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Pilot Plant Study on Biological Treatment of Domestic Sewage Using Biopipe System

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ABSTRACT

The Biopipe system is the first biological wastewater treatment system designed to remove carbonaceous and nitrogenous substances entirely within a pipe. The transformation mechanisms in the Biopipe system can be modelled using a physical model, and several experiments have been carried out to this study. The experimental work was carried out at the Al-Barakia wastewater treatment plant (BWWTP) in Iraq's Najaf governorate that will be done to obtain continuous source of sanitary sewage flow and thus, maintain the pilot plant operation. Two tanks, two pumps, a Flow Control and Measuring Device, PVC Pipes, and an Aeration System make up the physical model. Seeding using activated sludge from a similar plant, The Biopipe system requires 28 days to get steady results and maximal COD, TN and TSS removal efficiency. The tests were carried out on a Biopipe system with recirculation with different value of influent flow rate and different recirculation ratio. The most important findings of the Biopipe system application indicated that system is better for removing COD than TN. When the recirculation ratio was equal to 9, the removal efficiency of chemical oxygen demand (COD) and total nitrogen (TN) achieved 66.50% respectively. The dissolved oxygen concentration rises to 5.75 mg/l when the recirculation flow rate is increased to 216 m^3/day. In addition, it was found that the removal efficiency of biodegradable organics can be enhanced in case of low influent flow rate and high recirculation flow rate.

Keywords: biopipe system; aeration system; removal efficiency; recirculation flow rate.

INTRODUCTION

Biopipe is a biological treatment system by which the removal processes of carbonaceous and nitrogenous compounds are achieved entirely inside a pipe. It was invented by Misirli and Kutluca in 2013 [cited in Hariharan, 2016] and used in a variety of scales for treating domestic sewage in several places around the world. Biopipe system inventors and manufacturers indicated that it needs small footprint and thus its use can reduce the construction cost of wastewater treatment plant since the land expense forms an important part of wastewater treatment facilities' cost. They indicated, also, that Biopipe system is odorless, generates no sludge, and its final effluent has a quality that satisfied the EU Standards [Biopipe g.c., 2016]. In Iraq, such a treatment system is important, particularly for public facilities such as colleges, hospitals, and residential compounds built in the latest years. That is because the sites of these facilities frequently include green areas, and thus, the use of a Biopipe system can help to conserve the environment beside using the produced effluent for irrigation purpose.

The aforementioned Biopipe system characteristics have not been verified by any of the previously published studies. Thus, the current study aims to study the performance of Biopipe system in treating domestic sewage using a pilot plant. The outcomes of this study can expand the data circle of Biopipe system design and operation beyond that of its developers.

Although no previous research has demonstrated Biopipe system performance, investigations on biodegradation concept of organic compounds in sewers may reveal the conceptual origins of treating sewage inside a pipe. Many researchers investigated this concept in gravity sewers. Garsdal et al. (1995) showed the increase of soluble substrate removal and biomass growth as sewage flows towards the sewer end. Ozer and Kasirga (1995) developed a table relating the sewer length and diameter and to COD removal efficiency and showed that the COD removal efficiency is directly proportional to the sewer length and influent substrate concentration. Seidl et al. (1998) indicated that organic matter biodegradation rate is decreasing along with the sewer. Hvitved-Jacobsen et al. (2002) investigated the chemical and microbial transformation processes in sewers under dry weather conditions. They pointed out that the sewer behaves as a chemical and biological treatment system and if aerobic condition is preserved, the activity of heterotrophic bacteria will be high which may lead to organic matter removal and production of biomass.

Tanaka and Hvitved-Jacobsen (2000), Almeida et al. (1999), Huisman and Gujer (2002), Jiang et al. (2007), Ilie et al. (2018) developed a numerical model for simulating the biodegradation of organic matter in a gravity sewer and showed that the percentage of BOD_5 removal by microbiological activity in a sewer of 4900 m length was 35.44%. Zhao et al. (2019) simulated wastewater quality changes in a gravity sewer using a modified ASM in which anaerobic fermentation was incorporated.

