Integrated UASB and Batch Sequencing Reactor System for Domestic Sewage Treatment

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Abstract

The performance of a pilot scale Integrated UASB and Continuous Flow Intermittent Decant (CFID) type Sequencing Batch Reactor (SBR) treating actual sewage was investigated under ambient temperature conditions of 15^0C to 30^0C as a treatability screening procedure. Raw sewage characterized by parameters of 453±102 mg/L COD, 228±72 mg/L BOD, 72±16 mg/L T-N (NH_4-N + NO_3-N), 55±15 mg/L NH_4-N, 3.5±2.0 mg/L NO_3-N, 360±172 mg/L TSS and 9.2±4.3 mg/L PO_4-P generated UASB effluent parameters for the CFID feed of 149±46 mg/L COD, 70±19 mg/L BOD, 172±71 mg/L TSS, 65±19 mg/L NH_4-N, 4±2 mg/L NO_3-N and 9.1±1.2 mg/L PO_4-P as the feed. The hydraulic retention time (HRT) of the pilot scale UASB reactor was fixed at 8 hours with CFID operation at 20, 8 and 6 hours, respectively under both DO limiting (<0.5 mg/L) and non limiting (>2.5 mg/L) concentrations. Best effluent quality from the CFID over the six study phases was obtained with a 6 hour duration cycle, 8 hour HRT, non limiting dissolved oxygen (DO) concentration (2.5-3.5 mg/L) at MLVSS based organic loading (F/M) of 0.10-0.64 aerated day^{-1}. The corresponding mean BOD, TSS, Ammonia Nitrogen and fecal coliform removal efficiencies of the CFID reactor were up to 83, 90, 74 and 99%, respectively. The results of this short pilot study suggest that activated sludge used in an SBR/CFID system is a promising post-treatment technique for augmenting existing UASB based STPs for compliance with receiving water and effluent reuse discharge criteria.

***Keywords**:* Continuous Flow Intermittent Decant, Cyclical Activated Sludge, Dissolved Oxygen Limitation, Hydraulic Retention Time, Denitrification, Upflow Anaerobic Sludge Blanket, Sequencing Batch Reactor, Ammonia Removal.

Introduction

While UASB methodology has gained some recognition for the partial treatment of domestic sewage in a number of developing countries (Aiyuk et al. 2004) the effluent quality cannot comply with receiving water or effluent reuse discharge standards and requires a post treatment system for this purpose. Final polishing units (FPU) or ponds have been extensively used but have not provided adequate improvement as they only trap solids and do not address BOD/COD and nutrients. In order to meet this need a variety of post treatment methods based on diverse combinations with UASB treatment have been studied including polishing ponds, activated sludge process (ASP), trickling filter (TF), submerged aerated bio-filter (SABF), rotating biological contactor (RBC), wetlands, conventional sequencing batch reactor (SBR), chemically enhanced primary treatment (CEPT & zeolite column), dissolved air flotation (DAF) and recently studied aeration system (Khan, 2011) mostly at the laboratory and pilot scale. While a few systems such as polishing ponds, wetlands, ASP and aerated lagoons are in full scale application, the majority (TF, RBC, CEPT, SABF, DHS) remain mostly under investigation at the laboratory and pilot scale making claim to be an attractive technology for the post treatment duty. In the realm of wastewater treatment, UASB effluent poses a number of challenges due to the relatively low content of degradable organics in both the liquid and solids fractions. In some respects the UASB process converts what is normally a simple exercise of degradation into one of a much higher complexity.

The SBR is one of the more promising methodologies for UASB post-treatment having been successfully applied in many domestic dilute sewage treatment situations comparable to the relatively low concentrations of organics and nutrients in UASB treated domestic effluent. While the removal of residual BOD and TSS from the effluent of a UASB reactor using SBR methodology has been investigated (Souza and Foresti, 1996; Torres and Foresti, 2001; Moawad, et al. 2009), there is limited information available on the fate of nitrogen and coliforms.

This paper addresses the removal of residual BOD, SS and ammonia nitrogen and coliforms from UASB effluent using activated sludge in a bench scale continuous flow intermittent decant (CFID) reactor. The CFID operates with continuous inflow over all of the SBR sequences of aeration, settle and decant and includes a partial transverse wall to generate two reaction zones (approximately 1:10) in fluid communication (Goronszy, 1978). Whilst the CFID can be very effective for meeting BOD and TSS limits; consistent nitrogen removal is a function of organic loading, fill ratio, temperature and reactor geometry.

