Comparison between two Stages Up-flow Anaerobic Sludge Blanket and Activated Sludge Configuration for Municipal Sewage Treatment

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ABSTRACT — This study compares the performance of a pilot-scale Two Stages Up-flow Anaerobic Sludge Blanket (TSUASB) to that of Activated Sludge Configuration (ASC) for the treatment of municipal sewage. The two examined systems were operated at high hydraulic loading rates (the Hydraulic Retention Time (HRT) was reduced from 4.5 to 2.25 and then to 1.5hr). Both systems were operated in parallel with the same influent characteristics. The study was conducted at Al-Qenayat Waste Water Treatment Plant (WWTP) located in Zagazig, Egypt, which revealed that the BOD removal efficiency of the TSUASB was in the range of 75-84% compared to 86-94% of the ASC. These removals ranges were 68-80% and 74-89% for COD removals respectively. Moreover, unlike ASC, there is no requirement of aeration for the operation of the TSUASB system, which makes it an economical treatment system. Finally, it was concluded that the TSUASB system can be a cost-effective and viable option for the treatment of municipal sewage over ASC, especially for low-income countries.

Keywords —Activated sludge configuration, Aerobic, Anaerobic, Biological sewage treatment, High hydraulic loading rate, Two stages Up-flow anaerobic sludge blanket.

1 INTRODUCTION

RAPID growth in the human population has resulted in a significant increase in sewage production, results in great problems in sanitation and the spread of many diseases as a result of inefficient collection and treatment of sewage. In the past, the ASC has been widely used for the treatment of domestic and industrial sewage. The ASC has high efficiency, operational flexibility and the possibility of nutrient removal. However, there are several disadvantages associated with ASC: high mechanization, construction, and operational costs, sophisticated operation and generation of a large amount of sludge. In recent times the use of Up-flow Anaerobic Sludge Blanket (UASB) has overcome the disadvantages of mechanized aerobic systems especially because of the absence of energy consumption and lower excess sludge generation [1], [2].

It is worth mentioning that the selection of the sewage treatment systems is largely driven by the economy apart from the level of social and educational conditions. The ASC (the most popular aerobic treatment process) has long been a domain in the world of sewage treatment, especially in developed countries though it is complex and expensive. But for developing countries, economical aspect is essential for the establishment of a sewage treatment system. Anaerobic treatment systems could provide good alternatives for sewage treatment in developing countries [3].

Aerobic sewage treatment involves a process in which microorganisms convert organic components into more simple end products in the presence of oxygen. Anaerobic process involves three main steps; Hydrolysis (conversion of complex organic compounds into simple products such as sugars and amino acids), Acidogenesis (conversion of the simple products into simple organic acids such as acetic acid and propionic acid) and Methanogenesis (conversion of the organic acids into biogas (methane and carbon dioxide)). The methane is considered a useful source of energy [1].

The aerobic system is very useful for low strength sewage treatment. While the anaerobic system could withstand volumetric organic loading rates 5-10 times higher than for aerobic processes [4]. On the other hand; aerobic treatment systems can usually produce a better quality effluent than anaerobic systems. Low-quality effluent is generated by the anaerobic system because of the low growth rate of microorganisms [1].

Conventional aerobic treatment processes normally require primary sedimentation. This has two disadvantages: an extra vessel and appurtenances are required and the sludge that settles (primary sludge) required further treatment. Many anaerobic processes do not normally require primary sedimentation. Generally, all aerobic and anaerobic processes will require a secondary clarifier. On the other hand, the aerobic system does not require post-treatment of sewage as it provides better nutrient removal [4].

Anaerobic digestion reactors have now become a promising technique due to their efficiency, flexibility, smaller footprint with less maintenance, and accepted quality effluent as compared to aerobic systems which are high investment, operational and maintenance costs, labor-intensive, complex infrastructure and high space requirement [1], [5]. The anaerobic system produces very low sludge that is fully stabilized for disposal. Lower sludge production and lower costs associated with its disposal are major advantages of anaerobic treatment. Other advantages of anaerobic systems are lower energy consumption, no

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aeration energy requirements and lower nutrients requirements [4].

UASB Reactor; sewage to be treated is introduced from the bottom of the reactor. The performance of the UASB reactor depends mainly on the development of a dense sludge bed at the bottom of the reactor, where biological digestion takes place. The dense granules in this bed have good settling properties and therefore are not susceptible to washout from the system under operating conditions. The gases (methane and carbon dioxide) produced under anaerobic conditions cause internal mixing, which helps in the formation and maintenance of biological granules. A gas-liquid-solid separator (GLSS) is added on the top of the reactor for the effective separation of gas, liquid, and granules [6], [7]. Overall UASB technology has been found successful for treating domestic sewage. Therefore these reactors should be installed on a priority basis in small communities and towns especially in developing countries with suitable climate conditions [7].

