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Fate of Pathogenic bacteria in onsite biological compact unit treating domestic wastewater

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Abstract : Three stages characterize the level of treatment the domestic wastewater passes through in a biological compact unit (BCU). In the 1st compartment (stage 1) the suspended solids of sewage settles down and anaerobic treatment takes place. In the 2nd compartment (stage 2) the stacked packing material form is the catalyst for enhancing aerobic biological treatment process. The sewage is further settled in last compartment (stage 3) and full investigation was carried out for the BCU performance. The system was operated at a Hydraulic Retention Time (HRT) of 24 h. Final effluent Chemical Oxygen Demand (COD) reduction resulted in a concentration of only 40 ±11 mg O_2/l. Relatively low removal efficiency of Total Coliform (TC), Fecal Coliform (FC), and Fecal Streptococci (FS) was observed in 1st compartment where the anaerobic reaction occurs. The majority of TC, FC, and FS removal was found to have happened in the aerobic and settling compartments resulting to an average count of $4.8 \times 10^3 \pm 2.9 \times 10^2$/100 ml for TC, $2.9 \times 10^2 \pm 1.1 \times 10^2$/100 ml for FC, and $1.8 \times 10^2 \pm 1 \times 10^2$/100 ml for FS in the final effluent at 29 ºC. Temperature and concentration of BOD of wastewater that contained pathogens were found to have had important effect on the reduction rates. The main portion of TC, FC and FS removal in the BCU took place in the aerobic compartment assisted by the large contact surface of the packing materials.
Keywords : Sewage onsite, treatment, Pathogenic bacteria, survival rate.

Introduction

It is imperative that construction of Ethiopian El-Nahda dam and it's un-gradual filling rate will hamper the water resources of Egypt. The reuse of treated wastewater would partially release the demanding requirements on water supply for irrigation [1]. The key factor relies on an appropriate treatment process since domestic wastewater contains pollutants of human origin such as fecal bacteria, fungi and viruses that trigger variety of diseases if discharged directly to surface water or used for irrigation. As such, wastewater treatment processes designed to integrate high removal efficiency of pathogens, simple operation, low-cost maintenance and low capital investment can provide feasible solution for the problem[2].

On-site wastewater treatment systems represent an attractive solution for implementation in rural areas and developing countries compared to high cost of centralized systems[3,4]. However, these de-centralized systems should satisfy the requirements pertaining to desired level of technology to obtain high-quality effluent, reliable operation, in-frequent maintenance and monitoring[5]. De-centralized systems enable direct use of the treated wastewater. Subject systems constitute a promising future for under-developed and developing communities, where the water, sanitation and hygiene issues compose a primary issue necessary for infrastructure development[6,4].

Advantages of on-site, low-cost biological compact units (BCU) are diverse; reduce the demand for natural water resources via provision of highly treated wastewater for reuse, irrigation with treated wastewater would assist bridging the gap between crops production and consumption. A conventional compact biological treatment unit is composed of three stages: the first stage provides a room for sewage precipitation and anaerobic treatment whereas the liquid part is directed to an aeration chamber. Sewage is aerated, enriched with abundant oxygen and agitated to adhere to the microorganisms formed on the surface of contact materials In the second stage. In the third stage, the suspended matter in the liquid transferred from the second stage is settled and the settled sludge is returned to the contact aeration stage to stabilize the quality of the final effluent[7,8]. [9]observed that BCU reduces sewage content of oxygen-demanding materials, suspended solids, harmful bacteria and dissolved inorganic compounds. [10]found that in the anaerobic system, only less than 1 log10 of Escherichia coli was removed. The trickling filter (TF) scored 2 log10 removal at a surface loading rate of 2.6 m^3/m^2. The removal of pathogenic bacteria, reduction of FC in the aerobic lagoon achieved 99.99 % [11]. Rotating Biological Contactor 99 % ;[1] and the Activated Sludge system 90.8 % [12]. The E. coli reduction in the single-and two-stage RBC system treating domestic sewage was 0.9 log10 and 1.3 log10,respectively[13]. "Johkasou", a small sewage treatment apparatus commonly used in Japan, could reduce the concentrations of Escherichia coli and Salmonella enteritidis at a rate of more than 4 log units. The reduction rates depended significantly on the temperature and BOD of water that contained pathogens [14].