Pai et al. (2010) investigated wastewater quality changes in a trunk sewer and pointed out that organic matter decay, nitrification, and denitrification processes occurred in the sewer.

Some of previous studies investigated the biodegradation of organic matter in force mains (pressurized flow system). Tanaka and Takenaka (1995) showed that air injection into a force main can reduce the BOD at percentages dependent on wastewater temperature.

MATERIAL AND METHODS

Pilot plant description

A pilot plant for the Biopipe system has been constructed and installed in AL-Barakia sewage treatment plant (ALBSTP) in Al-Najaf governorate, central Iraq, to maintain the durability of domestic sewage influent flowrate. The influent of the pilot plant was the settled sewage withdrawn from the effluent of primary sedimentation unit in ALBSTP.

Figure 1 shows a schematic diagram for the pilot plant of Biopipe system. It shows that the components of the pilot plant include; Biopipe, influent tank, aeration system (Venturi injector), and final settling tank, beside pumps, flow meters, pressure gauges and valves.

The Biopipe is a PVC pipe of 100 mm diameter and 70 m length. The influent tank is

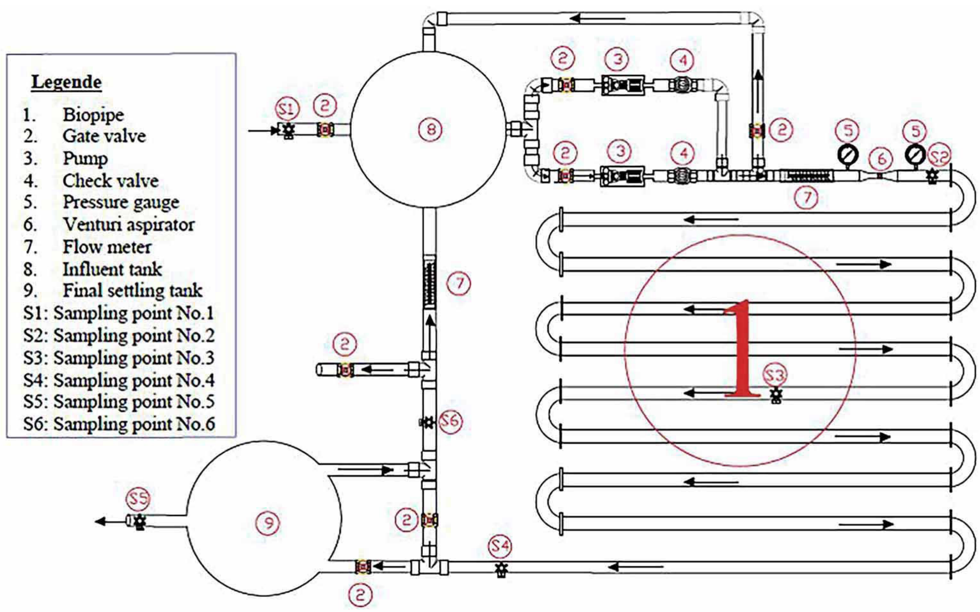

Figure 1. Schematic diagram of Biopipe system pilot plant

cylindrical and has a capacity 1 m^3. It has three inlet pipes and one outlet pipe. The first inlet pipe, which is connected to the primary sedimentation tank effluent in ALBSTP, transports the settled sewage to the tank. The second inlet pipe, which is connected transports the recirculate sludge to the tank. While, the third inlet pipe is used for controlling the influent flow to the Biopipe.

The outlet pipe of the influent tank is connected to the Biopipe, i.e., it represents the influent pipe of the Biopipe. The pilot plant includes two centrifugal pumps (one working and one standby) for withdrawing the sewage from the influent tank and pumping it to the Biopipe. The pumps are similar (Pentax pump model), each has capacity and head values vary over the ranges 100–450 l/min. and 10.6–26.3 m, respectively. The pumps were alternatively operated using a timer control connected to an electrical control panel. Figure 2 shows the Biopipe pilot plant in the field.

