



## TWO PHASE UPFLOW ANAEROBIC SLUDGE BLANKET (UASB) REACTOR ON THE REDUCTION OF CHEMICAL OXYGEN DEMAND IN DAIRY EFFLUENT

P. S. ARUNADEVI<sup>1\*</sup> AND M. SARAVANARAJA<sup>1</sup>

<sup>1</sup>PG and Research Department of Zoology, Sri Vasavi College, Erode, Tamil Nadu – 638 316, India.

### AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between both authors. Author PSA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript.

Author MS managed the analyses of the study the literature searches. Both authors read and approved the final manuscript.

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### ABSTRACT

An increasing pollution level leads to realization of the potential of anaerobic treatment. This led to the development of a range of reactor designs suitable for the treatment of low, medium and high strength waste water. With the increasing use of anaerobic technology for treating various process streams, it is expected that industries would become more economically competitive because of their more judicious use of natural resources. One of the most developments in anaerobic treatment process technology was the Upflow Anaerobic Sludge Blanket reactors. The reactor is being used extensively for a large number of different types of industrial effluents. Prevention and reduction of dairy waste water pollution can be achieved by means of direct recycling and reutilization of waste components. This study examined the feasibility of applying Upflow Anaerobic Sludge Blanket bioreactor with phase separation i.e. acidogenesis and methanogenesis, to treat dairy effluent. The aim of the study is developing anaerobic digestion as a two-phase process originated from the view that it is generally a process involving two different set of activities. The two reactors were constructed in transparent acrylic sheet. The dimension of the acidogenic reactor was 18 cm width, 18 cm breadth and 50 cm height. In the present study, the better performance of the reactors than the reactors reported by other investigators can be attributed to two reasons. One definite reason is the phase separation. In the present study, the high chemical oxygen demand removal rate achieved at a hydraulic retention time 2 days for the acidogenic reactor at an OLR rate of 4.01-4.21 kg chemical oxygen demand /m<sup>3</sup>/day and in the methanogenic reactor hydraulic retention time of 2.5 days at an organic loading rate 2.61-2.75 kg chemical oxygen demand. The results indicate that a sharp decrease in the chemical oxygen demand removal efficiency for loads above 2-4 g chemical oxygen demand /l/day in the operation of sludge bed anaerobic reactors fed with dairy effluents. Among the anaerobic treatment two phase Upflow Anaerobic Sludge Blanket reactor work efficiently to treat also to mitigate the issue of acidification nature of dairy effluent.

**Keywords:** UASB reactor; acidogenesis; methanogenesis; chemical oxygen demand removal.

## 1. INTRODUCTION

In the industrial sectors water pollution is caused by a few industrial sub sectors which release toxic wastes and organic pollutants. Total waste water generation from major water consuming industries such as agro based industries, refineries, petrochemicals, fertilizers and industrial chemicals was estimated to about 3000 million liters per day in 1997 [1]. Almost 65% - 70% of the organic pollutants released in the water bodies in the country accounted for by food and agro-based industries such as distilleries, dairies, sugar factories and pulp and paper mills. Of these most of the waste streams are treated by conventional means like aeration which is both energy intensive and expensive and generates a significant quantity of biological sludge which must then be disposed off. In this context, anaerobic digestion offers potential energy savings and is a stable process for medium and high strength organic effluents as well as methane produced from the anaerobic system can be recovered.

An increasing realization of the potential of anaerobic treatment is evident from the large number of research publications on this process. Till the late 1960s, aerobic processes were very popular for biological treatment of waste. The energy crisis in the early 1970s coupled with increasingly stringent pollution control regulations, brought about a significant change in the methodology of waste treatment. Energy conservation in industrial processes becomes a major concern and anaerobic processes rapidly emerged as an acceptable alternative.

This led to the development of a range of reactor designs suitable for the treatment of low, medium and high strength waste water. With the increasing use of anaerobic technology for treating various process streams, it is expected that industries would become more economically competitive because of their more judicious use of natural resources.

Conventional digesters such as sludge and Continuous Stirred Tank Reactors (CSTR) have been used for many decades in sewage treatment plants. In the late 1970s, one of the most developments in anaerobic treatment process technology was the Upflow Anaerobic Sludge Blanket which was developed by Lettinga and his co-workers [2].

