START-UP PHASE OF SOLID-STATE ANAEROBIC FERMENTATION OF SORTED MUNICIPAL SOLID WASTE IN THERMOPHILIC CONDITION

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Abstract: Solid state anaerobic digestion of manually sorted organic fraction of municipal solid waste with high solid content (20%) was investigated inthe pilot scale reactor under thermophilic condition (55^{0}C) to retrieve renewable energy like biogas. This paper concerns the results of simulation of startup phase of the reactor which was conducted over a period of 4 weeks in a batch process. The fresh organic fraction municipal solid waste (OFMSW) were collected and loaded in to the reactor as a feedand it was blended with two different inoculums ofcow dung and anaerobic sludge with mixing proportion of 2:1ratio which is of 30% of the weight of total feed. Firstly the reactor was operated in mesophilic condition (37^{0}C) and was shifted to thermophilic (55^{0}C) condition by gradually increasing the temperature rate by 2^{0}c per day. During the startup phase the gas production was fluctuated initially and gradually increased fromthe day of 9 to 19 and the highest gas production of 223L/d and the highest methane composition of 63% were achieved at the same day.In this study, the variations and trends of different parameters such as pH, Alkalinity and COD during start up process were discussed.

Keywords: Anaerobic digestion, fermentation, Inoculum, Organic fraction municipal solid waste, Thermophilic.

1. Introduction

Solid waste management is an important environmental issue in urban areas. Increased wastegeneration, rising proportions of packaging and toxic compounds in Municipal Solid Waste (MSW) lead to various problems in waste disposal (cheaEliyan, 2007). Increased environmental awareness and concerns overdirect landfilling have stimulated new approaches for the treatment of solid waste before disposal. Variousalternativesare available as a pre-treatment method to treat Organic Fraction Municipal Solid Waste (OFMSW) before disposal in which, biological treatment process had greater advantages in treating organic municipal solid waste. In the Biological treatment methods, Anaerobic Digestion technology is a fascinating treatment strategy to treat OFMSW than composting. It has been considered the main commercially option for both treatment and recycling of biomass wastes and had better treating efficiency in all aspects (Boualagui et al., 2004; De Baere, 2005).There are several reports on anaerobic digestion of different organic wastes: market waste (Mata-Alvarez et al., 1993), fruit and vegetable (Bouallaguiet al., 2005), household waste (Krzystek et al., 2001),kitchen waste (Rao and Singh, 2004),bio-waste (Gallertet al., 2003) and organic fraction of municipal solid waste (OFMSW) (Bonzonella et al., 2005). Sorted organic fraction of municipal solid wastes (SC_OFMSW) consists of all waste generated in large quantities in markets, restaurants and domestic homes, separated in origin for treatment. The sorted OFMSW composition can be affected by various factors, including regional differences, climate, collection frequency, season, cultural practices, as well as changes in the composition which could occur during a year.

Several new outlook have been tried to enhancethe efficiency of semi-dry anaerobic digestion (Pavan et al., 1994) and dry conditions or solid-state (20–35% TS) (Bolzonella et al., 2003), where no or little water, or sludge (De la Rubiaet al., 2002), is added to the OFMSW to produce an inertbiomass product with higher methane productivity (Mata- Alvarez et al., 2000). Additionally, there is an increased attention in applying the dry anaerobic digestion at thermophilic conditions (55^{0}C) to treat the organic fraction of municipal solids waste (OFMSW) due to its capacity for higher loading rate and greater volumetric gas production potential (Cecchi et al., 1991) than in mesophilic condition. Thethermophilic process has been established as a reliable and accepted mode of fermentation as claimed by several researchers (Mata- Alvarez et al., 2000) because of enhanced hydrolysis, increased organic solids destruction and better pathogen control.

