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Evaluation of decentralized treatment of sewage employing Upflow Septic Tank/Baffled Reactor (USBR) in developing countries

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ABSTRACT

A new concept for a low-cost modified septic tank, named Upflow Septic Tank/Baffled Reactor (USBR), was constructed and tested in a small village in Egypt.

During almost one year of continuous operation and monitoring, this system was found to have very satisfactory removal results, where the average results of COD, BOD, and TSS removal efficiencies were 84%, 81%, and 89%, respectively, and the results of the experiment proved that the second compartment (Anaerobic Baffled Reactor) was the main treatment unit in removing the pollutants during the start-up period and at the very early steady-state stage. However, after this period and during the steady-state operation conditions, the second compartment served as a polishing step. Also, it was observed that the USBR system was not affected by the imposed shock loads at the peak flow and organic periods.

The results showed that the system is slightly influenced by the drop in the temperature. Decreasing in BOD and COD removal by factor of 9% was observed, when temperature decreases from the average of 35 °C in summer time (for the first 127 days) to the average of 22 °C in winter time (between day 252 and day 280). Whereas, the TSS removals were not affected by the drop in temperature.

The results of the sewage flow variations during one year of operation were compared with Goodrich Formula to see the applicability of this equation in rural developing countries.

Main finding of the work: The Upflow Septic Tank/Baffled Reactor system could become a promising alternative to the conventional treatment plants in rural developing countries.

1. Introduction

Egyptian villages are experiencing a major threat represented in groundwater contamination resulting from untreated sewage and this threat is becoming a major issue of media focus. This, in turn, is creating great pressure on the Government of Egypt to urgently find appropriate low-cost solutions for sewage treatment.

The difficulties faced by the government in the installation of traditional wastewater systems in rural areas were due to the associated high installation, operation, and maintenance costs [1,2].

To reach the desired goals, the government is seeking an affordable, easy to manage wastewater treatment process that can serve small to medium size communities (up to 20,000 inhabitants).

This dilemma makes developing new, affordable and appropriate small to medium size technologies for domestic wastewater treatment before disposal an urgent need.

From this perspective, one technology that could deliver similar effluent quality, compared to the centralized conventional wastewater treatment plant, is the modified septic tank system, which is also able to do so at a much lower cost.

Anaerobic modified septic tank, compared to other treatment technologies, occupies smaller land area, does not need skilled labor to operate, has much less operation and maintenance requirements, involves less construction cost, generate much less sludge, and releases methane gas, which can be considered a good source of energy if properly recovered.

Many anaerobic modified septic tank systems were used and tested at different countries [3,4,5,6]. Panswad and Komolmethee [3] used full-scale septic tank/anaerobic filter unit with the tank's retention time varying from 22.5 to 90 h. They recommended a rather high retention period of not less than 48 h if the Thai effluent standards are to be met.

Elmitwalli et al. [4] used two-step anaerobic system to treat sewage. They tested the performance of the two upflow-hybrid septic tanks which require high power input or high excavation depth due to that the two treatment steps exist in a vertical order.

Mendoza et al. [6] studied in a lab-scale the design and performance of a novel Gradual Concentric Chambers (GCC) reactor, integrating anaerobic and aerobic processes, treating low (165 mg COD/L) and medium strength (550 mg COD/L) domestic wastewaters. Although the GCC reactor had reasonable performance, its

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operation is considered rather complicated due to using of anaerobic effluent recycling technique and aeration pump.

Due to its operational simplicity and its low cost, a new concept for an anaerobic modified septic tank containing two compartments Upflow Septic Tank compartment and Anaerobic Baffled Reactor compartment (USBR) was developed and tested at pilot scale for 6 months at Iowa State University [5] and for one year at Oseem village, Giza Governorate, Egypt. Results showed significant improvements in the effluent quality with a potential to minimize groundwater contamination. Moreover, this modified septic tank achieved effluent qualities that complies with Egyptian effluent standards.