[15]investigated the pathogens removal in Up-flow Anaerobic Sludge Blanket (UASB)-septic tanks and oxidation ditch wastewater treatment plant. The two pilot scale UASB-septic tanks (R1 and R2) were operated at HRT of tow and four days, respectively. The oxidation ditch was operated for one day HRT. The fecal coliform removal efficiency was 15.5% for R1 and 15% for R2 and 6.9% and 11% for fecal streptococcus, respectively, whereas the removal efficiency of the oxidation ditch was 38% for fecal coliform and 16% for fecal streptococcus. A small model of domestic wastewater treatment plant (Johkasou) type was investigated for Pathogenic bacteria removal. Under standard BOD loading of 0.076 BOD $kg/m^3/day$, 97% of E. coli was removed from influent wastewater by the system. Approximately, 80% was removed in the first and second anaerobic compartments under the standard conditions. When the loading rate was raised to double the standard loading (0.152 kg BOD $kg/m^3/day$), the removal rate dropped to 64% [16].

The main objective of the present study is to investigate the capacity of onsite system, biological compact unit to reduce concentration of pathogenic bacteria as a measure of effective wastewater treatment.

2- Material and methods

A Compact unit of 110 L capacity treatment unit was designed and manufactured from PVC material . The treatment unit consists of three stages; In the 1st stage (vol. 60 L), sewage is precipitated and anaerobic treatment occurs. In the 2nd stage (vol. 40L), aerobic biological treatment takes place where packing materials are stacked .The Packing is composed of equal length plastic tubes (3 cm) and of similar size. The tubes are engraved on both surfaces to create crests at equal pitch in order to maximize the contact surfaces where bacteria builds up. In the 3rd stage (vol. 10L), the sewage is settled and the settled sludge returns to the contact aeration stage (Figure 1). The Compact unit is located at NRC pilot area .The system is fed continuously with sewage via a connection from the sewerage system. The treatment unit will be operated during summer and winter, hence different organic loading rates (OLR) and different temperatures in order to arrive at the optimum operating condition for reducing pathogenic bacteria.

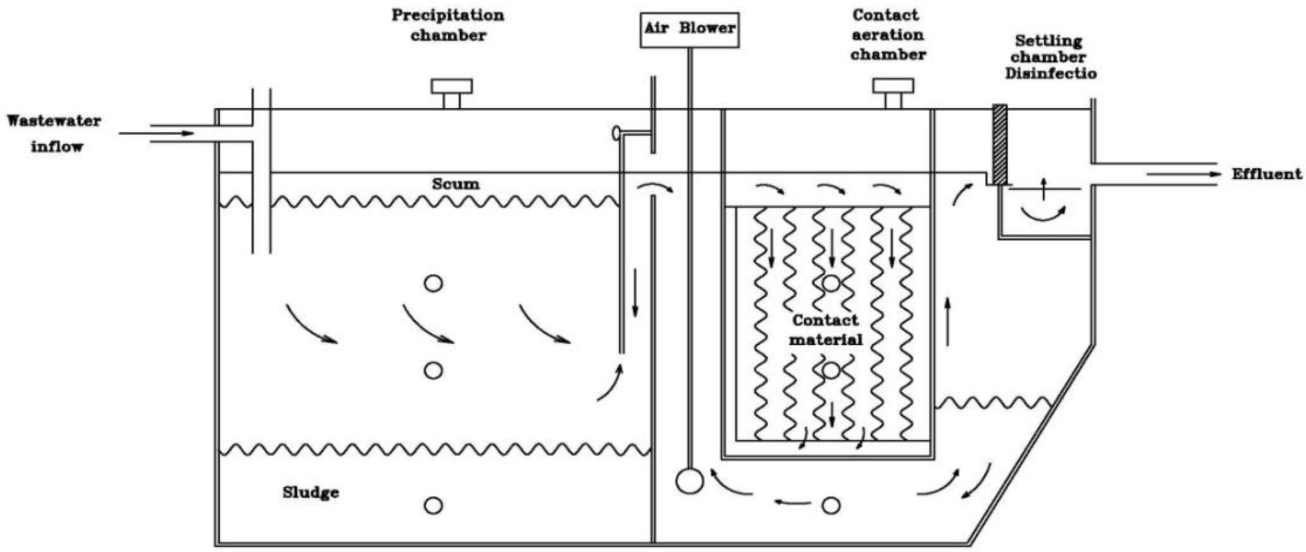


Figure (1) Schematic diagram of compact biological unit system(BCU).

