

## Treatment Of Slaughterhouse Effluent Using Upflow Anaerobic Packed Bed Reactor

Sindhu R<sup>1</sup> and Meera V.<sup>2</sup>

<sup>1</sup> Assistant Executive Engineer, Kerala State Pollution Control Board, Trivandrum, India

<sup>2</sup> Assistant Professor, Department of Civil Engineering, Government Engineering College, Thrissur, India

**Abstract.** Most of the slaughterhouses in the state of Kerala (India) do not have proper and effective effluent treatment facilities. Collection of blood and separation of manure to reduce the very high organic load of the effluent are also not practiced. As a result, large volumes of extremely complex effluents with high content of fat, grease, and protein are discharged into land or water bodies causing severe pollution. This study evaluated the performance of an upflow anaerobic packed bed reactor (APBR) with randomly packed PVC pipe pieces as packing media, in treating effluent from a municipal slaughterhouse. (pH 7, suspended solids  $1673 \pm 857$  mg/L, total dissolved solids (TDS)  $4017 \pm 1704$  mg/L, oil and grease  $107 \pm 54$  mg/L, chemical oxygen demand (COD)  $7600 \pm 3445$  mg/L, ammonia nitrogen  $102 \pm 57$  mg/L and total phosphates  $123 \pm 76$  mg/L). The effluent responded well to treatment in APBR with a significant reduction (>80%) of COD when operated for about 200 days. Pretreatment using aluminium chloride ( $AlCl_3$  at 100 mg/L) was found essential for removing oil and grease. For an organic loading rate (OLR) of 4-5 kg of COD/m<sup>3</sup>/day, and 24 hour hydraulic retention time (HRT) about 88% COD reduction, 85-98% suspended solid removal, 30% reduction of ammonia nitrogen and phosphates and 15% TDS removal were observed. A post treatment of the effluent was however found necessary to achieve land or inland water discharge standard.

**Keywords:** Ammonia nitrogen; Chemical oxygen demand; Hydraulic retention time; Long chain fatty acids; Organic loading rate; Upflow anaerobic packed bed reactor

### 1. Introduction

Slaughter houses produce large amounts of wastewater with high fat, grease, and protein content. In most of the slaughterhouses in Kerala effective collection of blood, separation of manure or effluent treatment methods are not practiced and extremely complex effluents are discharged into land or water [1]. Surface and ground water pollution in addition to the odour, fly and mosquito nuisances are posed by these practices.

The slaughterhouse wastewater is well suited for anaerobic treatment because of the presence of high concentration of biodegradable organics, alkalinity and adequate phosphorous. It does not include toxic compounds and has sufficiently warm (around 30<sup>0</sup>C) temperature. Anaerobic digestion provides high organic removal while producing recoverable source of energy in the form of methane. It generates low quantity of sludge which does not require aeration. Anaerobic bacteria can survive unfed for long periods of time which is an important factor for small slaughterhouses that operate only a few days a week [2,3]. The experimental evaluation of biodegradation of slaughterhouse effluent under anaerobic and aerobic conditions suggested the need for an anaerobic treatment stage prior to aerobic treatment [4].

Anaerobic high rate systems like upflow anaerobic sludge blanket (UASB) reactor, anaerobic filters, anaerobic packed bed reactors (APBR) *etc.*, are sophisticated systems developed for accelerating the treatment and reducing area requirement. The slaughterhouse wastewater has high lipids concentration which makes suspended biomass anaerobic reactors such as UASB unsuitable. This is because of the lipid accumulation over the flocs, with the consequent loss of efficiency. It leads to low methanogenic activity, biomass floatation and wash out [5,6].

Anaerobic filters having random support material have been successfully used in the treatment of poultry slaughterhouse wastewater obtaining a reduction in chemical oxygen demand (COD) up to 80-90% for organic load in the range of 20-25 kg COD /m<sup>3</sup>/day and a quick start up of two or three weeks[5]. The use of packed bed reactors in treating poultry slaughterhouses wastewater in lab-scale after pre-treatment using aluminium chloride (AlCl<sub>3</sub>) was also reported to have successful results. It was found that the inhibitory effects of long chain fatty acids (LCFA) on methanogens were reduced by the influence of aluminium ion at 40ppm concentration. Pretreatment of slaughterhouse effluent with aluminium chloride is reported to enhance methane yield also [7].

