Antai: Proc. ICCEM (2012) 115 - 125

Title of Paper: **Environmental Liquid Effluents, A Novel Approach For Treatment Of Industrial Waste Water**

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Abstract

Nutrient enrichment or eutrophication of aquatic ecosystems can cause an increase in algae and aquatic plants, loss of component species, and loss of ecosystem function. For these reasons, numerous studies were focused on nitrogen and phosphorus removal from wastewater streams. Most of these studies were based on biological processes and different combinations of anaerobic, aerobic, and anoxic zones such as Bardenpho, A_2O, UCT, and their modifications. Hence phosphate recovery from sewage is in synergy with reducing other environmental impacts and making it a long term economic resource. The aim of the novel treatment process is to highlight on studies investigated for the nutrient removal performance using Chorella-vulgaris at different nitrogen and phosphorus concentrations. The effect of ammonia nitrogen and phosphorus concentration on removal of these nutrients from synthetic wastewater by algae Chorella-vulgaris in batch cultivation have been investigated in this study and kinetic coefficients were determined. It is observed that an effluent may contain specific nutrients valuable for recovery and this observation may lead to the idea or understanding of treating an effluent from industrial source as a useful resource instead of the general idea of treating the effluent as waste products, and in the same process losing money in terms of expenses on chemicals and energy. Treatment and discharge of effluents into the receiving streams should not be an issue that will be considered as usual because there are specified standards required by the legislation, in terms of the quality and characteristic of the effluent before it is discharged into the waterways.

***Key words**: Liquid Effluents, Municipal waste water, Chorella-vulgaris, kinetic coefficients*

1. Introduction

For simplicity and clarity, the subject of waste water may be divided into three categories namely; domestic or sewage, industrial and municipal waste water. However municipal liquid effluents may further be classified as effluents from both domestic sewage and industrial sources.

Waste water contains a mixture of complex organic and inorganic matters combined with man- made substances. It also contains material washed from road and roofs as well as contaminated underground water which may run into the sewer system; thereby forming a complex waste water which will inevitably require some form of treatment before being discharged into receiving streams. According to Gray (1999), the strength and composition of sewage varies on hourly, daily and seasonal basis which also depends on individual water usage, infiltration, surface run off, local habits and diet.

The constituents of waste water may be categorized into physical, chemical and biological parameters. Physical include temperature, odour, turbidity, oil and grease etc. Solids are classified into dissolved, suspended as well as organic (volatile) and inorganic, (fixed) fractions.

Chemical organic parameters are BOD, COD, TOC, TOD and inorganic parameters may include pH acidity and Alkanity, salinity, chloride nitrate, ionized metals etc.

Biological parameters are Coli-forms, specific pathogen and viruses. All the constituents and concentration vary with time and local conditions (Metcalf and Eddy, 1991). But Kiely (1998) considers oil and grease as chemical organic and also Bacteria, Algae and protozoa are included as bacteriological parameters. Hence the characteristics of waste water may depend on the season of the year and may also vary in weekdays and holidays. Summer period discharges 10 – 20% more than winter and Industries discharges minimized on Sundays.

1.1 Composition Municipal Waste Water

The waste water composition contains about 70% organic matter and 30% inorganic. The volume of the domestic effluents discharged into sewer in a community varies from 50 to 250 gal per person depending on the sewer uses (Gray, 1999). Municipal effluents are low strength waste compared with industrial waste water that contains high strength waste of hazardous chemicals like phenols etc (Kiely, 1998). The solids content found in urban waste water can be classified into suspended and filterable solid. The suspended solid consist of settleable and non settleable accounting for 30.5% of the total solid. The filterable solid comprises of colloidal and dissolved solids given as 69.5% (Boari et al, 1997). Municipal waste water contain 75% SS and greater than 50% filterable solids of organic in nature and their sources are from animal, plants and synthesis of organic compounds. The organic material found in effluent include protein 40-60%, carbohydrates 25 – 50%, fats and oil -10% and some traces of phosphorus, sulphur compounds etc (Boari et al, 1997)

The composition of inorganic substances can have metal contents of salts associated with it, which include nitrate phosphorus, sulphur, chlorine and their compounds. The source of nitrate and phosphorus in domestic sewage is from human excreta and phosphorus specifically due to the use of detergents. The total nitrogen is categorised into organic (containing biodegradable and non-biodegradable) account for 25% and inorganic nitrogen given as 75% containing ammonia nitrogen (Boari et al, 1997). In UK, the nutrient production per capita is 5.9g N per day and 2.0g P per day (Gray, 1999).

