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Performance Evaluation of a UASB Reactor Using Dairy Wastes

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A UASB reactor of 6-litre capacity, made of acryl material, was operated continuously for 20–22 weeks in three different phases, using actual dairy mill effluent at a constant mesophilic temperature and neutral pH. The dairy wastewater was highly alkaline, turbid and milky in colour with a bad odour. The average COD and BOD concentrations of the dairy mill effluent were observed to be 2945 mg/l and 1070 mg/l, respectively. Phase I was the start-up phase, with OLR of 0.13 g COD/l.d. SLR, effluent VFAs, effluent TSS, biogas production and methane composition observed during this phase were 1.4 g COD/g VSS.d, 1240 mg/l, 240 mg/l, 1.74 l/COD_{rem}.d, and 62%, respectively. The overall observed biomass yield was found to be equal to 0.034 g VSS/g COD_{rem}. During phase II, the optimum pH was determined to be 6.8–7.1. In the last phase, phase III, the effects of OLR and HRT were observed. The optimum OLR and HRT were observed to be 4.76 g COD/l.d and 16 h, respectively. Correspondingly the COD removal efficiency, effluent VFA and TSS concentrations, and the amount of biogas production were observed to be 78%, 770 mg/l, 300 mg/l and 2.07 l/COD_{rem}.d, respectively. The results of this study suggest that a UASB reactor is an effective tool and viable option for reducing pollution from dairy mill effluent.

Key words: Dairy mill effluent; UASB reactor; COD; biogas; anaerobic digestion, OLR, HRT, pollution; treatment efficiency; wastewater

Nomenclature

COD	Chemical oxygen demand
BOD	Biochemical oxygen demand
HRT	Hydraulic retention time
OLR	Organic loading rate
CNP	Carbon-nitrogen-phosphorus
VFA	Volatile fatty acids
TSS	Total suspended solids
SLR	Solid loading rate
UASB	Up-flow anaerobic sludge blanket

Pakistan is a water-stressed nation, where per capita water availability is decreasing very rapidly due to many reasons, such as environmental pollution and improper water management. Furthermore, its existing water sources are also being polluted at an alarming rate due to the disposal of untreated domestic and industrial effluents into surface water sources (Pak-EPA 1999). Agricultural run-off too is a major cause of water pollution. Due to

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these factors, safe drinking water is available only to a limited proportion of the population, *viz*. about 20% (PCRWR 2005).

Different physio-chemical and biological methods have been developed for waste reduction. Due to the relatively high capital cost of the physical units, their use is not much encouraged for treatment on a large scale; thus, the biological methods are mostly preferred. Biological treatment is of two main types, namely aerobic and anaerobic. For developing countries, the anaerobic process is ideal because of their lower input of energy and nutrient requirements (Bhatti *et al*. 1996, Savant *et al*. 2005). The use of anaerobic technology is widely known for its simple design, compact structure, and low operational and maintenance costs. They can be used for the treatment of a variety of domestic and industrial effluents (Lettinga *et al*. 1984).

There are several anaerobic units operating throughout the world for the treatment of various types of pollutants. Their treatment efficiency in terms of pollution reduction is highly acknowledged (Hulshoff 1986; Schellinkhout 1993). However, treatability performance of the UASB reactor, using actual highly alkaline dairy mill wastes at the mesophilic temperature range still seems to be not convincing enough because the results from available studies do not precisely indicate the effects of the organic loading rate (OLR) and the hydraulic retention time (HRT) on COD reduction and biogas yield in the kinds of wastewater studied (Orhon 1993; Ozturk 1992). Therefore, this specific study was conducted in a single-stage UASB reactor, by using actual dairy mill effluent. The main objectives of the study were to evaluate the treatability performance of the anaerobic digestion system at varying OLR and HRT, and to determine the biogas production potential of a local dairy mill.

MATERIALS AND METHODS

UASB Reactor

A UASB rector of 6-litre capacity, made of acryl material, was used in the study. The

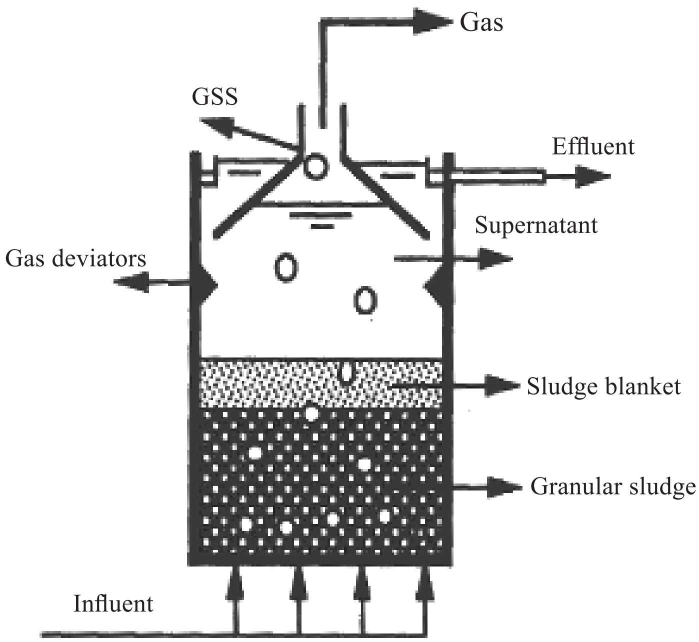

Figure. 1. Systematic diagram of a UASB reactor.

reactor was equipped with a water jacket to maintain a constant required temperature. It was also provided with a proper gas solid separator (GSS) and a mixer device to facilitate the mixing of the biomass and the substrate (Bhatti 1995). A systematic diagram of the UASB reactor is shown in *Figure 1*.