Upflow anaerobic packed bed reactors (APBR) use corrugated plastic crossflow arrangement or plastic pallings or tubular modules as packing material. Since the voids volume is more, choking of the media can be avoided. The large volume of voids maximizes the available reaction volume and provides space for unattached biomass. The advantages of upflow APBR are high organic loading, relatively small reactor volume and operational simplicity. They are stable under stressed operating conditions like shock loads, very low hydraulic retention time or low temperature and intermittent operation.

The objective of this study was to evaluate the performance upflow anaerobic packed bed reactor in the digestion of slaughterhouse wastewater. Poly Vinyl Chloride (PVC) pipe pieces with roughened surface were used as the packing. The experiments carried out in the APBR were designed to study the influence of concentration of COD, organic loading rate (OLR) and hydraulic retention time (HRT) in the treatment of slaughterhouse wastewater.

## **2. Materials and methods**

### **2.1. Materials**

A schematic diagram of the experimental set up of the upflow APBR is shown in Fig I. The reactor of size 12 cm x 12 cm x 50 cm was made of acrylic sheets. The reactor was randomly packed with PVC pipe pieces of 1.9cm diameter and 1.6cm length. Effective volume of the reactor with packing was 6L. The sludge formed could settle at the bottom portion of the reactor, below the packing. 1L space was provided at the top of the reactor, above the packing for collecting the gas developed.

The raw effluent collected from the settling tank of a municipal slaughterhouse was used for the study. About 70-80 cattle (bovines, buffaloes and goats) were slaughtered daily in this unit and the total water consumption averaged 400 L/head. 25 litres of effluent was collected at a time, screened and stored under refrigeration. The samples were collected approximately twice a month, for a period of 7 months. The average quality of the wastewater was found to be having pH 7, a total COD 7600±3445 mg/L, suspended solids 1673±857 mg/L, total dissolved solids 4017 ± 1704 mg/L, total protein concentration of 2523±870 mg/L, fat content 107±54 mg/L, ammonia nitrogen 102±57 mg/L and total phosphates of 123±76 mg/L. This raw wastewater with sufficient dilution to achieve the desired strength (in terms of COD) was fed to the reactor. After an initial upset of the reactor, a physico chemical treatment, using aluminium chloride (AlCl<sub>3</sub>), at the optimum dosage of 100ppm, was given to the raw effluent to remove the fats and oils. From 42nd day of start up, this pre-treated effluent was used for the experiment.

### **2.2. Operating conditions and procedure**

Throughout the study the bio-reactor was operated at room temperature, 30±2°C. The pH of the influent to the reactor was kept in the range 6.5-7.5. The pretreatment of the raw wastewater using aluminium chloride also helped in keeping the influent pH in the range of 6.5 – 7.5.

The reactor was seeded with anaerobic sludge, about 1litre, obtained from the anaerobic effluent chamber provided in the slaughterhouse. For start-up, the reactor was flooded with the wastewater collected from the anaerobic chamber itself. Raw wastewater placed in a tank was fed to the reactor by means of gravity. The direction of flow through the reactor was upwards. The influent strength was 480mg/L of COD. Gradually the influent strength was increased by mixing raw slaughterhouse effluent with this wastewater and feeding on alternate days, until the initial failure of the system due to scum formation.

The reactor was started again by seeding with anaerobic sludge. It was then batch fed on alternate days with raw wastewater, pretreated with  $\text{AlCl}_3$  and diluted to the strength of the wastewater from the anaerobic chamber. In 15 days of re-start up, progressive increase in COD reduction and gas formation in the reactor were observed. Then continuous feeding of the reactor was started. The effluent from the reactor was recirculated along with the influent wastewater to achieve the progressive increase in OLR. The maximum OLR of  $8.0 \text{ kg COD/m}^3/\text{day}$  was achieved by applying undiluted pre-treated wastewater to the reactor. The optimum OLR without system upset was found to be of  $4\text{-}5 \text{ kg COD/m}^3/\text{day}$  corresponding to a COD concentration of  $4000\text{-}5000 \text{ mg/L}$ . The reactor was operated at this influent strength for 30 days at an HRT of 24 hours. The recirculation ratio during this period was 1:1. In the 2<sup>nd</sup> phase of the study, the HRT was reduced to 18 hours and the reactor was operated for the same influent strength for another 30 days.

