewater then enters the aeration tanks through weirs and the retention time in this tank is approximately 7 hours
- The aeration is done through perforated pipes fixed at the bed of the tank and the holes was placed at equal spacing along the tank (every 2 cm)
- After the aeration tank, the wastewater then enters the final sedimentation tank where it stays for 2 hours before it exits through a weir at the end

- The sludge in the final sedimentation tank is pumped by dosing pump in the aeration tank with discharge equals to 50% of the design discharge (25 liter/day/tank)

In order to develop the currently 2 streams of conventional activated sludge tanks, a modification has been made to one of the streams therefore the streams will work as a step-feed aeration tank and CAS system.

- **Step-Feed Aeration Tank:** The aeration tank inlet is modified so that the wastewater enters the tank through several points along the length of the tank (at the beginning and at 8 cm, 16 cm and 24 cm) rather than at the beginning only.

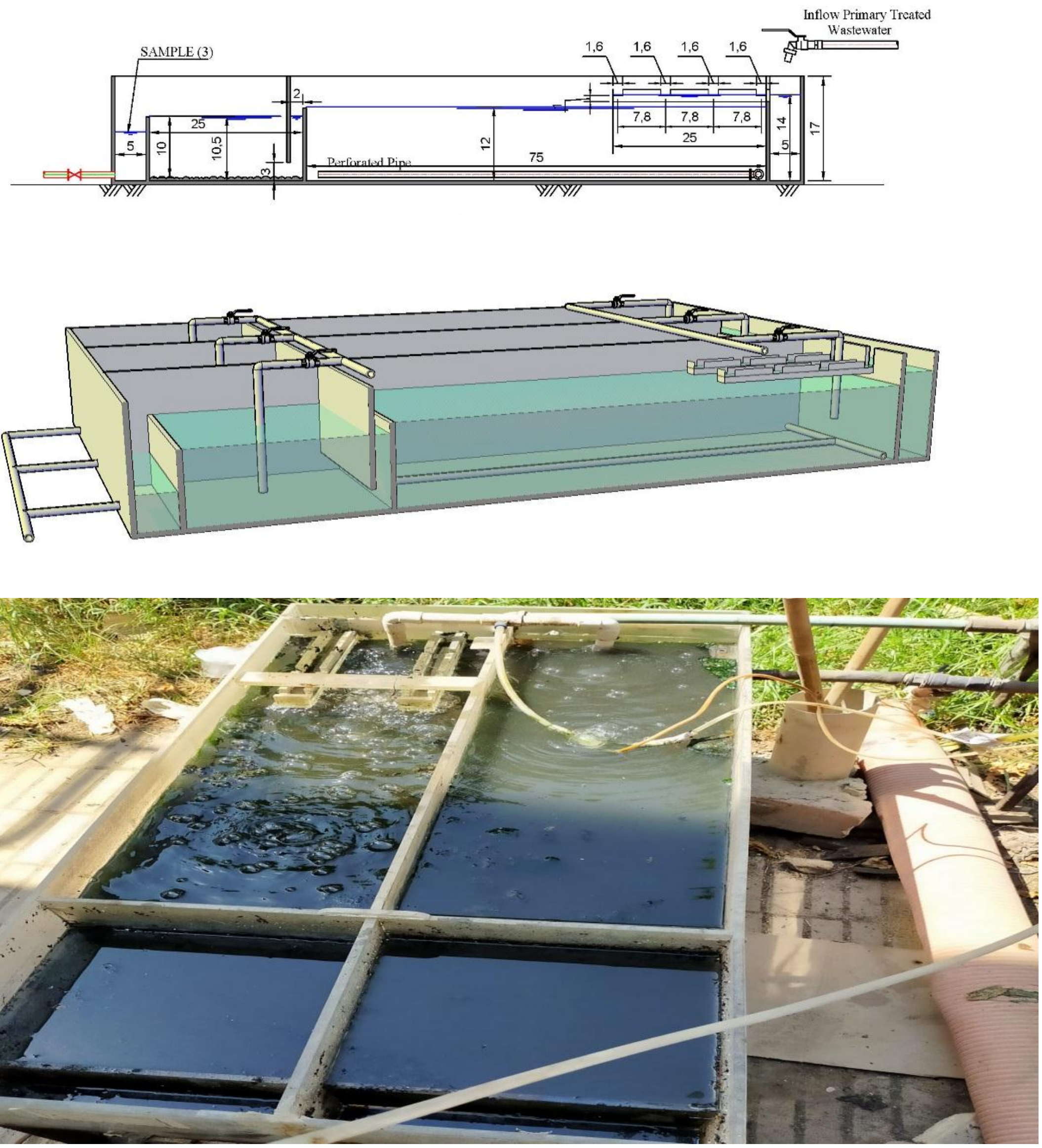

Figure (3) Pilot setup

In this phase, five different runs were done, each run extended for four weeks (twenty weeks total) and the flow was increased by 50 liter/day/stream each run, and samples was taken to determine the capacity of each system and to evaluate how much increase in the discharge that each system can handle according to Egyptian law 48/1982 as it shown in table (1).