Inoculum source is a very important operational parameter. Also, it is crucial the selection of waste/inoculum ratio as well as the assessment of anaerobic biodegradability of solid wastes. In dry-thermophilic digestion, the inoculum source and the total solid percentage selected are responsible to accomplish rapid onset of a balanced microbial population. The systematic of inoculation, the percentage of inoculation and wetting procedure differs between processes proposes by several authors. The percentage of inoculation for acidogenic fermentation of organic urban wastes is approximately 30% weight/weight (w/w). In case of the anaerobic biodegradability of solid waste, the use of a highly active anaerobic inoculum or animal inoculum waste will reduce significantly the experimental time, or reduced the amount of inoculum required in full scale batch digesters, and consequently, the corresponding digester volume.

Start-up is an important step in establishing a proper microbial community in thermophilic as well as other biological treatment processes. Poor start-up in biological treatment systems can lead to prolonged period of acclimation and ineffective removal of organic matter. Several researchers (Bolzonella et al., 2003a, b; Fernandez et al., 2001) states that successful start-up was related to a number of factors e.g., seed sludge source, initial loading rate, hydraulic retention time (HRT) and/or solids retention time (Fang and Lau, 1996).For a successful start-up and to reach the design load quickly, strategies such as the amounts of inoculum and the initiation of the feeding should be designed to avoid accumulation of anaerobic degradation intermediate products such as propionic acid and other volatile fatty acids(VFA's) and hydrogen, which could inhibit methanogenesis and acetogenesis.

This paper, concerns the start-up regime of a pilot scale solid state digester in thermophilic condition (55ºc) to achieve better biomass acclimatization to the digester.The efficiency of the start-up process of the digester was checked by the stability of the gas production and the volatile fatty acid formation and degradation within the operational time period. And also, thevariations and trends of different parameters such as pH, Alkalinity, COD during start-up phase were discussed.

2. Materials and Methods

Initially, the study consists of the start-up phase initiated in mesophilic condition (37ºC) and increased to thermophilic temperature (55ºC) at the rate of 2ºC/day. The feed was characterised with high solid content of 20% TS and it is loaded in batch mode.In this experiment, the pilot scale reactor of 200L stainless steel horizontal cylinder with working volume of 180L (80% of total volume) was used. The reactor was designed with double wall jacket through which the thermostatic bath (hot water bath) were made to maintain the optimum temperature (55ºC) and it was kept inclined at 30 degree for better substrate accommodation and digestate disposal. Heating rod (coil) was used in a separate water tank and the water heating temperature and the reactor temperature are controlled and maintained by digital temperature controller. Gas flow meter is connected to a gas outlet pipe in which the daily biogas production and methane concentration were monitored and additionally, outer portion of the reactor is well insulated to minimize the heat loss. Figure 1 shows the schematic representation of experimental set-up.

