Research Article ISSN: 2319-507X
Rinku Walia, IJPRET, 2014; Volume 2 (6): 41- 54 IJPRET

INTERNATIONAL JOURNAL OF PURE AND APPLIED RESEARCH IN ENGINEERING AND TECHNOLOGY

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AERATION OF THE EFFLUENT FROM UASBR: EVALUATION OF ORP AS A MONITORING PARAMETER

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Accepted Date: 21/01/2014 ; Published Date: 01/02/2014

Abstract: Effluent from upflow anaerobic sludge blanket reactors (UASBRs) were aerated by diffusers and the process was monitored by measuring the oxidation reduction potential (ORP), dissolved oxygen (DO), chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Experiments were conducted on effluents of bench scale 56 L UASB reactor as well as on the effluents from four UASB based sewage treatment plants (STPs) of capacities ranging from 34 to 70 ML/d. Redox potential of the effluents has been found to vary from -100 to -150 mV. Empirical correlations between ORP and other monitoring parameters have been established based on the observations recorded from the aeration of effluent from four field plants treating sewage and bench scale UASBRs treating soluble and complex synthetic wastewater. With the increase in ORP from -150 to +150 mV, COD of the effluent decreased by ~50 %. The increase in DO and decrease in COD have been found equal to 0.015 and 0.13 mg/L-mV respectively i.e. the reduction in COD is nearly eight times the increase in DO with respect to ORP.

Keywords: Aeration; Anaerobic treatment; Chemical oxygen demand; Wastewater; Regression model; oxygen transfer

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How to Cite This Article:

Rinku Walia, IJPRET, 2014; Volume 2 (6): 41- 54

PAPER-QR CODE

INTRODUCTION

The effluent from anaerobic process requires post treatment for the removal of residual BOD, COD, nutrients and pathogen indicators. Redox potential of anaerobically treated effluent varies from -180 to -220 mV and the corresponding oxygen pressure ranges from $10^{-83.12}$ to $10^{-63.12}$ atm. The ORP of the system depends on the ratio of the concentrations of oxidants (DO) to the reductants (COD). (Stumm and Morgan, 1981)

DO, therefore cannot be measured under these conditions and ORP can be used to monitor the process.

The ORP can be utilized over the full range of redox conditions i.e. from highly reduced to highly oxidized conditions. Peddie et al. (1990) monitored ORP within aerobic sludge digestion undergoing alternating aerated and non aerated conditions. The time response of ORP indicated DO elbow, DO knee and nitrate knee implying rapid nitrification, depletion in measurable DO and denitrification respectively. The ORP profile thus has been found to be sensitive to changes in biological or chemical activity. Nitrate breakpoint in the ORP-time profile was subsequently used by Wareham et al. (1993, 1994) in a real time control of aerobic-anoxic sludge digestion. The sludge digestor operated with 3 h of air-on and the air-off time was determined by computer detection of nitrate knee in ORP-time profile.

The simultaneous nitrification/denitrification processes are characterized by biochemical events such as depletion of organic carbon and ammonia nitrogen. Holman

and Wareham (2003) have demonstrated these events as COD knee and ammonia knee on ORP profile. Yu et al. (1997) used the real –time control operation based on ORP and pH for continuous –flow sequencing batch reactor. The real-time operation showed a better nitrogen removal than fixed –time control.

Charpentier et al. (1998) has reviewed the ORP monitoring in the activated sludge process and with the fifteen years of experience they concluded that the COD is satisfactorily eliminated at Eh=100mV whereas nitrification begins at Eh value of +300 mV. Subsequently monitoring of nutrient removal by ORP was investigated by Li et al. (2002) and nitrification was noticed at a higher ORP value (380mV) than the oxidation of organic substances which was found to occur at ORP of around (250mV).