The two stages anaerobic process was studied and investigated by many researchers. The first stage for the removal of soluble compounds and mainly the hydrolysis of particulate organic matter, and the second stage to complement the conversion of soluble compounds formed in the first stage. Besides, important contributions have been observed in the removal of N, P, metals, and coliforms in two-stage anaerobic systems [8], [9], [10].

The UASB system was proposed as an appropriate sewage treatment technology for developing countries in terms of efficiency, sludge production, energy requirement, cost and acclimation for developing countries. The present study aims to compare the efficiency of TSUASB system and the ASC at different operating conditions, using pilot-scale reactors.

2 MATERIALS AND METHODS

A pilot-scale combination of the TSUASB system, as well as ASC system, were set up in a municipal sewage treatment plant of Al-Qenayat City, Egypt. Influent sewage used for the pilot-scale systems was Gritted sewage that was taken after the grit removal chamber. Both systems were operated in parallel at an ambient temperature varied from 14 to 20 ^{o}C during the study period.

Experimental Test Rig and Operational Conditions Pilot-scale TSUASB

Two cylindrical tanks with an effective height of 147 cm and a diameter of 64 cm were used as UASB reactors for the study. A constant head tank was provided for pumping the influent. The system was operated by feeding gritted raw sewage to the first stage UASB1 and then it was transferred by gravity to the second stage UASB2. The TSUASB reactors were operated at an overall HRT of 4.5, 2.25, and finally at 1.5h. The stabilized excess sludge was removed from the bottom of the UASB rectors maintaining the solid retention time around 30days. The experimental test rig is illustrated in Figure 1-a.

Activated Sludge Configuration

The conventional type of ASC (Fig. 1-b) was used. Three main partitions of the process were; (1) rectangular primary sedimentation with an effective height of 100cm and cross-section (60x60 cm), (2) diffused air aeration tank with an effective height 75cm and cross-section (100x75 cm), and (3) final sedimentation tank with 150 dm^3 volume. Designed HRTs were 4.5, 2.25, and 1.5 h in the aeration tank. The excess sludge was withdrawn from inside the aeration tank to achieve Solid Retention Time (SRT) of about 10 days. The SRT recommended for a conventional ASC ranged from 4 to 9 days in a warmer climate (15–25 °C) and 10 days or more in cold climate [11].

Sampling and analysis

The performance of the two systems was monitored by analyzing samples of raw sewage, UASB effluent for each stage (UASB1 and UASB2), and the effluent of ASC was taken after the final sedimentation tank. The samples of the UASB reactors were allowed to settle for approximately 30min at the laboratory before analysis, to simulate the final settling process. The two examined systems were operated with the same sewage. Dissolved oxygen (DO), pH and temperature were measured regularly onsite.

Performance of the systems was individually evaluated, by analyzing the Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Volatile Suspended solids (TVSS), two times a week. All analytical procedures were carried out according to [12]. The characteristics of the raw sewage obtained from the present study were as follows: COD ranges from 700 to 1000mg/l, BOD ranges from 400 to 600mg/l, TSS ranges from 280 to 350 mg/l, TVSS ranges from 120 to 150 mg/l, and pH was around 7.

The DO values inside the aeration tank were maintained in the range of 1.5 - 4 mg/l for all runs. Shahzad et. al. [11] recommended DO values between 1.5 and 2.5 mg/l.