Physical–chemical analysis for the influent and effluent from each stage was carried out according to the standard method for examination of water and wastewater[17].

Bacteriological examination was carried out for the influent and effluent from each stage. The parameters under investigation are total coliforms (TC), Fecal coliforms (FC). The samples were collected in sterile containers (200 ml) and subjected to the bacteriological examinations within 2 hrs from collection. The direct **(**most probable number method**) -** (MPN) was employed. Direct inoculation of an appropriate dilution of each sample was introduced into three decimals with five replicates. The inoculated tubes were immediately incubated in sensitive**,** well controlled water bath incubator adjusted at 44.5^{o}C (+ 0.5^{o}C). The tubes were examined after 24 hrs for acid and gas production. Confirmation test was carried out using EMB agar plates. The MPN index of coliforms was obtained from Swaroop's table, [17].

3. Results and Discussion

The compact unit is fed continuously with sewage via a connection from the sewerage system. The treatment unit was operated during summer and winter at 24 HRT, hence different temperatures (14, 20 ,29^{o}C) and different organic load. The system reached the steady state after acclimatization period of 100 days from the first inoculation of the sludge into BCU. This was assured by constant measurements of pH, COD and total suspended solids for influent and effluent. These results were comply with [18]where the anaerobic reactor lasted 120 days for completing start-up .

3.1.Performance of the BCU at different temperature

The results of monitoring the BCU performance over summer and winter season show n in table (1-3). Temperature is directly proportional to removal efficiency as noted for COD where 90±3 % removal is reported at 29ºC dropping to 80 ±2 % at 14ºC. Consequently, corresponding residual COD has inverse proportion to decrease of temperature. The organic matter removal represented in residual COD form an indicator of the BCU performance where values ranged from 52 to 135 mg O_2/l, from 48 to 91mg O_2/l, and from 30 to 70 mg O_2/l at 14ºC, 20ºCand 29ºC,respectively. The corresponding average values at the same temperature are121 ±23mg O_2/l, 75± 20 mg O_2/L and40±11mg O_2/L respectively. The percentage removal values were 80±2, 84±2, and 90±3 %, respectively. COD variations and average values are indicated in Figure (2). Effluent residual BOD values ranged from 30 to 71 mg O_2/l, from 24 to 45 mg O_2/l, and from 10 to 35 mg O_2/l at 14ºC, 20ºCand 29ºC, respectively. The corresponding average values at the same temperature are 61±14 mgO_2/l, 39 ±12mgO_2/l and 19±5mgO_2/l respectively. BOD variations and average values are depicted in Figure (2).Residual TSS values in effluent ranged from 9 to 28 mg O_2/l, from 5 to 25 mg O_2/l, and from 2 to 12 mg O_2/lat 14ºC, 20ºCand 29ºC, respectively. The corresponding average values at the same temperature are 20±5 mg /l,15 ±4mg /l and10±2 mg /l respectively. The percentage removal values were 90±1, 93±1, 97±1%, respectively.

Table (1). Performance of the biological compact unit at T= 29°C.

Parameters	Units	Domestic wastewater	Anaerobic effluent	R %of anaerobic effluent	BCU effluent	R% of aerobic effluent	R% of BCU effluent
TSS	mg /l	203±40	45±14	80±1	10±2	77±5	97±1
COD	mgO_2/l	409±53	172±40	57.5±2	40±11	65±2	90±3
BOD	mgO_2/l	202±30	89±25	59±3	19±5	79±3	91±4
TKN	mg N /l	49±7	41.2±5	17±5	19.2±3	55±1	60±2
TP	mg N /l	3.7±2	2.5±1.4	26±2	0.67±0.2	73±4	93±5
NH_4-N	mg P /l	28±3	31±4	-27±3	2±2	93±0.5	80.3±0.5

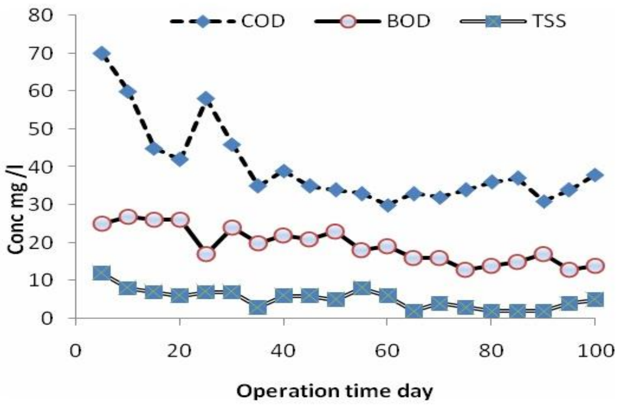
Table (2). Performance of the biological compact unit at T=20°C.