Table (1) Description of the runs

Run	Description
(1)	This run lasted for four weeks at discharge equals to 50 liter/day/stream
(2)	This run lasted for four weeks at discharge equals to 100 liter/day/stream
(3)	This run lasted for four weeks at discharge equals to 150 liter/day/stream
(4)	This run lasted for four weeks at discharge equals to 200 liter/day/stream
(5)	This run lasted for four weeks at discharge equals to 250 liter/day/stream

RESULTS & DISCUSSIONS

Samples were collected and analyzed in the ALBERKA WWTP laboratory. The measured parameters for each sample point in the tested system were; Total Suspended Solids (TSS) [mg/l], Chemical Oxygen Demand (COD) [mg/l], and Biochemical Oxygen Demand (BOD) [mg/l].

Table (2) presents the results analysis of the influent wastewater, the effluent of conventional activated sludge (CAS) and the effluent of the step-feed system during the first run where the flow was 50 liter/day/system, and this run lasted for a month (two samples were taken per week).

Table (3) shows the removal efficiency of both the CAS system and the step-feed system during the second run.

Table (2) Results of the first run (50 l/d)

Samples	Influent Wastewater			Effluent of CAS			Effluent of Step-feed		
	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)
(1)	250	396	363	58	95	68	33	48	30
(2)	320	472	406	57	110	61	28	53	28
(3)	395	549	450	57	126	53	24	58	26
(4)	325	445	351	46	93	45	29	56	36
(5)	256	340	252	36	61	38	34	54	47
(6)	348	461	256	40	73	38	36	71	42
(7)	438	582	260	44	85	38	39	87	36
(8)	400	582	260	51	85	38	41	87	36
Average	342	478	325	49	91	47	33	64	35
Low Limit	-	-	-	**60**	**80**	**50**	**60**	**80**	**50**

Table (3) Efficiency of the systems in the first run

Samples	Influent Wastewater	Effluent of CAS		Effluent of Step-feed	
	BOD (mg/l)	BOD (mg/l)	BOD Removal Efficiency (%)	BOD (mg/l)	BOD Removal Efficiency (%)
(1)	250	58	76.8	33	86.8
(2)	320	57	82.2	28	91.3
(3)	395	57	85.6	24	93.9
(4)	325	46	85.8	29	91.1
(5)	256	36	85.9	34	86.7
(6)	348	40	88.5	36	89.7
(7)	438	44	90.0	39	91.1
(8)	400	51	87.3	41	89.8
Average	342	49	85.3	33	90.0

According to the previous data, the following can be deduced:

- The two systems achieved good results for effluent criteria complying the Egyptian law No. 48 of 1982

Table (4) presents the results analysis of the influent wastewater, the effluent of conventional activated sludge (CAS) and the effluent of the step-feed system during the second run where the flow was 100 liter/day/system, and this run lasted for a month (two samples were taken per week).

Table (5) shows the removal efficiency of both the CAS system and the step-feed system during the second run.

Table (4) Results of the second run (100 l/d)

Samples	Influent Wastewater			Effluent of CAS			Effluent of Step-feed		
	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)
(9)	373	661	440	58	91	80	43	71	66
(10)	322	546	420	59	94	62	40	67	57
(11)	270	432	400	60	97	45	38	63	48
(12)	272	449	279	58	99	73	40	66	47
(13)	274	466	158	55	100	102	41	69	46
(14)	244	408	207	56	98	93	38	62	50
(15)	213	351	256	58	97	84	35	56	54
(16)	228	382	208	60	83	62	46	74	75
Average	275	462	296	58	95	75	40	66	55
Low Limit	**-**	**-**	**-**	**60**	**80**	**50**	**60**	**80**	**50**

Table (5) Efficiency of the systems in the second run

Samples	Influent Wastewater	Effluent of CAS		Effluent of Step-feed	
	BOD (mg/l)	BOD (mg/l)	BOD Removal Efficiency (%)	BOD (mg/l)	BOD Removal Efficiency (%)
(9)	373	58	84.5	43	88.5
(10)	322	59	81.7	40	87.6
(11)	270	60	77.8	38	85.9
(12)	272	58	78.7	40	85.3
(13)	274	55	79.9	41	85.0
(14)	244	56	77.0	38	84.4
(15)	213	58	72.8	35	83.6
(16)	228	60	73.7	46	79.8
Average	275	58	78.3	40	85.0

