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RESEARCH PAPER

Pilot plant investigation on the start-up of a USAB reactor using sugar mill effluent

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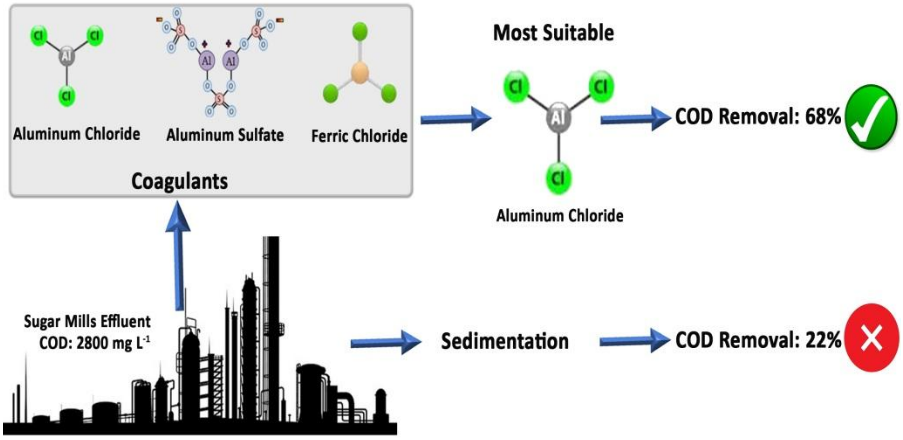
Highlights

- The use of alum in sugar mills effluent treatment is cost-effective and available.
- Water pollution and the shortage are now at a warning level in Pakistan.
- Major of parameters were not in Pak-EPA NEQS limitations in the studied area.
- The application of the UASB reactor is an entirely achievable and viable option for reducing the pollution load of sugar mills outflow.

Graphical Abstract



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Abstract

The existing pollution in the environmental system is adversely deteriorated by the disposal of untreated domestic and industrial effluent. Moreover, in developing countries, the current and emerging energy crises compel to work out the treatment technologies that should not only reduce the pollution load but could also be able to assist in solving the energy problems. The anaerobic digestion process not only reduces the high strength pollution load but it also converts the wastes into biogas. Since in Pakistan, some sugary mills are discharging their organic-rich wastes without any proper treatment or utilization, therefore, using actual sugar mill effluent at constant pH and temperature this study was designed to evaluate and study the start-up of the UASB reactor. It was noticed during the study that at an organic loading rate of 2.1 kg-COD/m^3-day and a hydraulic retention time of 16 hours, more than 70% of COD could be reduced. It was observed that in terms of COD decreasing the longer retention time appears to be more encouraging and vice-versa. The average VFAs 340 mg/L and biogas generation 0.30 L/g-CODrem-d was observed, respectively. And 58-59% composition of methane was found there. The results of this study insinuate that to reduce the pollution load of sugar mills outflow, the use of the UASB reactor at neutral pH and mesophilic range of temperature is a quite achievable and viable option.

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1. Introduction

Pakistan's resources of water have been declining day by day due to a variety of environmental and inappropriate water management factors resulting in a severe water shortage. Also, due to the disposal of untreated domestic and industrial effluents and agricultural/surface runoffs into the receiving watercourses, the approachable water is being polluted at a shocking rate. Owing to which the clean drinking water is available for use by only 18% of the population, and the rest of the 82% population is using unsuitable drinking water (Ahmed et al., 2015). In addition to a deficiency of water, it is an admitted reality that although Pakistan has a vast potential of its production still lacks the energy sector. The limitation of energy sources is not only bound to electrical energy, but the bio-gas also has a significant contribution in this sector, almost equivalent to 37%. Since it's the most environmentally friendly and economical source of energy, therefore, it needs more attention to tackle the issue of energy crises (Ali et al., 2010).

Industrialization plays an important elemental roll in the country's financial system. In the current situation, more than seventy-five sugar mills are present throughout the country, nearly all of the base on sugar cane. The environmental concerns associated with sugar manufacturing consist of air and water pollution and the disposal of solid wastes. Wastes generated during the process in sugar mills are rarely reused or converted into by-products in Pakistan. Millhouse, process house, boiler house, and cooling pond are the primary water pollution sources within the sugary industries. Moreover, most of the solid wastes are generated by a mill house, process house, and boiler house, whereas the boiler house is responsible mainly for the release of flue gases. The effluent of sugar mills usually contains a high concentration of suspended solids (SS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD). About 240 m^3 per ton of sugar produced from wastewater, and 112 kg suspended solids (SS), 65 kg biochemical oxygen demand (BOD), and 195 kg chemical oxygen demand (COD) generated respectively. And without any treatment, all these wastes are disposed of, which is absolutely an environmental hazard (Albrizio et al., 2017).