Accordingly, a full-scale USBR system was constructed in a small community near El Tel El Sagheer village in El Tel El Keeber district, Ismailia governorate. This village is located 120 km away from Cairo. The present population in the village is approximately 80 inhabitants in 18 houses. The full-scale tank was built near El Wady agricultural drain and the effluent wastewater is discharged into this drain.

In a comparative study [7] on different technologies used for sewage treatment in small communities in Egypt, the costs of construction, operation and maintenance of these technologies were collected. The costs were based on the actual costs of existing treatment plants in Egypt. Five sewage treatment technologies were involved in the study; these were: activated sludge process, oxidation ditch, trickling filter, oxidation ponds, aerated lagoons and USBR. The study revealed that USBR could be considered the best alternative for sewage treatment in terms of the required space, construction, maintenance and operating costs and finally the ease of operation. It was found [7] that the operation and maintenance of the USBR would cost USD 4.5 per cubic meter of treated sewage as compared to USD 44 per cubic meter of treated sewage for the activated sludge system. Similarly, the construction of the USBR may cost as low as USD 270 per cubic meter of treated sewage as compared to USD 440–730 per cubic meter of treated sewage for the activated sludge system.

The performance results of this unit (organic and solids removals and tolerance to organic and hydraulic shock loads) in treating year-round variation in sewage characteristics and temperatures is the subject of this research paper.

The treatment unit was observed and tested for almost one year to investigate the following:

1. Study the system behavior and long-term performance efficiency.
2. Evaluate the system's capability to handle year-round variation in sewage characteristics and temperature.
3. Document the system's capability in tolerating organic and hydraulic shock loads.

2. Material and methods

2.1. Experimental setup

The USBR system consists of two compartments. The first compartment serves as a sludge settling and digestion zone and the second compartment functions as a polishing unit (Fig. 1).

In the Upflow Septic Tank/Baffled Reactor system, the upflow mode of operation in the first compartment improves the physical removal of suspended solids through gravity settling and an entrapment mechanism. As a sludge blanket forms in the first compartment, the second compartment serves as a polishing step, thereby converting the remaining volatile fatty acids and escaped suspended BOD to biogas. This second compartment is divided into sections through vertical baffle walls. These baffle reactors can be regarded as a quasi-plug flow reactor configuration that provides kinetic benefits to enable microorganisms to degrade the residual organics to the lowest level of concentration possible.

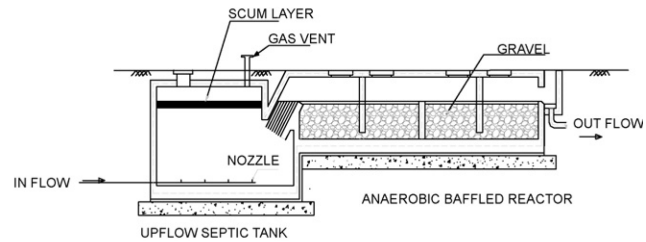

Fig. 1. Cross-sectional view in the modified septic tank system (USBR).

Plate settlers were also installed at the top of the first compartment below its effluent port to give the same function of a solid–liquid separator in an Upflow Anaerobic Sludge Blanket (UASB) reactor. Their function is to reduce at most the solids from escaping to the second compartment. The angle of the plates inclination are 60 degree to the horizontal projection.

The detailed configurations of the system and performance results of the pilot scale were published at the International Water Association IWA Bi-Annual Conference in Marrakech [5].

The USBR treatment plant involves the following elements:

1. *Pumping station:* Two submersible pumps of 3 l/s for each.
2. Valve chamber and electrical control room.
3. *USBR reinforcement concrete tank* with dimensions: width × length × average depth of 2.1 × 4.2 × 2 m. USBR also involves the following elements:
   Piping arrangement includes inlet distributor pipes, decanting, and biogas pipes.
   Other accessories of the tank include PVC plate settlers (60-degree inclination to the horizontal) erected at the top of the first compartment below its effluent port.
   Gravels were used as a filter medium in the second compartment. The medium was sieved into particles of 5/8″–1.5″ (15–37 mm). The reason for using a filter medium is its ability to retain active biological solids for longer periods of time [8].
4. *Disinfection unit:* A disinfection unit was added to inject the sodium hypochlorite solution to the effluent treated water to make the effluent water comply with the wastewater discharge rule imposed by the Ministry of Environment. The solution dose was adjusted to 3 ppm based on average daily flow.