***Table 1.0** Major Composition of untreated Domestic waste water*

	Concentration mg/l		
Constituents	**Weak**	**Medium**	**Strong**
Total solid (TS)	350	720	1200
Total dissolved solid (TDS)	250	500	850
Suspended solid (SS)	100	220	350
Nitrogen (N)	20	40	85
Phosphorus (P)	4	8	15
Chloride	30	50	100
Alkalinity (as $CaCO_3$)	50	100	200
Grease	50	100	150
BOD at 20°C Over 5 days	110	220	400
COD	250	500	1000

Source: Adapted from Metcalf and Eddy inc. 1991

1.2 Composition Industrial Waste Water

Within municipal limits it is often a conventional practice for Industries to pre-treat their effluents before discharge into sewer system due to the nature of toxicity and treatability of the waste water. It considerably varies from one industry to another (Gray, 1999).

It is quite normal for Industrial waste water to have a strong odour due to the presence of phenol and sulphur compounds etc. generated in gas industries, refineries and other chemical processing plants.

The color of industrial waste water is also affected due to the presence of organic materials such as blue copper and green nickel. Yellow and brown iron may also be found in industrial waste effluent from textile, paper, and food processing industries. (Boari et al, 1997) mentioned that, the coloring may also be due to the presences of oily material such as fat and lubricants found in the waste water.

Recent studies (Hammer et al, 2004) show the average characteristics of selected Industrial waste waters. It is advisable that the pre-treatment process at industrial site must be considered for high strength waste water, different from domestic waste water. By comparing effluents from domestic sources with some selected industries listed in table 1.1, it is observed that the BOD contents is 5- 20 times greater than domestic effluent and the level of total solids vary significantly. (Hammer et al, 2004).

Table 1.1 Average characteristics of selected Industrial waste waters

Constituents	Milk Processing	Meat Packing	Synthetic Textile	Chlorophenolic Manufacture
BOD, mg/l	1000	1400	1500	4300
COD, mg/l	1900	2100	3300	5400
Total solids, mg/l	1600	3300	8000	53000
Suspended solids, mg/l	300	1000	2000	1200
Nitrogen, mg N/l	50	150	30	0
Phosphorus, mg/l	12	16	0	0
pH	7	7	5	7
Temperature ^{o}C	29	28	-	-
Grease, mg/l	-	500	-	-
Chloride, mg/l	-	-	-	27, 000
Phenols, mg/l	-	-	-	140

Source: Hammer et al. water and Waste water Technology. International Ed.

1.3 Environmental Effects

(Mara et al, 1992) and (Sung et al, 1977), in their study mentioned that the presence of endocrine in municipal sewage treatment plant (STP) is responsible for the environmental effect observed in the aquatic environment concerning the reproductive system. For instance feminisation of male fishes within the STP effluents. They explained that the chemical substance responsible for this harmful effects are yet unknown and still under investigations; but the presence of substance like nonylphenols, phthalic esters, PCB`s, Dioxins. Phyto-estrogens and human estrogens are suspected to influence the hormonal system. (Russell and Gordon,1971).

From hypothesis (Richardson et al, 2001).based on the statistically derived data; commented on the disorder relating to male infertility, low sperm count, testicular cancer, etc. to be caused by the intake of estrogens in drinking water. This they explained that as drugs are used in medicine to influence the endocrine (hormonal)system e.g. contraceptives used as ingredients of birth control pills are excreted after ingestion into the municipal sewage.

In general these pharmaceuticals and natural hormones would have to pass through an STP prior to entering rivers or streams. Hence a precise quantification of natural estrogens and contraceptives in STP effluents is essential for risk assessment regarding the endocrine disruption in aquatic environment.