ORP as a controlling and monitoring parameter is well cited for nitrification/denitrification in activated sludge process and sequencing batch reactors. However, information on the monitoring of the aeration of anaerobically treated sewage and other wastewater by ORP is not available. Realizing the potentials of ORP as a controlling parameter, a few experiments have been designed to monitor aeration of effluents from four full scale UASB based STPs and a bench scale UASBR treating synthetic wastewater. UASB based STPs are comprised of a screen, grit removal unit, UASBR and polishing pond with one day detention.

EXPERIMENTAL SET UP

Effluents from 4 STPs and bench scale UASB reactors were aerated using sintered disc in batch reactors. Description of samples and STPs location are shown in Table 1a. Table 1b gives details of synthetic wastewater used in a 56 L UASBR housed in a temperature controlled chamber maintained at 30±2°C. The bench scale reactor charged with the sludge from 38 ML/d STP at Saharanpur was operated to get the effluent under controlled conditions. During first 30 days of study, the reactor was fed with sucrose based soluble synthetic wastewater (SW1). HRT was reduced stepwise from 12 hour to 6 hour. Later the reactor was fed with the sucrose based synthetic wastewater mixed with cellulose (SW2). Effluents from UASBR treating SW1 and SW2 were also aerated and analyzed in a manner similar to effluents from UASB units of STPs.

Schematic presentation of batch reactor is shown in Fig.1. Air at a rate of 0.75 L/min was diffused through 0.5 L of effluent contained in a 1L reactor for 2 h. Experiments were conducted at room temperature (15-22°C). After every 5 min ORP and pH were recorded. Samples were drawn at regular intervals and analyzed for COD, TOC, BOD and NH3 as per Standard Method (APHA, 1995). ORP was measured by Toshicon ORP meter. The electrode was standardized daily by Zobell's solution and the reading was converted to standard hydrogen electrode. TOC concentration was determined with a total organic carbon analyzer (Shimadzu TOC-5000A). DO was analyzed with Aqualytic OX 24 DO meter. Measurements were done in duplicate or triplicate. Data is presented as the average value or the range of observations.

RESULTS AND DISCUSSION

The characteristics of the effluent collected from six sources (4 STPs and 2 bench scale UASBRs) are given in Table 2. Soluble COD is 40 to 70 % of COD total (CODt) where as BOD/COD ratio varies from 0.3 to 0.5. The ORP of the effluents from all the sources has been found to vary from -100 to -150 mV (pE+pH in the range of 4 to5). Such a wastewater when aerated is likely to have immediate oxygen demand with or without reduction in COD. The time response of ORP of S1, G1, N1 and N2 STPs is shown in Fig 2.

Observations from the aeration of effluent from UASBRs treating SW1 and SW2 are presented in Fig.3. An instantaneous increase in ORP characterized by feature A, followed by relatively slow rate of increase in ORP (feature B) is noticeable in all the cases. The temporal trend, in general, for all the effluents is same. Same kind of trend was observed by Peddie et al. (1990) during aerobic/anoxic digestion of waste activated sludge. The small amounts of oxygen made available by the reduced demand were enough to rapidly relieve the oxygen tension of their system. During aeration, the two probable consecutive reactions that occur are interphase oxygen transfer and subsequent assimilation of DO or oxidation of organics resulting in COD, BOD and TOC removal. Both the processes would increase ORP.

COD Profile

Time response of mean of COD for different effluents is shown in Fig.4. After initial instantaneous drop in COD, it decreases steadily with time. The rate of decay for COD is ~25 mg/L per hour. TOC also steadily decreases with aeration; however the ratio of COD/TOC i.e. 2.29 remains same during the course of aeration. The COD or BOD removal in general follow first order kinetics i.e. the reduction is exponential in nature. However, the linear correlation is also in conformity in concentration range considered herein.