Substrate and Nutrients

Actual dairy mill effluent was used in the study as the sole carbon source for the reactor. Nitrogen and phosphorous were added in the form of $(NH_4)_2SO_4$ and KH_2PO_4, respectively, in accordance with the C:N:P ratio of 350:5:1. Trace nutrients were also added in the concentrations shown in *Table 1* (Lettinga *et al*. 1980).

Table 1. Concentrations of the trace nutrients.

Trace Nutrient	Concentration (mg/l)
$FeCl_3.6H_2O$	4.90
$CoCl_2.6H_2O$	0.30
$ZnSO_4$	0.35
$CaCl_2.2H_2O$	0.35
$CuSO_4$	0.09

Wastewater Characteristics of the Dairy Mill

The wastewater characteristics of the nearby dairy mill were studied by collecting various composite and representative samples from it. The data obtained are shown in *Table 2*. The findings indicate that the dairy mill discharged highly polluting effluent, both in terms of physic-chemical and aesthetic parameters. The samples were highly turbid and milky in colour with a bad odour. The average COD and BOD concentrations were recorded as 2945 mg/l and 1070 mg/l, respectively.

Operating Conditions of the Reactor

The UASB reactor was operated for 20–22 weeks in three different phases. In Phase I, the reactor was started up by seeding the dairy mill effluent with a granular sludge which had been developed in a laboratory-scale reactor from domestic wastes. This acclimatization phase took about 3–4 weeks. During Phase II, the optimum pH was established for the maximum treatment performance of the reactor using dairy mill effluent. This phase lasted about 5–6 weeks. Finally in Phase III of the project, the effects of the engineering parameters, such as OLR and HRT, were studied for a period of 9–10 weeks.

Monitoring and Analysis

pH, temperature, influent and effluent CODs, effluent VFA and TSS concentrations, biogas yield and methane composition were monitored regularly, i.e. 2–3 times weekly. Gas was collected over tap water saturated with NaCl.

Table 2. Wastewater characteristics of the dairy mill.

Parameter	Value	NEQS* limits
Turbidity (NTU)	1.4	–
Colour	Highly turbid/milky	–
Odour	Objectionable	–
pH	8.23	6–10
BOD (mg/l)	1070	80
COD (mg/l)	2945	150
Iron (mg/l)	0.03	–
Nitrates (mg/l)	10.09	–

*NEQS = National Environment Quality Standards

All analyses were carried out using standard analytical procedures (AWWA 2005).

RESULTS AND DISCUSSION

Phase I (Start-up of the Reactor)

The reactor was started with an influent COD concentration of 200 mg/l and at HRT of 36 h, corresponding to OLR of 0.13 g COD/l.d. The influent COD concentration was increased stepwise, in order to avoid sudden volumetric shocks to the reactor, to the level of 3000 mg/l at a constant HRT of 36 h. The final OLR during this phase was recorded as 2.0 g COD/l.d. During this phase, the average temperature and pH were observed to be 32°C and 7.0, respectively. Initially the reactor was started with OLR of 0.13 g COD/l.d, but it was increased gradually to 2.0 g COD/l.d in the last stages of Phase I. During this time period, HRT was kept constant as far as possible at 36 h.

The percentage of COD removal was observed against the influent COD during Phase I, and the treatability performance of the reactor during this phase was quite successful, being more than 80% on average, as shown in *Figure 2*. Maximum COD removal was observed on the 22nd day of operation when the influent COD concentration was about 2200 mg/l, corresponding to an OLR of 1.82 g COD/l.d. The results at this stage indicate that the acclimatization process was going on very well with the passage of time, and that the substrate and the operating conditions were helpful for the granulation process.

The time courses of SLR (g COD/g VSS.d), effluent VFA and TSS concentrations, production of biogas and methane content of the biogas during Phase I of the study are shown in Figures 3–7, respectively. The average values obtained during this phase of the study for SLR, effluent VFAs, effluent TSS, biogas production and methane composition were 1.4 g COD/g VSS.d, 1240 mg/l, 240 mg/l, 1.74 l/COD_{rem}.d and 62%, respectively. The overall observed biomass yield after about 4 weeks of the study was calculated as:

$$Y_{obs} = \sum X \text{ (total biomass produced, g VSS) } / \sum S \text{ (total substrate removed, g COD)}. \quad (1)$$

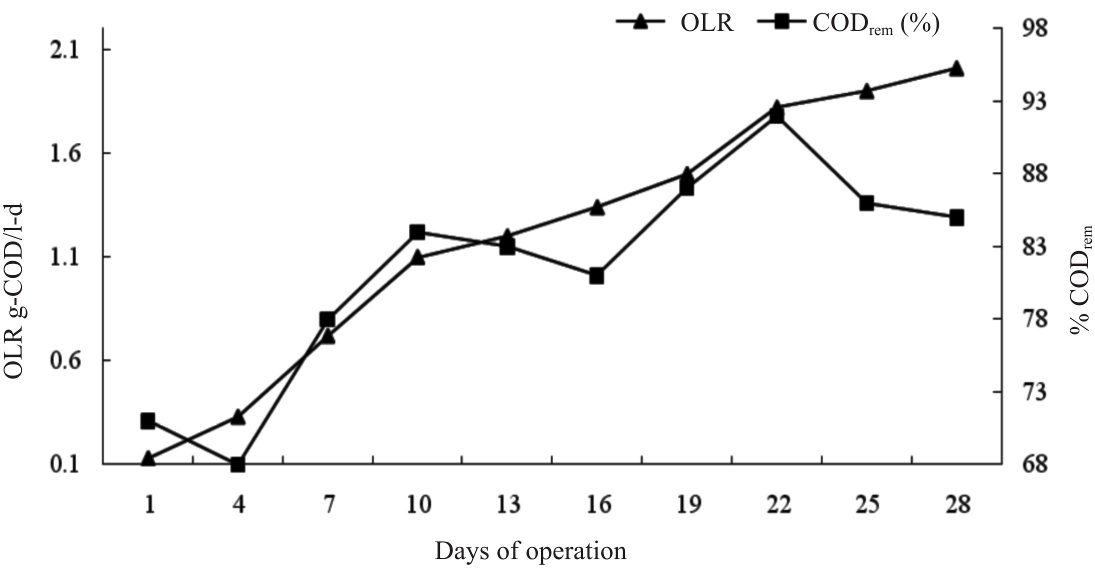

Figure 2. Time course of OLR and COD removal during Phase-I.