Material and Methods

UASB Reactor

The pilot scale Upflow Anaerobic Sludge Blanket (UASB) reactor had dimensions of 1500 mm in height and 200 mm × 200 mm internal base (Fig.1) giving an effective volume of 45 L. The reactor was operated at a fixed HRT of 8 hours using sewage from the campus of the Indian Institute of Technology, Roorkee, India.

Continuous Flow Intermittent Decant (CFID) Reactor

CFID operating conditions are summarized in Table 1.0. The top water level working volume was 125L, 28.5L and 22.5L with a fill ratio of 0.40 for each of the 8 hour, 6 hour and 4 hour operating cycles, respectively (Fig.1). UASB effluent was fed continuously for each phase of the study. After settling, supernatant (effluent) was gravity removed (decanted) through a flow controlled 12 mm dia. pipe to simulate the variable volume operation of a full scale reactor. Effluent was received and accumulated daily in order to provide representative and composite 24 hour samples. The reactor contents were mechanically mixed (double paddle, 100-150 rpm) during the aeration sequence in order to maintain the different DO reaction conditions, especially at low DO. Process air was introduced through nine fine porous ceramic stone diffusers at the bottom of the reactor from a 53 psi, 135 L/min air pump. The air flow was controlled by a gas flow meter in order to achieve set point DO concentrations. The pumps, mixing stirrer, and solenoid decant valve were controlled by a programmable timer. The reactor was operated with continuous inflow and intermittent aeration and decantation for the six study phases at three different cycles and two DO regimes as summarized in Table 1. Both reaction zones in the CFID were aerated (Fig. 1). Aeration sequencing was standardized at half the total cycle time in each case. MLSS, MLVSS, SV_{30}, and temperature and relative duration of the six phases of operation are shown in Fig 2. Phases 1 and II each of 240 SBR cycles were conducted in sequence; Phase III following a gap of about 15 days was conducted over 360 SBR cycles. Phase IV was conducted over 120 SBR cycles after which Phases V and VI followed in sequence over 300 and 250 SBR cycles, respectively. Representative track runs were conducted two times in each phase; the data in Fig. 3 accords with days 8, 41, 100, 155, 200, and 275 relative to each phase.

Analytical Procedure

Temperature, pH, Alkalinity, COD, ORP were monitored daily; data on biogas production and ORP were collected to gauge operational stability of the UASB. BOD, Sulfates, total sulfides, NH_4-N, NO_3-N, PO_4-P and BOD were determined twice a week; TSS, VSS, SV_{30} in the CFID reactor and Fecal Coliform densities were measured weekly. UASB redox was checked with an ORP electrode (Aqua Lytic, Model E-27006-21) by comparing and standardizing with the redox potential of ZoBell's solution. All wet analyses were performed according to Standard Methods of Examination of Water and Wastewater (APHA, 1998).

Table 1.0 Operating Conditions for the CFID Reactor

Case of Study	HRT (h)	DO Level (mg/L)	Study Period (days)	No. of Data points (n)	Cycle Duration (h)	Aeration (h)	Settling (h)	Decantation (h)	F/M (gm BOD/gm MLVSS. Aerated day)
I	20	4.0 –5.0	30	25	8	4	3.0	1.0	0.06-0.14
II	20	< 0.5	20	14	8	4	3.0	1.0	0.06-0.14
III	8	2.5 – 3.5	90	70	6	3	2.0	1.0	0.1-0.64
IV	8	< 0.5	30	20	6	3	2.0	1.0	0.14-0.24
V	6	2.5 – 3.5	75	60	4	2	1.5	0.5	0.2-0.64
VI	6	< 0.5	50	42	4	2	1.5	0.5	0.22-0.82