1.4 Application of Nutrient Recovery from Wastewater Streams

The detergent phosphate industry recognises that phosphate is the only recyclable components in detergents. More importantly weather phosphate is used for detergent or not the fact remains that the bulk of phosphate in sewage comes from natural human emissions.

Practically, biological-removal in sewage works is a process which may require higher investment cost and requires better process engineering; but the advantage is such that it avoids chemical consumption and subsequent disposal can be combined with different technologies with recovery of the phosphate and nitrogen for recycling.

This therefore makes it a target for sustainable sewage treatment i.e., making sewage a resource rather than continue to treat it as a waste with the loss of nutrients and increasing energy consumption, chemical use and greenhouse emissions.

The Ostara process, developed by the University of British Columbia has been proved to be a success in many sewage plants in Canada and USA and it is now being tested in China, Israel and the UK. The process allows for the recovery of phosphate from sewage world operating biological P- removal, as struvite, a high quality slow release fertiliser with high economic value.

Recycling of phosphate, Nitrogen and organics from wastewater such as municipal sewage treatment plants or even animal manure directly contributes to reducing green house gas emissions.

1.5 Other Application Process

- ***1.5.1*** *Direct recycling of sewage nutrients*
- ***1.5.2*** *Phosphorus recovery by precipitation*
- ***1.5.3*** *Operational Struvite recovery*
- ***1.5.4*** *Calcium phosphate precipitation*
- *1.5.5* *Sludge incineration by ash*

2. Review of Relevant Literature

2.1 A Novel Approach

Novel treatment approaches have been developed for treatment of effluents either from industrial and municipal sewage treatment plants. The studies reveals that the Novel processes being developed are capable of extracting and recovering several nutrients like phosphorus, Nitrogen, Organic, Estrogens', indirubin, etc; from wastewater streams.

An international conference on nutrient recovery form wastewater streams held in Vancouver May 10th to 13th 2009; confirmed the increasing recognition that recycling of Phosphorus and Nitrogen will be essential for a sustainable development.

To this end, a novel approach was tested in Oregon, involving the online monitoring of ammonia in Municipal STP`s. Also the batch kinetics of nitrogen and phosphorus removal from synthetic wastewater using algae has also been tested.

Due to the broad scope, quantity and application of both industrial and municipal wastewater effluents; the future role of the use of sewage effluent for irrigation in the Middle East has been considered. Hence based on these studies, the physiochemical treatment of both industrial and municipal effluents as a process can be optimised to treat an effluent according to the specific makeup or characteristics of the contamination.

Examples of some innovative processes or novel approaches may combine two or more operational steps easily performed on site. A more practical example was the study of the behaviour and occurrence of estrogens in municipal STP`s, this novel process which was investigated in Germany, Canada and Brazil was found to be effective in quantifying the level and amount or quantity of estrogens in municipal sewage samples.

Using the method for investigating the behaviour and occurrence of natural estrogens and synthetic contraceptives in municipal STP`s, it was discovered that the mean recoveries of the analytes in ground water after extraction ,clean-up and derivation was generally above 75%.

In recent study (Clayton et al, 1999) a sewage treatment plant in Germany close to Frankfort main was determined to have been contained with 17β-estradiol and estrogens with mean concentrations' 0.015µg/L and 0.027µg/L respectively. Similarly investigations carried out in Canada and Brazil also discovered that the STP discharges estrogens

Studies on treatment of industrial liquid effluents (Daniels et al ,1977) laid emphasis on the fact that Global biochemical cycles have been largely affected by human activities thus increasing the input of nutrients into biochemical cycles through agricultural practices, urbanization, industrialization, and other alterations, especially nitrogen and phosphorus.

The aim of these studies was to evaluate the ammonium nitrogen removal performance of algae culture (*Chlorella vulgaris)* in a novel approach using an immobilized photo-bioreactor system under different operating conditions and to determine the bio-kinetic coefficients using the Stover-Kincannon model.

In these approaches batch experiments were performed to determine the effect of initial nitrogen and phosphorus concentration on nutrients removal performance of microalgae (*chorella vulgaris)* and to obtain bio-kinetic coefficients such as K, reaction rate constant K_m, half reaction rate constant and yield coefficients using "Michaells-Menten" rate expression.

