CHAPTER 5

WASTEWATER TREATMENT

IN DRAFT TUBE

BUBBLE COLUMNS
5.1 INTRODUCTION

Nutrient removal has become a research focus in wastewater treatment with the occurrence of severe eutrophication problems, especially in closed water environment such as bays, lakes and ponds. The removal of nutrients like nitrogen and phosphorus compounds is essential to depress the eutrophication. Nitrogen removal has been achieved by biological methods, ion exchange, reverse osmosis and chemical methods. Among the variety of treatment systems proposed so far, the biological method is considered the most promising from an economical viewpoint. Biological nitrogen removal from organic wastewater using activated sludge consists of two stages, namely, the aerobic stage (ammonification and nitrification) and the anaerobic stage (denitrification). It is also known that uptake of phosphorus in microorganisms named PAO- Phosphate Accumulating Organisms, gets enhanced when the activated sludge is placed under an aerobic condition after the anaerobic one.

Conventional treatment systems for nutrient removal thus requires separate aerobic and anaerobic tanks leading to requirement of large area for installation of these treatment systems and it often leads to additional need for facilities such as energy and maintenance. The establishment of such facilitated treatment process is quite difficult in crowded downtown areas and neither is the network of sewer pipes fully equipped in developing areas or depopulated areas to transport the sewage to central facility. Therefore, there exists a need to develop compact, economical and efficient apparatus where aerobic and anaerobic conditions coexist in a single vessel for onsite continuous treatment of wastewater. This requirement can be fulfilled by using a draft tube bubble column. The draft tube bubble column provides both aerated and unaerated compartments in the same vessel which serve for the aerobic and anaerobic processes. The operation of draft tube bubble column requires relatively low energy input when compared stirred tank, since there is no need for mechanical circulating devices, which makes the system attractive as an alternative treatment process.

In the present study, the performance of rectangular bubble column and rectangular draft tube bubble column (RDTBC) were evaluated for ammoniacal nitrogen (NH$_3$–N) and phosphorus (PO$_4^{3-}$-P) removal from sewage wastewater using activated sludge method. Investigations were carried out to study the influence of air flow rates, draft tube height, shape of draft tube and main column as well as the scale of operations on nutrient removal from sewage water using activated sludge process. Experiments were also
performed using synthetic wastewaters having identical nutrient concentration as that of sewage water to test the efficacy and pattern of nutrients removal from streams having lesser degree of complexity using draft tube bubble columns

5.2 LITERATURE SURVEY

5.2.1 The necessity of nutrient removal from wastewater

Wastewater from rural areas contain high level of nitrogen and phosphorus because of excessive use of fertilizers, while in urban areas these nutrient levels are high due to domestic and industrial wastes. The buildup of these nutrients in environment is called eutrophication. Thus, the grey water discharged to rivers and lakes without treatment has caused a serious problem of eutrophication, which in turn encourage the overgrowth of various types of algae. This causes a rapid growth in the population of algae. The algae numbers are unsustainable and eventually die. The decomposition of the algae by bacteria uses up so much oxygen from the water that most of the marine life forms die this creates more organic matter for the bacteria to decompose. In addition to causing deoxygenation, some algae species produce toxins that contaminate drinking water supplies. Hence, to avoid these ill effects and for environmental sustainability different treatment processes are inevitably required to remove nitrogen and phosphorus from wastewater. The biological method for removal of these nutrient pollutants from organic wastewater has received wide attention in literature.

5.2.2 Mechanisms of removal of nitrogen and phosphorus from wastewater using activated sludge

Biological nitrogen removal from organic wastewater using activated sludge occurs in two stages, namely, aerobic stage wherein the steps of ammonification and nitrification occurs, and the other stage is anaerobic one where denitrification is carried out. Organic nitrogen is transferred to ammonia (NH₃) at the stage of ammonification, while in the nitrification step, biological oxidation of ammonia with oxygen into nitrite (NO₂⁻) occurs in the presence of organisms such as nitrosomonas and nitrosococcus, followed by the oxidation of these nitrites into nitrates (NO₃⁻) facilitated by bacteria of the genus nitrobacter. Nitrate and nitrite is finally converted to nitrogen gas (N₂) by the denitrifying bacteria such as Paracoccus denitrificans, Pseudomonas denitrificans, Thiobacillus denitrificans, etc… under the anaerobic condition.
The nitrifying organisms use carbon dioxide as their carbon source for growth. Thus, together with ammonification, nitrification forms a mineralization process which leads to the complete decomposition of organic material, with the release of available nitrogen compounds in waste water. Thus, nitrification is a process of nitrogen compound oxidation or effectively, loss of electrons from the nitrogen atom to the oxygen atoms and the chemistry of the process can be written as

\[
\text{NH}_3 + \text{CO}_2 + 1.5 \text{O}_2 + \text{Nitrosomonas} \rightarrow \text{NO}_2^- + \text{H}_2\text{O} + \text{H}^+
\]

\[
\text{NO}_2^- + \text{CO}_2 + 0.5 \text{O}_2 + \text{Nitrobacter} \rightarrow \text{NO}_3^-
\]

\[
\text{NH}_3 + \text{O}_2 \rightarrow \text{NO}_2^- + 3\text{H}^+ + 2\text{e}^-
\]

\[
\text{NO}_2^- + \text{H}_2\text{O} \rightarrow \text{NO}_3^- + 2\text{H}^+ + 2\text{e}^-
\]