The initial COD of the anaerobically treated effluents ranging from 100 to 120 mg/L was reduced to 90 to 104 mg/l in 5 min. The oxygen supplied during 5 min equals to 0.75× 5 ×0.21 = 0.79L (≈ 1.03g). The oxygen (i) dissolved and (ii) utilized for COD reduction after 5 min is the sum of DO (2.5 mg/L) and COD reduced (13 mg/L). The oxygen transfer efficiency initially is $(15.5 \times 10^{-3}/1.03)$ x100 =1.5%. The standard oxygen transfer efficiency (SOTE) has been found to be 1.5% which subsequently reduces with time. The overall SOTE has been 0.06%. The oxygen transfer efficiency factor can be improved by altering aeration device and reactor configuration.

With the onset of aeration ORP increases and COD decreases. Higher is the ORP, lesser is the COD. As the ORP increases from -150 to +150 mV, COD of the effluent from all the four field UASB plants decreases to ~ 50%. From the COD and COD removal profiles with ORP shown in Fig 5, the decrease in COD and COD removal have been found equal to 0.13 mg/L-mV and 0.1 % /mV respectively. Charpentier et al. (1998) observed satisfactory elimination of COD at initial COD of 60 mg/L on increasing E_H from 100 to 340 mV. Li et al. (2002) have studied the ORP-COD relationship in the aeration tank of wastewater from three treatment plants. Their findings show an increase in COD removal and ORP along the length of the tank. In the aeration tank of activated sludge process COD decrease is 0.5 mg/L –mV which is high as compared to 0.12

mg/L-mV in the present case. In the aeration tank of ASP the DO remained at 2-3 mg/L at high ORP .Air supplied brought about reduction in COD i.e. DO transferred is utilized only for COD reduction. However, in the batch aeration of anaerobic effluents, increase in DO & ORP and decrease in COD take place concomitantly.

BOD and NH_3 profile

Aeration of the effluent is also expected to bring about changes in BOD and NH3. Fig.6 shows the variation of BOD with ORP. As the ORP increases from -150 mV to 200 mV BOD decreases from 90 to 30 mg/L (67% reduction). With one mV increase in ORP, the decrease in BOD is 0.127 mg/L. The reduction in BOD is nearly equal to COD reduction of 0.13 mg/L. It therefore suggests that anaerobic treatment renders easily oxidisable organics in the effluent.

During the course of aeration, ammonia decreases from 80 to 40 mg/L. Nitrification does not take place in the reactor as it is possible at ORP > 300 mV and also effluent contains low values of NO_3 (0 to 0.01 mg/L). In the absence of nitrification the ORP is not expected to be influenced by decrease in ammonia.

DO profile

DO profile shown in Fig.7 indicates a sharp instantaneous increase, followed by relatively slow increase in DO. Initial fast increase in DO and ORP and reduction in COD are due to reducing conditions of the effluents. The rate of increase in DO and decrease in COD are 2.36 and 25.0 mg/L per hour respectively.

Within experimental conditions a linear correlation has been found between DO and ORP (Fig.8). At zero ORP DO is 2.7 mg/L. With 1 mV increase in ORP, DO increase is 0.0152 mg/L.

COD-DO correlations are indicative of DO absorption by a particular system. The DO absorption can be estimated from the data given in Fig.9. The slope of the linear correlation physically signifies the fact that for every mg/L increase in DO, 7 mg/L of DO is used up in meeting out the oxygen demand. It can also be stated that in order to increase DO by 1 mg/L, oxygen assimilation by the wastewater is nearly 8 mg/L. The rate of COD reduction is more than the rate of DO increase. This correlation appears to be sensitive to the aeration device.

The pH of the effluent increases during aeration. The pH, however, does not appear to influence ORP, because reductant has been taken as COD and DO is the oxidant. The $[H^+]$ decrease during electron acceptance by DO is balanced with decrease in H^+ during COD reduction. The increase in pH during aeration is due to the escape of CO_2. The ORP therefore depends on COD & DO as well as initial COD of the wastewater. Since ORP is inversely correlated with COD or BOD (Fig.5 or 6) and linearly correlated with DO (Fig.8), an attempt has been made to correlate ratio of COD to DO (values in mg/L) with ORP. The data conforms to logarithmic correlation (Fig.10). The decrease in fraction of COD with respect to CODi (COD initial) and increase in DO fraction with respect to DO saturation (DOs) can find wide application. The multiple regression analysis of the pE found significant correlation coefficients for the variable COD, CODi, DOs and DOi. The equation, which accounted for 75 % of the observation, is given as under