According to the previous data, the following can be deduced:

- For the step-feed system, the results were still good for the effluent criteria complying the Egyptian law No. 48 of 1982
- For the CAS system, the results shows that the system is still working efficiently even though the flow rate has been doubled and that is because the influent BOD was not high like it was in the first run (it ranged from 213 mg/l to 373 mg/l), furthermore, the tanks were designed on the average criteria. But the system efficiency was near the limit which indicates that that is the maximum flow rate that the CAS system can reach.
- Max. flow for CAS system = 2.00 X design flow

Table (6) presents the results analysis of the influent wastewater, the effluent of conventional activated sludge (CAS) and the effluent of the step-feed system during the third run where the flow was 150 liter/day/system, and this run lasted for a month (two samples were taken per week).

Table (7) shows the removal efficiency of both the CAS system and the step-feed system during the third run.

Table (6) Results of the third run (150 l/d)

Samples	Influent Wastewater			Effluent of CAS			Effluent of Step-feed		
	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)
(17)	322	550	160	80	128	55	51	88	40
(18)	255	530	195	73	139	67.5	52	129	50
(19)	188	510	230	67	150	80	54	170	60
(20)	299	585	245	98	165	72.5	55	131	50
(21)	410	660	260	130	180	65	56	92	40
(22)	295	616	235	112	178	84	54	129	63
(23)	180	573	211	95	176	103	52	167	87
(24)	165	531	215	60	183	96	56	148	78
Average	264	569	219	89	162	78	54	132	59
Low Limit	**-**	**-**	**-**	**60**	**80**	**50**	**60**	**80**	**50**

Table (7) Efficiency of the systems in the third run

Samples	Influent Wastewater	Effluent of CAS		Effluent of Step-feed	
	BOD (mg/l)	BOD (mg/l)	BOD Removal Efficiency (%)	BOD (mg/l)	BOD Removal Efficiency (%)
(17)	322	80	75.2	51	84.2
(18)	255	73	71.4	52	79.6
(19)	188	67	64.4	54	71.3
(20)	299	98	67.2	55	81.6
(21)	410	130	68.3	56	86.3
(22)	295	112	62.0	54	81.7
(23)	180	95	47.2	52	71.1
(24)	165	60	63.6	56	66.1
Average	264	89	64.9	54	77.7

According to the previous data, the following can be deduced:

- For the step-feed system, the results were still good for the effluent criteria complying the Egyptian law No. 48 of 1982
- For the CAS system, the results have failed the law, and the effluent parameters exceeded the limit.

Table (8) presents the results analysis of the influent wastewater, the effluent of conventional activated sludge (CAS) and the effluent of the step-feed system during the fourth run where the flow was 200 liter/day/system, and this run lasted for a month (two samples were taken per week).

Table (9) shows the removal efficiency of both the CAS system and the step-feed system during the fourth run.

Table (8) Results of the fourth run (200 l/d)

Samples	Influent Wastewater			Effluent of CAS			Effluent of Step-feed		
	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)
(25)	150	550	220	125	128	90	60	88	70
(26)	335	700	328	185	269	181	77	122	70
(27)	520	850	437	246	411	273	95	156	70
(28)	530	870	444	288	470	274	107	173	65
(29)	540	890	452	330	530	275	120	190	60
(30)	485	915	442	265	414	285	112	175	66
(31)	430	940	433	200	298	296	104	160	72
(32)	323	735	327	166	322	214	66	115	52
Average	414	806	385	226	355	236	93	147	66
Low Limit	-	-	-	**60**	**80**	**50**	**60**	**80**	**50**

Table (9) Efficiency of the systems in the fourth run

Samples	Influent Wastewater	Effluent of CAS		Effluent of Step-feed	
	BOD (mg/l)	BOD (mg/l)	BOD Removal Efficiency (%)	BOD (mg/l)	BOD Removal Efficiency (%)
(25)	150	125	16.7	60	60.0
(26)	335	185	44.8	77	77.0
(27)	520	246	52.7	95	81.7
(28)	530	288	45.7	107	79.8
(29)	540	330	38.9	120	77.8
(30)	485	265	45.4	112	76.9
(31)	430	200	53.5	104	75.8
(32)	323	166	48.6	66	79.6
Average	414	226	43.3	93	76.1

According to the previous data, the following can be deduced:

- The CAS system effluent parameters have exceeded the limits in the law 48/1982
- Most of the samples of the step-feed system have failed the requirements due to the high flow rate and the high concentration of the influent BOD which exceeded 500 mg/l and reached 540 mg/l in sample No. (29). And that case did not happen in the previous runs.
- The maximum flow for the step-feed system = 3.00 X design flow of the CAS system

Table (10) presents the results analysis of the influent wastewater, the effluent of conventional activated sludge (CAS) and the effluent of the step-feed system during the fifth run where the flow was 250 liter/day/system, and this run lasted for a month (two samples were taken per week).