The principal types of anaerobic sludge blanket processes include,

1. The original UASB process and modification of the original design.

2. The anaerobic baffled reactor (ABR).
3. The anaerobic migrating blanket reactor (AMBR).

Of these sludge blanket process, UASB reactor is being used extensively for a large number of different types of industrial effluents. The system uses sludge granules as a means of achieving highly mean residence time (MCRT) there by achieving highly cost effective designs. UASB processes have found a variety of applications in recent years in the treatment of high strength and low/medium strength waste water and a variety of other substrates. A major advantage is that the technology has less investment requirements compared to an anaerobic filter or a fluidized bed system. The process has been applied to waste water generated from a wide cross section of industries such as distilleries, food processing unit, tanneries etc., in addition to municipal waste water.

### 1.1 Dairy Industry

The dairy industry in India has grown from an almost completely unorganized in to a vastly complex organized industry of a large magnitude during the last 35 years, with an annual milk production of about 88 million metric tons and it may be expected to reach 220-250 MT in 2020. India contributes to world milk production rise from 12 -15% and it will be expected to rise up to 30 – 35%. There are 173 co-operative dairy plant units in India.

In Tamil Nadu there are 20 cooperative milk production unit, 26 private organized and 34 unorganized units are in operation with an average milk production 129 lakhs/day. Of these 40% of milk used as consumed milk and other 60% of milk processed in to various products like butter, cheese, yogurt, condensed milk, dried milk (milk powder) and ice cream, so each division produces waste water of a characteristic composition depending on the kind of product that is produced.

So, Dairy processing effluent contains predominantly milk and milk products which have been lost from the process, as well as detergents and acidic and caustic cleaning agents. The constituents present in dairy effluent are milk fat, protein, lactose and lactic acid as well as sodium, potassium, calcium and chloride. Milk lost to the effluent stream can amount to 0.5 – 2.5% of the incoming milk, but can be as high as 3-4% and the volume of waste generated during dairy processing may be as high as 2.5 liters of waste water per liter of milk processed. Potential environmental issues associated with dairy processing activities include the significant

consumption of water for processing and cleaning, the discharge of waste water with high organic load which is higher than that of the community wastes, unpleasant odors and consumption of energy.

Dairy products present in waste water are rich nutrient for bacteria; bacteria degrade these compounds aerobically and deplete the dissolved oxygen content of water, making it unfit for aquatic species. The high fat content of milk and its products can also cause physical problems with in drainage systems, solidified fat can cause blockages, resulting in overflows from the system and possible pollution of watercourses. Apart from that, dairy processing effluents would alter the environmental values of surface water, ground water and ecosystems from an increase in organic matter, nutrients, salts, chemical and biological contaminants, pH and temperature.

Land application of waste waters produce unacceptable changes including structural decline, increased salination, acidification, chemical and biological contamination, water logging, soil loss via erosion and decrease in permeability. The main contributors to the organic load of these waste wasters are lactose, fats and proteins [3].

Prevention and reduction of dairy waste water pollution can be achieved by means of direct recycling and reutilization of waste components (e.g. the use of cheese whey for animal feed) [3] or by using different waste water treatments; physical-chemical, aerobic and/or anaerobic biological treatments [4].

Physical-chemical treatments allow the partial removal of the organic load by protein and fat precipitations with different chemical compounds such as aluminium sulphate, ferric chloride and ferrous sulphide [5]. However, the reagent cost is high and the removal of soluble chemical oxygen demand (COD) is poor; therefore, biological processes are often used [6].

Several conventional aerobic treatments have been used extensively in the dairy industry; aerated lagoons, activated sludge processes [7], trickling filters [8] and rotating biological contactors [4]. However, the energy requirements for aeration in these installations are high and problems such as bulking and excessive growth often occur.

Dairy processing waste water contains a high biomass concentration of organic matter. The ratio of BOD/COD is high, ranged from 0.6 to 0.8. Therefore, application of the anaerobic process for treating dairy processing waste water appears to be

the most logical and feasible option. This technology is now functional in over 65 countries and the total number of installed anaerobic treatment plants is estimated at around 2,000 with UASB technology being the most predominant process [9].