$$pE = 0.923 - 7.89 \log(CODt/CODi) + 2.59 \log(DOt/DOs) \quad \text{----(1)}$$

CODt/CODi = COD at particular time/ initial COD value before aeration

DOt/DOs = DO at particular time/ saturation DO at temperature

Eq. (1) indicates that pE is positively correlated to DO ratio and negatively correlated to COD ratio. Reduction in COD and increase in DO during aeration by diffusers can be estimated by monitoring ORP.

CONCLUSIONS

Aeration of effluent from UASB can be monitored by ORP. Empirical correlations between ORP & COD, ORP & COD removal and ORP &DO have been found. ORP increases with time. The rate of decay for COD and increase in DO has been found equal to 25 and 2.36 mg/L per hour respectively.

With 1 mV increase in ORP, DO increased by 0.0152 mg/L and COD & BOD decreased by 0.12 mg/L. DO absorption can be ascertained from COD DO correlation. In this system, in order to increase the DO by 1 mg/L oxygen absorbed is 8 mg/L. Nitrification does not take place although ammonia stripping takes place. The standard oxygen transfer efficiency has been found to be 1.5% which subsequently reduces with time. Reduction in COD and increase in DO during aeration by diffusers can be estimated by equation (1).

TABLE 1a -: Sample and site description of four STPs

S.NO.	STP DESCRIPTION				Effluent sample description
	Location	Latitude (N)	Longitude(E)	Capacity(ML/d)	
1	Saharanpur	29.58N	77.23 E	38	S1
2	Noida	28.38 N	77.12E	34	N1
3	Noida	28.38N	77.12 E	27	N2
4	Ghaziabad	28.4N	77.28E	70	G1

Table 1b -: Composition of synthetic wastewater

Feed	Composition	Particulate COD (CODp) %	Soluble COD (CODs) %	Total COD (CODt)mg/L
SW1	Sucrose only	Nil	100	475-550
SW2	Cellulose, Sucrose and Peptone	Cellulose 40	60	525-600

TABLE 2-: Characteristics of effluent from different sources

Parameter	Units	S1	N1	N2	G1	SW1	SW2
ORP	mV	-130 -160	-140 - -156	-120- -140	-96 - -130	-100 - -120	-100 - -160
BODt	mg/L	42-60	60-100	50-90	80-120	50-60	60-72
BODs	mg/L	36-45	22-38	34-65	33-55		
CODt	mg/L	85-123	180-260	60-140	183-320	100-115	90-120
CODs	mg/L	75-102	79-90	56-104	103-150	100-105	72-80
DO	mg/L	0	0	0	0	0	0
TOC	mg/L	58-68	45-53	34-50	49-53	40-60	45-70
NH_3	mg/L	57-67	30-44	54-71	44-56	70-80	60-90