Other study (Curtis, 1994) reveals that Immobilization techniques have been applied to algae to solve harvesting problems encountered in suspended growth systems. Internal immobilization (of *Chlorella vulgaris)* in sodium-alginate beads provided higher nutrient removal from raw sewage treatment compared to external immobilization on polyurethane foam.

3. Materials and Methods

3.1 Microorganism

The green algae (*C. Vulgaris)* should be used for the process. The diagram below shows the cycle of nutrient flow in the proposed treatment system, where manure from dairy cows in free-stall barns could be mechanically scraped (or flushed with water) and the resultant manure slurry subjected to a solid separation step prior to treatment of the solids by composting and treatment of the effluent by anaerobic digestion and algal scrubbing. Values for input N and P, was emphasised in (Van Horn et al., 1994). Biomass from the algal scrubbers can either be recycled into farm operations as a feed supplement or fertilizer or exported from the farm.

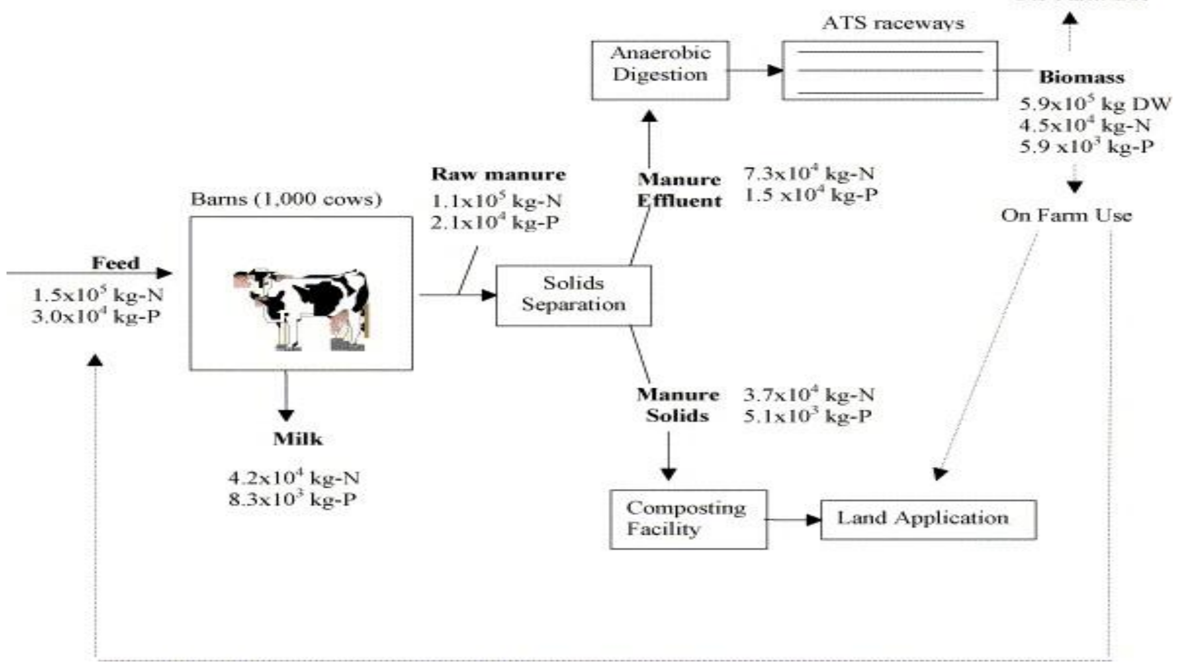

Figure 3.1 *Schematic diagram of nutrient flow in the proposed treatment system.*
Source: Van Horn et al, 1994

Figure 3.2 below shows a Schematic diagram of an algae turf scrubbers (ATS) unit with associated equipment and water reservoir. Manure effluent is added continuously to the equalization reservoir. Algal biomass is harvested weekly, removed from ATS effluent using a mechanical rake, dewatered with a screw press, and dried using a belt drier. A 1000-animal farm-scale system would be composed of eleven ATS units that would share reservoirs and the harvesting, dewatering, and drying equipment.