## 1.2 Advantages of Two Phase UASB System

Treatment of dairy waste waters by means of upflow anaerobic sludge blanket [10], hybrid UASB reactors [11]; expanded granular sludge bed (EGSB) reactors [12], as well as others based on anaerobic filters [13] have been reported.

Anaerobic digestion of cheese whey offers an excellent solution in terms of both energy saving and pollution control [14]. The major advantage of this processes are low cost, higher energy efficiency and process simplicity compared to others waste treatment methods.

However, despite these advantages, anaerobic digestion is not widespread in the dairy industry, largely due to the problems of slow reaction, which requires longer HRT, and poor stress stability, especially for effluents rich in components that are subject to rapid acidification.

The idea of developing anaerobic digestion as a two-phase process originated from the view that it is generally a process involving two different set of activities. Over all, the two-phase process takes advantage of the phase separation phenomenon, deriving naturally from different kinetic rates. This provides separate acidogenic and methanogenic reactors to decrease the cost, and to improve treatment efficiency, energy production and process stability of anaerobic systems [15].

This study examined the feasibility of applying UASB bioreactor with phase separation (acidogenesis/methanogenesis) to treat dairy effluent. Apart from effluents the management of the solid wastes continues to be one of the most difficult and expensive problems. Unless appropriate methods of management are evolved, the large scale accumulation of these wastes will pose disposal and pollution problems [16].

## 2. MATERIALS AND METHODS

The dairy effluent was collected from a nearby dairy processing industry. Waste generation in dairy processing facilities is characterized by high daily fluctuations. Therefore samples were taken at different time intervals of a day. The collected samples were analyzed by following the Standard

Methods of “Water and waste water analysis” by APHA [17]. The seed slurry was collected from EID Parry Distillery Unit located at SIPCOT, Cuddalore, Tamil Nadu, India. The acidogenic and methanogenic seeds were collected in separate airtight plastic containers (35 litre volume). The collected seeds were stored at room temperature. The distillery slurry was presented as dispersal (floculent) form.

## 2.1 Construction of Laboratory Scale Two-phase Anaerobic Digestion System

Fig. 1 shows the schematic diagram of laboratory scale two-phase anaerobic digestion system used in this study. It consisted of an acidogenic reactor for the purpose of pre-acidification of the influent and an Upflow Anaerobic Sludge Blanket (UASB) with internal packing column as the methanogenic reactor.

The two reactors were constructed in transparent acrylic sheet. The dimension of the acidogenic reactor was 18 cm width, 18 cm breadth and 50 cm height. The bottom of the reactor was provided with a feed distribution system to ensure maximum contact between influent and the microbes. The diameter of

the inlet and outlet nostrils was of 10mm in order to avoid clogging.

The UASB reactor used in this experiment was designed having the following specifications like 1 m height, 16 cm breath, 16 cm width, 4 number of feed inlet points (sample port) with 4 mm diameter, 5 cm aperture area, 25 l of volume, 5 l volume of gas separator, 4-40 ml/min peristaltic pump and 20 l of effective volume of the reactor.

To assess the performance of the two phase UASB reactor, all relevant parameters were examined regularly. Other parameters like Total COD and Soluble COD levels were measured on alternate days.

The formula used to calculate the percentage of acidification was:

$$\text{Percentage of acidified COD (\%)} = \frac{\text{COD of VFA (mg/l)}}{\text{Soluble COD (mg/l)}} \times 100$$

COD was measured by chromic acid digestion-reflux method. Soluble COD was determined by filtering the sample through Whatman filter paper No. 40 and COD was determined after filtration.