### 2.3. Analytical methods

The samples from the inlet and outlet of the reactor were collected twice a week and analysed in duplicate for SS, TDS, COD, phosphates, and ammonia nitrogen according to standard methods [8,9]. The effluent samples were also analysed for alkalinity and volatile fatty acids (VFA) according to the method described in [10].

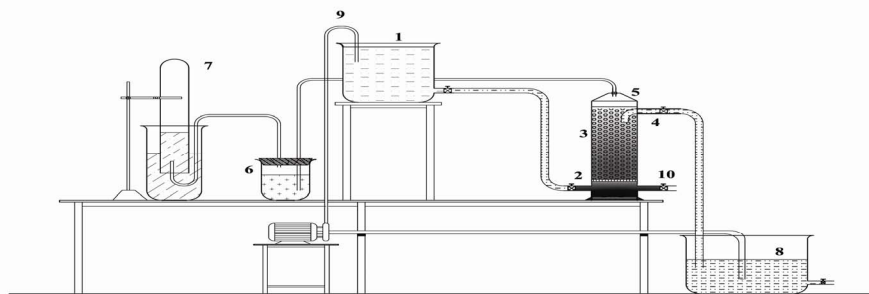


Fig 1. Schematic diagram of the experimental setup of upflow APBR

1) Influent Tank, 2) inlet to APBR, 3) APBR packed with PVC pipe pieces, 4) outlet of APBR, 5) gas dome, 6) NaOH solution, 7) methane collected by water displacement, 8) collection tank of effluent from APBR, 9) recirculation inlet of treated effluent, 10) sludge outlet

The volume of methane produced was determined by the liquid displacement method after removing acidic gases like  $\text{H}_2\text{S}$  and  $\text{CO}_2$  by absorption into NaOH solution and ammonia in water [11].

## 3. Results and discussions

### 3.1. Start up and operation of the reactor

The Fig. II. illustrates the variation in inlet and outlet COD and HRT during the entire period of the study. In 20-35 days of the start-up, the COD removal efficiency was found to be decreasing. During this period a superficial scum layer was seen developed in the reactor. The pH of the effluent from the APBR was in the range 8.2-8.4, much higher than the optimum range. These indicated upset of the reactor [12,13].

The failure of the reactor during the start up can be attributed to the presence of fats, grease and protein in the raw wastewater. These components are rapidly hydrolysed to long chain fatty acids (LCFA), glycerol and amino acids, respectively. The increase in effluent COD and scum layer formation can be associated with the combined effects of two factors: 1) the LCFA are acutely toxic to methanogens and acetogens and causes bacterial inhibition, 2) excessive adsorption of these substances to the sludge granules causes the formation of a lipid film around the biomass particles. Under these conditions the continuous operation of the reactor allows an increase in size and loss of density of these granules causing the formation of scum[13] .

Pre-treatment of the wastewater using  $\text{AlCl}_3$  at the rate of  $100 \text{ mg/L}$ , helped in overcoming this problem. It is illustrated in Fig. II as 2<sup>nd</sup> start-up. About 25-30% reduction in influent COD was effected by the addition of  $\text{AlCl}_3$ . Coagulation with aluminium was reported to remove a part of the phosphates present in the influent [14]. In this study also, 30-35% total phosphates reduction was noticed.

During the start-up the reactor had to be kept without fresh feeding for a period of 10 days, from day 104 to 114, due to non availability of raw effluent from the slaughterhouse. However the system endured the bad condition and recovered quickly. This period is represented in Fig. II. by a sharp fall in inlet COD concentration. The % COD removal of the reactor with respect to OLR throughout the period of study is illustrated in Fig. III.