Denitrification is a microbially facilitated process of nitrate reduction that may ultimately produce molecular nitrogen (N\(_2\)) through a series of intermediate gaseous nitrogen oxide products. This process reduces oxidized forms of nitrogen in response to the oxidation of an electron donor such as organic matter and use nitrate as the electron acceptor. The preferred nitrogen electron acceptors in order of most to least thermodynamically favourable include: nitrate (NO\(_3^-\)), nitrite (NO\(_2^-\)), nitric oxide (NO), and nitrous oxide (N\(_2\)O). Generally several species of bacteria as mentioned earlier are involved in the complete reduction of nitrate to molecular nitrogen. Thus, denitrification occurs under special conditions where oxygen, a more energetically favourable electron acceptor, is depleted, and bacteria respire nitrate as a substitute terminal electron acceptor, i.e. denitrification only takes place in anaerobic environments where oxygen consumption exceeds the rate of oxygen supply. Thus, denitrification generally proceeds through some combination of the following intermediate forms:

\[
\text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{NO} + \text{N}_2\text{O} \rightarrow \text{N}_2(\text{g})
\]

The complete denitrification process can be expressed as a redox reaction:

\[
2 \text{NO}_3^- + 10 \text{e}^- + 12 \text{H}^+ \rightarrow \text{N}_2 + 6 \text{H}_2\text{O}
\]

Carlson et al. (1997) have reported high removal of phosphorus from wastewater in the anaerobic – aerobic operation using activated sludge process. Under these conditions, a group of bacteria called polyphosphate accumulating organisms (PAO) are selectively enriched in the bacterial community within the activated sludge, these bacteria
accumulate large quantities of polyphosphate within their cells and the removal of phosphorus from wastewater is enhanced over the conventional activated sludge systems. Generally speaking, all bacteria contain a fraction (1-2%) of phosphorus in their biomass due to its presence in cellular components, therefore as bacteria in a wastewater treatment plant consume nutrients in the wastewater, they grow and phosphorus is incorporated into the bacterial biomass. When PAOs grow they not only consume phosphorus for cellular components but also accumulate large quantities of polyphosphate within their cells. Thus, the phosphorus fraction of phosphorus accumulating biomass is 5-7%. Separation of biomass from treated water at the end of the process removes the phosphorus. Thus, if PAOs are selectively enriched by the presence of an anaerobic zone prior to the aerobic region, then considerably more phosphorus is removed, compared to the relatively poor phosphorus removal in conventional activated sludge systems.

It has been reported by Barnard (1973) and Argaman & Brener (1986) that an additional anaerobic operation in addition to the aerobic one was effective for the enhancement of nitrogen removal from wastewater using the activated sludge process. The use of draft tube bubble column for wastewater treatment was pioneered by Hano et al. (1992) they removed nitrogen using the activated sludge method. The draft tube functioned as an aerobic region and the annulus as an anaerobic zone to enhance the nitrogen removal. Later Bando et al. (1999) used draft tube bubble columns, for the removal of nitrogen and phosphorus in wastewater treatment using activated sludge and noted the enhancement of removal in draft tube bubble columns over the ordinary bubble columns. These investigators also studied the effect of geometry and examined the contribution of anaerobic region volume on the nutrient removal and found that maximum removal of nitrogen and phosphorus occurs when the volume fraction of anaerobic region was 40-60%.

Yoo et al. (1999) developed an intermittently aerated and decanted single-reactor process for wastewater treatment and proposed key control parameters for nitrogen removal from two types of synthetic wastewater by simultaneous nitrification and denitrification (SND) via nitrite. In this work under optimal conditions nitrogen removal efficiency was found above 90%. for both types of wastewater In this process, nitritation (1st step of nitrification) was induced but nitratation (2nd step of nitrification) was effectively suppressed and denitrification was carried out using nitrite.
Meng et al. (2004 a) used rectangular airlift bubble column for wastewater treatment in a continuous mode, a partition plate segregated the column into anaerobic and aerobic regions. They investigated the effect of equipment size and operational conditions on gas holdup, liquid phase volumetric mass transfer coefficient, and liquid circulation flow rate on the biological nitrogen removal. They observed that removal of total nitrogen was maximized when the volume fraction of anaerobic region was about 0.5. In a subsequent work these investigators (Meng et al. 2004 b) used cellulose particles as immobilizing carrier in the airlift bubble column and observed that the volume fraction of the anaerobic region and the concentration of the immobilizing particles strongly affected the nitrogen removal from waste water.

Further, Meng et al. (2004 c) devised a unique method for retaining the microorganisms in the bubble column by installing polypropylene ring lace as a support system for the microorganisms to grow. The aim of using these support material was to immobilize nitrifying and denitrifying bacteria in the aerobic and anaerobic regions respectively and prevent them from washing out with effluent from the column. They reported considerable enhancement of nitrogen removal in this apparatus in comparison to conventional airlift bubble columns.

A packed bed external loop airlift bioreactor was proposed for the removal nitrogen compounds from wastewater by Silapakul et al. (2005). Their column consisted of aeration and non-aeration zones, both of which were packed with plastic bioballs to enhance the surface area for the attachment of bacteria and to achieve complete removal of all nitrogen compounds with simultaneous nitrification and denitrification.

The literature survey presented above as well as in Chapter 2 reveals that although draft tube bubble columns have been investigated for their hydrodynamic and mass transfer behavior but their application for wastewater treatment is only sparingly investigated. Further, it was observed that while some information on nitrogen removal was available but information on biological phosphorous removal using activated sludge process in draft tube bubble columns was very scarce. It was also noted that most of the investigations involved the use of synthetic wastewater rather than sewage wastewater for nutrient removal experiments.