Parameters	Units	Domestic wastewater	Anaerobic effluent	R %of anaerobic effluent	BCU effluent	R% of aerobic effluent	R% of BCU effluent
TSS	mg /l	220±47	51±17	75±1	15±4	75±1	93±1
COD	mgO_2/l	499±76	224±47	55±3	75±20	60±4	84±2
BOD	mgO_2/l	254±37	137±23	69±1	39±12	70±3	86±3
TKN	mg N /l	54±5	43±6	14±0.5	22±4	48±1	54±2
TP	mg N /l	4.52±1	2.7±1.5	27±5	0.9±0.3	65±2	78±3
NH_4-N	mg P /l	26.4±4	29.5±4	-21±1	6±2	78±0.5	58±1

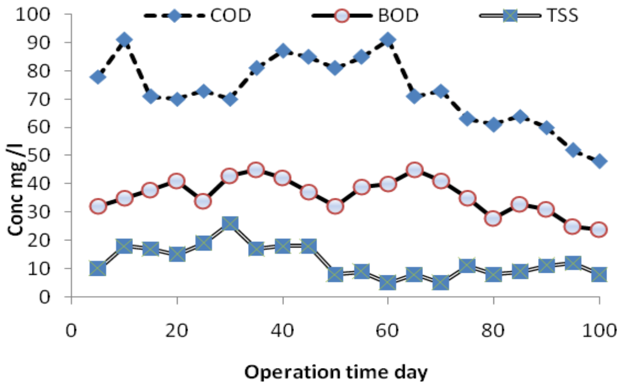
Table (3). Performance of the biological compact unit at T=14°C .

Parameters	Units	Domestic wastewater	Anaerobic effluent	R %of anaerobic effluent	BCU effluent	R% of aerobic effluent	R% of BCU effluent
TSS	mg /l	273±49	68±19	70±1	20±5	71±1	90±1
COD	mgO_2/l	512±81	255±51	56±3	121±23	53±4	80±2
BOD	mgO_2/l	261±39	145±27	60±2	61±14	60±3	86±4
TKN	mg N /l	58±6	47.4±7	16±1	27±6	43±2	53±2
TP	mg N /l	5.1±1	3.4±2	20±5	1.35±0.5	60±3	73±3
NH_4-N	mg P /l	24.8±4	28.7±6	-19±1	13±3	55±1	59±1

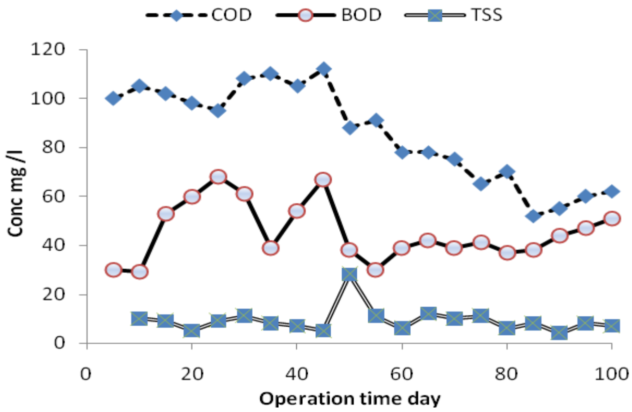
TSS variations and average values are shown in Figure(2). The results achieved by the present study in terms of COD, BOD and TSS are satisfactory and better than that obtained by [19]who obtained average removal efficiencies of 80%, 85% and 87 %for COD ,BOD and TSS when treating wastewater using onsite system. The results are comparable to those obtained by [20] who used anaerobic followed by aerobic bio film for treatment of domestic wastewater (BOD 88%) and in line with those obtained by [21] and [22]. The results are lower than those obtained by [23]who obtained 93% BOD removal when treating domestic wastewater using UASB followed by aerobic treatment.