The maximum OLR was applied on 151th day of reactor operation. Since the system showed signs of upset like scum formation and biomass wash out the OLR was reduced to a more stable rate of 4-5 kg COD/m<sup>3</sup>/day for 24 hours HRT. The reactor was operated at the optimum OLR of 4-5kg COD/ m<sup>3</sup>/day for 30 days. Since the percentage reduction was more or less steady at 86-88%, the HRT was reduced to 18hours keeping the strength of the influent constant at 4000-5000 mg/L of COD.

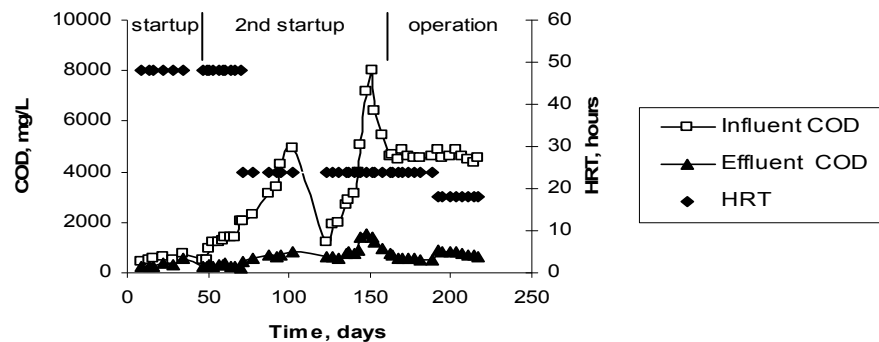


Fig 2. Variations in influent and effluent COD and HRT during reactor startup and operation

### 3.2. pH, volatile fatty acids (VFA) and alkalinity in the reactor

Except for the initial 42 days, the influent pH remained in the range 6.5-7.5 desirable for anaerobic digestion]. The effluent pH was always slightly higher than the influent pH due to the formation of ammonia. The mineralization of protein into ammonia causes an increase in alkalinity in slaughterhouse effluents[3]. Since the slaughterhouse effluent itself had high alkalinity, pH correction, as usually required in anaerobic processes, was not required at any stage of the experiment. Moreover the ratio, VFA/alkalinity remained below 0.4 indicating favorable fermentation conditions [11]. Only when the OLR was high (7.2 and 8 kg of COD/m<sup>3</sup>/day), the ratio exceeded 0.4.

### 3.3. Reduction in effluent COD and SS concentration

Fig II. illustrates that for all concentrations of influent COD, the strength of the effluent remained less than 2000mg/L. For an influent strength of 4000-5000 mg/L of COD (OLR 4-5kg COD/ m<sup>3</sup>/day) and HRT, 24hours, the APBR attained 87-88% efficiency in COD reduction (Fig. III). The effluent COD was less than 900mg/L but not within the permissible limit of 250mg/L. Thus a post treatment was required for the effluent. A lower HRT of 18hours was then tried which resulted in 82-85% reduction in COD.

In biodegradability study of slaughterhouse wastewater subjected to aerobic and anaerobic systems, it was found that the wastewater responded well to anaerobic treatment with a COD removal of 80%. Further anaerobic degradation was much slower [4]. The study suggested that an appropriate combination of anaerobic and aerobic reactors would have to limit anaerobic degradation around 80% of the total COD and an effluent concentration of about 1000mg/L for the optimum operation of the following aerobic stage. The results attained in the present study are also similar and can be considered favourable for aerobic post treatment.

In APBR the total COD reduction is attained in two steps: 1) by the settling of the SS present in the influent 2) by the degradation of the COD by the action of the anaerobic microorganisms [3]. In this study the SS in the influent samples varied between 267-1735 mg/L The removal efficiency of SS in the APBR remained in the range of 90- 98% (Fig.III).