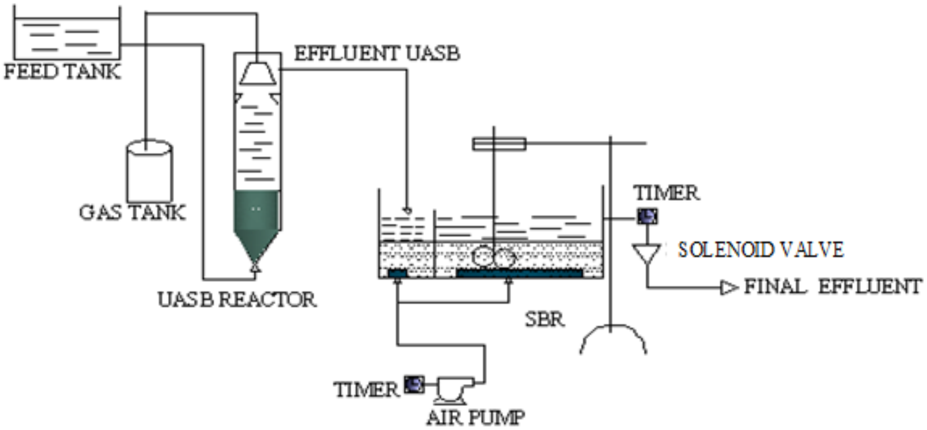

Fig. 1 Schematic of the Integrated UASB-CFID Batch Reactor

Results and Discussion

Performance of the Integrated UASB-CFID System Treating Domestic Sewage

UASB influent and effluent parameters are summarized in Table 2 which shows values of the range, mean and standard deviation. CFID effluent parameters for each study phase are shown as mean and standard deviation. Fecal coliform density information is included for completeness. CFID influent and effluent parameters represent daily composite samples. Mean operating temperatures of the CFID during the various phases are summarized in Table 3. Fig. 2 summarizes the operating conditions for MLSS, MLVSS and SV_{30} during each phase of the study. Representative track run data are shown in Fig. 3 for each of the six phases. Fig. 4 summarizes influent and effluent ammonia nitrogen into and out of the CFID at summary mean temperature of the non limiting DO phases I, III and V.

UASB Reactor

Mean percentage removal of BOD, COD and TSS varied between 60-70%, 60-65% and 60-65%, respectively. This performance is similar to that reported for full scale facilities in India. The removal of Nitrogen and Phosphorus was not significant; the effluent pH remained within the optimal working range for anaerobic digestion (6.9–7.9) throughout the experimental program.

CFID Reactor

The BOD and COD removal efficiencies in the CFID varied from 78 to 87% and 70 to 85% respectively at different times of the study. The removal of BOD and COD was not significantly affected by HRT, DO and cycle time for all phases of the program (I, II, III, IV, V and VI). Ozer et al. (2008) have also reported similar COD removals for different cycle times. The TSS removal efficiency under all operating conditions ranged from 70 to 80% resulting in a total removal of TSS of 80 to 90% in the overall system. The considerable fluctuation in TSS concentration in the influent to the UASB reactor (150-450 mg/L) was fully dampened by the CFID. The relatively low mean concentration of TSS in the effluent of the SBR system (< 32 mg/L) suggests the presence of an adequately flocculent biomass. Values of SV_{30} graphed in Fig. 2 also corroborate the comment of adequate settling of the biomass, particularly as the settling time was always greater than 90 minutes.

The overall effect of DO on nitrogen (ammonia) was very clear. Best ammonia nitrogen removal of 70% resulted from operation under non limiting DO conditions (>2.5 mg/L). Under reaction conditions of DO limitation (<0.5 mg/L) removal was markedly affected from a low of 21% (Phase IV) to 42% (Phase II) and 60% (Phase VI). This study showed very similar ammonia removal for Phases I, III and V, the common factor being non limiting DO; HRT was 20, 8 and 6 hours, respectively using associated cycles of 8, 6 and 4 hours. Under the conditions of operation, temperature did not appear to affect ammonia removal provided the DO was non limiting.

The data shows that there was insignificant removal of PO_4-P in the CFID under all cases of the study (I, II, III, IV, V and VI). Influent PO_4-P was more than 30 mg/L on a few occasions otherwise it remained between 5-8 mg/L. The small fraction of phosphorus removed reflects assimilation by cell growth. Reaction conditions did not favor enhanced biological phosphorus removal.

Variation of BOD Removal Efficiency in UASB-CFID

The mean BOD in the effluent was less than 20 mg/L over all phases. Best results were obtained using 6 and 4 hour cycles at 8 and 6 hours HRT, respectively under all DO conditions. The BOD removal was almost unaffected by the large variation in organic loading; hence, it can be presumed that the system can cope with organic load fluctuations and would be sufficiently sturdy under full scale varying BOD conditions.