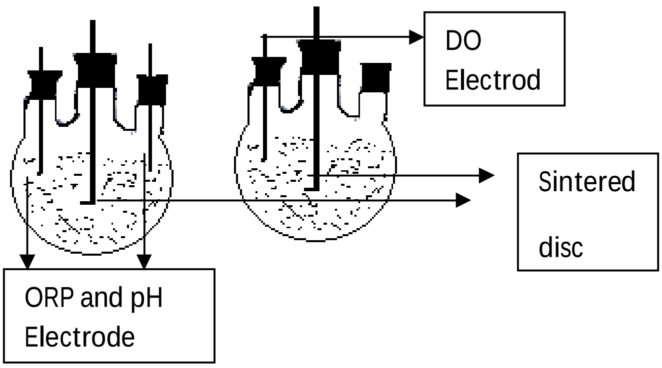

Fig. 1 Schematic presentation of batch reactor

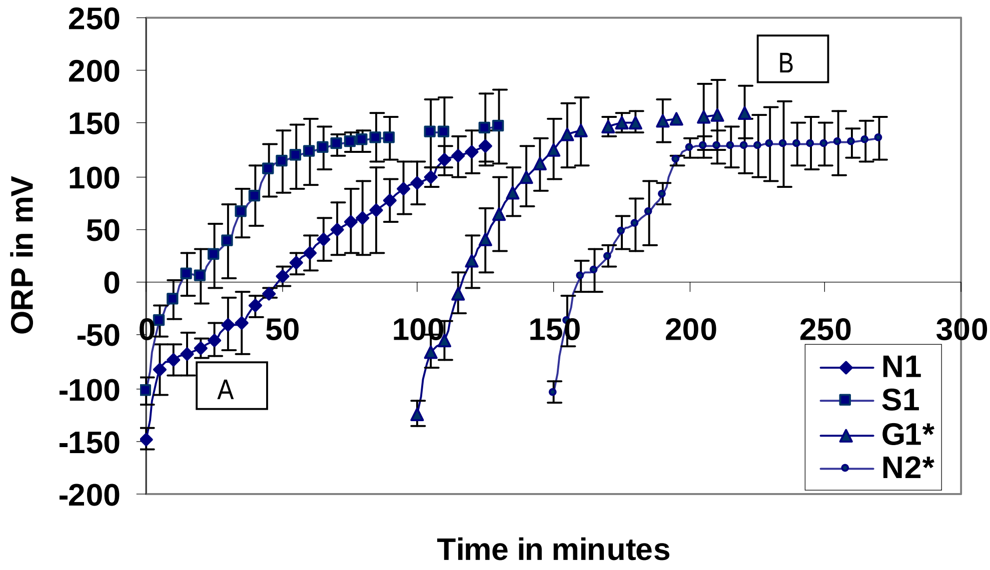

Fig. 2 Aeration of effluents from four field UASBRs: Temporal variation of ORP

* For G1 and N2 time starts from 100 and 150 minutes respectively.