In order to establish the efficacy of draft tube bubble columns for removal of nitrogen and phosphorus from waste waters using the activated sludge process and address some of the issues discussed above, draft tube bubble columns were used for water purification
in the semi-batch mode (air continuous). Effect of geometrical shape of draft tube bubble column, height of draft tube, scale of operations, and effect of process parameters on nutrient removal were investigated. This experimental investigation therefore, focuses primarily on these uncultivated areas of wastewater treatment for nitrogen and phosphorus removal using activated sludge.

5.3 MATERIALS AND METHODS

5.3.1 Sewage water and its composition

Sewage water for the experiments was obtained from downstream of Athamiya River, beneath an over bridge on Kalawad road, near village Motamava, Rajkot, Gujarat as shown in Fig.5.1 and Fig. 5.2. This sewage water contains adequate amount of nutrients such as nitrogen and phosphorus since village Motamava and some small scale industrial units are located on the upstream side of the river. This sewage water was filtered to remove large suspended physical impurities before adding to the column for treatment. Typical analytical composition of this sewage water is given in Table 5.1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD (Biological Oxygen Demand)</td>
<td>225</td>
</tr>
<tr>
<td>COD (Chemical Oxygen Demand)</td>
<td>450</td>
</tr>
<tr>
<td>SS (Suspended Solids)</td>
<td>250</td>
</tr>
<tr>
<td>Ammoniacal Nitrogen</td>
<td>49.7</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>4.56</td>
</tr>
<tr>
<td>Sulphates</td>
<td>110</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>85</td>
</tr>
<tr>
<td>Chlorides</td>
<td>200</td>
</tr>
</tbody>
</table>

5.3.2 Activated sludge and its preparation

Activated sludge having very high concentration of microorganisms responsible for activities of both nitrification and denitrification was obtained from the sewage water treatment plant, RMC (Rajkot Municipal Corporation), Madhapar near Rajkot. This dry activated sludge was procured from sludge bed/lagoon area of plant situated after tertiary treatment process of wastewater.
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Fig. 5.1 Sample collection point of sewage water in downstream of Athamiya river
(courtesy from Google earth)

Fig. 5.2 Location of sewage water sample collection
Dry sludge was crushed to small size by pestle and mortar in laboratory and then screened to remove physical impurities. The required amount of activated sludge for various experiments was then acclimated over a month in feed sewage water by adding appropriate amount of sewage water in it to maintain its semi-solid form.

5.3.3 Chemicals and glassware

The chemicals used for all the wastewater experiments to measure ammoniacal nitrogen concentrations by manual phenate method, such as phenol (purity \( \geq 89\% \)), methyl alcohol (\( \geq 99\% \)), sodium nitroprusside (99%), trisodium citrate (99-100%), sodium hydroxide (98%, dry basis), sodium hypochlorite solution (4% w/v), and ammonium sulfate (98%) were of analytical reagent grade quality and procured from Merck India Pvt. Ltd.

Similarly, the chemicals used in another colorimetric ascorbic acid method for estimation of phosphorus, such as concentrated H\(_2\)SO\(_4\) (98%), potassium antimonial tartrate, K(SbO)C\(_4\)H\(_4\)O\(_6\)-½H\(_2\)O (purity \( \geq 99\% \)), ammonium molybdate, (NH\(_4\))\(_6\)Mo\(_7\)O\(_24\)-4H\(_2\)O (98%), ascorbic acid (99%), potassium dihydrogen phosphate, KH\(_2\)PO\(_4\) (98%), phenolphthaline indicator solution (1%), and HCl (\( \geq 35\% \)) diluted for washing etc. were also of analytical grade and procured from Merck India Pvt. Ltd. Deionized water was used for preparing the solutions.

Synthetic wastewater using tap water was prepared using chemicals such as glucose, polypeptone, ammonium chloride, potassium dihydrogen phosphate (98%), and sodium bicarbonate (99.7%) etc. were also of analytical grade and also procured from Merck India Pvt. Ltd. Glassware used for the experiments such as measuring cylinders, beakers, volumetric flasks, amber bottles, pipettes, stirring rods, glass-stoppered bottles etc. were procured from Borosil Pvt. Ltd.

5.3.4 Synthetic wastewater and its composition

The synthetic wastewater for experiments was prepared in a fashion that the initial concentration of ammoniacal nitrogen (49.7 mg/L) and phosphorus (4.56 mg/L) was identical to that of the sewage water. It composed of glucose as a main carbon source, polypeptone and ammonium chloride (NH\(_4\)Cl) as nitrogen sources, Potassium dihydrogen phosphate (KH\(_2\)PO\(_4\)) as a phosphorus source along with some inorganic nutrients added in the tap water. Composition of the synthetic wastewater is given in Table 5.2.
Table 5.2 Composition of synthetic wastewater

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypeptone</td>
<td>160</td>
</tr>
<tr>
<td>KH$_2$PO$_4$</td>
<td>20</td>
</tr>
<tr>
<td>Glucose</td>
<td>350</td>
</tr>
<tr>
<td>NH$_4$Cl</td>
<td>190</td>
</tr>
<tr>
<td>NaHCO$_3$</td>
<td>100</td>
</tr>
</tbody>
</table>

(Ammoniacal nitrogen = 49.7 mg/L; Phosphorus = 4.56 mg/L)

5.3.5 Operational methodology

Wastewater experiments were carried out in draft tube bubble columns and bubble columns as well. Effect of presence of draft tube, draft tube height, shape of column, column capacity and air flow rates on nitrogen and phosphorous removal was investigated. All the experiments performed at ambient temperature and pressure, the initial concentration of ammoniacal nitrogen, phosphorus, and activated sludge was maintained 49.7 mg/L, 4.56 mg/L and 3.33 kg/m$^3$ respectively in the experiments. Total duration of experiments was about 7 hrs.