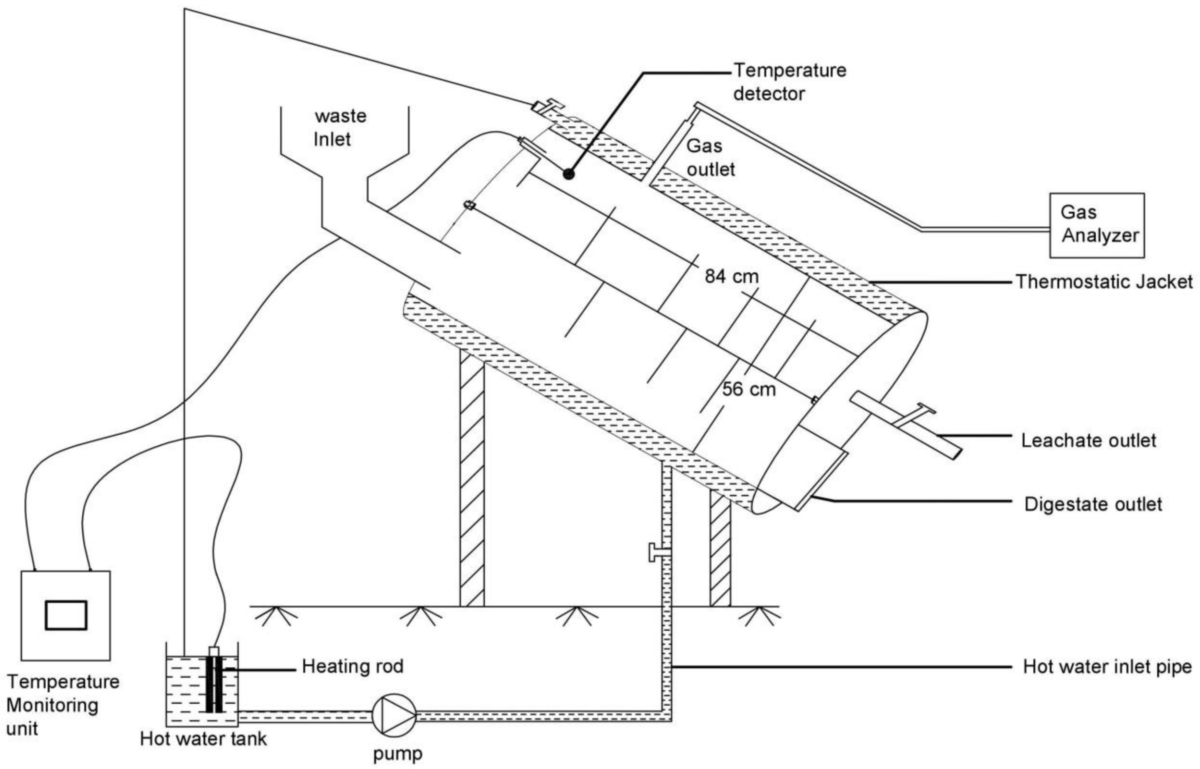

Figure 1. Schematic representation of experimental setup of a solid state anaerobic inclined reactor

During the start-up, the feedstock were firstly, Organic fraction municipal solid waste (OFMSW)collected from Chidambaram municipality waste yard and was blended withinoculum (30% of total waste loaded) consists of combination of cowdung and Anaerobic sludge mixed with 2:1 ratio. The MSW collected were manually sorted to retain the organic fraction andtends to particle reduction of 10mm using mechanical shredder. The physical and chemical analyses were carried out for every collection of samples and the characterisation of the feedstock and inoculum were illustrated in Table 1.

Table 1. Initial mean characteristics of the selected collected organic municipal solid waste, inoculum sources and the raw feedstock.

Parameter	Weight fraction or ratio			
	SH OFMSW	COWDUNG	ANAEROBIC SLUDGE	FEEDSTOCK
Density (kg/m3)	500.0	1270	1100	1060
Moisture (%)	18.2	49.4	98.7	79.6
Solids (%)	82.8	51.6	1.3	20.4
Total solids (g/kg)	828.0	516.0	23.5	204.0
Volatile solids (g/kg)	690.4	76.0	12.5	140.8
Alkalinity (g/kg)	0.01	0.15	0.7	1.40
Amon-N(g/kg)	0.007	0.05	2.03	0.46
TNK (g/kg)	1.3	2.1	6.3	1.5
N-total (%)	0.1	0.2	0.7	0.1
TOC (g/kg)	24.0	37.2	12.1	70.6
COD (g/kg)	32.2	52.8	27.3	87.9
Carbon (%)	47.1	33.2	59.3	47.1
C/N ratio(organic matter)	36.9	14.3	7.9	31.7

The parameters analyzed for the characterization of OFMSW include Moisture Content (MC), Total Solid (TS), and Volatile Solid (VS), and Carbon, Nitrogen, potassium (K) etc, (APHA standards).Leachate was analyzed daily for the following parameters, pH, alkalinity, VFA and COD using Standard Method for Examination of Water and Wastewater (APHA standards).