The Biopipe was maintained to be an aerobic system by supplying it with air using Mazzei Venturi air injector, model 1584, Figure 3.

The principle of air supply using Venturi air injector (VAI) is based on pressure drop at the contracted section (throat), where the reduction in flow cross-sectional area at the throat increases the flow velocity and subsequently the kinematic energy. According to conservation of energy law, the increase in kinematic energy will drop the pressure in the throat to be below the atmospheric pressure (vacuum) which leads to air suction via the suction port.

The inventers of Biopipe system have applied this aeration technique, in addition to a number of researchers who applied this technique to aerate water flowing in pressurized pipes such as; Ozkan et al. (2006), Zhu et al. (2007), Baylar et al. (2009), and Bagatur et al. (2018).

The final settling tank has a capacity of 1 m^3. It received biologically treated sewage from the Biopipe end. The underflow of this tank (settled sludge) is recirculated to the influent tank while the overflow represents the plant effluent. The pilot plant includes two flow meters to measure the mixed liquor flowrate and recirculated flowrates. It, also, contains two pressure gauges which are essential to monitor VAI operation. The pilot

Figure 2. Pilot plant components

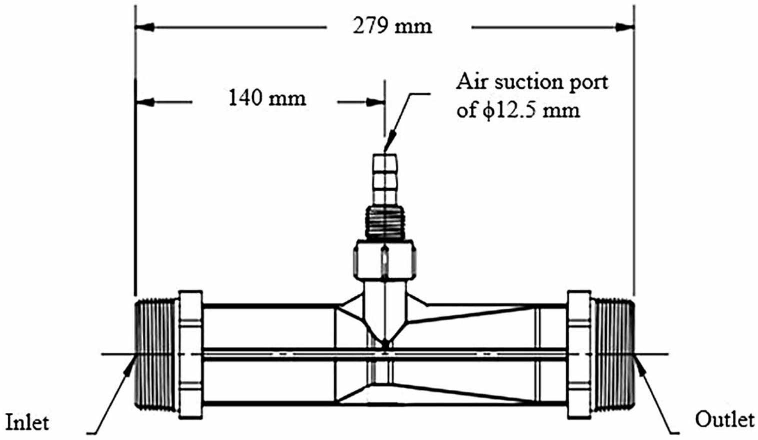

Figure 3. Mazzei VAI, model 1584 (Mazzi I.C., 2016)

plant operation was controlled by closing and opening the gate valves.

The pilot plant was provided with six taps to be sampling points as shown in Figure 1. The locations of sampling point Nos. 1, 2, 3, 4, 5, and 6 were at influent pipe, 1.5 m downstream from VAI, mid span of Biopipe, 3 m upstream of final settling tank, effluent pipe of final settling tank, and at sludge recirculated pipe, respectively.

Pilot plant startup

One of the most critical stages of biological treatment system operation is the start-up period. The plant startup requires careful attention, since the incorrect start-up can cause system failure. After completing the pilot plant installation, its operation was started by; (1) filling the influent tank with settled sewage, (2) adding an activated sludge (seeding of biomass) from a nearby sewage treatment plant to the influent tank at a percentage (7%), and (3) operating the pilot plant with nearly all the treated sewage was recirculated to the influent tank. The time required to complete the startup period was determined by continuous monitoring of plant performance in removing the chemical oxygen demand (COD) and total nitrogen (TN) in samples withdrawing from sampling point Nos. 1 and 5.

Measured parameters

During the course of pilot plant operation, samples were drawn from the six sampling points and analyzed for COD, dissolved oxygen (DO), TN, total suspended solids (TSS), pH, and temperature as shown in Figure 4. During this experiments period, PH levels varied from (7.3

Figure 4. Sampling point

to 9.2) while temperature values ranged from (33 to 49°C)

The plant efficiency in removing the COD and TN was assessed based on the values of these two parameters in samples withdrawn from sampling point No.1 (plant influent) and sampling point No. 5 (plant effluent).