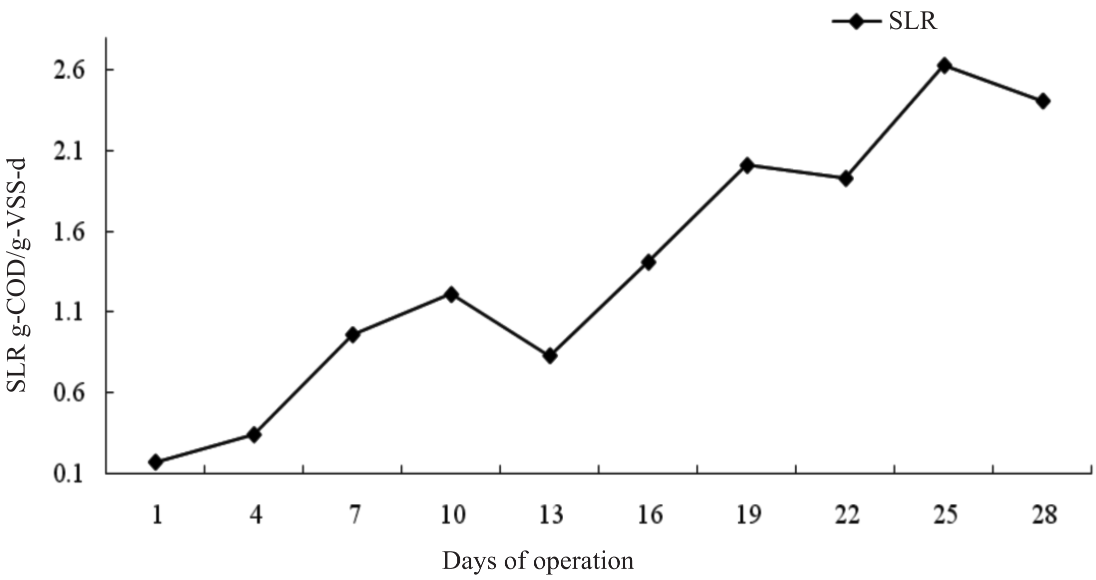

Figure 3. Time course of SLR during Phase-I.

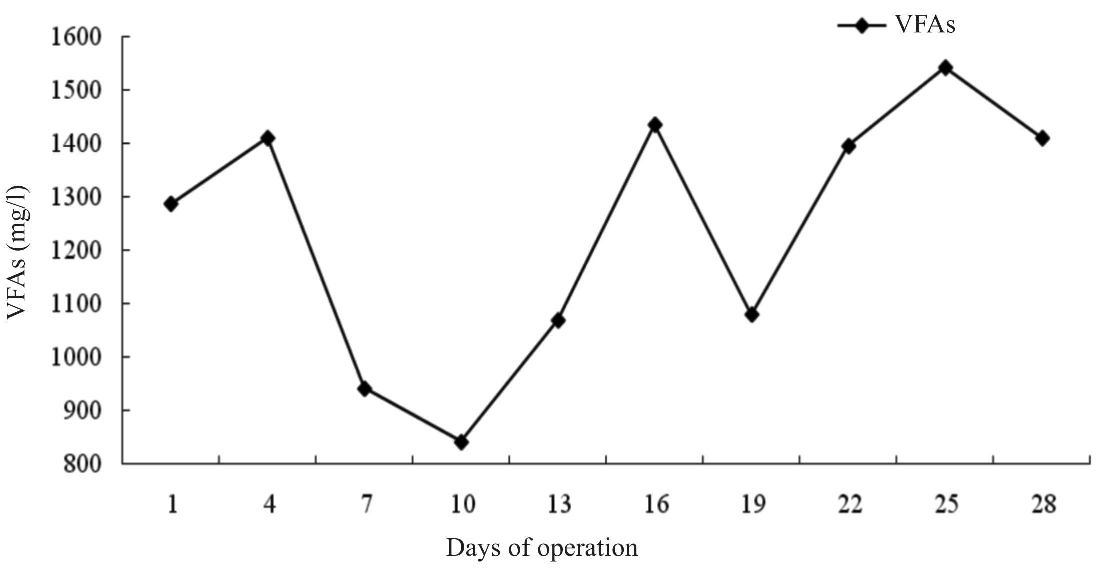

Figure 4. Time course of effluent VFAs during Phase-I.

The biomass yield was found to be equal to 0.034 g VSS/g COD_{rem}. This yield was almost one-tenth that of the conventional activated sludge process.