3. Results and Discussion

3.1 Reactor Start-upprocess

In the start-up phase, the reactor was initiated with the fresh waste of 56kg wereloaded to thereactor. The total volume of the reactor was 200L and working volume was 160L (80% of total volume). From the measurement the density of the waste was around 500 kg/m^3. Therefore, by the calculation, the total weight of the waste fed including inoculums was 80 kg (equal to 80% of total volume) in which 30% of waste was inoculums (i.e., 24kg). The reactor was operated in batch mode for 4 weeks for start-up process. The inoculum was comprised of cow dung, anaerobic sludge. The mixing ratio of these inoculums was 2:1(Eliyan, 2007; Adhikari, 2006; Jean, 2005). Homogenization of fresh wastes with inoculums was done properly before feeding into the system. The composition of waste was 56 kg of fresh solid wastes, 16 kg cow dung, 8 kg anaerobic sludge. To avoid the risk of thermal shock inside the reactor, the reactor was initiated with mesophilic temperature 37^{o}C and the temperature was gradually increased to a thermophilic temperature 55^{o}C by increasing 2^{o}C daily. The main feature of this system was to avoid the use of leachate for the mixing. To enhance the biodegradability of the substrates, the mixing was performed by circulating the waste inside the reactor periodically by rotating the mechanical agitator fitted into the reactor.

3.1.1 Biogas generation and quality

Digestion during start-up ran for a total of 40 days, during that period start-up reached methanogenesis, characterized by high methane composition (>60%). Figure 3.1, indicates the daily and cumulative biogas production. The biogas production was high for the first 4 days, which was due to the entrapped air inside the reactor and the waste itself because the methane composition during that period was almost zero. The biogas production gets fluctuated during the first 7-8 days, and from day 9-19 it increases gradually.Likewise, the methane production was obtained at the day 4 gets increased day by day reached the maximum value of 63% (see figure 3.2) at the day 19 with highest volume of biogas yield of 223 L/d.From figure 4.2 and 4.3, it is clearly seen that the biogas production and methane composition increased with the operation time indicating the better digester performance during start-up phase. This was achieved by the proper agitation system provided in the digester tends to better circulation of waste inside the digester.

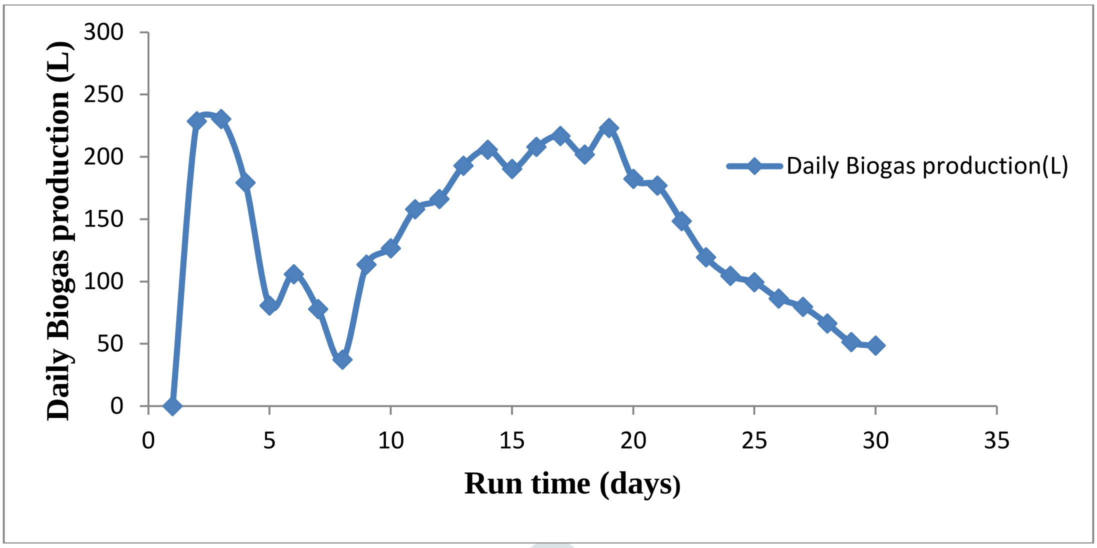

Figure 2. Daily biogas production during start-up.