To assess the system performance, grab samples were taken in a weekly basis from the influent, effluent, and after the first compartment (after the plate settler).

2.2. Experimental operating conditions

The designed operating conditions of the system were

- The average hydraulic retention time in the first and second compartments is 20 h.
- Upflow velocity at maximum daily flow is 0.125 m/h.
- Average organic loading rate in the second compartment is 0.42 kg BOD/m^3 d.
- Average hydraulic loading rate in the second compartment is 3 m^3/m^2 d.

2.3. Analytical methods

The total chemical oxygen demand (COD), total suspended solids (TSS), and total biochemical oxygen demand (BOD) were

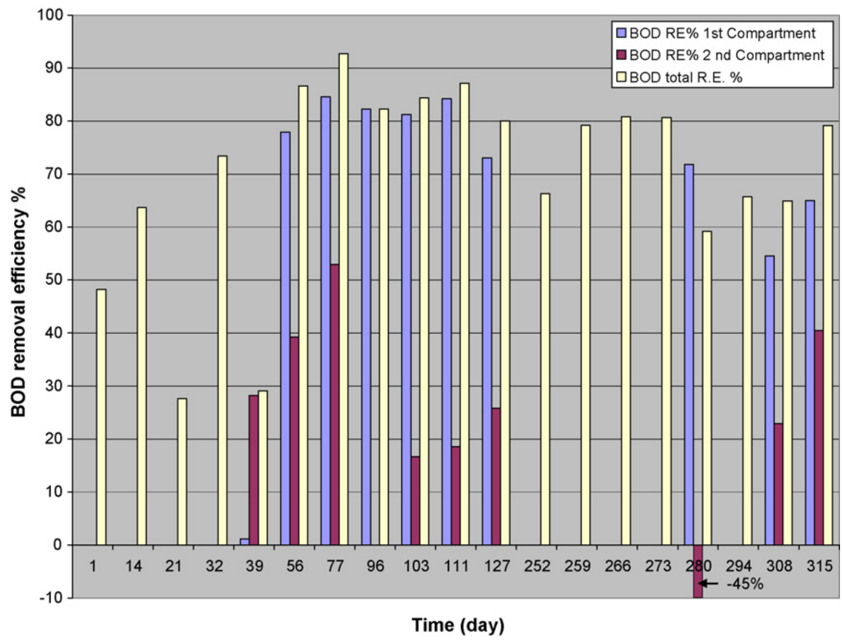

Fig. 2. The BOD removal efficiencies % of the first (1st) compartment and the second (2nd) compartment.

measured according to the Standard Methods for the Examination of Water and Wastewater [9].

Sewage flow quantity was measured with PVC flow meter erected on the outlet pipe and no gas measurement equipment was used in this experiment.

The experiment was carried out in ambient temperature measured by thermometer. All the temperature measurements were done during day light.

For each sample collected from the effluent water, the pH value was measured. pH was measured by a portable pH meter with an accuracy of ±0.1. The average pH value was 7.3 and the standard deviation was ±0.13.

3. Results

The USBR unit was operated in March 2006. For the first 60 days, the USBR unit was considered to be in its start-up period due to its low efficiency of pollutant removal. The results of these 2 months were not included in this paper. During the start-up period, flow was adjusted many times to reduce the pump flow by adjusting the opening of the inlet valve. This was a result of the high pump capacity as compared to that of the USBR. This is because the smallest available raw sewage submersible pump in the market is 3 l/s and the system designed flow at maximum flow is 0.5 l/s. Although the pumps were adjusted afterwards and the start-up period and design flow was achieved, water blockage happened after 190 days of continuous operation (130 days after steady-state condition). Due to that, no samples have been obtained from the system between day 130 and day 252 as a result of these frequent water blockages in the second compartment. This can be attributed to the fact that during the start-up period, the flow of the selected pumps was many times greater than the actual designed flow. This caused washout of the solids from the first compartment to the second one. The system was operational again after the gravel was taken out, washed, and returned to the tank. After resuming operations, no sample was taken from the tank for 1 month (between day 222 and day 252).