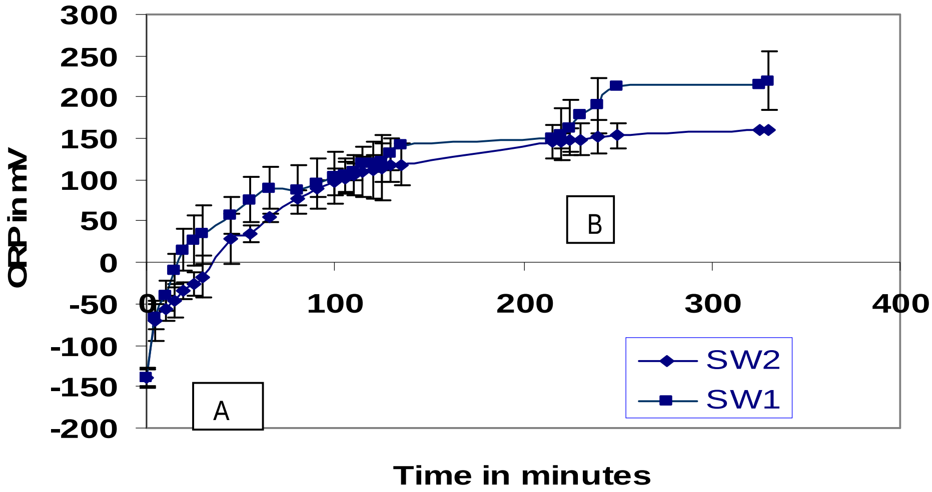

Fig. 3 Aeration of effluents from bench Scale UASBRs: Temporal variation of ORP

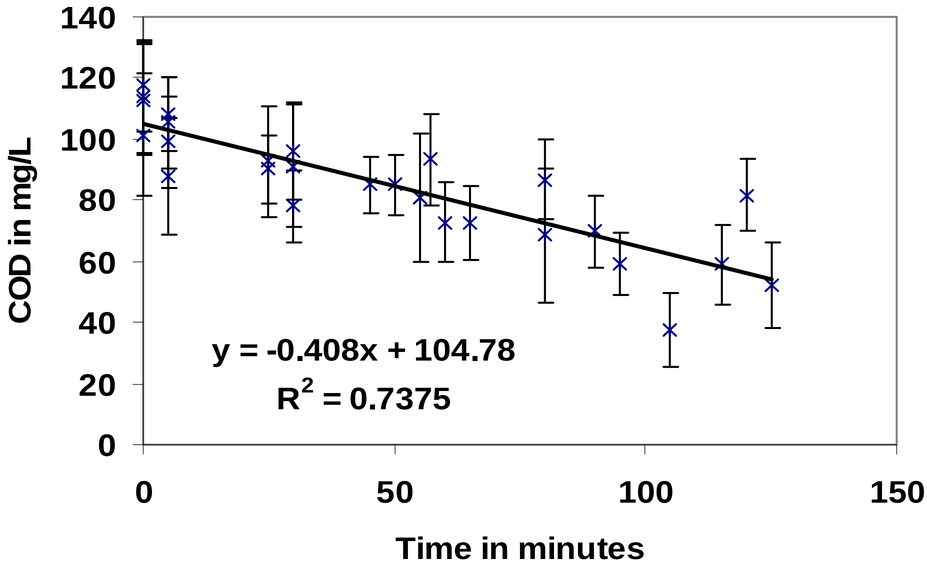

Fig. 4 Temporal variation of CODs

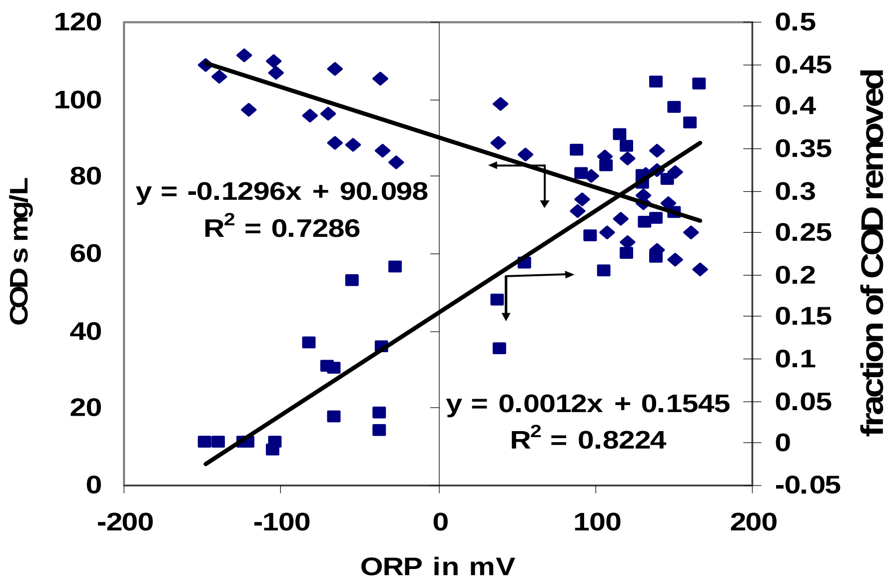