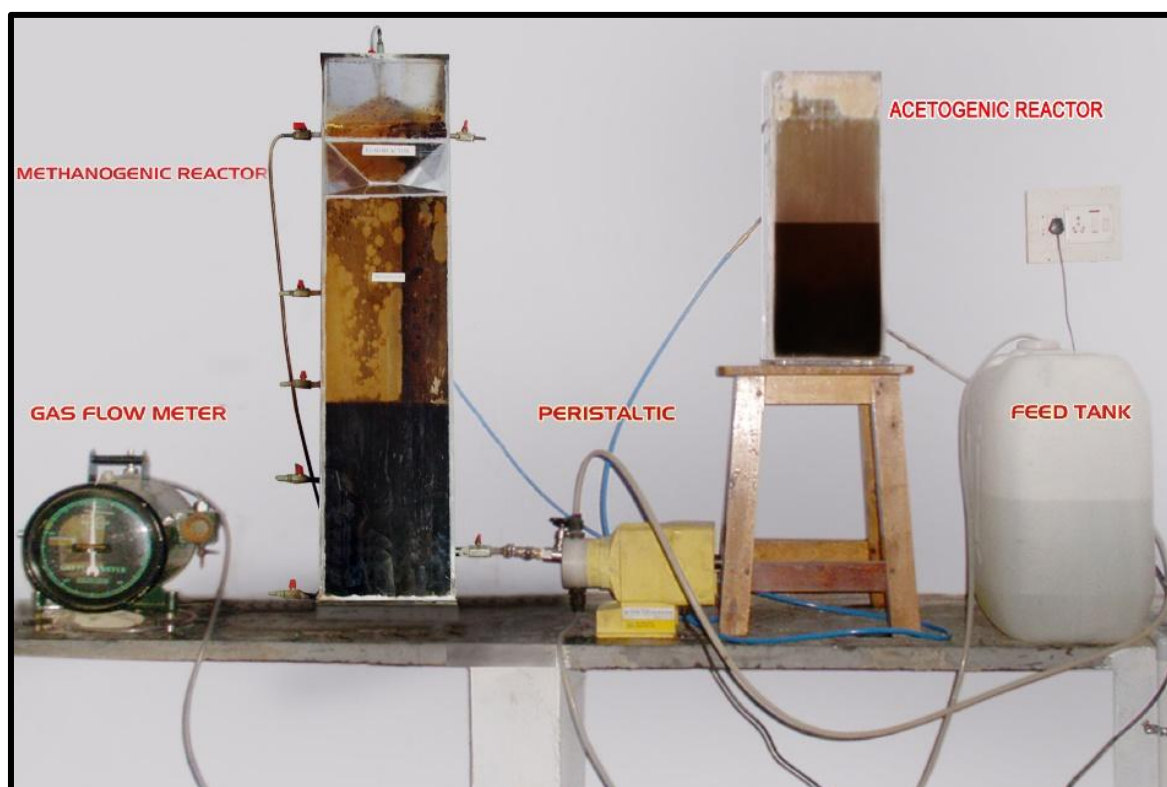


Fig. 1. Laboratory Upflow Anaerobic Sludge Blanket (UASB)

### 3. RESULTS

The general characteristics of the dairy waste water are presented in Table 1. The results indicate that the organic strength of the dairy waste water was high, it extended from 2000-8000 mg/l of COD and 1200-6500 mg/l of BOD.

**Phase - I:** The COD of the effluent was maintained between 1000 and 1150 mg/l for the first 15 days. The maximum COD reduction achieved during this period was only 44%. In another 30 days operation the COD reduction was increased from 44 to 73%.

**Phase - II:** The effluent was diluted until the COD was brought down to 1350-1500 mg/l, which gave an organic loading rate of 0.747-0.840 kgCOD/m<sup>3</sup>/day for the acidogenic reactor.

At a HRT of 2.5 days, the reduction of COD in methanogenic reactor was gradually increased from 42% to 81%. Above 70% COD reduction was achieved from 75<sup>th</sup> day onwards reached to 81% at the end of this phase. Soluble COD reduction was at 69% initially and at 89% during the later days of the phase. Similarly, the VFA utilization rate was 68% in the beginning and increased upto 88%.

**Phase - III:** In this phase, the COD of the influent was fixed between 2500 – 2800 mg/l. Thus, the organic loading rate to acidogenic reactor was 1.38 – 1.55 Kg COD/m<sup>3</sup>/day and for the methanogenic reactor the ORT was between 0.9 and 1.008 Kg COD/m<sup>3</sup>day. Total COD removal and soluble COD removal efficiency was in the range of 72 – 87% and 83 – 94% respectively.