Therefore, wastewater treatment is not only a crucial obligation to secure the environment, but a useful end-product like biogas might generate from it. Although better treatability performances were shown by physiochemical methods, but are still proved very costly on field-scale application. Thus biological treatment systems should be more emphasized in developing countries (Bhatti et al. 1996; Lu et al., 2017). Primarily the two main kinds of biological treatment methods are; aerobic process and anaerobic process. Since the aerobic methods are costly due to the necessity for large input of energy, therefore, potentially the use of anaerobic methods are one of the most appropriate options left to treat a large number of industrial effluents which are in practice due to its cheaper costs (Rosas-Mendoza et al., 2018). For the better treatability performance of industrial and different domestic effluent, the anaerobic methods drastically recognize throughout the world (Schellinkhout, 1993).

The emergent acceptance of anaerobic digestion as an easy, technically feasible, inexpensive, intensified, well-organized, and efficient waste treatment technology makes it a possible solution for the control of pollution. The efficient treatment of various kinds of wastes is generally carried out by the compact structure of an up-flow anaerobic sludge blanket (UASB) reactor (Sun et al., 2018). Therefore, this study designs to investigate the start-up of the UASB reactor by the usage of actual sugar mill effluent. To examine the effects of design parameters like organic loading rate (OLR) and hydraulic retention time (HRT) was the critical objective in the treatability performance and bio-gas production determination under constant pH (neutral) and temperature in potential UASB reactor.

2. Materials and Methods

2.1. Experimental UASB reactor

A UASB reactor was utilized in this study, made up of PVC material with a total efficient volume of 6.5 liters. The reactor was equipped with a water jacket to keep a steady temperature, and it also designs to have a mixing apparatus and gas-solid separator (GSS).

2.2. Substrate and nutrients

For the sole carbon source, actual sugary wastes are utilized to feed over in tributary (influent). The addition of Nitrogen and Phosphorous was in the form of $(NH_4)_2SO_4$ and KH_2PO_4 in harmony with the COD: N: P ratio of 550:5:1, also a minor concentration of the trace nutrients were added (Urasaki et al., 2019).

2.3. Seed sludge

After acclimatization with sugary wastes for a couple of days in the laboratory, digested sludge seed in the UASB reactor. The characteristics of the seeded sludge at the start-up process of the reactor are shown in Table 1 about 35 grams of volatile suspended solids (VSS) are provided by the seeded sludge. A stepwise increment in the organic loading rate is done to avoid organic loading shocks. Mixing was done 2-3 times a day. The monitoring of hydraulic retention time (HRT) was also carried out.

Table 1. Characteristics of Seeded Sludge

Parameters	Value
Total Solids, TS (mg/L)	84
Total Suspended Solids, TSS (mg/L)	49
Volatile Suspended Solids, TVS (mg/L)	35
Color	Blackish

2.4. Operational conditions

About 30-33 °C was the temperature maintenance level, similar to that of the wastewater during the study duration. pH was kept controlled at about 7.0 by adding $NaHCO_3$ to the feed solution in the reactor. The reactor was started-up in stepwise loading rates starting from 0.01 kg-COD/m^3.day to 2.45 kg-COD/m^3.day to avoid any organic shocks to the reactor. A slight decrease from 86 h to 12 h in the HRT was carried out.

2.5. Monitoring and analysis

Temperature, pH, influent and effluent COD, VFAs, and gas production were monitored regularly; 2 times every week. Gas was collected by tap water saturated with NaCl. All analysis was performed according to the Standard Methods.

3. Results and Discussion

The COD removal efficiency and the gas production were observed in an account for various HRT and OLR at constant temperature and pH during the study duration.

3.1. Treatability performance of the reactor

The two very significant and principle operational parameters of anaerobic digestion are pH and temperature. The most favorable pH, in the beginning, was reported as 5.5-6.0, but due to the detection of human microbial activities, the neutral pH was considered the best appropriate range concluded afterward for the anaerobic digestion (Pol and Lettinga, 1986; Urasaki et al., 2019). As a result, in this study, $NaHCO_3$ was introduced as an external buffer together with the feed solution to keep the pH of the reactor close to neutral. Moreover, in normal conditions, the 30-40 °C mesophilic range is well-thought-out to be the most suitable range of temperature due to some possible operational problems associated with the unstable weather during the anaerobic digestion. (Henze and Harremoës, 1983). For this reason, in this study, the reactor's temperature was reserved constant at about 31°C by means of an external heating and thermostatic device system. The time course of pH and temperature throughout the study period is revealed in Fig. 1. Initially, the reactor's pH, varying from 4.0-5.6, was acidic, but later on, by adding 60 mL of 0.5 M $NaHCO_3$ per liter of the feed solution, it was controlled approximately to neutral. 6.7 was the observed average pH obtained during the study phase.