Water samples from the column was collected every hour after start-up of experiment and centrifuged (Biolab, 120 D) at 5000 rpm for 10 minute duration and then analyzed for nutrients. The manual Phenate method 4500-NH$_3$ F, APHA (1998) was used to determine the concentration of ammoniacal nitrogen and the Ascorbic acid method 4500-P E, APHA (1998) was used to determine the concentration of phosphates in the wastewaters. These methods are described in detail in the section 5.3.6 of analytical techniques. Since, both these methods involve colorimetric measurements; a spectrophotometer Hach, DR/2400 with 400 to 800 nm wavelength range and linear photometric range of -2.000 to +2.000 absorbance was used in the present investigation.

5.3.6 Analytical techniques

5.3.6.1 Ammoniacal nitrogen estimation

In wastewater the forms of nitrogen of greatest interest are, in order of decreasing oxidation state, nitrate, nitrite, ammonia, and organic nitrogen. Among these, ammonia is present naturally in surface and wastewaters. Ammoniacal nitrogen, NH$_3$-N concentrations in some wastewaters at concentration levels greater than 30 mg/L is quite
common. The two major factors that influence selection of the method to determine ammoniacal nitrogen are concentration and presence of interferences. Titrimetric method, ammonia selective electrode methods, phenate method and its variants are the usual methods available to determine ammoniacal nitrogen in wastewaters.

The titrimetric method is used only for samples that have been subjected to distillation step, to eliminate interferences excessively present in wastewaters. Due to this step additional requirements arise that enhance cost and time of the analysis. Other methods for ammoniacal nitrogen measurement can be used without this preliminary distillation step.

Although ammonia-selective electrode methods are applicable in the range from 0.03 to 1400 mg NH₃-N/L, these methods require a specific ion meter and ammonia selective pH electrode. The automated phenate methods is applicable over the range of 0.02 to 2 mg NH₃-N/L but, these methods require sophisticated ammonia manifold analytical equipment, flow injection analysis equipments and data acquisition system.

The colorimetric manual phenate method (Appendix-5) does not require preliminary distillation step and is applicable over 0 - 0.6 NH₃-N mg/L. This method was used in the present investigation to determine ammoniacal nitrogen in wastewaters. In the present work, it was required to dilute the sample of wastewater from column by hundred fold of the initial concentration of 50 mg/L of ammoniacal nitrogen. A standard calibration curve was generated by plotting absorbance readings of standard solutions versus known ammoniacal nitrogen concentration of standards as shown in Fig. 5.3. The standard

![Fig. 5.3 Calibration curve of absorbance Vs ammoniacal nitrogen concentration](image)
calibration curve was used to obtain the ammoniacal nitrogen concentration of the diluted samples which were then normalized to account for the dilution.

5.3.6.2 Phosphorus estimation

Phosphorus occurs in wastewaters almost solely as phosphates. These are classified as orthophosphates, condensed phosphates (pyro-, meta-, and other polyphosphates), and organically bound phosphates. They occur in wastewaters, in particles or detritus, or in the bodies of aquatic organisms. These forms of phosphate arise from a variety of sources. Small amounts of orthophosphate or certain condensed phosphates are added to some water supplies during treatment. Larger quantities of the same compounds may be added when the water is used for laundering or other cleaning, because these materials are major constituents of many commercial cleaning preparations. Phosphates are used extensively in the treatment of boiler waters. Orthophosphates applied to agricultural or residential cultivated land as fertilizers are carried into surface waters with storm runoff. Organic phosphates are formed primarily by biological processes and they are contributed to sewage by body wastes and food residues, and also may be formed from orthophosphates in biological treatment processes or by receiving water biota.

Phosphorus analyses embody two general procedural steps: (a) conversion of the phosphorus form of interest to dissolved orthophosphate, and (b) colorimetric determination of dissolved orthophosphate. Phosphates that respond to colorimetric tests without preliminary hydrolysis or oxidative digestion of the sample is termed "reactive phosphorus" and it occurs in both dissolved and suspended forms, reactive phosphorus is largely a measure of orthophosphates present in wastewaters as phosphorus compounds. In the present investigation reactive phosphorous was determined using the direct colorimetric method without digestion treatment.

Three colorimetric methods of orthophosphate determination in wastewaters are available namely- the vanadomolybdophosphoric acid method, the stannous chloride method, and the ascorbic acid method. Selection of appropriate method among the available methods depends largely on the concentration range of orthophosphate. The vanadomolybdophosphoric acid method is most useful for routine analysis in the range of 1 to 20 mg P/ L, while the stannous chloride method and the ascorbic acid method is more suited for the range of 0.01 to 6 mg P/ L.
The ascorbic acid method as described in Appendix-6 was used to determine phosphorus concentration in wastewaters. A calibration curve of absorbance versus phosphate concentration was obtained as shown in Fig. 5.4.

![Calibration curve of absorbance Vs phosphorus concentration](image)

**Fig. 5.4 Calibration curve of absorbance Vs phosphorus concentration**

### 5.4 RESULTS AND DISCUSSION

#### 5.4.1 Sewage wastewater treatment using activated sludge

Removal of nutrients - nitrogen and phosphorus from sewage wastewater using activated sludge was performed in bubble columns and draft tube bubble columns. The decline in the concentration of nitrogen and phosphorus with time was noted for total treatment duration of seven hours for all the variations studied. The performance of various column geometries on nutrient removal was compared with each other and the configuration that gave the best performance was identified.