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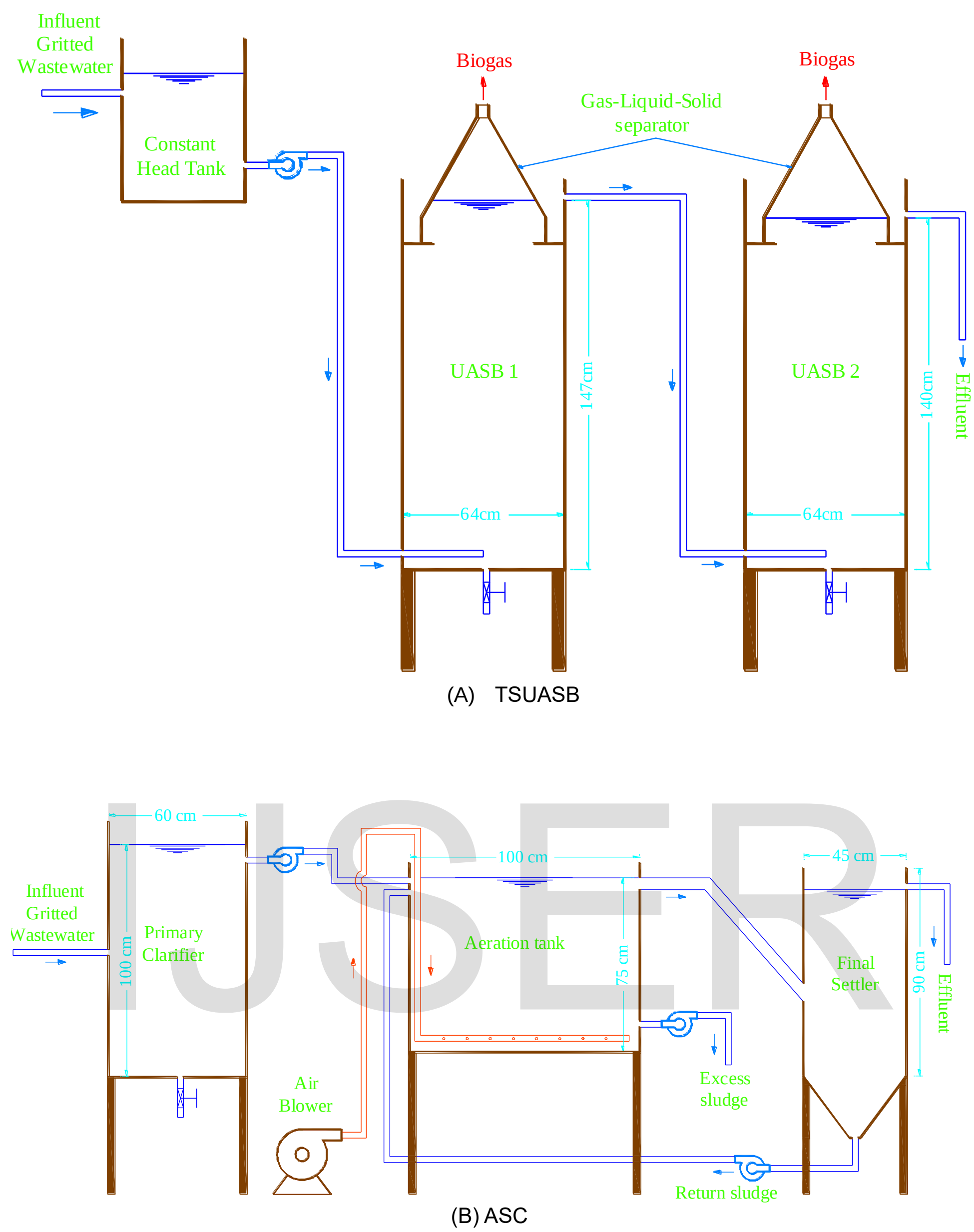

Figure 1 Schematic Diagram of the Experimental Test Rig

3 RESULTS AND DISCUSSION

Figures 2 illustrates the variation in the effluent COD and the performance of the reactors at different HRTs. The results show the comparison between TSUASB and ASC systems in terms of COD removal percent. The performance of UASB reactors was calculated by dividing the amount of COD removed by each unit with the initial influent COD of the overall system. The influent COD values were 700, 740 and 800 mg/l at HRTs of 4.5, 2.25 and 1.5hr respectively. The removal ratios for the ASC system were 88.6, 79.5 and 73.8% at HRTs of 4.5, 2.25 and 1.5hr, the corresponding removals percent for the TSUASB system were 79.3, 73.5 and 67.5% respectively. The results revealed that the removals of COD in the ASC were higher than that of the TSUASB system by a maximum value of about 9%. As expected, the removal efficiency for the two examined systems decreased as the HRT decreased.

The obtained removal ratios in the present study are comparable to the published results. For example, El-Sheikh et. al. [9] confirmed the present results and concluded that the mean values of the overall COD removal through the TSUASB reactors ranged from 65 to 83%. Also Yan at. al. [13] investigated two pilot-scale systems: an UASB reactor followed in series by a membrane bioreactor, and a single aerobic membrane bioreactor system, which were used to treat synthetic molasses sewage at HRT around 30h. The COD removal efficiency of the first stage UASB reactor was 71%. On the other hand, the overall COD removal of the single aerobic membrane bioreactor was 84%. The present results also approached the results presented by Navarro et al. [14], who concluded that; the removal efficiency of an activated sludge based conventional process reached 93%, at HRT equals 10hrs and influent COD of 697 mg/l, this removal efficiency of conventional ASC was also confirmed by Mehta et. al. [15].