Phase II (Optimum pH Value for Dairy Wastes)

This phase lasted about 5–6 weeks with the main objective of determining the optimum pH

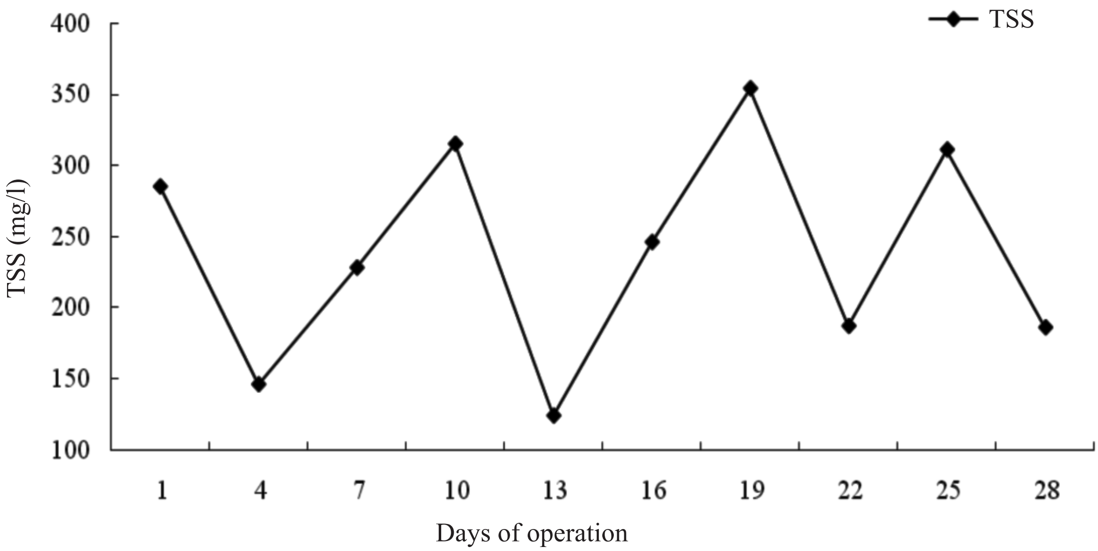

Figure 5. Time course of effluent TSS during Phase-I.

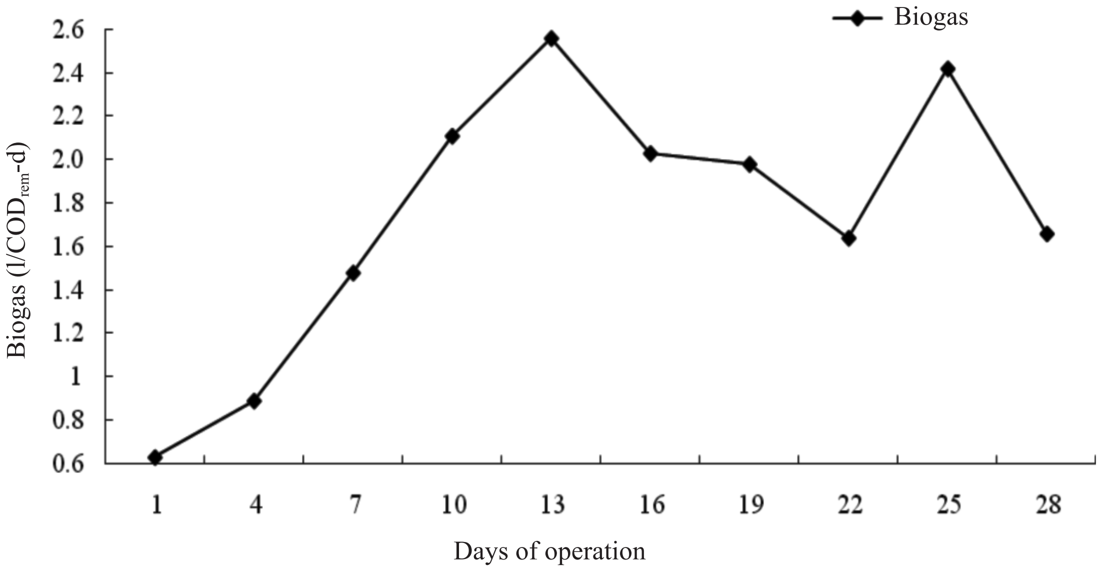

Figure 6. Time course of biogas production during Phase-I.

value for the anaerobic digestion of dairy wastes using the UASB reactor. The reactor was started with an influent COD concentration of 2200 mg/l at HRT of 36 h, corresponding to OLR of 1.82 g COD/l.d. During this phase, temperature was again kept constant at about 32°C. The pH of the reactor dropped slightly to an acidic medium in the region of pH 5.2, and this was then gradually increased by adding an external buffer solution of 0.5 M $NaHCO_3$. The buffer solution was added at a concentration of 64 ml/l to a maximum of 920 ml/l. Consequently, the pH was slowly increased from 5.2 to 8.5 as in *Figure 8*.

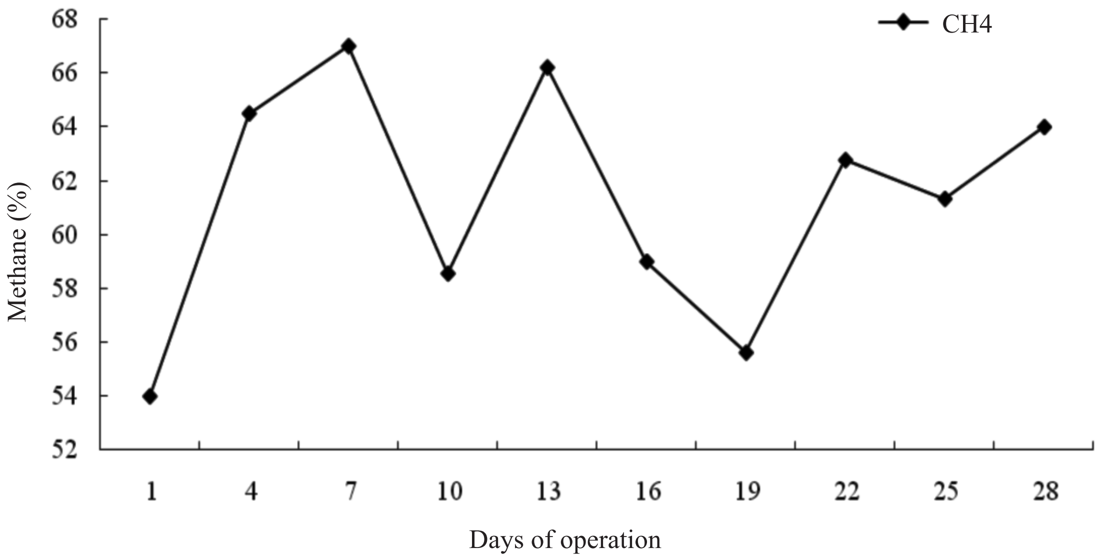

Figure 7. Time course of methane composition during Phase-I.