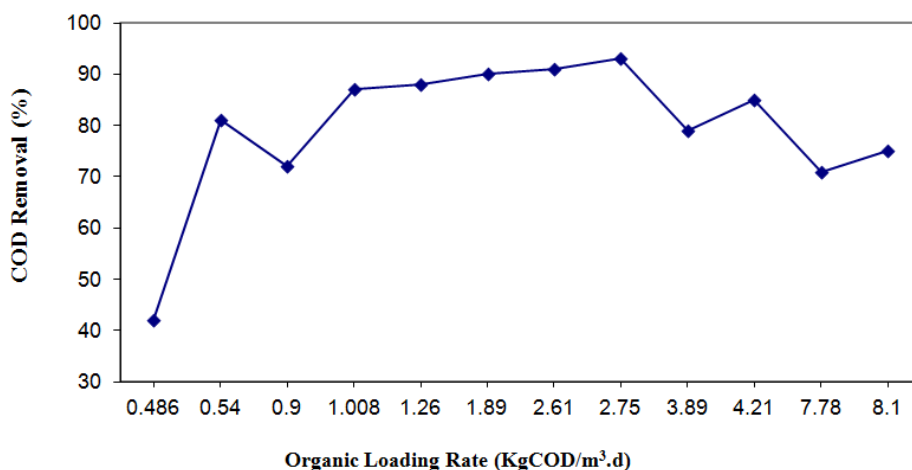
**Phase – IV:** In the Phase IV, COD of the influent was doubled to 4500 – 5250 mg/l. Thus, the organic loading rate for acidogenic reactor was 2.49 – 2.91 Kg COD/m<sup>3</sup>day and for the methanogenic reactor it was 1.62 – 1.89 Kg COD/m<sup>3</sup>d. In the methanogenic phase, 88-90% of COD reduction was than phase observed. 96% of soluble COD reduction was observed during this phase.

**Phase – V:** With the good COD removal rate by methanogenic sludge, the organic loading rate was further enhanced. The dairy effluent with the COD of 7250-7650 mg/l was fed into the reactor. The reactor was 4.01 – 4.21 Kg COD/m<sup>3</sup>d and the organic loading rate for methanogenic reactor was 2.61 – 2.75 Kg COD/m<sup>3</sup>d. In the methanogenic reactor 93% COD reduction was achieved. Almost 95 – 96% of soluble COD was removed at the end of this phase.

**Table 1. Characteristics of dairy waste water**

S. no.	Parameters	Variable concentrations	Composite sample value
1	pH	4-11	7.2
2	EC	713-1114	814
3	BOD	1,200-5,000	3,460
4	COD	2,000-8,000	5,280
5	TKN	39-141	89.6
6	Total phosphorus	20-104	63
7	TSS	450-1400	1,246
8	VSS	330-940	885
9	Alkalinity	375-1476	1180
10	Oil & grease	33-104	86
11	Na	30-76	48
12	K	35-78	37
13	Ca	46-102	94
14	Mg	5-37	18
15	Fe	2-5	3.5
16	CO	0.05-0.15	<0.1
17	Ni	0.5-1	0.8
18	Mn	0.02-0.10	0.04
19	Cu	0.01-0.05	0.02
20	SO <sub>4</sub>	28-87	42

*Note: All the parameters are expressed as mg/l except pH and EC*



**Fig. 2. Removal of COD at different organic loading rates**

**Phase - VI:** In this phase raw composite dairy effluent was fed into the reactor. The organic loading rate was increased by reducing hydraulic retention time as well. The organic loading rate for the acidogenic reactor was 5.98 – 6.48 Kg COD/m<sup>3</sup>day as the hydraulic retention time was one day only. The organic loading rate for the methanogenic reactor was 3.89 – 4.21 Kg COD/m<sup>3</sup>day as the hydraulic retention time (HRT) was reduced to 1.25 days. In the methanogenic reactor the maximum COD reduction rate was 79-85%. The COD reduction was lesser than the previous phases. Soluble COD concentration was reduced by 92-94%.

**Phase – VII:** In this phase also, composite dairy effluent without any dilution was used as the influent. However, the HRT was further reduced by half. The organic loading rate for acidogenic reactor was 11.96 – 12.46 Kg COD / m<sup>3</sup>d and their Hydraulic Retention Time was 12 hours. The methanogenic reactor operated with an organic loading rate of 7.78 – 8.1 Kg COD/m<sup>3</sup>d with a HRT of 15 hours. Methanogenic phase also disturbed by the washout of sludges. Maximum total COD reduction attained was 71-75%. Reduction of Soluble COD was 81-84%.