In the present study, the ASC removal ratio at HRT of 4.5hr reached 88.5%, with better efficiency than the results presented by Hendy et. al. [16] who compared the performance of the ASC versus that of the Hybrid Moving Bed Biofilm Reactor (HMBBR) in the process of sewage treatment. The HRT of the aeration tank was 4hr. The values of effluent COD for AS system was 72 mg/l at influent of 430 mg/l, with removal efficiency equals 83%, this removal percent (83%) was also matched with the results observed by Shahzad et. al. [11]. Also Masse et al. [17] compared the removal efficiency for a submerged membrane bioreactor and a conventional ASC, at HRT (16h). The removal efficiencies based on total COD for ASC were ranged between 87.4% and 90.3%.

The present results also indicated that; for the TSUASB system, most of the organic matter was removed by the first stage, while the second stage improved the removal efficiency by about 3%. This observation was confirmed by other researchers. For example; Bruno and De Oliveira [8] evaluated the efficiency of the treatment of wet-processed coffee sewage in TSUASB reactors. The overall HRT of the reactors was 9.3 days. The average influent COD value was 13,890 mg/l. The first stage achieved 91% removal percent, while the second stage enhanced the COD removal by 4%.

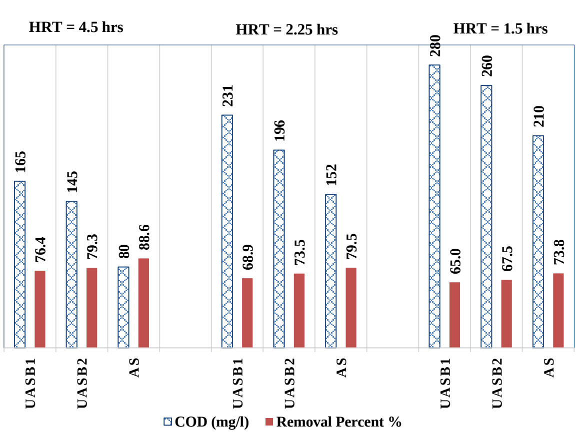

Fig. 2. COD removal percent at different HRTs

Figures 3 illustrates the variation in the effluent BOD and the performance of the reactors at different HRTs. The influent BOD values were 455, 480 and 520 mg/l at HRTs of 4.5, 2.25 and 1.5hr respectively. The removal ratios for the ASC system were 94, 89 and 86% at HRTs of 4.5, 2.25 and 1.5hr, the corresponding values for the TSUASB system were 84, 80 and 75% respectively. The results revealed that the removal of BOD has the same trend as that of COD. The ASC achieved higher removal than the TSUASB system by a maximum value of about 11%. As mentioned before; for the TSUASB system, most of the organic matter was removed by the first stage, while the second stage improved the removal efficiency slightly by about 2-4%.

The value of BOD effluent for ASC at 4.5 hr was 28mg/l, this observation was confirmed by Hendy et. al. [16] who examined a conventional ASC and observed that the BOD effluent at 4hr HRT was 23 mg/l.

The first stage UASB reactor achieved 82% BOD removal ratio at 4.5 hr HRT. This result was matched with that of Musa et. al. [5], who compared the performance of Conventional and Modified UASB reactors treating high-strength cattle slaughterhouse sewage, and concluded that the BOD removal ratio by the conventional UASB reactor reached 87% at 24hr HRT. It is worth mentioning that the present results were higher than the results observed by El-Sheikh et. al. [9], who concluded that the overall removal values of BOD for TSUASB reduced from 78 to 59% as the HRT decreased from 24 to 5hrs.