Variation of MLSS, MLVSS and SV$_{30}$ under Different Operating Phases

Fig. 2 shows the relative profiles of SV$_{30}$, MLSS and MLVSS in the CFID during the different phases. Phases I and II were operated at low organic loading beginning with a sludge that had a VSS/TSS ratio reflective of the STP from which it was taken. Because of re acclimation, an initial rapid VSS destruction occurred in phase I due to the low loading (soluble and particulate) on this biomass and the relative over aeration in the non limiting DO reaction conditions. Phase II indicates a slowing of the rate of VSS destruction because of DO (mass flow rate) limitation. In the study fractional VSS reduction occurs from a combination of low degradable organic concentrations in the liquid and solid substrates, over aeration during the non limiting DO reaction conditions and the relatively higher fraction (variable) of inerts in the influent TSS under the temperatures at which the CFIDs were operated. In many cases the loss of volatiles through endogenation exceeded the metabolic yield because of the low strength of the influent substrates; hence the decrease of the volatile fraction (MLVSS). Biomass settling (SV$_{30}$) was generally reflective of varying reaction conditions that took place under the low organic loading and the different DO regimes of this screening study. Of note was the reduction from 750 mL/L to circa 150 mL/L during the initial 20 days of phase 1.

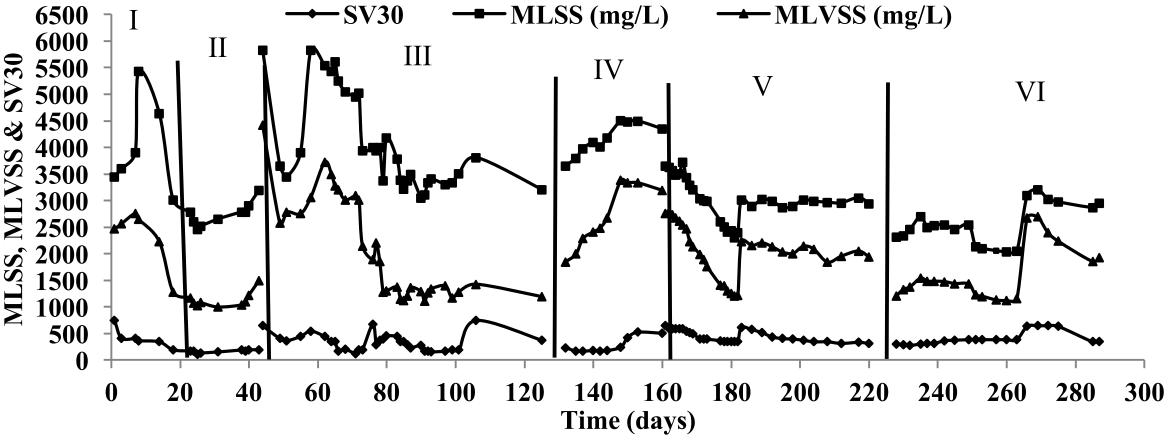

Fig. 2 Operating Conditions for MLSS, MLVSS and SV$_{30}$ at Different Phases

Table 2.0 Performance of Integrated UASB-CFID System for Sewage Treatment at Different Operating Conditions

Influent and Effluent of UASB Reactor							**CFID Effluent**											
							Phase of operational study											
							I		**II**		**III**		**IV**		**V**		**VI**	
Parameters	**Influent (Sewage)**	**Mean**	**S.D[a]**	**UASB Effluent**	**Mean**	**S.D[a]**	**Mean**	**S.D[a]**	**Mean**	**S.D[a]**	**Mean**	**S.D[a]**	**Mean**	**S.D[a]**	**Mean**	**S.D[a]**	**Mean**	**S.D[a]**
COD (mg/L)	200- 650	435	102	88 – 213	149	46	39	32	24	5	24	12	20	4	22	12	17	12
BOD (mg/L)	89-350	228	72	46 -102	70	19	17	18	13	4	9	6	6	1	12	9	9	7
TSS (mg/L)	60- 450	360	172	104 – 273	172	71	32	14	18	5	26	12	27	8	16	8	14	7
T-N (mg/L)	23- 158	72	16	20-150	70	20	29	6	42	19	21	11	57	12	23	13	29	12
NH_4-N (mg/L)	22-153	55	15	15-145	65	19	28	6	40	18	17	11	55	11	17	13	24	11
NO_3-N (mg/L)	0.30-7.0	3.5	2.0	4.0-10.0	4	2	1.3	0.9	2.2	0.6	0.98	0.55	2	0.44	6	3	5	2
PO_4-P (mg/L)	2-10	9.15	4.26	7.82 – 11.2	9.12	1.15	3	1	5	1	9	7	3	1	4	5	4	0.3
FC[b] MPN/100mL	4.3E+05	4.3E+05	4.3E+05	4.3E+04 – 4.3E+05	1.89E+05	2.10E+05	2.12E+03	1.84E+03	1.2E+03	8.20E+02	1.80E+03	1.94E+03	1.58E+03	9.05E+02	1.75E+03	1.71E+03	1.34E+03	9.04E+02