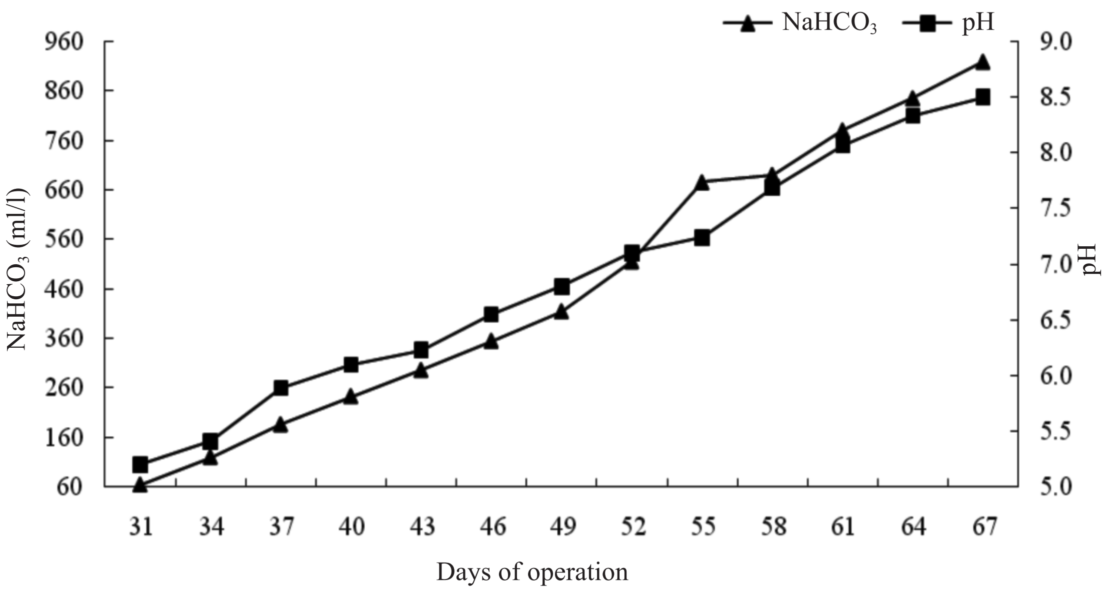

Figure 8. Time course of $NaHCO_3$ and pH during Phase-II.

The time courses of the COD removal efficiency of the reactor, effluent VFA concentration and biogas production, corresponding to the pH value during phase II of the study, are shown in *Figures 9–11*. As shown, corresponding to the pH value of 6.8–7.1, the effluent concentration of VFAs was minimum, i.e. 200 mg/l, thereby giving maximum treatability performance in terms of COD reduction at constant OLR and HRT. Corresponding to these optimum conditions, the amounts of COD reduction and biogas production were observed to be maximum, i.e. 80% and 2.94 $l/COD_{rem}.d$, respectively. The

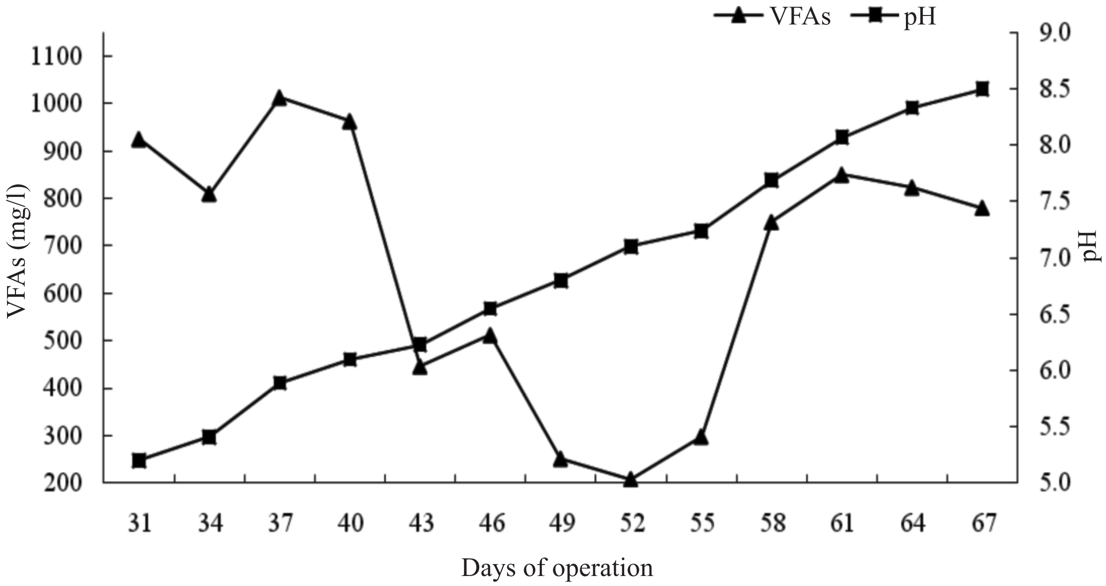

Figure 9. Time course of effluent VFAs and during Phase-II.