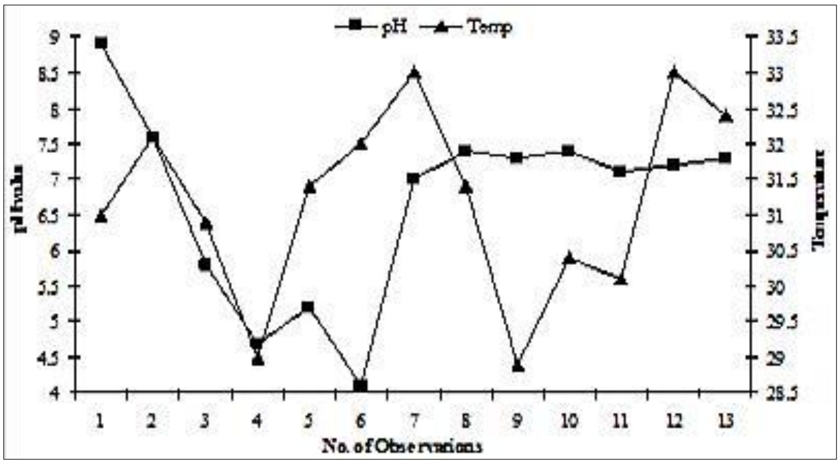

Fig. 1. Time course of pH and temp during the study period.

It was noticed that the manufacture of bicarbonate alkalinity was considerably affected by the reactor's pH level. There will be more production of bicarbonate alkalinity with a higher pH level of the system and vice-versa. Figs 2 and 3 represent the effects of pH on COD removal efficiency of the reactor and the development of volatile fatty acids (VFAs) within the system.

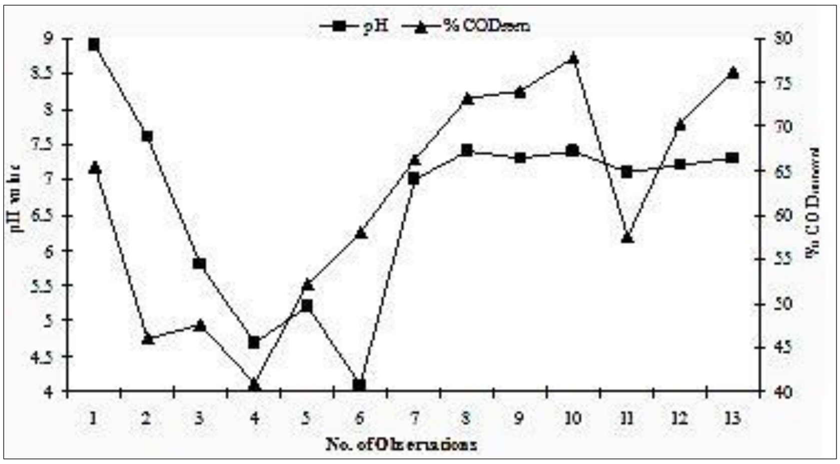

Fig. 2. Effect of pH on the COD removal efficiency of the reactor.

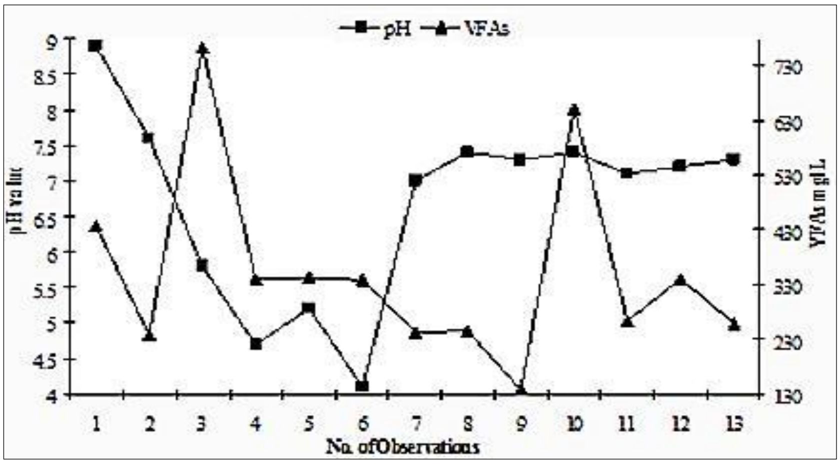

Fig. 3. Effect of pH on the VFAs formation within the reactor.