RESULTS AND DISCUSSION

The pilot plant was used to study Biopipe system performance under the impact of influent flow rate and recirculation ratio. The system performance was measured in terms of COD and TN removal efficiencies.

COD and TN during the startup period

The temporal variations of influent and effluent COD values are illustrated in Figure 5. This figure shows that, the difference in influent and effluent COD values increased and became significant after thirteen days from the start of pilot plant operation. It shows also that the effluent COD fluctuated according to the fluctuation of influent COD. After 28 days of pilot plant operation, the effluent COD dropped to a value of 66 mg/l. Change in COD concentration indicates the start of aerobic processes in the physical model (Biopipe system). The COD concentration in the influent wastewater varies between 60 and 180 mg/L. The Biopipe system effluent follows the same tendency.

The higher the influent COD measured as the running time increased, while the low value measured at the same time decreased. Because the microorganisms are still in the domestication and screening stages, the Biopipe system removal rate is less than 20% for the first six days. Biopipe removal efficiency varies from 20 to 59 percent when the running time is between 7 and 13 days.

After the 13th day of operation, rising influent COD has no influence on removal efficiency, which could be attributable to the development of microbes with increased organic nutrition. The COD removal rate becomes more stable as the running time increases. After 28 days of operation, the removal rate was over 86 percent, and the effluent COD concentration was 66 mg/l.

The concentration of TN in the influent ranged from 20 to 55 mg/l, as shown in Figure 6. The concentration of TN in effluent exhibits a similar trend throughout the first seven days. The effluent concentration dropped to (10–12 mg/l) after this period.

The TN elimination rate can reach more than 32% in the first four days of the system. After seven days of operation, the removal efficiency increased by 60%. At 22 days after the operation, the maximal removal rate was over 75%.

Total suspended solid during the startup period

Figure 7 shows the temporal fluctuations in influent and effluent (TSS) readings. It is evident that the start of operation The concentration measurements entering and exiting the station are not significantly different from one another. The performance of the startup, as well as microbial growth and degradation, would be limited if mass transfer was minimal owing to low hydraulic load in the feed. When activated sludge and medium were mixed together, hydraulic circulation improved the transfer of mass between the two.

The effluent (TSS) concentrations at the pilot scale have improved during the course of the first five days of operation. when the entering and leaving concentrations are clearly different.

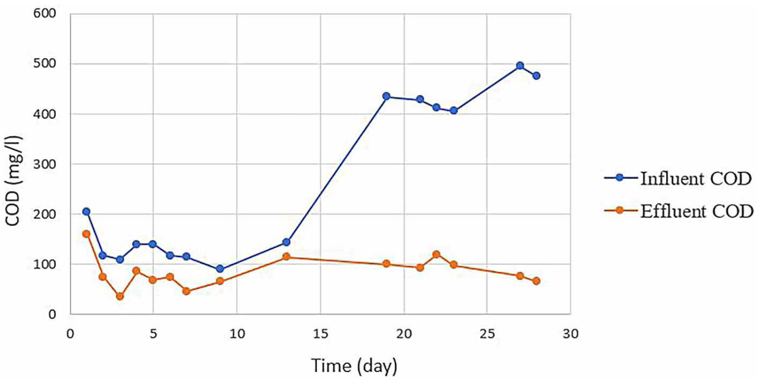

Figure 5. Temporal variation of influent and effluent COD values during the startup period