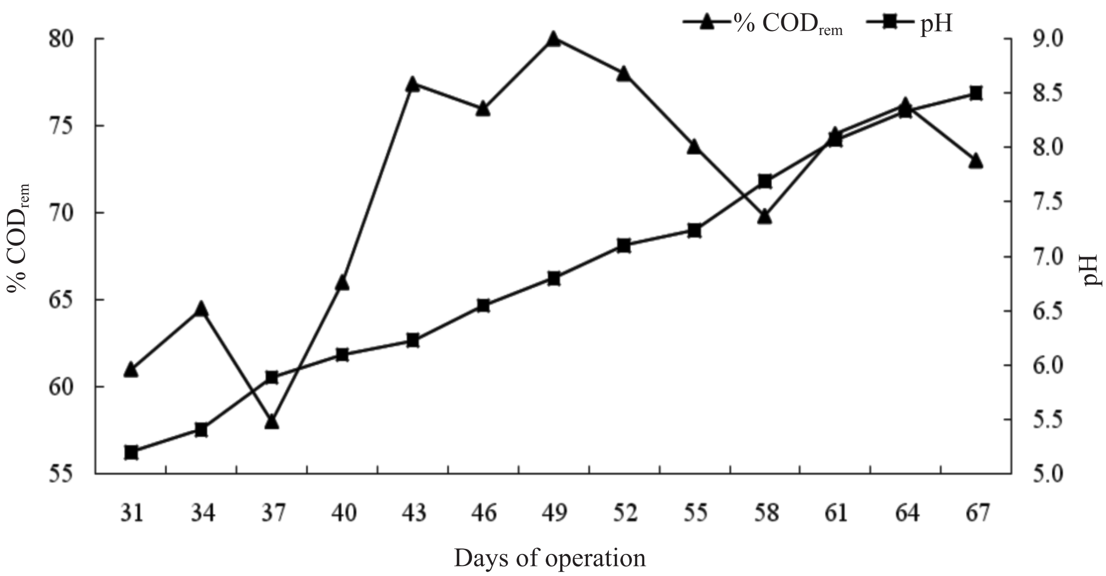

Figure 10. Time course of COD removal and pH during Phase-II.

results of this phase indicate that the optimum pH for the anaerobic degradation of dairy wastes under controlled operating conditions of OLR, HRT, temperature, etc. was 6.8–7.1, i.e. a neutral pH value.

Phase III (Effects of OLR and HRT on the Treatability Performance of the Reactor)

This phase lasted about 9–10 weeks with the major objective of determining the optimum organic loading rate and hydraulic retention

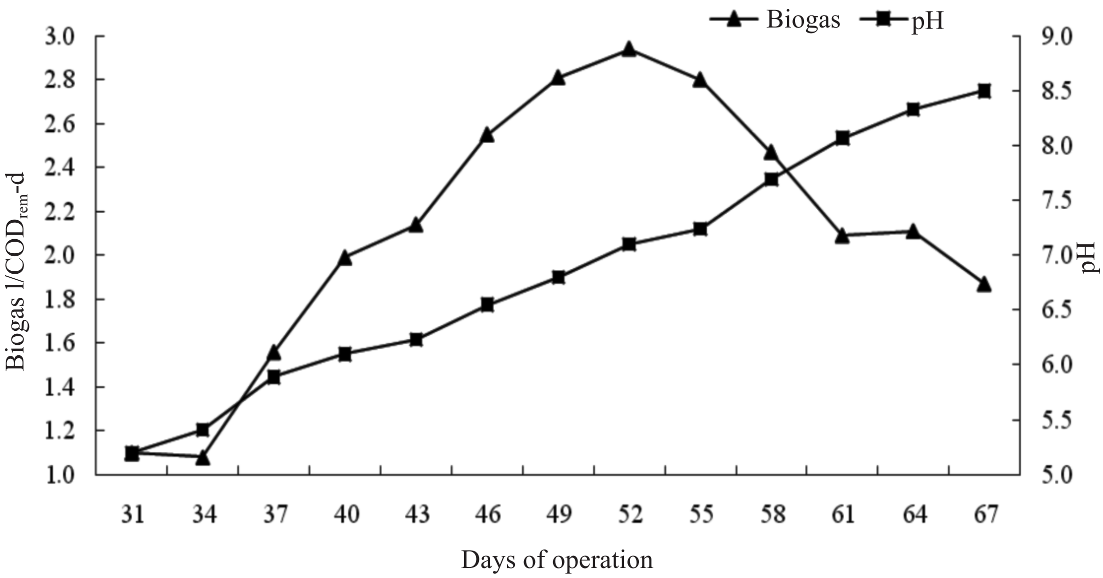

Figure 11. Time course of biogas production and pH during Phase-II.