Fig. 5 Variation of COD and COD removal with ORP

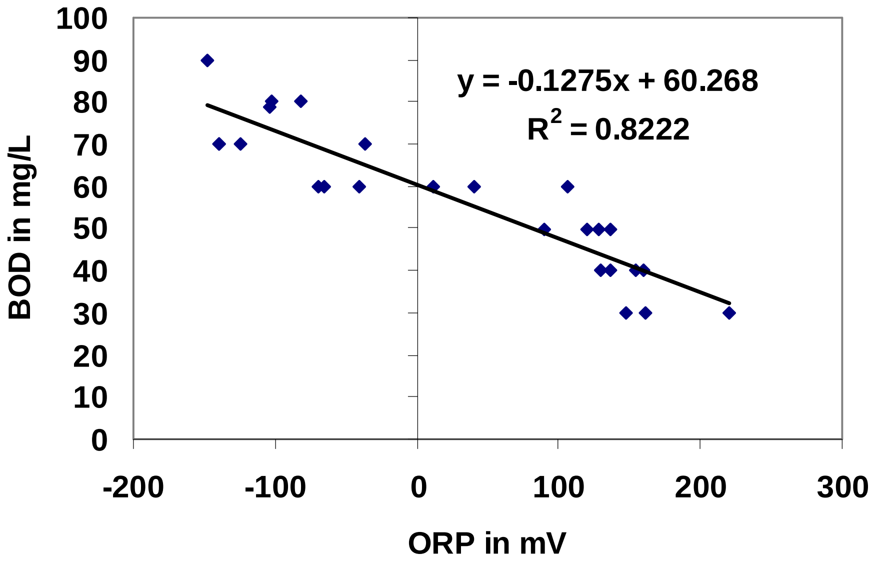

Fig. 6 Variation of BOD with ORP

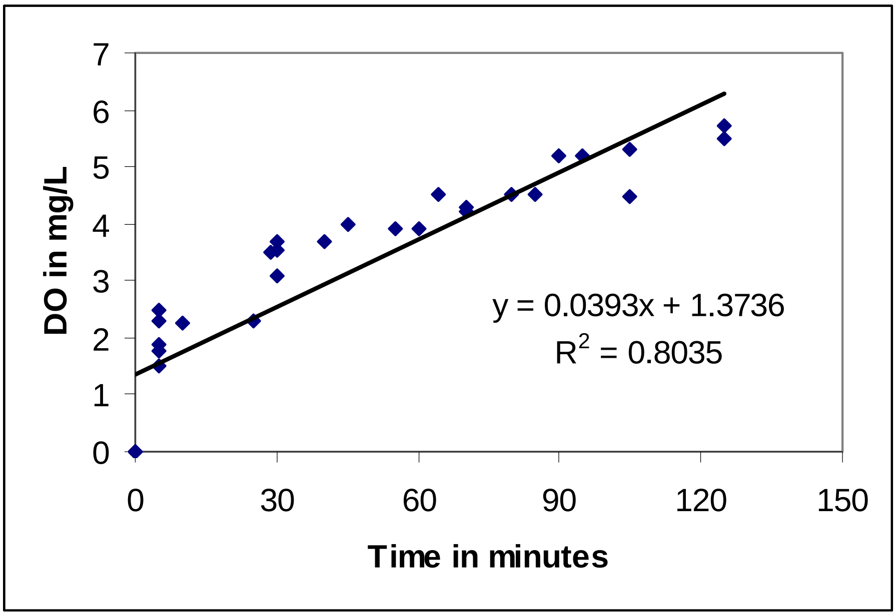

Fig. 7 Temporal variation of DO

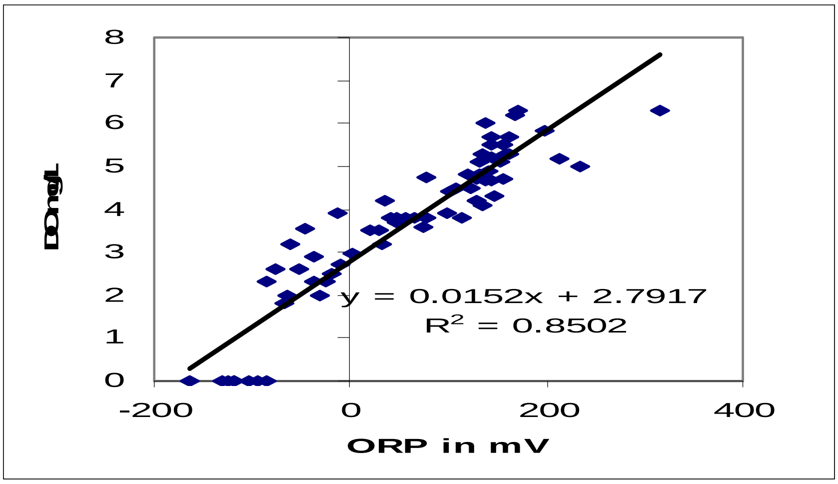