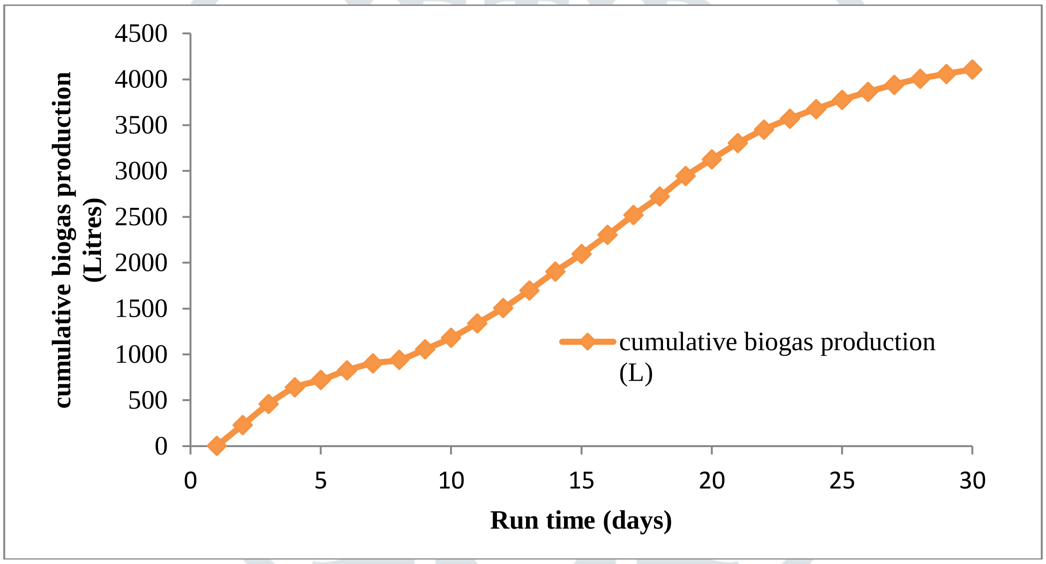

Figure 3.Cumulative Biogas Production during start-up

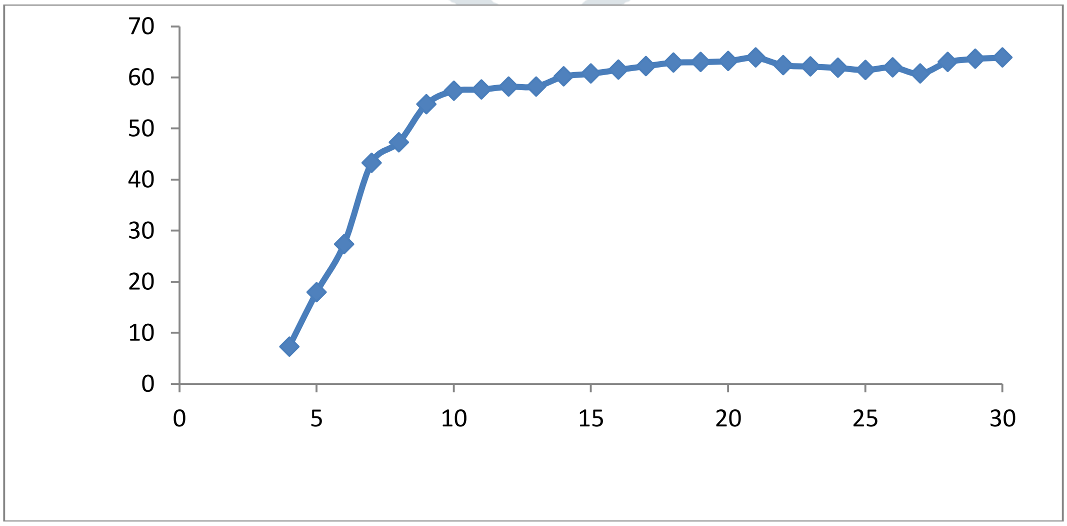

Figure 4. Composition of methane in daily biogas generated during start up.

3.2 Leachate characteristics

Leachatefrom the digester was analyzed regularly or periodically for various parameters, to ensure the stability of the start-up phase.The pH and the VFA are the important parameters tested during start up to check the efficiency of biogas production and the stability of the process.

3.2.1 The profile of pH and alkalinity during start-up phase

The pH profile during start-up isshown in the Figure 5 and also the figure 6 shows the variations of both pH and alkalinity. During start up process, initially the pH was at a lower value below 7 during first 10 days of operation. This was due to the formation of organic acids e.g. volatile fatty acid. The alkalinity was also found lower and reached to around 1500 mg/L as $CaCO_3$. Due to lower alkalinity and pH, the methanogenic activity was not initialized and the composition of methane was below 50%.