#### 4. DISCUSSION

In the present study, the increase in organic load with the increasing of COD without disturbing Hydraulic Retention Time resulted in high COD removal efficiency. Treatment of Dairy waste water and COD reduction was studied by many authors. Satyanarayan et al. [18] used a single-stage anaerobic filter for synthetic milk waste. The reported COD removal efficiency ranged between 80 and 90% at an OLR of about 0.8-4 kg COD/m<sup>3</sup>/day and HRT of 1.55-5.1 day.

Laboratory experiments have also established the feasibility of UASB process for the treatment of dairy waste water. Mehrotra and Jain [19] studied the performance of a 2.8 litre capacity UASB reactor using simulated dairy waste water. The reactor was found to remove COD by 90% at an organic loading rate of 8 kg COD/m<sup>3</sup>/day. Bench scale studies undertaken by Shastry and Kaul [20] on a UASB reactor revealed optimum COD loading conditions to be 3.6 kg/m<sup>3</sup>/day with a retention period of 1 day at an influent concentration of 3.6 g/l and the COD removal efficiency obtained was only 80%.

Roy and Chaudhuri [21] conducted pilot scale experiments on a 20 m<sup>3</sup>/day fixed film reactor for bimethanation of dairy waste water. COD feeding into the digester was 40 kg/day at a flow loading of 20 m<sup>3</sup>/day. However they could achieve COD reduction of 70% only after 25 days of HRT.

The present study the two phase UASB reactor could achieve much better performance. COD reduction of 81-84% at an organic load of 7.78-8.1 kg COD/m<sup>3</sup>/day with the HRT of just 15 hours.

Young [22] reported that HRT had an important influence on reactor performance. Good flow balancing and a steady hydraulic load would be necessary to achieve a consistent effluent quality. According to his report 70-75% COD removed at a steady 24-40 h HRT and 80-90% removal at 72-96 h HRT. Kennedy and Droste [23] reported that performance of the reactor in COD removal was between 70 and 80% at 5-15 kg COD/m<sup>3</sup>/day at HRT of 12-24 h. Saravanane et al. [24] also reported that more HRT was preferred to increase the COD removal and to prevent the washout of inoculated biomass.

According to Demirel and Yenigun [25] the activity of *Methanococcus* and *Methanosarcina* decreases at the HRT of 24 hours. Omil et al. [26] conducted experiment with dairy effluent in an Anaerobic filter, the OLR maintained as 5-6 kg COD/m<sup>3</sup>/day at an HRT of 48 hours to remove 90% COD. Tawfik et al. [27] also reported that treatment of a combined dairy and domestic waste water in an UASB reactor operated at a HRT of 24 hours and OLR range from 1.9-4.4 kg COD/m<sup>3</sup>/day resulted in only 69% COD removal. Treatment of cheese-whey with two-phase anaerobic digestion was studied by Yilmazer and Yenigun [28]. The system consisting of a continuous stirred tank reactor (CSTR) as the acidogenic reactor and an upflow anaerobic filter (UFAF) as the methanogenic reactor. The maximum acidification achieved at an HRT of 24 hours. The maximum COD removal of 90% achieved in the methanogenic reactor at a HRT of 4 days.

Nadais et al. [29] studied the influence of HRT on COD reduction and conversion to methane of the removed COD. For HRT under 12 hours continuous UASB reactors used for the treatment of dairy waste water presented conversion of methane and the COD reduction was lower than 30%. The author concluded that for maximum reduction, the reactor operated with maximum load around 3.0 g COD/l/day and the HRT must be more than 12 hours. Several other investigators also concern with the above conclusion [26].