(a, T=29^{O} C)



(b, T=20^{O} C)



(c, T=14^{o} C)

Figure 2 (a, b, c) Variation of COD, BOD and TSS of final effluent in the biological compact unit at T= 29ºC, 20ºC and 14ºC

The average residual TKN and ammonia concentration values in the effluent are 27±6 and 13±3 mg/l at 14ºC, 22±4 and 6±2 at 20ºC, 19 ±3and 2±2 at 29ºC, respectively. The percentage removal values were53,54 and 60 %for TKN, respectively. The TKj-N removal was relatively high (60 ±2 %). Similar trends were observed by [24]. According to [25] ammonia–nitrogen may be adsorbed in the biomass cells. It is known that the biomass consists mainly of bacterial and extracellular polymeric substances which all have a negative charge. Consequently, various cations of monovalent, divalent, and trivalent can be bound, including ammonia.

3.2. Removal of pathogenic bacteria in the BCU

The results presented in Table (4 -6) show the removal of pathogenic bacteria in the BCU. The total coliform (TC), fecal coliform (FC), and fecal streptococci (FS) in the treated effluent of anaerobic compartment decreased from $5.5\times10^{6}\pm1.9\times10^{3}$ to $3.5\times10^{5}\pm1\times10^{3}$/100 ml, from $6.4\times10^{5}\pm2.7\times10^{2}to2.9\times10^{4}\pm4.4\times10^{2}$/100ml, andfrom$3.1\times10^{4}\pm1.1\times10^{2}$to $4.2\times10^{3}\pm1.13\times10^{2}$/100ml at 29 ºC, respectively. The corresponding removal efficiencies of TC, FC, and FS were 95.2±0.71, 91.1±0.45, and 85.9±0.38 %, respectively.

Table(4) Mean pathogenic bacteria removal in the compact unit system at temperature 29^oC.

Parameters	Domestic wastewater	Anaerobic effluent	R%	BCU effluent	R%
Total bacterial count 37 ^0C/1ml	$7.3\times10^6 \pm4\times10^3$	$4.5\times10^5 \pm 2.5\times10^3$	93.7±0.5	$1\times10^3 \pm 1.8\times10^2$	99.9±0.06
Total bacterial count 22 ^0C/1ml	$8.8\times10^6 \pm2.1\times10^3$	$5\times10^5 \pm 1.5\times10^3$	95.8±0.62	$1.5\times10^3 \pm 1.8\times10^2$	99.4± 0.05
Total coliform (T C)/100ml	$5.5\times10^6 \pm1.9\times10^3$	$3.5\times10^5 \pm 1\times10^3$	95.2±0.71	$4.8\times10^2 \pm 2.9\times10^2$	99.9 ±0.02
Fecal coliform (FC)/100ml	$6.4\times10^5 \pm2.7\times10^2$	$2.9\times10^4 \pm 4.4\times10^2$	91.1±0.45	$2.9\times10^2 \pm 1.1\times10^2$	99.9±0.03
Fecal streptococci (FS)/100ml	$3.1\times10^4 \pm1.1\times10^2$	$4.2\times10^3 \pm 1.3\times10^2$	85.9±0.38	$1.8\times10^2 \pm 1\times10^2$	99.4±0.04

Table (5) Mean pathogenic bacteria removal in the compact unit system at temperature 20^oC.

Parameters	Domestic wastewater	Anaerobic effluent	R%	BCU effluent	R%
Total bacterial count 37 ^0C/1ml	$8\times10^6 \pm2.4\times10^3$	$4.8\times10^5 \pm 3.3\times10^3$	92.9±0.6	$1.8\times10^3 \pm 1.1\times10^2$	98.4±0.07
Total bacterial count 22 ^0C/1ml	$9.5\times10^6 \pm1.8\times10^3$	$5.5\times10^5 \pm 1.1\times10^3$	94.5±0.78	$2\times10^3 \pm 1.8\times10^2$	98.3±0.05
Total coliform (T C)/100ml	$6.22\times10^6 \pm1.1\times10^3$	$4\times10^5 \pm 1.8\times10^2$	95.3±0.65	$7.1\times10^2 \pm 2.9\times10^2$	98.7±0.03
Fecal coliform (FC)/100ml	$7.1\times10^5 \pm2.7\times10^2$	$4\times10^4 \pm 1.7\times10^2$	90.3±0.47	$4.1\times10^2 \pm 75$	98.7±0.04
Fecal streptococci (FS)/100ml	$3.4\times10^4 \pm1.1\times10^2$	$5\times10^3 \pm 1.3\times10^2$	82.8±0.39	$2.1\times10^2 \pm 1\times10^2$	98.3±0.06

Table (6) Mean pathogenic bacteria removal in the compact unit system at temperature 14^oC.