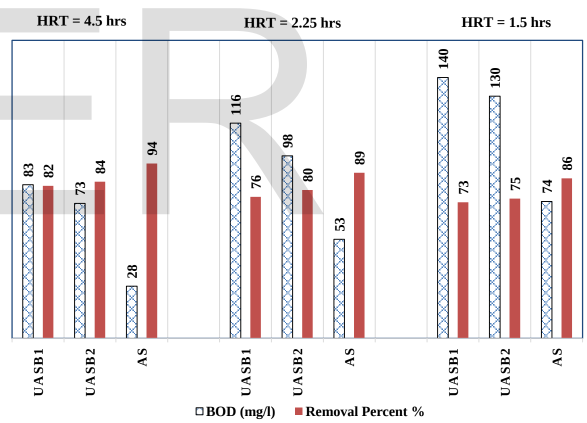

Fig. 3. BOD removal percent at different HRTs

Figures 4 and 5 illustrate the variation in the effluent and removal efficiency of suspended solids. The influent TSS values were 335, 325 and 288 mg/l at HRTs of 4.5, 2.25 and 1.5hr respectively. The corresponding values for TVSS were 114, 134 and 120 mg/l. The removal ratios of TSS for the ASC system were 87, 83 and 79% at HRTs of 4.5, 2.25 and 1.5hr, the corresponding values for the TSUASB system were 69, 65 and 63% respectively. These results were confirmed with other researchers such as; Navarro et al. [14] in their work observed that for the activated sludge based conventional process operated at HRT of 10hrs and was fed with TSS influent value equals 230 mg/l, the system achieved an effluent equals 19 mg/l with removal ratio equals 92%. The present removal efficiencies values were also confirmed by

Masse et al. [17].

For the TSUASB system; when the HRT was decreased, this resulted in higher up-flow velocity within the reactors. The TSS concentrations in the effluent showed a continuous increase leading to a trend of decreasing removal efficiency from 69 to 63% as HRT decreased from 4.5 to 1.5hrs. This declining efficiency occurred due to the increasing concentration of sludge formation in UASB reactors coupled with an increase in up-flow velocity. This led to a rise of the sludge blanket along with the reactor height. These results were matched with the results presented by El-Sheikh et. al. [9] who observed that as the HRT decreased from 24 to 5hrs the TSS removal efficiency declined from 79% to 60.4%.

The present results indicated that the second stage UASB enhanced the removal ratio of TVSS by about 5%. This result approached the result obtained by Bruno and De Oliveira [8] who evaluated the efficiency of the treatment of wet-processed coffee sewage in TSUASB reactors, and concluded that the second stage UASB reactor enhanced the TVSS removal by 9%.

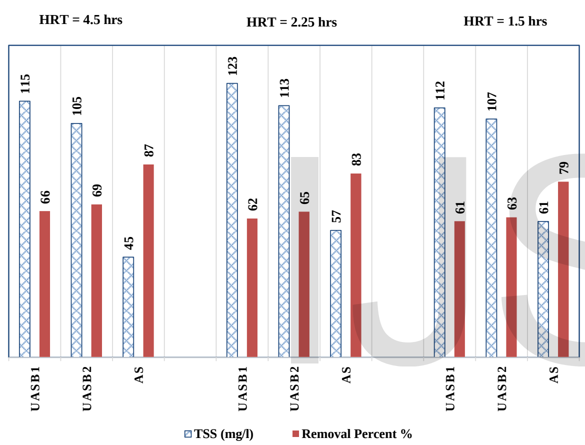

Fig. 4. TSS removal percent at different HRTs

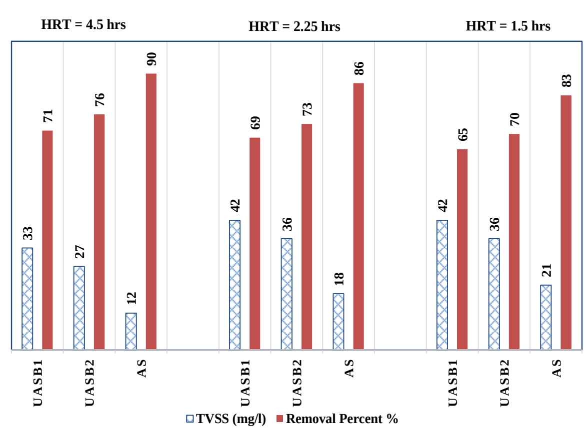

Fig. 5. TVSS removal percent at different HRTs

4 Conclusion

The present study is a comparison between pilot-scale TSUASB reactors (that is proposed as an appropriate sewage treatment technology for developing countries) and the ASC (the most popular sewage treatment system) at different HRTs. The study performed at a municipal sewage treatment plant. Based on the results of the current study, the following conclusions can be drawn:

1- The two examined systems show good performance stability even at high hydraulic loading rates. At HRT of 1.5hr; the BOD removal efficiency of the TSUASB was 75% compared to 86% of the ASC. These values were 68% and 74% for COD removals.
2- The organic removal ratios achieved by the TSUASB system were comparable to that of ASC, the later system achieved higher removal by about 10%.
3- The removal efficiency for the two examined systems (ASC and TSUASB) decreased as the HRT decreased.
4- Most of the organic matter was removed by the first stage UASB1, while the second stage improved the removal efficiency by only 2-4%.

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