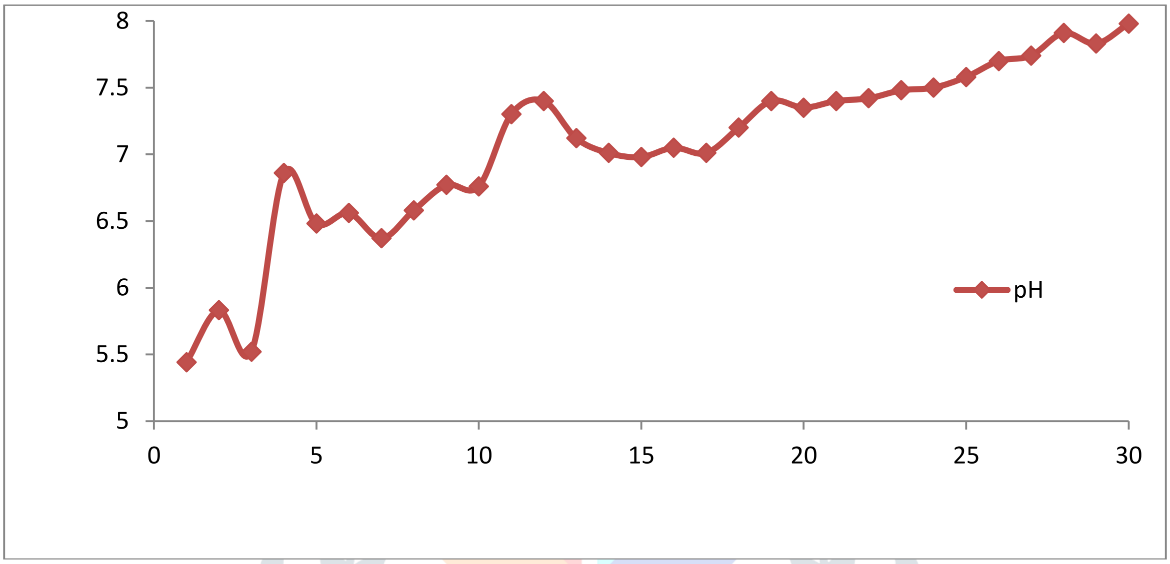

Figure 5. Profile of pH with respect to run time (days)