**5.4.1.1 Effect of draft tube in a rectangular bubble column on nitrogen and phosphorus removal**

The decrease in concentration of ammoniacal nitrogen and phosphates from sewage water using activated sludge was observed in both Rectangular bubble column (RBC) as well as Rectangular draft tube bubble column (RDTBC) having column specifications detailed in Table 3.1,
RDTBC was equipped with draft tube of 70 cm height. Sparger C having four holes of 1 mm diameter each and pitch of 20 mm was used in both the devices. The operating conditions were identical for both cases the initial concentration of nitrogen in sewage water was 49.7 mg/L and the air flow rate was maintained at 2 LPM, after 7 hrs of experiment the final concentration in RBC was 30.1 mg/L while that in RTDBC was 10.9 mg/L as shown in Fig.5.5, indicating a decline of ammoniacal nitrogen to the tune of 40% and 80% in RBC and RDTBC respectively. This result brings forward the singular advantage obtained by using RDTBC for nitrogen removal from wastewaters.
Similarly, starting with the same initial feed phosphorus concentration of 4.56 mg/L in RBC as well as RDTBC, the final phosphorous concentration obtained after seven hrs of aeration was 2.37 mg/L and 1.855 mg/L in RBC and RDTBC respectively, as shown in Fig. 5.6. Thus the removal of phosphorus from wastewater was also more in RDTBC then in RBC throughout the run duration at identical flow rates of 2 LPM, accounting for phosphorus removal of 48% and 60% in RBC and RDTBC respectively.

At 2 LPM air flow rate, which corresponds with $U_g$ of 0.78 cm/s, in RBC, the gas holdup observed from Fig. 4.11 is 0.017 while in an RDTBC the gas holdup is 0.034 that is twice that of RBC. The corresponding values of specific gas-liquid interfacial area are 0.601 cm$^{-1}$ for RDTBC ($U_g = 4.167$ cm/s) and ~ 0.3 cm$^{-1}$ for RBC as shown in Fig. 4.22 and Fig. 4.24, which returns $k_{L,a}$ of 0.168 min$^{-1}$ in RDTBC. The enhanced decrease of ammoniacal nitrogen and orthophosphates from sewage water in RDTBC compared with RBC is attributed to not only superior aeration that is apparent from the parametric values of gas holdup, interfacial area and mass transfer coefficient reported above but also due to, and perhaps to a greater extent on the presence of aerobic and anaerobic regions in RDTBC through which the liquid flows sequentially on account of formation of circulatory flow patterns arising out of density difference between the draft tube and the annulus. The annulus region is largely anaerobic in nature while the draft tube through which the air is sparged operated as aerobic region. Thus the combination of both regions- aerobic and anaerobic is solely the feature of RDTBC, while in RBC only aerobic region exists. These aspects have been investigated earlier (Hano et al., 1992; Bando et al., 1999) as described in the section 5.2.2 of literature survey.

The flow rate of 2 LPM in draft tube bubble column marked the beginning of heterogeneous region; it was selected to take advantage of greater liquid circulation between draft tube and annulus and at the same time to maintain conditions such that air bubbles were not dragged into downcomer with circulating liquid, thus the entire downcomer could be considered anaerobic zone, while the whole riser functioned as aerobic region. Thus, enhanced removal of nitrogen as well as phosphorus from sewage water was achieved in RDTBC compared to RBC, since both nitrification and denitrification get facilitated in draft tube bubble columns. Hence, it is concluded that by simply inserting a draft tube in the bubble column added the anaerobic region and thus resulted in the increase of nutrient removal of draft tube bubble column compared to ordinary bubble column.
5.4.1.2 Effect of draft tube height on nutrient removal in RDTBC

The influence of draft tube height on nutrient removal efficiency of RDTBC was assessed by changing draft tube height from 70 cm to 60 cm; this resulted in increasing, Region 2 (Fig. 4.15), the liquid height above the draft tube. Runs were performed under identical conditions of initial nutrients concentration and temperature (30°C) at flow rates of 2 LPM, the initial unaerated liquid height in the column was maintained at 75 cm.

![Fig. 5.7 Effect of draft tube height on ammoniacal nitrogen removal in RDTBC](Air flow rate = 2 LPM; Sparger C)

![Fig. 5.8 Effect of draft tube height on phosphorus removal in RDTBC](Air flow rate = 2 LPM; Sparger C)
The extent of removal of ammoniacal nitrogen as well as phosphorous was consistently more in RDTBC with 70 cm draft tube in comparison with the 60 cm draft tube column as shown in Fig. 5.7 and 5.8. In case of nitrogen removal the difference between the performances of the two devices was \( \sim 15\% \) but for phosphorous removal it was \( \sim 25\% \). Phosphorous removal was very steep in the initial hours while nitrogen removal was more gradual. The principal reason for greater removal of N and P compounds in RDTBC with 70 cm draft tube compared with 60 cm draft tube was the increase of gas holdup, specific interfacial area and volumetric mass transfer coefficient as observed earlier in Fig. 4.13, Fig. 4.23 and Fig. 4.31 respectively. The relative values of these parameters at the specified operating conditions of 2 LPM air flow rate, corresponding to U_gr of 4.167 cm/s are listed in the Table below:

<table>
<thead>
<tr>
<th>Column</th>
<th>( \varepsilon_g )</th>
<th>( a ) (cm(^{-1}))</th>
<th>( k_L a ) (min(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDTBC with 70 cm draft tube</td>
<td>0.0335</td>
<td>0.601</td>
<td>0.168</td>
</tr>
<tr>
<td>RDTBC with 60 cm draft tube</td>
<td>0.0209</td>
<td>0.480</td>
<td>0.137</td>
</tr>
</tbody>
</table>

Decreasing the height of draft tube in the column increases the liquid height above the draft tube, this region behaves like an ordinary bubble column with intense backmixing, further decrease in draft tube height reduces the fraction of the anaerobic region of the annulus that adversely affects the degree of removal of nitrogen and phosphorus compounds from sewage water. It was noted that reduction in the draft tube height increases the liquid circulation rate in RDTBC, increase in Region 2 facilitates coalescence of gas bubbles that results in substantial reduction in gas holdup and other mass transfer parameters that contribute to the decline of the performance of the aerobic region of the RDTBC.