However, some of the studies reported that high COD removal rate at lower HRT and in high organic loading rates. This was due to the reactors processed synthetic steady-composition wastes, with dairy wastes being simulated by powdered milk for example. These synthetic wastes contain much less Oil and Grease than real effluents. Indeed real effluents also contain additives such as disinfectant and cleansing agents that may jeopardize the biological treatment process. In the work of Ramasamy et al. [30], for example, the authors established the feasibility of UASB reactors in treating dairy waste waters. They reported COD reduction rates greater than 90% at HRT of 3 and 12 hours and their COD loading rates was 2.4 to 13.5 kg COD/m<sup>3</sup>/day [29]. For these experiments, powdered milk was used as effluent.

From the above discussion, it was concluded increasing of OLR by reducing HRT has much influence on the COD removal efficiency. In the present study also the COD reduction was declined at 79-81% at an OLR rate of 11.96-12.46 kg COD/m<sup>3</sup>/day with the HRT of 12 hours for acidogenic phase and in the methanogenic phase the OLR was 7.78-8.1 kg COD/m<sup>3</sup>/day at a HRT of 30 hours.

In the present investigation, raw effluent from one of the largest dairy processing unit was used instead of simulated ones and the COD removal of about 81-84% suggests the two phase UASB reactor could perform with higher organic load (7.78-8.1 kg COD/m<sup>3</sup>/day) and lesser HRT (12 hours). Other works on anaerobic treatment of dairy effluents in continuous reactors have reported a significant decrease in reactor performance or failure due to build-up of organic matter inside the reactors at lower HRT although no numerical data were presented for this accumulation [31].

In the present study, the better performance of the reactors than the reactors reported by other investigators can be attributed to two reasons. One definite reason is the phase separation. In the acidogenic phase rate of acidification was faster resulting in lowering of pH level (4.7-5.2) favored VSS production which in fact served as nutrient medium for the methanation in the methanogenic phase. The other reason could be that the operation of the reactors was so planned, that the Organic Loading Rate was stepped up in a phased manner by gradual increase of the concentration of the dairy waste water. After establishing a reasonable stability more quantum of dairy waste water was sent as influent by increasing the flow rate as well as by reducing the hydraulic retention time.

In the present study, the high COD removal rate achieved at an HRT 2 days for the acidogenic reactor at an OLR rate of 4.01-4.21 kg COD/m<sup>3</sup>/day and in the methanogenic reactor HRT of 2.5 days at an organic loading rate 2.61-2.75 kg COD. The maximum COD of the influent was 7,250-7,650 mg/l. This was comparatively higher than that of other reports, with single phase treatment method. The results indicate that a sharp decrease in the COD removal efficiency for loads above 2-4 g COD/l/day in the operation of sludge bed anaerobic reactors fed with dairy effluents.

## 5. CONCLUSION

Dairy industry is one of the main agro industry in all over the world. At the same time the dairy industry is one of the most polluting of industries, not only in terms of the volume of effluent generated, but also in terms of characteristics as well.

Many treatment methods are available to treat this wastes, but the anaerobic treatment methods is seems to be more viable for treatment of dairy waste as well as recover energy during this process.

Among the anaerobic treatment two phase UASB reactor work efficiently to treat also to

mitigate the issue of acidification nature of dairy effluent. The outcome of the work are described as following:

- The treatment of dairy waste water by the Two Phase Anaerobic UASB reactor showed that 91-93% of COD removal efficiency at an OLR of 4.01-4.21 kg COD/m<sup>3</sup>/day in the acidogenic reactor with an HRT of 2 days and for the methanogenic reactor the OLR was 2.61-2.75 kg COD/m<sup>3</sup>/day with an HRT 2.5 days.
- A maximum acidification rate of 67-70% achieved at the influent COD of 7,250-7,650gCOD/l.
- Two Phase Anaerobic UASB reactor is clearly an excellent feasible system for treating dairy processing waste water.
- Separation of acid and methane fermentation process produces high COD reduction and methane yield irrespective of the negative aspect of the dairy effluent like pH, quick acidification, Oil and Grease content also.
- A high COD reduction and methane conversion recorded even at a high loading rate of 5-7 kg COD/m<sup>3</sup>/day with a HRT of 2.5 days, without showing any sign of instability.
- VFA produced by acidogenesis are effectively consumed by the methanogenic phases.
- In methanogenic phase pH of 6.9 to 7.2 is maintained for 120 days without addition of any alkali which indicated the self-sustainability of the reactor.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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