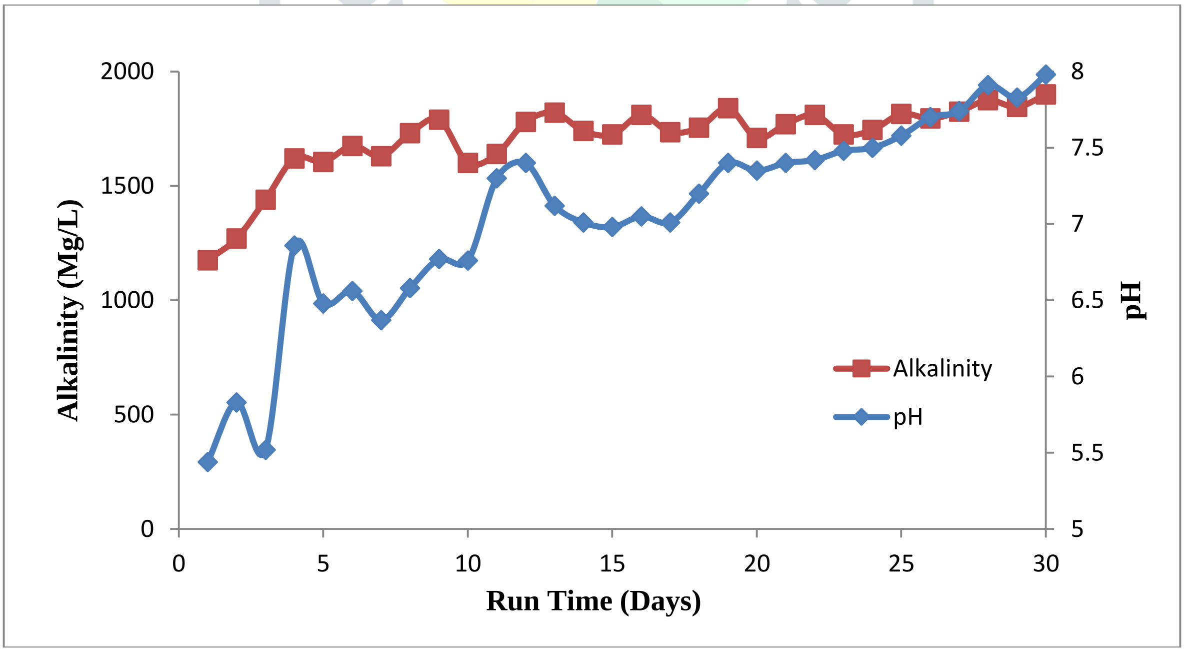

Figure 6.The variation of pH and alkalinity during start-up phase

The pH of the leachate was monitored regularly and an attempt was made to keep it above 6.5 by the addition of commercial NaOH. On days 5, 7 and 9, 1.5 kg of NaOH were added. From day 10 to 30, the pH and alkalinity wasalmost found steady and showing good performance of the digester.The pH reached above 7.5 but not exceeded 8.5 which are inhibiting condition for methanogenesis. During that period, the biogas production reached the maximum value of 223L/d and the highest methane generation of 63% was achieved at the same day itself.

3.2.2 The variation and trends of volatile fatty acids degradation

Figure 7 shows the variation of volatile fatty acids (VFA) concentration and pHduring start-up period. The VFA generation in the beginning was high due to higher acidogenic and lower methanogenic activity. As the Organic Fraction Municipal Solid Waste (OFMSW) consists of highly putrescible fraction, they were degraded quickly and the concentration of VFA was found elevated. Initially, the VFA accumulation was high with lower pH range of 5.4 to 5.8. During the first 9 days of operation, the pH was below 7 and the VFA accumulation were found 3000mg/L. when the PH gets adjusted to 6.6 to 7, the methanogenic activity initiated and the VFA accumulated gets gradually dropped and reached the steady range of 1200 mg/L. Its shows that, when the methanogenisis begins, the organic acids (VFA) was started converted in to biogas. The pH dropped in the beginning, corresponding to the transient accumulation of volatile acids, but then increased as the VFAs were converted to methane. Thus, this confirms that the reactor shows the good stability with better biogas production efficiency and gradual VFA degradation range during the start-up phase.