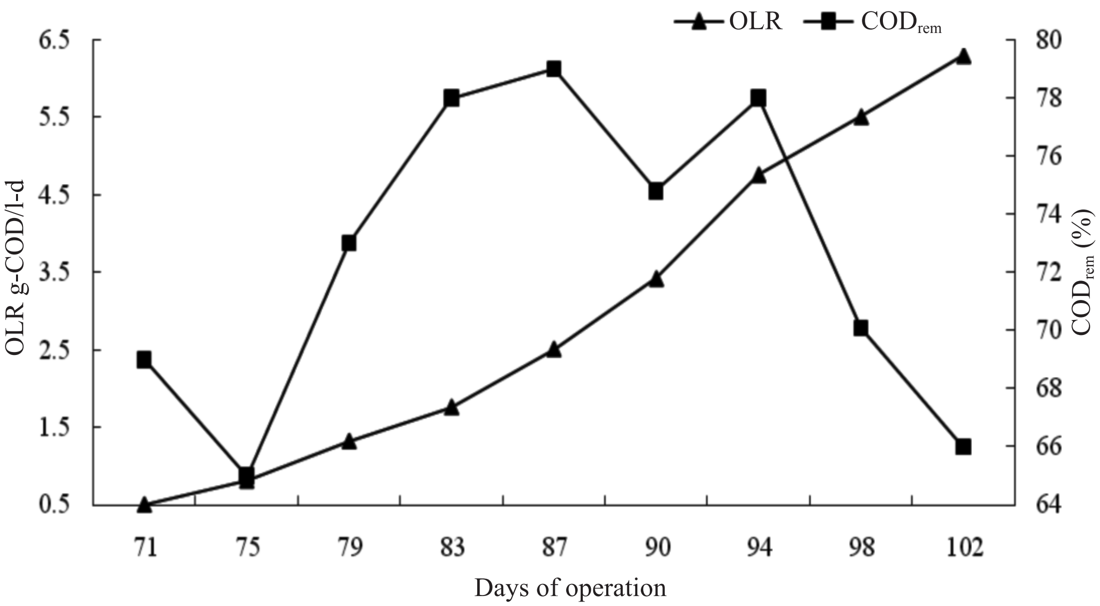

Figure 12. Time course of OLR and COD removal during Phase-III at constant OLR.

time at constant neutral pH and mesophilic temperature. The pH was controlled by adding an external buffer solution of 0.5 M $NaHCO_3$ to the feed solution at the required proportionate. Initially, HRT was kept constant at the same level of 36 h as before, and OLR was varied from 0.5 g to 6.3 g COD/l.d. Later, OLR was fixed at the optimum level of 4.76 g COD/l.d and HRT was varied from 36 h to 13 h. The time courses for COD removal efficiency of the

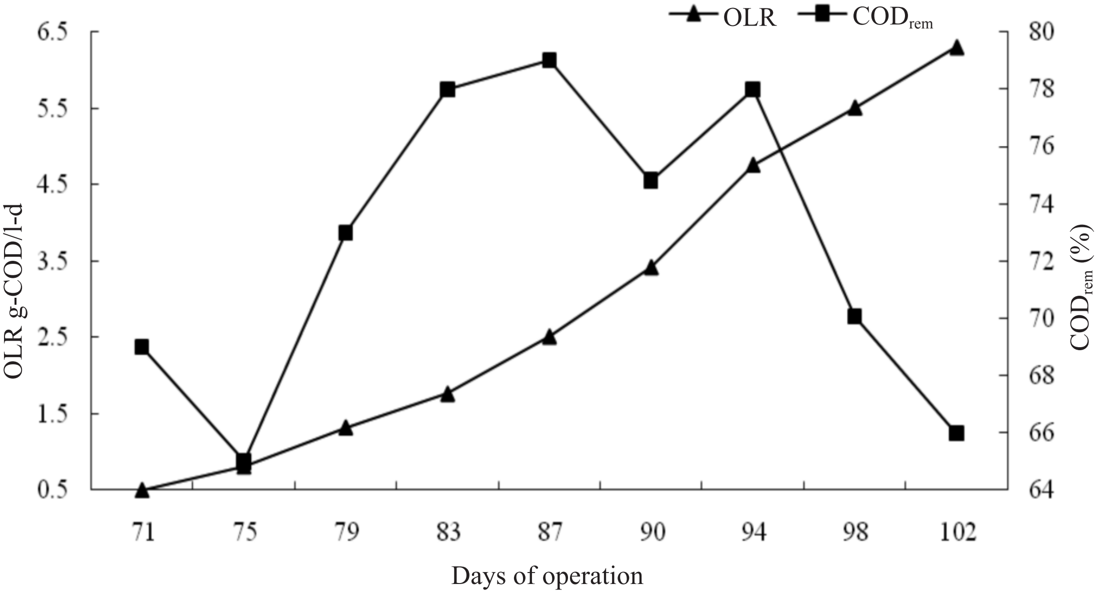

Figure 13. Time course of HRT and COD removal during Phase-III at constant OLR.

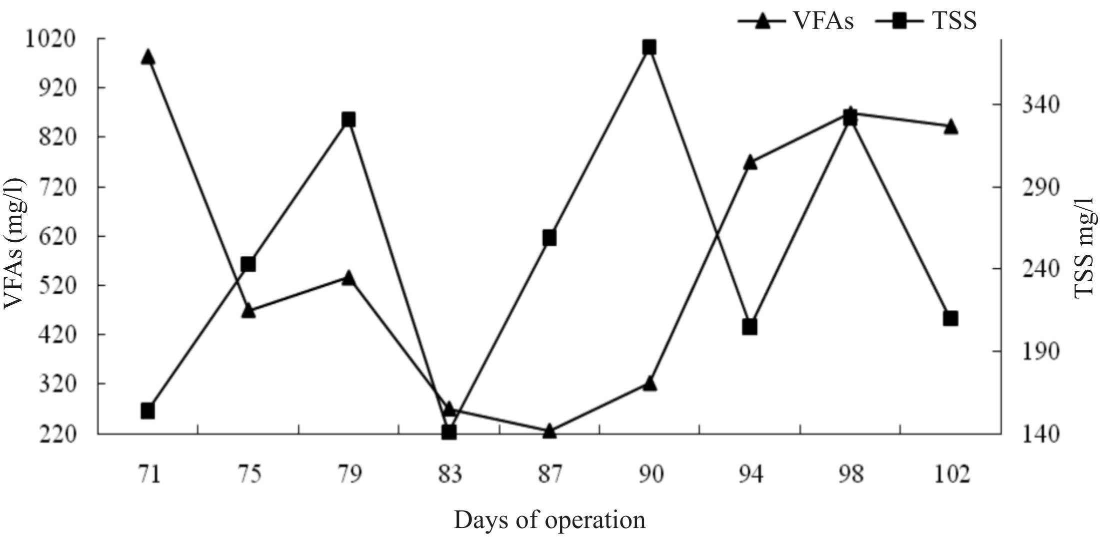

Figure 14. Time course of VFAs and TSS removal during Phase-III.