The relative variation in the extent of removal of the nutrients between the two RDTBC with different draft tube heights was attributed to both these factors, the decline in factors influencing aeration of the water and also to the suppression of denitrification and other anaerobic mechanisms. Consequently, only draft tube with 70 cm height was chosen for further work in all draft tube bubble columns for sewage wastewater treatment using activated sludge.

### 5.4.1.3 Effect of air flow rate on nitrogen and phosphorus removal in RDTBC

The effect of air flow rate on removal of nitrogen and phosphorus from sewage water in RDTBC was investigated at air flow rates of 2, 4 and 6 LPM corresponding to U_gr of.
4.167, 8.333 and 12.5 cm/s respectively. The activated sludge was in the suspended state at these flow rates. The extent of removal of ammoniacal nitrogen and orthophosphate decreased with increasing air flow rate; the removal of nitrogen was 80%, 45% and 38% at flow rates of 2, 4 and 6 LPM respectively in a time span of seven hours, similarly the orthophosphate concentrations declined and registered a removal of 60%, 50% and 46% at 2, 4 and 6 LPM respectively.

Fig. 5.9 Effect of air flow rate on ammoniacal nitrogen removal in RDTBC

(DT height = 70 cm; Sparger C)

Fig. 5.10 Effect of air flow rate on phosphorus removal in RDTBC

(DT height = 70 cm; Sparger C)
Fig. 5.9 and 5.10 show the removal profiles of nitrogen and orthophosphate respectively in RDTBC at the varying flow rates. It is interesting to note from Fig. 5.10 that the maxima of removal of phosphate takes place in 6 hours time span. The decline in the nutrient removal is attributed to enhanced aeration of the water mass in the RDTBC. Runs performed earlier at 2 LPM flow rate corresponding to $U_{gr}$ of 4.17 cm/s were designed to have controlled liquid circulation so that the liquid circulation rate does not drag air bubbles into the annulus and disturb its anaerobic nature. At flow rates of 4 and 6 LPM many air bubbles were entrained in the downcomer by the accelerated liquid circulation owing to increased air flow through the riser.

These results give credence to the model that DTBC, at modulated flow rates, comprise of aerobic and relatively anaerobic zones that support the enhanced removal of nutrients as expressed by Barnard (1973) & Argaman and Brener (1986). Interestingly it is observed that at elevated gas flow rates of 6 LPM, the circulation rates become so large that the entire DTBC become aerobic behaving just as an ordinary bubble column resulting in nearly same extent of removal of phosphorous (~47%) and nitrogen (~40%) in seven hours duration. Thus, it was observed that the fraction of anaerobic region in the column decreased with increasing air flow rate resulting in the suppression of anaerobic steps, leading to decline of nitrogen and phosphorus removal. Therefore, to achieve enhanced nutrient removal during wastewater treatment, the fractions of anaerobic and aerobic regions in the column must be well balanced not only in terms of draft tube height but also by modulating the liquid circulation rates by adjusting air flow rate.

**5.4.1.4 Effect of geometrical shape of draft tube bubble column on nutrient removal**

The effect of geometrical shape of draft tube bubble column on the nutrient removal pattern from sewage water using activated sludge was investigated by using a cylindrical DTBC (CDTBC-1) having equivalent cross-sectional area of draft tube as that of the RDTBC and comparing the results. Both the draft tube columns (CDTBC-1 and RDTBC) had draft tube height of 70 cm and spargers with same number of holes ($N_h=4$) and were operated at air flow rate of 2 LPM, which corresponds to $U_{gr}$ of 4.15 cm/s.

The removal of ammoniacal nitrogen from sewage water under otherwise identical conditions in CDTBC-1 and RDTBC in the runtime duration of seven hours is shown in Fig. 5.11 and that of phosphorus compounds is shown in Fig. 5.12.
Chapter 5: Wastewater treatment in draft tube bubble columns

Investigations on Hydrodynamic and Mass Transfer Behavior of Draft Tube Bubble Columns

It is seen in Fig. 5.11 that the nitrogen removal profiles observed in RDTBC and CDTBC-1 almost superimpose due to almost similar values of gas holdup, interfacial area and mass transfer coefficients in both these columns at 2 LPM air flow rate, as shown in Fig. 4.16, Fig. 4.25 and Fig. 4.30, The specific values of these parameters at 2 LPM air flow rate which corresponds to $U_{gr}$ of 4.15 cm/s, are listed in the following Table:
The orthophosphate removal profiles are also quite close but jerky that may be attributed to external effects. Thus, no significant effect of the cross-sectional shape—whether rectangular or circular on the nutrient removal capacities of these draft tube bubble columns at 2 LPM was observed since at the specified air flow rate with 70 cm draft tube height in RDTBC and CDTBC-1, the fraction of aerobic and anaerobic regions are well balanced.