Parameters	Domestic wastewater	Anaerobic effluent	R%	BCU effluent	R%
Total bacterial count 37 ^0C/1ml	$9.3\times10^6 \pm4\times10^3$	$6.2\times10^5 \pm 3.3\times10^3$	91.7±0.71	$2.1\times10^3 \pm 1.8\times10^2$	97.4±0.08
Total bacterial count 22 ^0C/1ml	$1\times10^7 \pm2.1\times10^3$	$7\times10^5 \pm 1.1\times10^3$	93.6±0.8	$2.5\times10^3 \pm 1.8\times10^2$	97.3±0.09
Total coliform (T C)/100ml	$7.9\times10^6 \pm1\times10^3$	$5.5\times10^5 \pm 6.3\times10^3$	92.9±0.68	$1.1\times10^3 \pm 1.5\times10^2$	97.6±0.05
Fecal coliform (FC)/100ml	$8\times10^5 \pm1.6\times10^2$	$5.1\times10^4 \pm 6.3\times10^2$	89.8±0.54	$5.6\times10^2 \pm 2.5\times10^2$	97.6±0.03
Fecal streptococci (FS)/100ml	$4.2\times10^4 \pm1.1\times10^2$	$5.9\times10^3 \pm 1.3\times10^2$	79.4±0.41	$2.8\times10^2 \pm 1.1\times10^2$	97.3±0.07

These results are in line with [26],[27]who found coliform removal efficiency is low in anaerobic systems. The results are comparable to [10]who found that the removal of Escherichia coli was limited in the anaerobic system, amounting to less than 1 log10. The Total portion of TC, FC, and FS was removed in the aerobic and settling compartments resulting in an average count of 4.8×102±2.9×10^2/100 ml for TC, $2.9\times10^2 \pm 1.1\times10^2$/100 ml for FC, and $1.8\times10^2 \pm 1\times10^2$/100 ml for FS at 29ºC in the final effluent. This can be attributed to the adsorption of pathogenic bacteria onto the packing material [28]. These results are similar to that obtained by [29,30] who found that the removal of various types of pathogenic bacteria (fecal coliform, E. coli, enterococcus, and coliphages) and helminthes in membrane bioreactor, porous media, and biological sand filters were mainly due to adsorption (sorption) to the biofilm. The anaerobic compartment alone achieved a mean reduction of 91.1±0.45% in fecal coliform (FC). Addition of the aerobic compartment raised the FC reduction to 99.9±0.03%. Similar reduction was seen in total coliform concentrations[11,31,12]. Total bacterial concentrations of raw wastewater at 29ºC are about 7.3 $x10^6 \pm 4x10^3$ /ml ,the concentration of pathogenic bacteria in the anaerobic compartment is $4.5x10^5 \pm 2.5x10^3$ /ml and in the final effluent is1 $x10^3 \pm 1.8x10^2$ ml . As shown in Figure(3), both kinds of bacteria decreased with the course of time.