Figs. 2–4 show that in the first month of steady-state operation the second compartment compensated for the low efficiency of the first compartment, where the removal of BOD, COD, and TSS took place in both compartments. After that, most of the BOD, COD, and TSS concentrations were removed by the first compartment "upflow anaerobic compartment." The low removal efficiency of the organic and suspended removals in the first compartment during the initial operation period can be attributed to the absence of a sufficient amount of proper biomass populations to carry out the degradation process. However, these populations have gradually developed in the tank.

During the first 3 months of tank operation, the function of the second compartment was to break down the escaped part of the influent BOD, which enhanced bacterial immobilization on the surface of the filter media. As the sludge (biomass) blanket formed in the first compartment, the second compartment served as a polishing step, thereby converting the remaining volatile fatty acids and escaped suspended BOD to biogas.

During almost one year of continuous operation and monitoring, the USBR unit has very satisfactory removal results. The average results at an average retention time of 20 h were 84% for the COD removal, 81% for the BOD removal, and 89% for the TSS removal. Whereas, when conventional septic tank/anaerobic filter unit was used, the removal results were 52.1%, 56%, and 53.6% for the COD, BOD, and TSS removals, respectively, at an average retention time of 22.5 h [3]. With using one-step anaerobic hybrid septic tank, the COD removals were as high as 87% at a low temperature of 13 °C and at retention time of 5.5–7.5 days [4].

Based on the experimental results and mathematical model calculations, an HRT of 5.5–7.5 days is needed for a one-step AH septic tank to treat concentrated domestic sewage at a low temperature of 13 °C. Such system can provide a COD removal efficiency as high as 87% and will be full of sludge after a period of more than a year.

Figs. 5–7 show that almost all the treated effluent results for the BOD, COD, and TSS had values less than that required by Egyptian law 48, year 1982 for disposing treated effluent water into an agricultural drain. However, few results of the effluent COD at the wintertime (between day 252 up to day 280) and few days after the winter period were slightly above the lower limit required by law (80 ppm), but they were still less than the higher limit defined by law (100 ppm).

Results also showed that USBR has tolerance to the hydraulic shock loads (165% of average flow in the maximum weekly flow

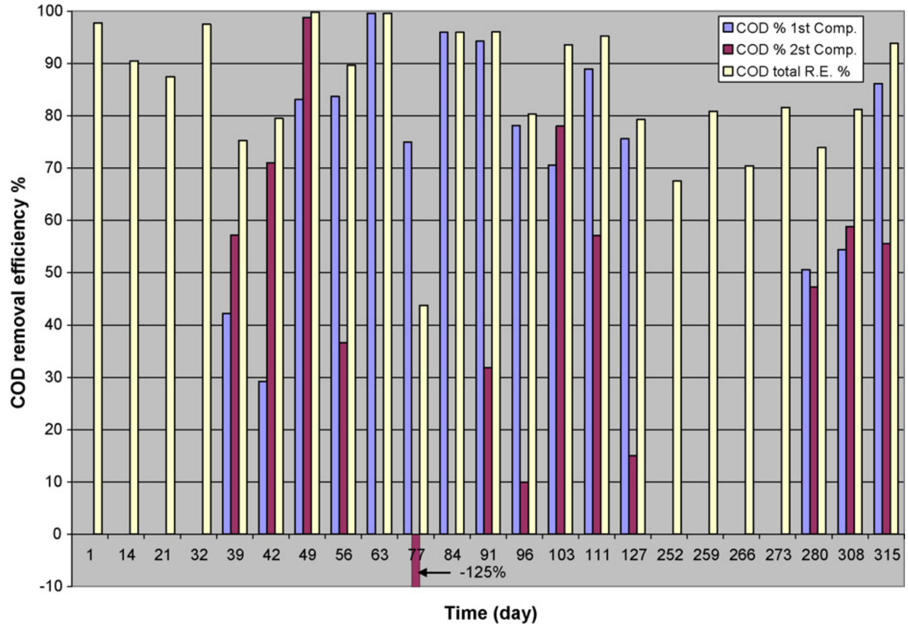

Fig. 3. The COD removal efficiencies % of the first (1st) compartment and the second (2nd) compartment.