### 5.4.1.5 Effect of scale of operation in CDTBC on nutrients removal

The extent of removal of ammoniacal nitrogen and orthophosphates from sewage water in CDTBC-2 at 12.5 LPM air flow rates were 86% and 64% respectively in a time span of seven hours, in comparison with 80% and 60% removal observed in CDTBC-1. The extent of nutrient removal was higher in CDTBC-2 compared to CDTBC-1 at U_{gr} of 4.14 cm/s, as shown in Fig 5.13 and Fig. 5.14. The better performance of CDTBC-2 could be attributed to a number of reasons, which are not easy to quantify.

#### Table 5.2: Hydrodynamic and Mass Transfer Behavior

<table>
<thead>
<tr>
<th>Column</th>
<th>εg</th>
<th>a (cm⁻¹)</th>
<th>k_{1a} (min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDTBC</td>
<td>0.0335</td>
<td>0.601</td>
<td>0.168</td>
</tr>
<tr>
<td>CDTBC-1</td>
<td>0.0385</td>
<td>0.674</td>
<td>0.157</td>
</tr>
</tbody>
</table>

The effect of scale of operation on removal of ammoniacal nitrogen and phosphorus compounds from sewage water was investigated by performing experiments under identical conditions in cylindrical draft tube bubble columns of different diameters. Column CDTBC-1 had a column ID of 6.4 cm and draft tube ID of 3.2 cm the cross-sectional area of draft tube was 8.042 cm², while column CDTBC-2 had an ID of 14 cm and draft tube ID of 8 cm the cross-sectional area of draft tube was 50.3 cm². In CDTBC-1 sparger with 4 holes of 1 mm diameter while for CDTBC-2 a sparger with 8 holes of 1 mm diameter was used. The height of column in both the cases was 1 meter and draft tube height was 70 cm.

Runs were performed by filling the sewage water in the columns up to initial unaerated liquid height of 75 cm that corresponded to wastewater volume of 2.2 liter in CDTBC-1, and 10.5 liter in CDTBC-2. Since earlier experiments were performed in CDTBC-1 and RDTBC at gas flow rate of 2 LPM that was equivalent to U_{gr} of 4.14 cm/s hence experiments were performed in CDTBC-2 at identical U_{gr}, which corresponded to 12.5 LPM air flow rate due to enhancement of draft tube cross-sectional areas of this column.
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Fig. 5.13 Effect of scale of CDTBC on nitrogen removal at varying air flow rates
(DT height = 70 cm; of $A_r$ of CDTBC-1 = 8.042 cm$^2$; $A_r$ of CDTBC-2 = 50.3 cm$^2$)

Fig. 5.14 Effect of scale of CDTBC on phosphorus removal at varying air flow rates
(DT height = 70 cm; of $A_r$ of CDTBC-1 = 8.042 cm$^2$; $A_r$ of CDTBC-2 = 50.3 cm$^2$)

The gas holdup at $U_{gr}$ of 4.14 cm/s in CDTBC-1 and CDTBC-2 were 0.0385 and 0.033 respectively, while specific interfacial area in CDTBC-2 was 0.8 cm$^{-1}$ while in CDTBC-1, it was 0.674 cm$^{-1}$ as shown in Fig. 4.26. The above data indicates that the extent of aeration in both the columns is nearly identical however, the volumetric mass transfer coefficients was found to be 0.157 min$^{-1}$ in CDTBC-1 and 0.09 min$^{-1}$ in CDTBC-2, from which it can be inferred that $k_L$ in CDTBC-2 was quite low; this result is however expected in view of larger size of the column and lesser degree of turbulence created by circulatory flows.
Another aspect contributing to superior performance of CDTBC-2 is the enhanced fraction of the anaerobic region in this column. The annulus cross-sectional area of CDTBC-2 was 90.4 cm² in comparison with 20.8 cm² in CDTBC-1 accounting for a 4.34 fold increase in annulus volume. Therefore, there was no constraint of space for the anaerobic processes at the specified gas velocities.

The effect of air flow rate on removal of nitrogen and phosphorus from sewage water was also investigated in CDTBC-2 at 12.5 LPM and 25 LPM as shown in Fig.5.13 and Fig.5.14 respectively. Increasing air flow rate had deleterious effect on removal of both the nutrients- nitrogen and phosphorus in the larger scale operations, in almost a similar fashion as observed in RDTBC. The decrease in the removal of nutrients from sewage water at higher air flow rate is again attributed to increased liquid circulation causing entrainment of air bubbles in the annulus zone, leading to suppression of anaerobic mechanisms thus causing inferior performance of the column at high air velocities.

Further it is observed that the removal profile of nutrients from CDTBC-2 at 25 LPM air flow rate (U_gr = 8.28 cm/s) matched closely to that obtained in CDTBC-1 at 2 LPM air flow rate having U_gr = 4.14 cm/s. Moreover, CDTBC-2 at U_gr = 4.14 cm/s (12.5 LPM air flow rate) returned marginally superior nutrient removal profiles compared to CDTBC-1 and RDTBC at the same superficial velocity of U_gr = 4.14 cm/s obtained at 2 LPM air flow rates as seen in Fig. 5.13 and 5.14. This behavior is largely attributed to the presence of larger anaerobic zone in CDTBC-2; it also reinstates the observation that at relatively higher air flow rates the performance of draft tube bubble column falters for nutrient removal.

These results illustrate some important characteristic of DTBC with respect to nutrient removal they are the following:-

- Device geometry has almost no effect on overall device performance
- Large annular space in DTBC generally favors nutrient removal and does not hamper overall performance of the devices
- Superficial velocities are key performance parameters and changes of scale of operation maintaining the superficial gas velocity will return almost identical removal profiles.
5.4.2 Synthetic wastewater treatment using activated sludge in rectangular columns

Rectangular draft tube bubble columns (RDTBC) as well as rectangular bubble columns were also used for the removal of ammoniacal nitrogen and orthophosphates from synthetic wastewaters, prepared in laboratory, using activated sludge. The objective of this investigation was to check the efficacy of the data obtained in laboratory with actual field data.