If the reactor's pH is reserved at neutral, then the pH effect over the COD deduction efficiency illustrates 68% removal of the COD. The concentration of waste matter COD can be dropped down with no trouble by maintaining a pH of about 7.0 to the limitations lay down by the local effluent discharge standards of Pak-EPA.

Considerably pH depended parameter whose higher concentration in the reactor's effluent validates the incompetence of the reactor to change acetic acid into methane is VFAs. As the pH was neutral; therefore, during this approach, the average VFAs construction was seen as 340 mg/L, which means they were at an adequate lower concentration. The maximum development of VFAs, i.e., 753 mg/L, was seen when the pH of the reactor was dropped down to 5.6, as revealed in the figure. Consequently, just 47% of the COD was observed to be removed at this stage of the study duration.

By the reactor's percentage COD removal efficiency, the reactor's treatability act is estimated. It is shown by the current study that the COD removal at constant pH and temperature is deeply dependent on HRT and OLR, as mentioned in Figs. 4 and 5. In terms of declining the COD concentration, more extended retention periods emerge to be more encouraging and vice-versa. More than 70% COD reduction was observed the same as in the time of the initial phase of the conducted test, while the HRT was at higher rates. But during the process, some additional parameters also play a crucial role. As shown, 40% of the least exclusion of COD was noticed at 46hours of HRT, but that might be due to the fall of pH to 4.7 and also the extreme buildup of VFAs within the system. When the average HRT was lower, 76% maximum COD was seen i.e. 18hours, and the OLR was 2.1 kg-COD/m^3-day, but the reactor's pH at that phase was neutral, indicating the influential performance of the UASB reactor's pH also. This shows that neutral pH gives better treatability results.

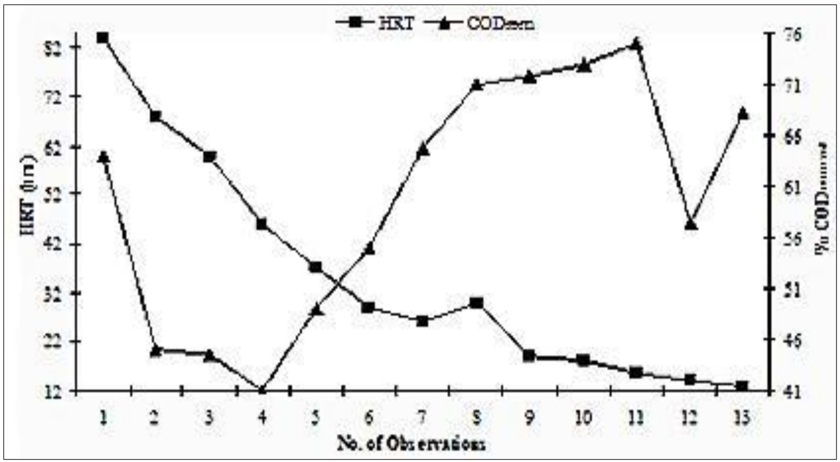

Fig. 4. Effects of HRT on the COD removal efficiency of the reactor.

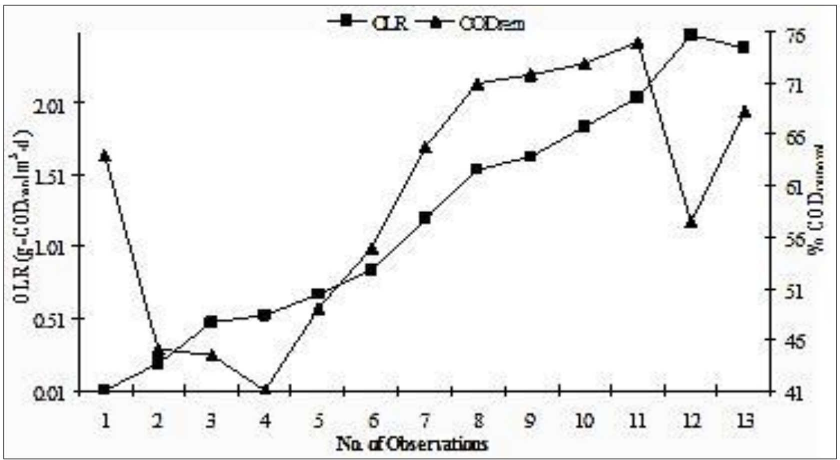

Fig. 5. Effects of OLR on the COD removal efficiency of the reactor.