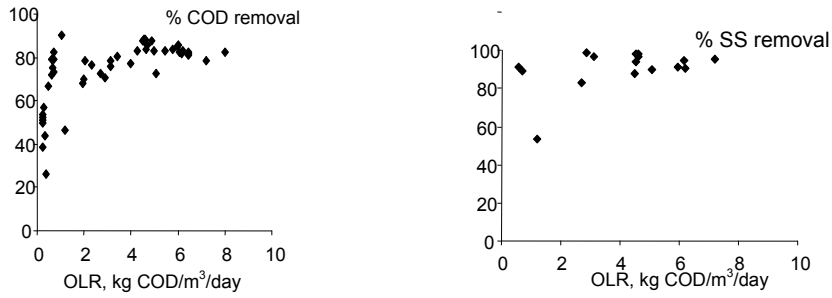


Fig 3. Removal efficiency of COD and SS with respect to organic loading rate

### 3.4. Removal of TDS, phosphates and ammonia nitrogen

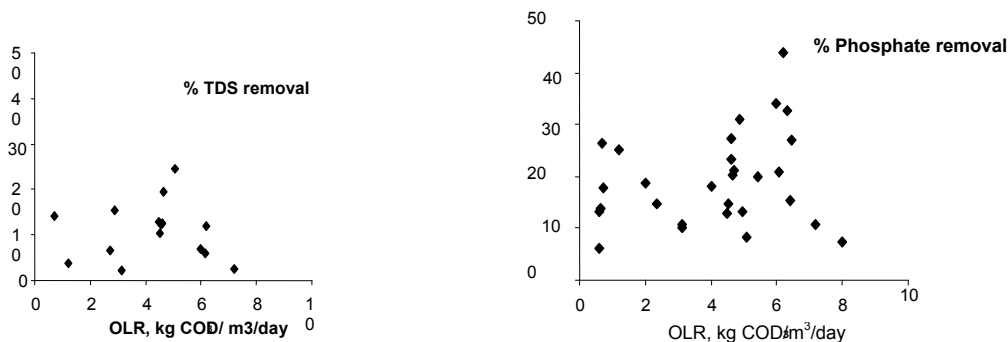
Fig. IV illustrates the efficiency of reduction of TDS, phosphates and ammonia nitrogen. The rate of removal of TDS was below 20%. Phosphates and ammonia nitrogen removal were found to be less than 30%, which may account for the low removal efficiency of TDS. High efficiency in phosphate reduction is not achieved from anaerobic treatment. The removal of phosphates requires anaerobic contact zone followed by an aerobic zone [14]. The low reduction rate for ammonia nitrogen in the present study may also be due to the conversion of protein present in the influent into ammonia nitrogen. Low rate of bacterial synthesis in anaerobic process translates into low overall nitrogen removal.

### 3.5. Methane yield

Waste stabilization in anaerobic treatment is directly related to methane production. The methane yield from the APBR in the present study was found to be averaging between 175 - 220 mL/g COD removed. The rate of gas production was lower than the theoretical value of 350mL/g COD removed at Standard Temperature and Pressure (STP) [7,14]. It may be due to the effects of ammonia nitrogen present in concentrations higher than the beneficiary levels in the influent [15].

### 3.6. Production of sludge

The sludge inside the reactor was of rapidly settling nature. The rate of sludge production in the reactor was found to be very low. Less than 2 L sludge was produced during the entire period of the study. This suggests that most of the soluble as well as settled matter in the wastewater was degraded during the treatment in the APBR.



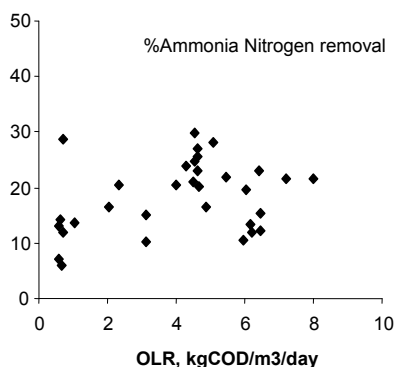


Fig 4. Removal efficiency of TDS, phosphates and ammonia nitrogen with respect to organic loading rate

## 4. Conclusions

The slaughterhouse effluent responded well to anaerobic treatment in an upflow APBR with more than 80% COD removal efficiency. Addition of  $\text{AlCl}_3$  at 100mg/L to the influent helped in coagulating and removing the long chain fatty acids. About 25-30% reduction in influent COD and 30-35% reduction in total phosphates was effected by the addition of  $\text{AlCl}_3$ .