in day 42) and organic/solid shock loads (influent COD and TSS in days 1 and 32 had values above 1200 ppm and 1800 ppm, respectively), where the BOD, COD, and TSS removal efficiencies have not been affected during the shock load periods due to system stability. This observation is in agreement with another study done by the author who observed the same tolerance with the Upflow Anaerobic Sludge Blankets (UASB) system when it is imposed to different hydraulic shock load periods [10]. Also, Panswad and Komolmethee [3] observed the same result in Thailand when they used septic tank/anaerobic filter unit.

The drop in the efficiencies of COD in day 77 and TSS in days 14 and 84 can be attributed to washout of some active solids from time to time as a result of formation of new bacterial cells on the gravel media. This washout can be more detected in the grab sample results more than composite sample results.

In addition, it was observed that organic biodegradation is influenced by the temperature where the temperature during the whole experiment ranged from 17 °C to 43 °C. In wintertime (between day 252 and day 280), when ambient temperature at night is sometimes less than 14 °C, the effluent BOD and COD increased compared to that in summertime (Figs. 5 and 6). However, the effluent TSS concentrations were not affected by the drop in temperature (Fig. 7). This can be attributed to the physical removal (entrapment and settling process) of the TSS by the blanket biomass layer that formed in the bottom of the first compartment.

The weekly sewage flows were measured from the water meter erected on the effluent pipe. The average sewage flow during the

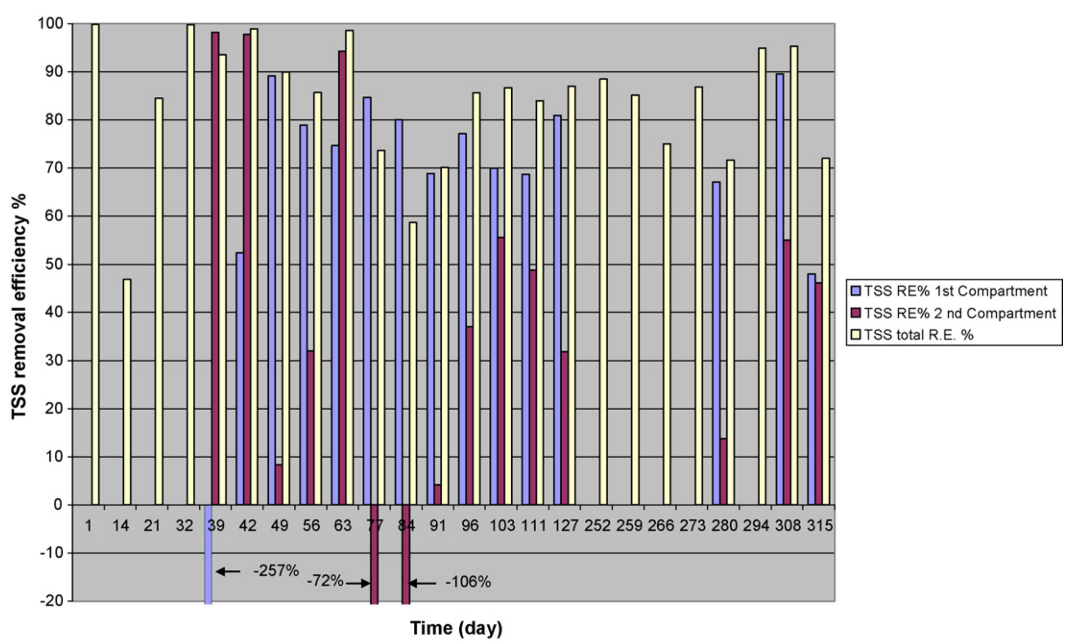

Fig. 4. The TSS removal efficiencies % of the first (1st) compartment and the second (2nd) compartment.