The reactor's minimum COD elimination efficiency was observed during the start-up phase, and that was mainly due to the variation in the flow or might be due to the short acclimatization of seeded sludge with the sugary wastes. Raise in the reactor's COD removal efficiency was noticed in each phasing stage after launching steady operating circumstances corresponding to a constant OLR. And it was notified that there was an abrupt decrease in the COD removal efficiency with the increase in the OLR in each step, which might be due to the more VFAs formation within the reactor. In terms of treatability performance, the current studies indicate a very close resemblance to the previous similar work is done (Dos Santos et al., 2016; Schellinkhout 1993; Seghezzo et al., 1998). The average COD removal that could be accomplished at neutral pH and mesophilic range of temperature, subsequently to an OLR of 1.2 kg-COD/m^3-d, was noticed as 62%. And this amount of efficiency could quickly meet the requirements of the local effluent discharge standard set by Pak-EPA.

3.2. Biogas generation within the reactor

From the start of the study period minute, gas bubbles notice with the help of a saturated NaCl solution, and the generated biogas collection is done as per standard technique. The generated biogas amount during the study period is revealed in Fig. 6.

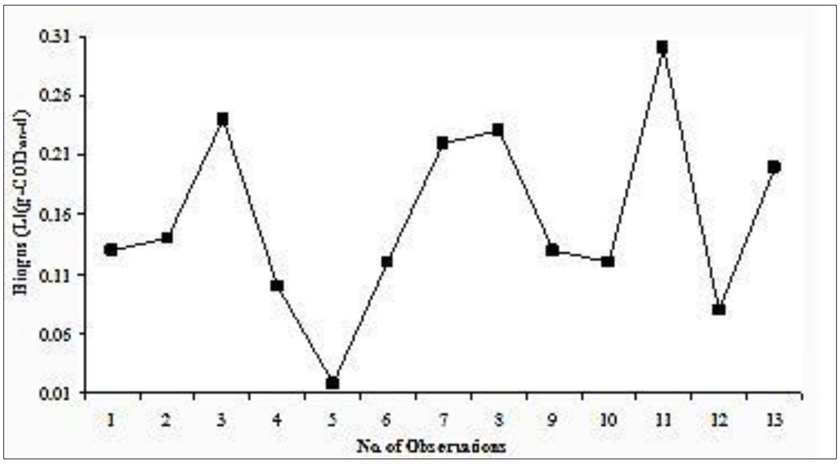

Fig. 6. Amount of biogas generated during the study period.

The lower biogas production was observed as 0.01L/g-COD_{rem}-d, and this is due to the reason that at this stage, the concentration of VFAs within the system was considerably high. That had decreased the number of methanogenic bacteria within the reactor, and the facultative microbes had become dominant over it. The average biogas generation was determined as 0.30 L/g-COD_{rem}-d, with average methane composition of 58-59%. This shows that the operating conditions within the reactor were a little bit unfavorable for the hydrogen-producing acetogenins to convert the VFAs to acetate and then to methane, or the sugary wastes may contain certain recalcitrant material that inhabits the microbial activity to give better methane composition.

4. Conclusions

a) The technique of using the UASB reactor at neutral pH and mesophilic range of temperature is quite a feasible and viable option to reduce the pollution load of sugar mills effluent.

b) The volumetric loading rate of 2.1 kg-COD/m^3.day and an HRT of 16 hours at steady-state operating conditions are the conservative figures that warrant a removal efficiency of more than 70%. Thus for practical purposes, the UASB reactor could be efficiently designed to treat sugary wastes working at such optimum operating conditions to achieve the desired efficiency as per the required effluent disposal standards.

c) The biogas generation rate of 0.30L/g-COD_{rem}-d suggests that by supporting such treatment techniques, not only the pollution load will be reduced, but also the existing energy crises could tackle to a certain extent.

For sugary wastes based on sugar cane under changeable environmental and operating conditions, a long-standing and comprehensive study is mandatory to examine the actual performance of the UASB reactor, mainly to study the consequence of changeable pH of the treatability performance. And the expenditure of developing the UASB technology on a larger filed scale and its technical and supervision skill are required to be determined and assessed.

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