[a]S.D. = standard deviation; [b]FC = fecal coliform

Table 3.0 Mean Operating Temperature for CFID

Temp. / Phases	**I**	**II**	**III**	**IV**	**V**	**VI**
Min. (Avg.)	22	23	15	21	22	24
Max. (Avg.)	26	25	17	24	27	30
Temp. during track runs	23	24.5	16.5	21.5	23	25

Nitrification Denitrification during CFID Cyclic Operation

Representative track runs from each of the six phases in which the reactor is aerated and mixed during the initial half cycle period and non mixed conditions exist during the second half cycle period are shown in Fig 3 (A-F). Parameters are shown for the mixed sludge and settled sludge environments.

Ammonia nitrogen introduced during the non aeration react sequencing is conservative and partly remains in the reactor for reaction in the subsequent aeration sequence or is partly removed hydraulically (bypassed) during the removal of the treated effluent. Ammonia bypass is related to the cycle time and fill ratio and is a feature of CFID processing. Bypass can be addressed with proper design in which the organic loading, and retention time is by necessity relatively low and high, respectively and with limitation of the fill ratio.

Operation under (assumed) DO limiting conditions (<0.5 mg/L) clearly shows suppression of nitrification and negligible removal of NH_4-N for each of the three phases II, IV and VI (B, D, F). This mode of operation would be limited to meeting a mean discharge specification of less than 15 mg/L BOD and 30 mg/L TSS, provided nitrogen was not a constraint and low DO and low F/M filamentous sludge bulking did not eventuate. Nitrifer growth does take place at 0.5 mg/L DO, but at a lower rate than at the normally accepted DO concentration of 2.0 mg/L.

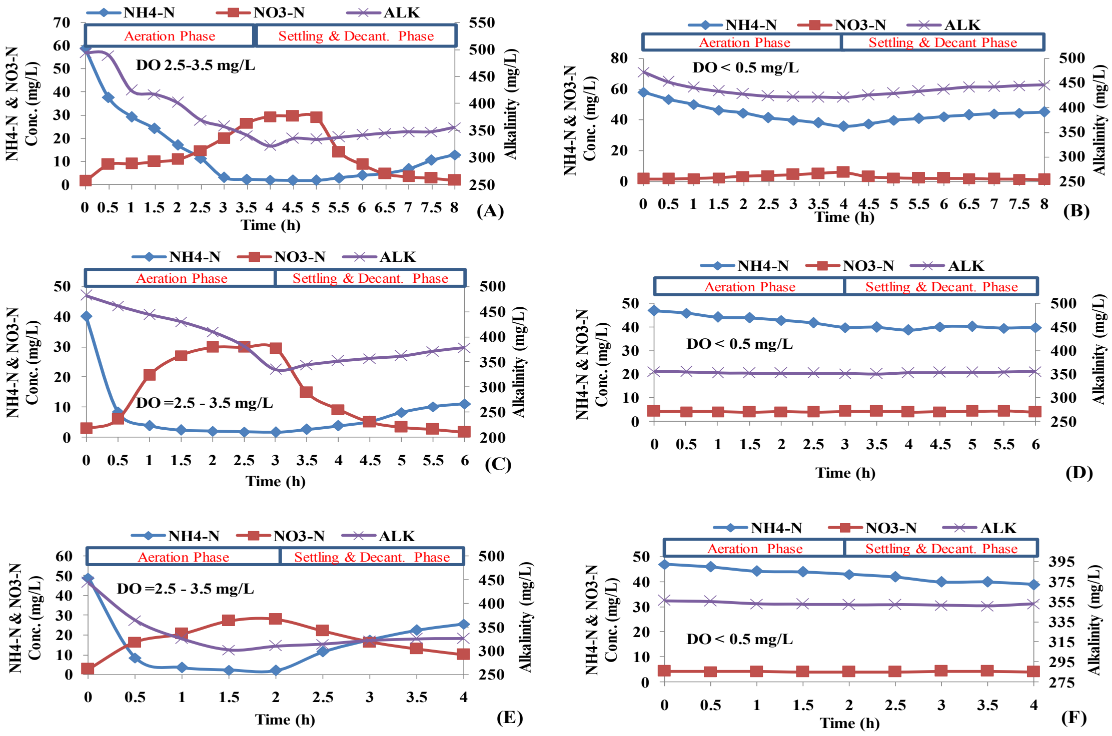

Fig. 3 (A-F) Temporal Variation of NH_4-N, NO_3-N and Alkalinity during Representative Cycles