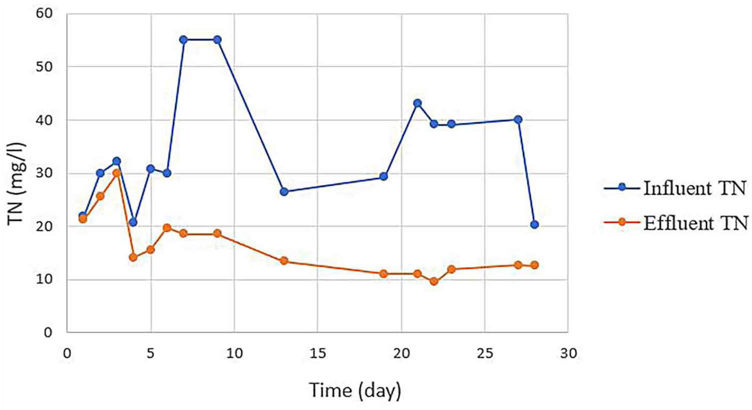

Figure 6. Temporal variation of influent and effluent TN values during the startup period

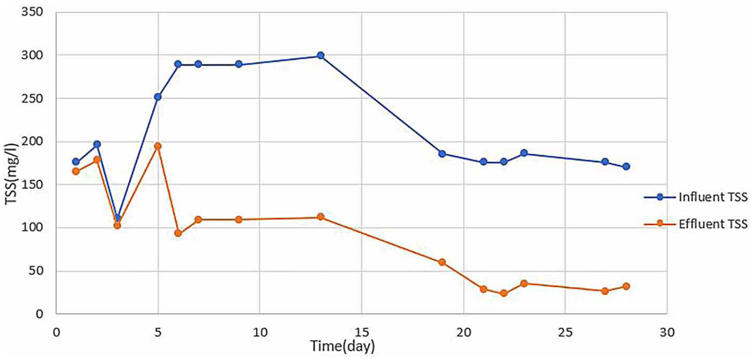

Figure 7. Temporal variation of influent and effluent TSS values during the startup period

As a result, the last week of operation yielded (23–35 mg/l) outgoing concentration values, that means that 28 days is the optimal period for seeding.

Removal efficiencies of COD and TN

As illustrated in Figure 8, the removal efficiency of the Biopipe system increases as the influent flow rate is reduced.

At a given influent flow rate, it is obvious that this system eliminates COD more effectively than TN. For example, COD removal is greater than 86 percent when the waste water flow rate is 36 m^3/day while TN removal is 75%.

The influent flow rate was stabilized at 24 m^3/day to investigate the influence of recirculation flow rate on removal efficiency, and the recirculation flow rate was gradually reduced to indicate their effect on removal efficiency. The removal efficiency increases as the recirculation flow rate is raised, as seen in Figure 9.

The removal efficiency of COD and TN was improved by raising the recirculation ratio, which resulted in more mass liquor suspended solid (MLSS) being introduced into the influent tank.

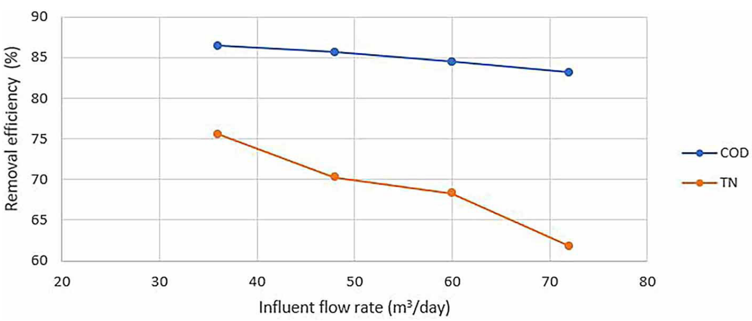

Figure 8. Effect of influent flowrate on COD and TN removal efficiencies

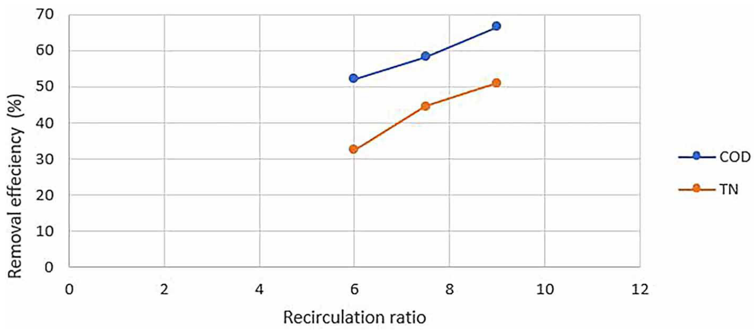

Figure 9. Effect of recirculation ratio on COD and TN removal efficiencies

COD removal exceeds 66 percent at a given recirculation flow rate (R = 9), while TN removal exceeds 50 percent.