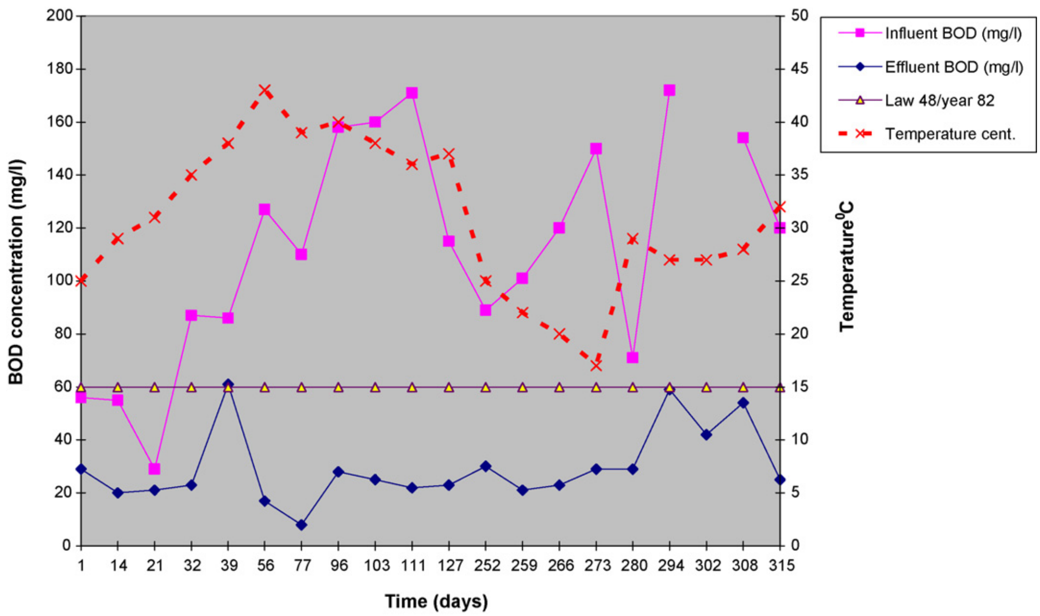

Fig. 5. The BOD influent and effluent results compared with the allowable limit by law at different temperature values.

year was found to be 141 l/capita/day. The sewage flow variations (liter/capita/day) during the year have been detected in this experiment; the results were then compared with the Goodrich Formula for the ratio of the maximum weekly and monthly flows to the average flow to see the applicability of using this equation with the flow variation in rural Egypt.

Goodrich Formula : $P = 180\,t^{-0.10}$

where P is the percentage of the annual flow rate that occurs during shorter periods and t is the length of the period in days.

A small difference was observed between the results from the Goodrich Formula and the flow variation in rural Egyptian. Measuring the weekly flows during the year, it was noted that the ratios of the maximum weekly (in June) and monthly (in July) flows to the average flow are 165% and 114%, respectively, whereas the values are 148% and 128% when calculated by the formula.

The utilization scenarios of the possibly released biogas from the anaerobic digestion of sewage in this treatment unit were mentioned in a technical memorandum from Black & Veatch Corporation [11].

The preliminary recommendations for biogas utilization at the site, including using the gas for cooking in conventional low-pressure gas burners or burning the gas in an engine generator for electricity generation, are found in the technical memorandum. These gas utilization scenarios have low labor requirements and require minimum technical expertise for maintaining the used equipment.