For OLR of 4-5 kg of  $\text{COD}/\text{m}^3/\text{day}$  and HRT of 24 hours, 87-88% COD removal was achieved. When the OLR was increased to 5-6 kg of  $\text{COD}/\text{m}^3/\text{day}$ , by reducing the HRT to 18 hours, 82-85% efficiency was observed. When the applied OLR was in the range of 7-8 kg of  $\text{COD}/\text{m}^3/\text{day}$ , at 24 hours HRT, the reactor showed signs of upset, but an efficiency of 82% in COD removal was still achieved.

The reactor had an efficiency of 85-98 % in removing the suspended solids. But the TDS removal efficiency was about 15%. The reactor could only remove <30% of the ammonia nitrogen and phosphates present in the influent. The upflow APBR was found to be easy to operate and stable. The reactor stability was easily achieved after intermittent operation or break

The treatment of slaughterhouse wastewater in an upflow APBR, using randomly packed PVC pipe pieces as packing medium, achieved satisfactory results. But the effluent quality still did not meet the discharge standards. A post treatment method is therefore required to bring the quality of the effluent within the standard limits.

## 5. References

- [1] CPCB 1992 *Comprehensive industry document on slaughterhouse, meat and sea food processing*, Comprehensive industry document series COINDS/38/1992, Central Pollution Control Board, Delhi.
- [2] McArty, P.L. 1964d Anaerobic waste treatment fundamentals, Part four, Process design, *Public Works*, 95-99.
- [3] Masse,D.I & Masse,L.2000Treatment of slaughterhouse wastewater in anaerobic sequencing batch reactors, *Canadian agricultural Engineering*, **42(3)**, 131-137.
- [4] Del Pozo,R., Tas,D.O., Dulkadiroglu, H., Orthon,D., Diez,V. 2003 Biodegradability of slaughterhouse wastewater with high blood content under anaerobic and aerobic conditions, *Journal of Chemical Technology & Biotechnology*, **78(4)**, 384-391
- [5] Del Pozo,R., Diez, V., & Beltran,S. 2000 Anaerobic pre- treatment of slaughterhouse wastewater using fixed film reactor, *Bioresource Technology*, **71**, 143- 149.
- [6] Caixeta,C.E.T., Cammarrota,M.C.C. & Xavier,A.M.F. 2002 Slaughterhouse wastewater treatment: evolutions of a new three phase separation system in a UASB reactor, *Bioresource Technology*, **81**, 61-69.
- [7] Martinez, J.A. 2003 *Influence of aluminium ion on the anaerobic treatment of a poultry slaughterhouse wastewater*. Degree of Master of Science thesis. Dave C. Swalm school of Chemical Engineering, Mississippi, U.S.A.
- [8] *Standard Methods for the Examination of Water and Wastewater* 1971 13th edition, American Public Health

Association/American Water Works Association/Water Environment federation , Washington DC.

- [9] *Standard Methods for the Examination of Water and Wastewater* 1995 19th edition, American Public Health Association/American Water Works Association/Water Environment federation , Washington DC.
- [10] Anderson,G.K., Yang, G. 1992 Determination of bi carbonate and total volatile acid concentration in anaerobic digesters using a simple titration, *Water Environment Research*, **64**, 53-59.
- [11] Iscen,F.C., Ilhan,S. & Yildirim,M.E. 2007 Treatment of cake production wastewater in upflow anaerobic packed bed reactors *International Journal of Natural and Engineering Sciences*, **1 (3)**, 75-80.
- [12] De Villiers,G.H. 2000 Slaughterhouse effluent treatment and protein production: Full-scale application, *Water SA*, **26(4)**, 559-562.
- [13] Miranda,L.A.S., Henriques,J.A.P., & Monteggia,L.O. 2005 A full scale UASB reactor for the treatment of pig and cattle slaughterhouse wastewater with a high oil and grease content. *Brazilian Journal of Chemical Engineering*, **22(4)**, 601-610.
- [14] Metcalf & Eddy, Inc., 2003 Fourth Edition *Wastewater Engineering: treatment disposal and reuse*, McGraw-Hill, New York, N.Y.
- [15] McArty, P.L. 1964c Anaerobic waste treatment fundamentals, Part three, Toxic materials and their control, *Public Works*, 91-94.