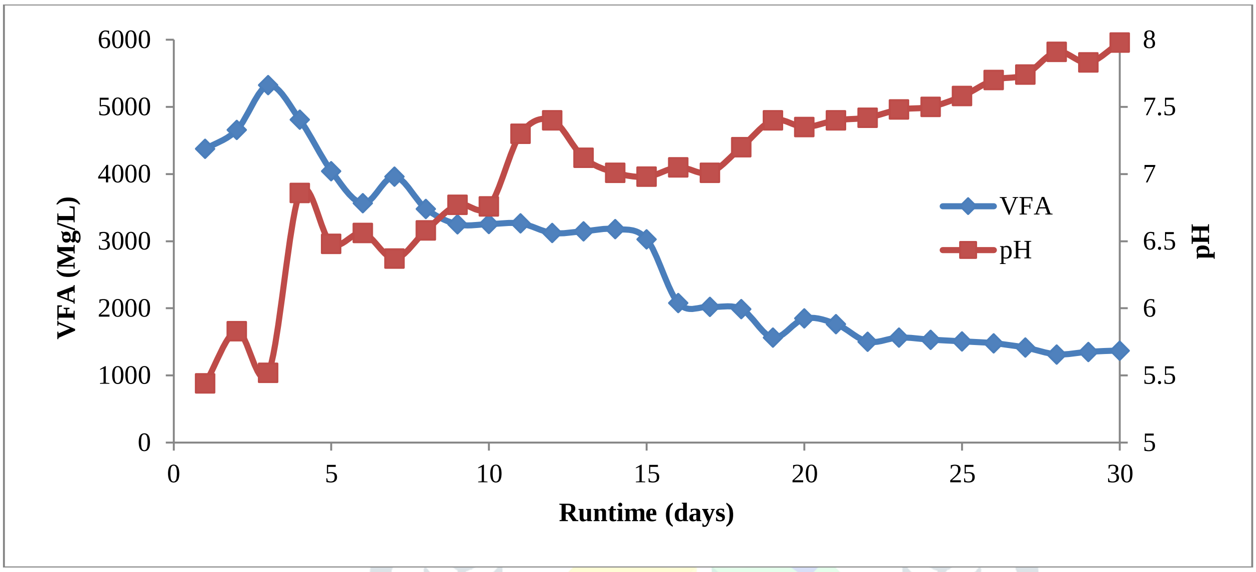

Figure 7. Trends of VFA degradation and the variations of pH

3.2.3 The variations of COD

The organic content of substrate was measured periodically in terms of Chemical Oxygen Demand (COD) and the Figure 8 depicts the variation of COD during start-up process. The significant increase in COD in leachate was observed in the beginning which was the sign of active hydrolyze phase. The COD of the leachate were found decreasing due to conversion of organic matter into biogas.

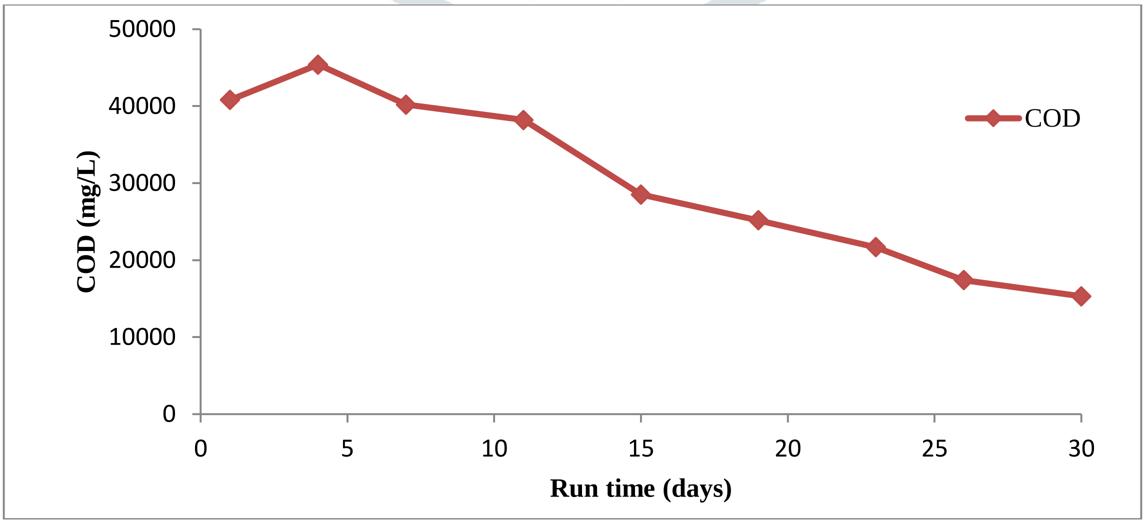

Figure 8. The variation of COD during start-up process

Conclusion

The reactor shows the efficient start up with increasing biogas production at the operational time period and it ensures the better performance of the reactor. The highest biogas yield of 223L/day was achieved at the 19th day and the initial methane production began after 4th day of operation and it reaches the highest yield of 63% at the day. The separate agitation system ensures the better mixing of waste inside the reactor that tends to get increased biogas yield at the right time. The pH was below 7 during first 10 days and this was due to the formation of organic acids e.g. volatile fatty acid. The pH was adjusted to 6.5 to 7 and above thereby the methanogenesis gets initiated and highest volume of biogas was produced during that stage. The VFA generation in the beginning was high due to higher acidogenesis and lower methanogenic activity and after methanogenesis initiated the increased VFA is converted in to biogas. Thus the variations of pH and trends of VFA and COD degradation during digestion process and increased methane yield ensure the better start-up of the reactor.

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