Operation under non limiting DO conditions (>2.5 mg/L) was shown to promote nitrification in the aerated mixed condition with denitrification taking place within the settling sludge layer in each of the three phases I, III and V (A, C, E). This mode of operation is limited to meeting a mean discharge specification of less than20 mg/L BOD, less than 35 mg/L TSS and less than 30 mg/L NH_4-N provided filamentous sludge bulking did not eventuate. Bypass, as measured by NH_4-N, was essentially the same for all cycles and HRTs.

Significant denitrification was shown to take place take in the settled sludge layer with best apparent removal in the 8 and 6 hour cycles even though the influent COD: TN ratio shows soluble carbon to be limiting.

Ammonia Nitrogen Removal at Ambient Temperature in the CFID

Fig. 4 summarizes the ammonia nitrogen data relative to the influent to and effluent from the CFID under the three non limiting DO phases relative to the phase mean operating temperature. The data are shown as mean and maximum-minimum values over each of the phases and serve to indicate the measure of attenuation of influent variation offered by the CFID.

Effluent ammonia concentration for the three periods can be regarded as similar at around a mean of 20 mg/L.

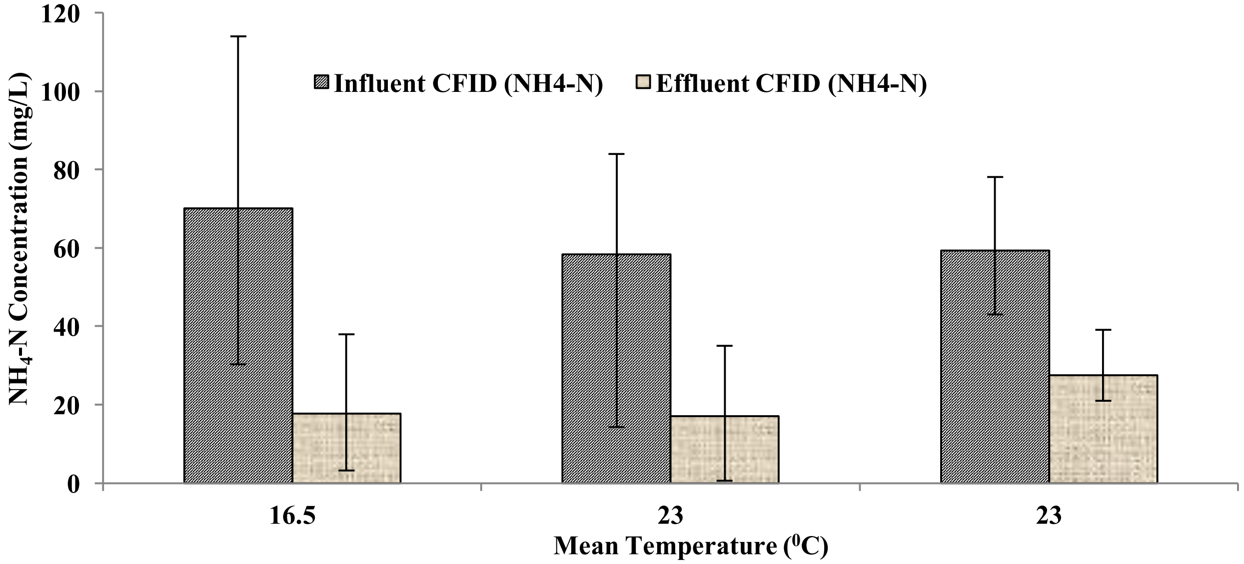

Fig. 4 Distribution of Effluent NH_4-N from Integrated UASB-CFID System

Conclusions

The screening procedure used for assessing the treatment of UASB domestic sewage effluent under equivalent ambient conditions has shown that activated sludge used in an SBR/CFID system is a promising post treatment technique for augmenting existing UASB based STPs to meet receiving water and effluent reuse discharge criteria. Effective BOD and TSS removal can be obtained with limited aeration provided filamentous sludge bulking can be contained. Effective ammonia removal can be obtained using all cycles and HRTs provided the process oxygen supply is not limiting. Effective sequenced nitrification denitrification takes place under sequenced aeration and non aeration. Full scale adaption of these results requires a design and configuration that properly manages inherent carbon limitation and ammonia leakage with efficient nitrification and denitrification.

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