Table (11) shows the removal efficiency of both the CAS system and the step-feed system during the fifth run.

Table (10) Results of the fifth run (250 l/d)

Samples	Influent Wastewater			Effluent of CAS			Effluent of Step-feed		
	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)
(33)	216	530	221	132	346	133	29	70	33
(34)	199	511	211	131	345	88	84	268	120
(35)	310	512	167	217	345	139	156	292	72
(36)	320	505	165	206	349	119	184	348	56
(37)	310	480	152	203	325	95	164	284	80
(38)	288	490	160	189	336	109	160	221	55
(39)	308	570	172	193	357	115	117	54	25
(40)	304	570	172	193	357	115	126	54	25
Average	282	521	178	183	345	114	128	199	58
Low Limit	**-**	**-**	**-**	**60**	**80**	**50**	**60**	**80**	**50**

Table (11) Efficiency of the systems in the fifth run

Samples	Influent Wastewater	Effluent of CAS		Effluent of Step-feed	
	BOD (mg/l)	BOD (mg/l)	BOD Removal Efficiency (%)	BOD (mg/l)	BOD Removal Efficiency (%)
(33)	216	132	38.9	29	86.6
(34)	199	131	34.2	84	57.8
(35)	310	217	30.0	156	49.7
(36)	320	206	35.6	184	42.5
(37)	310	203	34.5	164	47.1
(38)	288	189	34.4	160	44.4
(39)	308	193	37.3	117	62.0
(40)	304	193	36.5	126	58.6
Average	282	183	35.2	128	56.1

According to the previous data, the following can be deduced:

- Both systems have completely failed to achieve the required efficiency in the law 48/1982

CONCLUSION

From the previous figure we can conclude the following:

- The Step-feed system has achieved good results compared to the CAS system as was to be expected due to the following:
  - The hydraulic retention time in the CAS system (according to the Egyptian code) is 4-8 hours while in the step-feed system it's 3-5 hours
  - The allowable organic load in CAS system is 0.3-0.7 kg BOD/m^3/day while in the step-feed system it's 0.7-1.0 BOD/m^3/day
- The maximum flow rate that can be achieved by the CAS system alone is two times its average flow
- The maximum flow rate that can be achieved by the step-feed system is three times the average flow of the CAS system
- From the previous data we can conclude that the maximum flow rate that can be achieved by the step-feed system is 1.5 times the maximum flow rate that can be achieved by the CAS system

REFERENCES :

[1] U. States, "How Wastewater Treatment Works... The Basics," no. May, 1998.

[2] W. P. George Tchobanoglous, H. David Stensel, Ryujiro Tsuchihashi, Franklin Burton, Mohammad Abu-Orf, Gregory Bowden, "Metcalf and Eddy, AECOM-Wastewater Engineering-5th Edition.pdf." McGraw-Hill Education, New York, p. 2044, 2014.

[3] M. N. Abdallah, "International Journal of Sciences : Wastewater Operation and Maintenance in Egypt (Specific Challenges and Current Responses)," pp. 125–142.

[4] M. Osman et al., "Population Situation Analysis," no. December, 2016, [Online]. Available: https://egypt.unfpa.org/sites/default/files/pub-pdf/PSA Final.pdf.

[5] A. Prüss, D. Kay, L. Fewtrell, and J. Bartram, "Estimating the burden of disease from water, sanitation, and hygiene at a global level.," Environ. Health Perspect., vol. 110, no. 5, pp. 537–542, 2002, doi: 10.1289/ehp.110-1240845.

[6] U. States, "How Wastewater Treatment Works... The Basics," no. May, 1998.

[7] A. Butler, G. Carty, M. Crowe, P. Flanagan, and M. Lambert, Wastewater Treatment Manuals - Preliminary Treatment. 1995.

[8] U.S. EPA, "Wastewater Technology Fact Sheet Package Plants," United States Environ. Prot. Agency, pp. 1–7, 2000, doi: EPA 832-F-99-062.