The composition of synthetic wastewater was adjusted to exactly match with the initial concentration of ammoniacal nitrogen (49.7 mg/L) and phosphorus (4.56 mg/L) of the sewage water so that the nutrient removal profiles from these two wastewaters could be meaningfully compared. Table 5.2 gives the components and composition of the wastewater synthesized in the laboratory. All the experimental runs with synthetic wastewater were performed in rectangular columns; both the draft tubes (70 cm height as well as 60 cm height) were used at airflow rates of 2 LPM corresponding to \( U_{gs} \) of 4.167 cm/s in draft tube columns, the unaerated liquid height was kept 75 cm. The total duration of the runs were seven hours similar to the run time for sewage waste water.

The nitrogen and phosphorus removal profiles of synthetic waste water and sewage waste water in three different devices rectangular bubble column and rectangular draft tube bubble columns are shown in Fig 5.15 at a fixed gas flow rate of 2 LPM. The removal profiles of nitrogen in both waste waters in bubble columns intermingle closely while in RDTBC with 70 cm draft tube also the removal profiles are quite close up to 5 hrs thereafter the curves diverge out, same is the case with 60 cm draft tube.

Phosphorous removal from synthetic waste waters in DTBC was substantially larger than from sewage waste water, in 70 cm DT column the final extent of removal was 77% for synthetic waste water and 60% for sewage waste water while in 60 cm draft tube phosphorous removal was 70% and 55% respectively for synthetic and sewage wastewaters. In bubble columns as well the extent of phosphorus removal achieved from synthetic wastewater was 58% while from sewage wastewater it was just 48% under identical conditions.

The greater extent of phosphorus removal from synthetic waste water is attributed to the relatively simple phosphorus compound present in synthetic wastewater vis-à-vis the sewage water.
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Fig. 5.15 Comparison of synthetic wastewater and sewage water for nitrogen and phosphorus removal in rectangular columns. (Air flow rate = 2 LPM; Sparger C)
The relative performance of the three devices - the rectangular bubble column, the rectangular draft tube bubble column with 70 cm draft tube and one with 60 cm draft tube- for removal of nitrogen and phosphorous based nutrients from the synthetic wastewater are shown in Fig 5.16 and Fig 5.17. It is observed that the device performance followed the order RDTBC > RBC, in RDTBC the draft tube with 70 cm height outperformed the RDTBC with 60 cm height. Similar results were obtained earlier with sewage waste water as well; the cause for such performance is elaborated earlier in sections 5.4.1.1 and 5.4.1.2. One interesting departure that was noticed was that unlike
sewage wastewater the depletion profile of phosphorus in synthetic wastewater was relatively smooth and gradual. The net removal of nitrogen and phosphorus from both wastewaters after seven hours operation in the three devices are listed in the Table 5.3 below.

### Table 5.3 Comparison of nutrient removal from synthetic and sewage wastewater

<table>
<thead>
<tr>
<th>Column</th>
<th>Synthetic wastewater</th>
<th>Sewage water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% N removal</td>
<td>% P removal</td>
</tr>
<tr>
<td>RBC</td>
<td>44</td>
<td>58</td>
</tr>
<tr>
<td>RDTBC with 70 cm draft tube</td>
<td>92</td>
<td>77</td>
</tr>
<tr>
<td>RDTBC with 60 cm draft tube</td>
<td>86</td>
<td>70</td>
</tr>
</tbody>
</table>

These results home in the point that device specific data portability is possible between laboratory developed synthetic wastewater systems and sewage wastewaters without substantial loss of information but such data transfer across devices such as bubble column to draft tube bubble columns is not advisable without appropriate scaling.

### 5.5 CONCLUSIONS

The significant conclusions drawn from this investigation on wastewater treatment using activated sludge in draft tube bubble columns are as under:

- The draft tube bubble column proved to be a superior device for the biological removal of nitrogen and phosphorous compounds from wastewater in comparison to the bubble column. These results validate the hypothesis forwarded by Barnard (1973) that aerobic and anaerobic regions are required for enhanced biological treatment of nitrogen and phosphorus compounds from waste water.

- The geometric shape of the column did not influence the removal rates of N and P when design and operational parameters in different geometries were nearly identical.

- Superficial velocities are key performance parameters and changes of scale of operation maintaining the superficial gas velocity returns almost identical removal profiles.
• Height of draft tube influenced the rates of N and P removal from wastewater. Draft tube height needs to be optimized for specific applications, it was observed that lower draft tube height made the DTBC device more like a bubble column reducing the specific interfacial area and mass transfer coefficient, that had a bearing on the overall removal rates.

• Annular region in the DTBC functions as the anaerobic zone, large annular space generally favors nutrient removal and does not hamper overall performance of these devices.

• Nitrogen and phosphorus removal from sewage waste water and synthetically prepared waste water show similar removal patterns although the extent of removal from sewage water is about 10% less which is expected in view of the relative complexity of molecular species involved in sewage water.

• Results indicate that device specific data portability is possible between field data and laboratory data developed based on synthetic wastewater systems without substantial loss of information but data transfer across devices such as bubble column to draft tube bubble columns is not advisable without appropriate scaling.

• The draft tube bubble column turns out to be a simple, compact and effective device for nutrient removal from wastewaters and is a tool for process intensification.