DO concentration with different recirculation flow rate

Sufficient dissolved oxygen is a significant indicator of water quality and is required for aerobic biological treatment of waste water. As previously stated, this study used a new technique (venturi aspirator) to supply air or dissolved oxygen. Every 8 hours, oxygen dissolved as measured with a calibrated portable (B.C OD 125.2) DO meter at a sampling location (point 2, 3, 4, 6) to monitor the level of dissolved oxygen. Figure 10 shows that dissolved oxygen concentrations rise over time as the total flow rate (influent flow rate + recirculation flow rate) rises, while Figure 11 shows an increase in DO as pipe length increases all the way to mid length, but little depression occurs at the remining length.

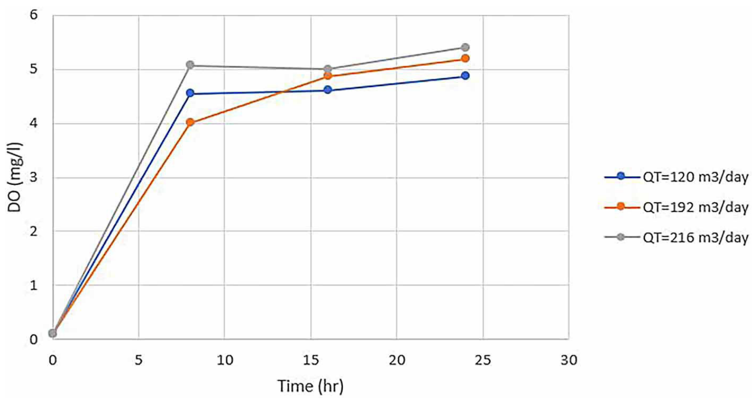

Figure 10. Temporal variation of DO concentration at different total floe rate

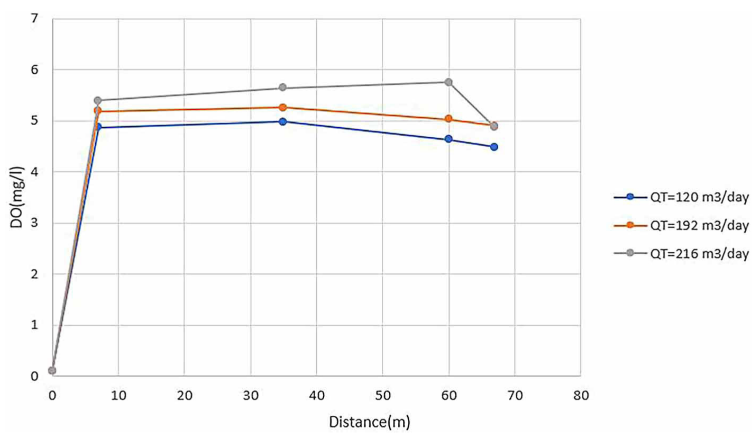

Figure 11. Longitudinal distribution of DO concentration

CONCLUSIONS

A pilot plant, has been constructed to investigate the performance of Biopipe system in treating domestic sewage. The main findings of this study are:

1. The system requires 28 days to get steady results with high COD and TN elimination efficacy.
2. After 20 days following seeding, effluent total suspended solid reached its lowest point and fluctuated between (35–23 mg/l).
3. COD removal rate is higher in this system than TN removal rate.
4. In order to improve removal efficiency, the influent flow rate must be reduced while the return flow rate must be increased.
5. With increasing total flow rate, higher dissolved oxygen levels are achieved, reaching 5.75 mg/l at 216 m^3/day of total flow rate.

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