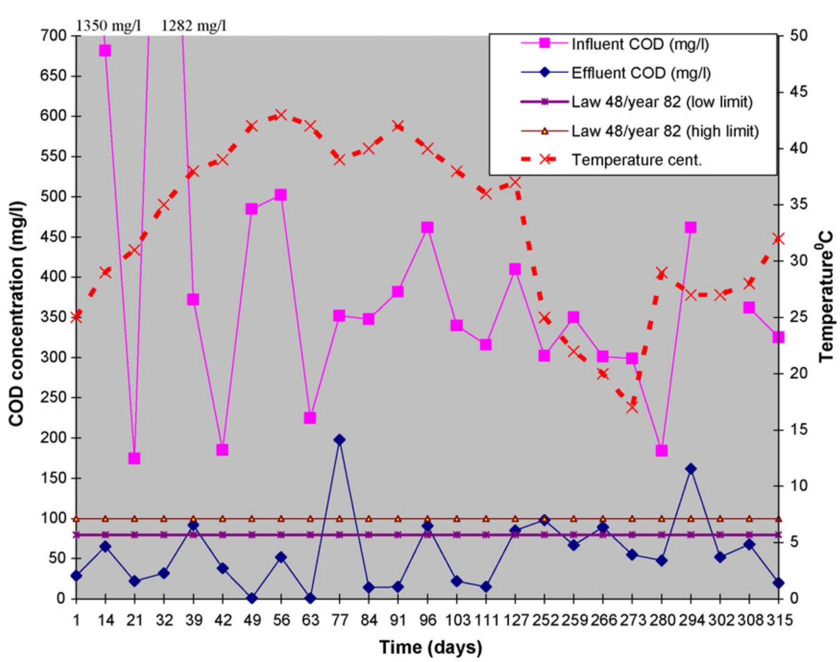

Fig. 6. The COD influent and effluent results compared with the allowable limits (low and high) by law at different temperature values.

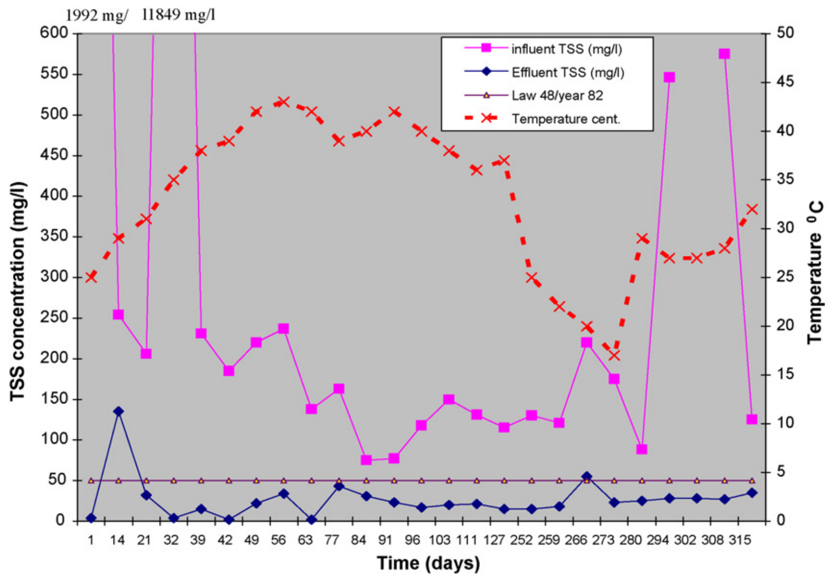

Fig. 7. The TSS influent and effluent results compared with the allowable limit by law at different temperature values.

4. Conclusions

The research work proved that the second compartment is considered the main support unit for the first compartment in removing the pollutants in the start-up period and at very early steady-state stage.

The results also showed that in a semi-tropical region such as Egypt, the anaerobic biodegradation process is slightly influenced by the drop in the temperature at wintertime. However, at these low temperatures, the effluent results for the BOD, COD, and TSS were almost always less than the limit required by Egyptian law (law 48/year 1982). Thus, this system could become a promising alternative to the conventional treatment plants in Egypt, because it is cheap and the effluent quality complies with the Egyptian domestic effluent standard.

Also, it was noticed that the Goodrich Formula can be applied to obtain the approximate ratio between the maximum weekly and monthly flows and the average flow in rural Egypt.

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A patent has been applied for the technology with the Egyptian Ministry of State for Scientific Research on 30/11/2005, file number: 2005110499.

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