reactor, and the amounts of effluent VFAs, TSS and biogas production at varying OLR and HRT are shown in *Figures 12–15*. As may be seen, the optimum OLR and HRT were observed to be 4.76 g COD/l.d and 16 h, respectively. Corresponding to the optimum operating conditions, the COD removal efficiency of the reactor, effluent VFA and TSS concentrations, and the amount of biogas production were observed to be 78%, 770 mg/l, 300 mg/l and 2.07 l/COD_{rem}.d, respectively. A comparison of the work done in UASB reactors using different substrates is shown in *Table 3*. It is apparent that anaerobic digestion is effective not only for

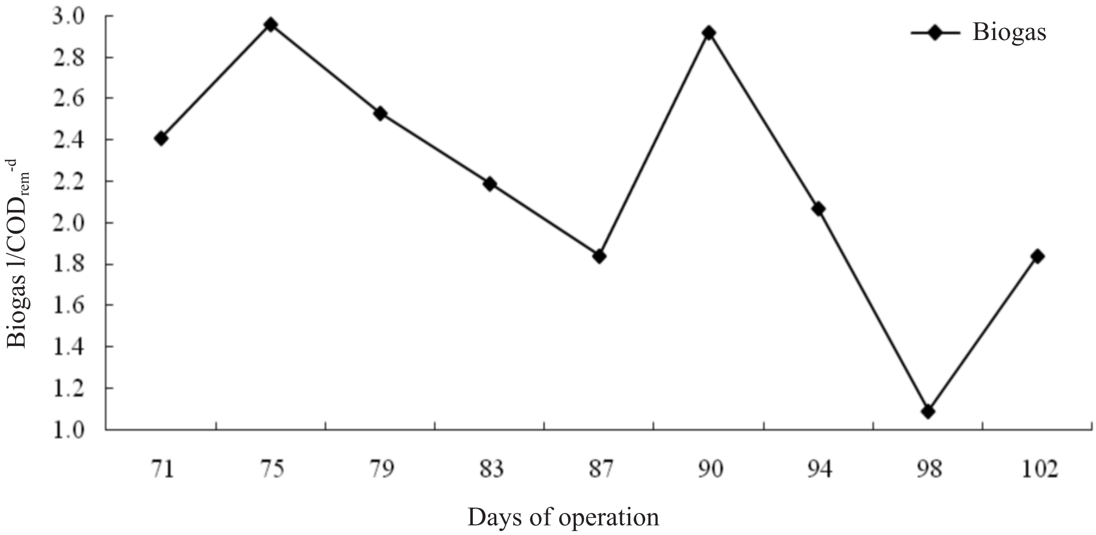

Figure 15. Time course of biogas production during Phase-III.

Table 3. Comparison of similar work done using UASB reactor.

Substrate	Operating conditions	Treatment efficiency	Biogas production	Reference
NSSC* pulping mill effluent	2.75 kg/m^3. day HRT=38 h	35% COD	0.17 m^3/kg COD_{rem}	Arshad *et al*. 2009
Sugar mill effluent	2.10 kg/m^3. day HRT=16 h	70% COD	0.30 L-CH_4/g COD_{rem}	Arshad *et al*. 2010
Textile mill effluent	2.2 kg/m^3. day HRT=20 h	80% COD	0.17 m^3/kg COD_{rem}	Arshad *et al*. 2011
Dairy mill effluent	4.70 kg/m^3. day HRT=16 h	78% COD	2.07 L/g COD_{rem}	This study

*Neutral sulphide semi-chemical

pollution reduction but is also a viable option for biogas production.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been acquired from this study:

- A dairy farm emits a wide variety organic-rich pollutants, which are currently disposed of directly into the open atmosphere. The wastewater characteristics of the dairy wastes indicate that they are highly turbid, alkaline and have a bad odour. The concentrations of COD, BOD, nitrates and iron are found to be 2945 mg/l, 1070 mg/l, 10.09 mg/l and 0.03 mg/l, respectively.
- The anaerobic treatment of the dairy wastes is a viable option both in terms of pollution reduction and in terms of biogas-producing potential.
- The optimum pH for the anaerobic treatment of dairy wastes is close to the neutral pH value, i.e. 6.8–7.1. The addition

of an external buffer solution of 0.5 M $NaHCO_3$ is an effective means for maintaining a neutral buffer capacity within the reactor.

- The optimum OLR and HRT for more than 78% COD reduction are 4.76 g COD/l.d and 16 h, respectively.
- At optimum operating conditions, SLR, effluent VFAs and TSS, biogas production and methane composition are observed to be 1.4 g COD/g VSS.d, 770 mg/l, 300 mg/l, 2.07 l/COD_{rem}.d and 62%, respectively.
- The overall observed biomass yield from dairy mill effluent during the process of anaerobic degradation is calculated at 0.034 g VSS/g COD_{rem}, which is almost one-tenth that of the conventional activated sludge process.

With Pakistan facing a shortage of energy, encouraging the use of such technologies can help to tackle the problem of energy crises. For this purpose, a comprehensive and long-term study is required to determine the exact behaviour of the dairy mill effluent at varying pH and temperature ranges. However, the cost of developing the UASB reactor for large- scale application needs to be reduced, and studies in this direction are required.

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