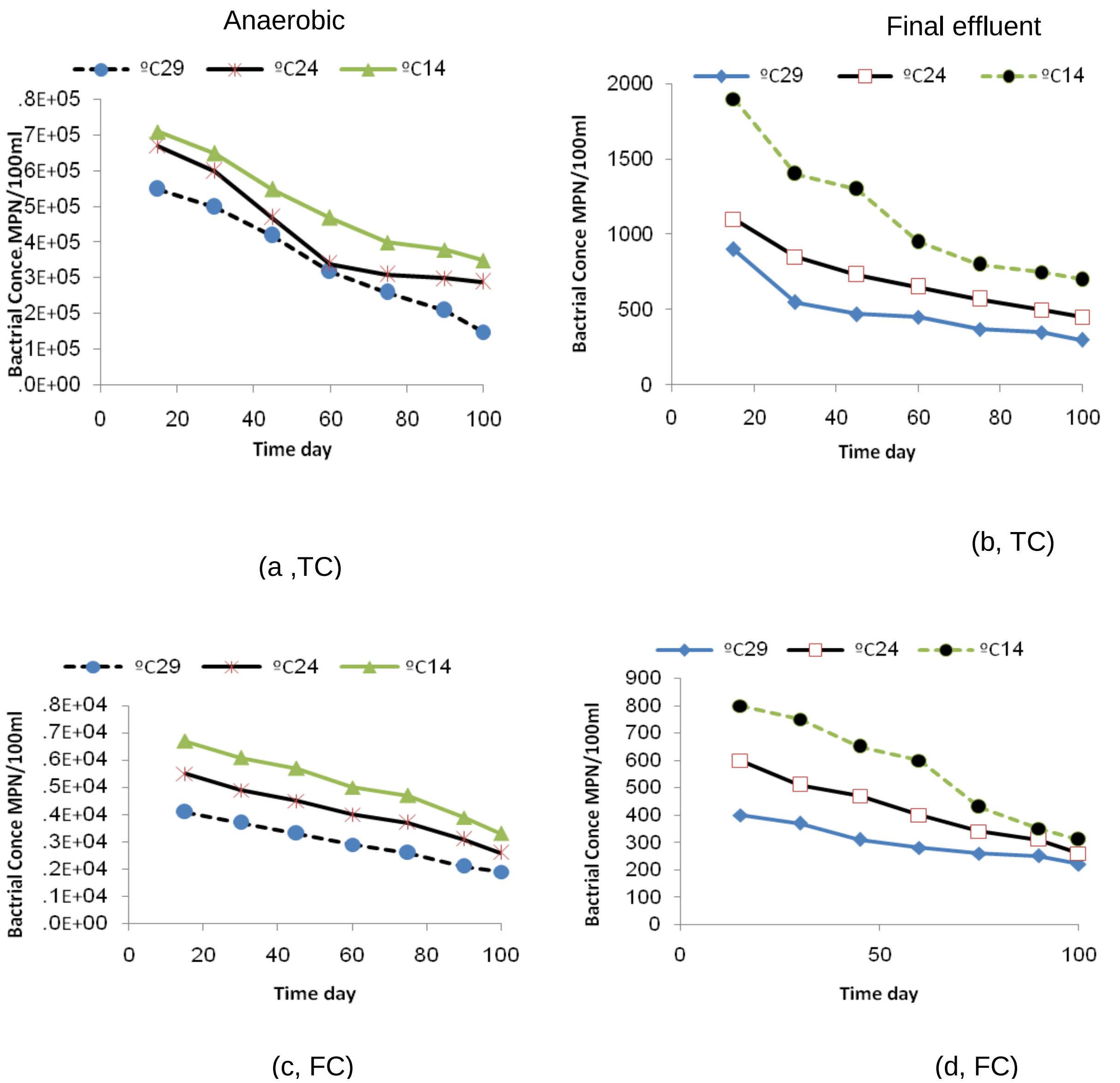
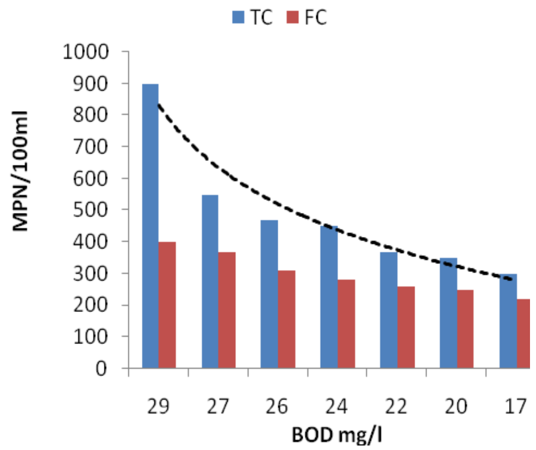
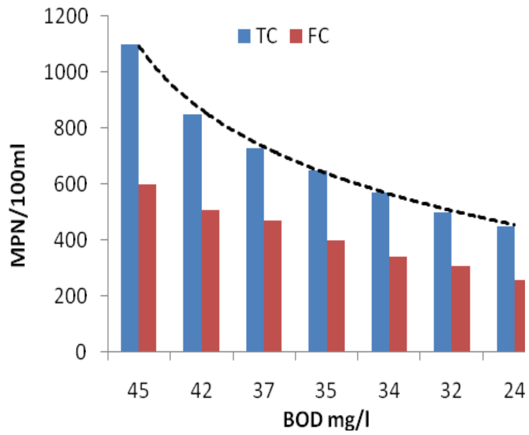