Fig. 8 Variation of DO with ORP

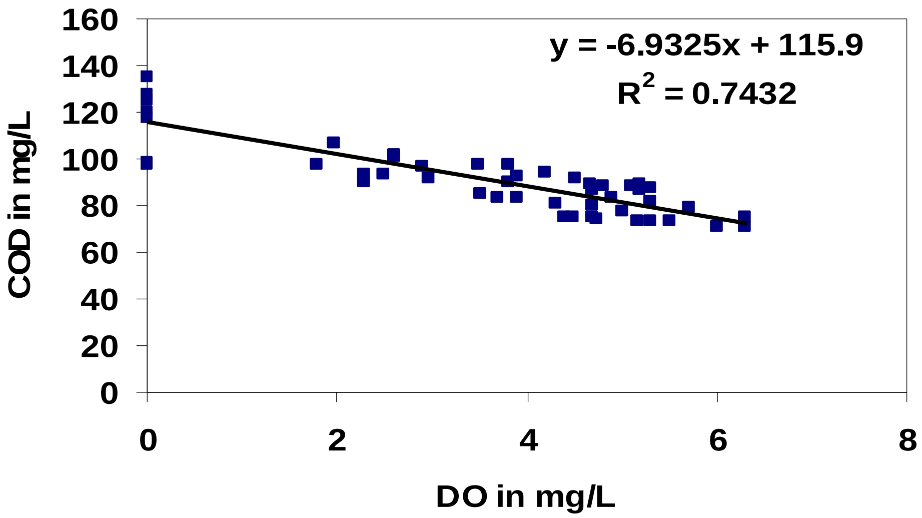

Fig.9 Variation of COD with DO

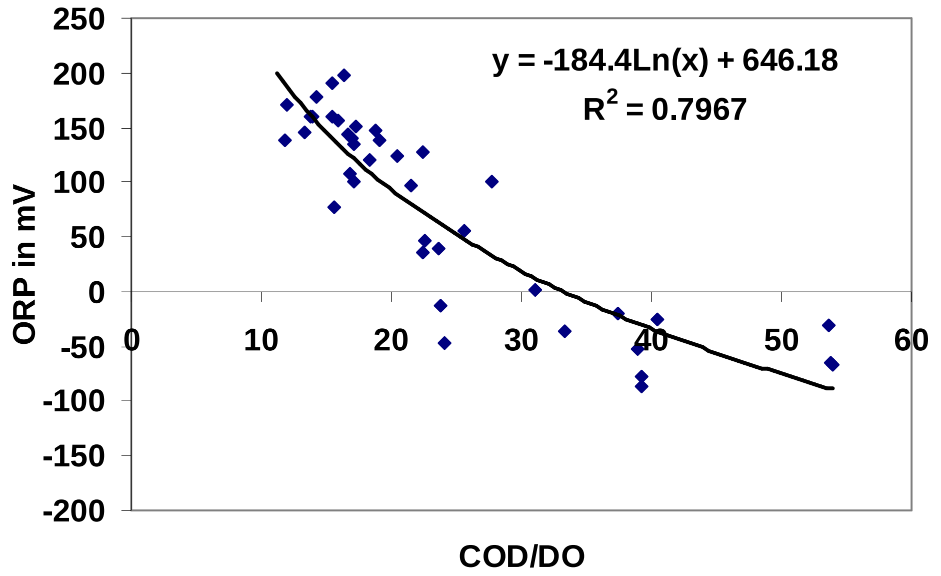

Fig. 10 Variation of COD/DO with ORP

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