Figure 3 (a ,b, c, d) Variation of Total Colifrom and Fecal Coliform in anaerobic effluent and final effluent in the biological compact unit

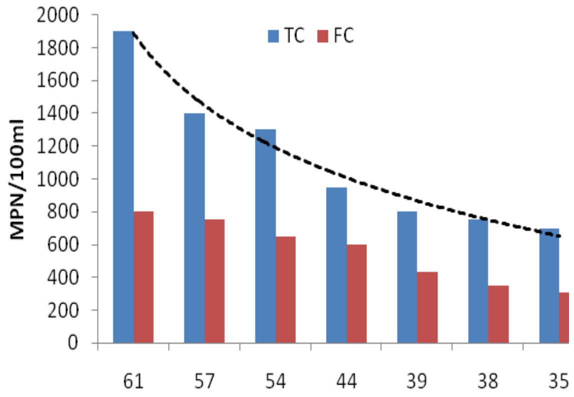
The bacteria in effluent from the final settling tank also decreased under condition of 20ºC and 29ºC although the reduction rate was not effective at 14ºC.Figure (4) shows the relation between the bacterial concentration and BOD values from the end of anaerobic zone and the final sedimentation zone. The higher the BOD values of solutions, the lower the survival rates. However, the survival rates at 20ºC were lower than at 14ºC.



(a, T=29°C)



(b, T=20°C)



(c, T=14°C)

Figure 4 (a ,b ,c) Relation between Total Colifrom and Fecal Colifrom of final effluent and BOD in the biological compact unit at temperatures 29°C ,20°C and 14°C .

Wastewater temperature in BCU showed the change of seasons. In some places, the temperature rises up to around 29ºC in summer and comes down to 14ºC in winter. Moreover, the BOD concentration of water in the first anaerobic zone is high and that in the final effluent is low. Considering these conditions, pathogens tested in this study might not be reduced during winter in the first anaerobic zone whereas during summer when the water temperature is high, reduction of pathogens may be expected to a certain extent. The BOD of effluent from BCU was low, therefore, the reduction of pathogens can be expected in summer but the effluent will be expected to contain some pathogens in other seasons. To keep receiving waters safe, the disinfection process of the BCU must be operated satisfactorily[32]. However, these reductions are not enough to achieve a final effluent that would meet the WHO guidelines fecal bacteria limit and recent revisions for use of treated wastewater in agricultural unrestricted irrigation[31]. However, the BCU is ranked higher than other systems for the removal of pathogenic bacteria, i.e., reduction of FC in the aerobic lagoon (99.99 %; [11]), rotating biological contactor (99 %;[1])and the activated sludge system (90.75% ;[12]). This study demonstrates that BCU system is a reliable, low-cost, and appropriate technology for the treatment of domestic wastewater for restricted agricultural reuse, based on the recommended measures of the Egyptian code for wastewater reuse.

4. Conclusions

1. BCU, a small sewage treatment apparatus commonly used in small community, could reduce the concentrations of total coliform at a rate of 4 log units.
2. The reduction rates depend significantly on the temperature and BOD of wastewater that contained pathogens.
3. The survival rates is inversely proportional to temperature and BOD.
4. The packing material biofilm. in aerobic compartment greatly enhances removal of the major portion of TC, FC and FS .
5. As wastewater temperature in BCU showed the change of seasons, pathogens tested in this study might not be reduced during winter in the first anaerobic zone whereas during summer when the water temperature is high, reduction of pathogens may be expected to a certain extent
6. The system achieved a substantial reduction of total COD resulting in an average effluent concentration of only 40±11 mg O_2/l and FC of $2.9\times10^2\pm1.1\times10^2$/100 ml. The effluent quality is Satisfactory for reuse in restricted irrigation purposes based on the recommended measures of the Egyptian code for wastewater reuse.
7. The BCU is ranked higher than other systems for the removal of pathogenic bacteria as compared to performance of aerobic lagoon, rotating biological contactor and the activated sludge system.

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