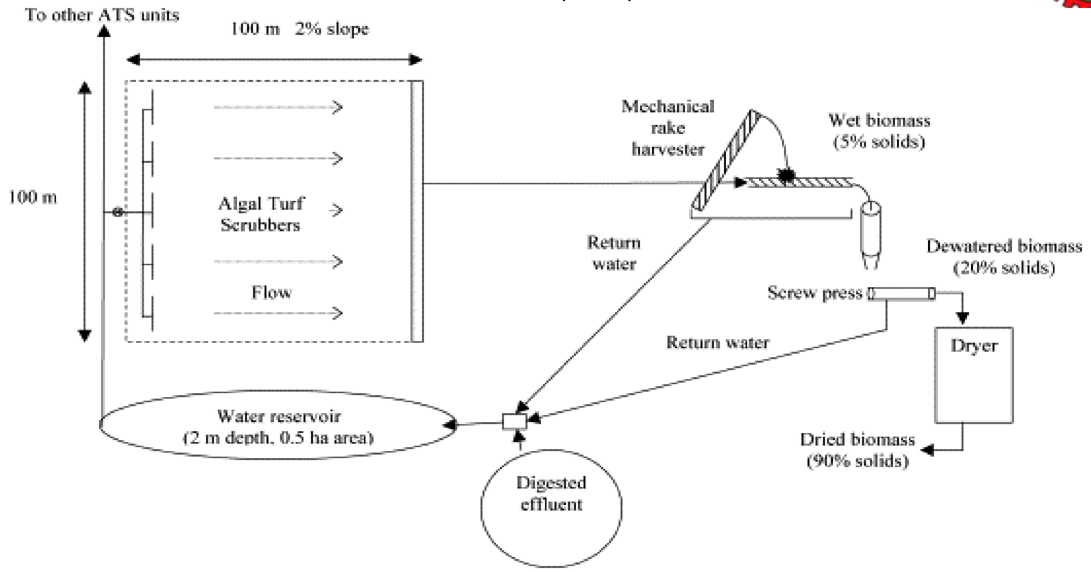

Figure 3.2 *Schematic diagram of 1ha ATS unit with associated equipment and water reservoir*
Source: Van Horn et al, 1994

3.2 Culture Medium

Synthetic wastewater was used throughout the experiments. The growth media contained: $MgSO_4 \cdot 7H_2O$, 1000 mg l^{-1}; $CaCl_2$, 84 mg $l^{-1}$and 0.5 ml of trace elements.

NH_4Cl and KH_2PO_4 were used as nitrogen and phosphorus sources, respectively. The trace elements were composed of H_3BO_3, 57 mg l^{-1}; $FeSO_4 \cdot 7H_2O$, 25 mg l^{-1}; $ZnSO_4 \cdot 7H_2O$, 44 mg l^{-1}; $MnCl_2 \cdot 4H_2O$, 7 mg l^{-1}; MoO_3, 35 mg l^{-1}; $CuSO_4 \cdot 5H_2O$, 8 mg l^{-1}; $Cu(NO_3)_2 \cdot 6H_2O$, 2.5 mg l^{-1}; Na_2EDTA, 250 mg l^{-1}; and $NaHCO_3$, 2500 mg l^{-1}.

3.3 Experimental Set-Up

The experiments were conducted in batch by using 1000 ml flasks. At the beginning of each series of experiments, 800 ml of culture medium was inoculated to flasks with a suspension of pre-cultured cells.

The initial chlorophyll *a* (chl *a*) concentration was kept constant around 3.5 ± 0.5 mg l^{-1} throughout the experiments. NH_4-N concentration was varied between 13.2–410 mg l^{-1} while PO_4-P concentration was between 7.7–199 mg l^{-1} by keeping N/P ratio around 2/1.

The flasks were aerated to provide CO_2 and for mixing via an air pump. The pH was maintained at 6.5–7.0 by the addition of 5% potassium hydroxide (KOH) and 10% acetic acid (CH_3COOH) solutions. Illumination was provided continuously from one side of the flasks by using 36 W/54 fluorescent lamps with 4100 flux and continuous illumination.

Light intensity was measured by a digital light meter (Luxeron LX-1108). The experiments were conducted at room temperature (20 ± 2 °C) for 10 days.

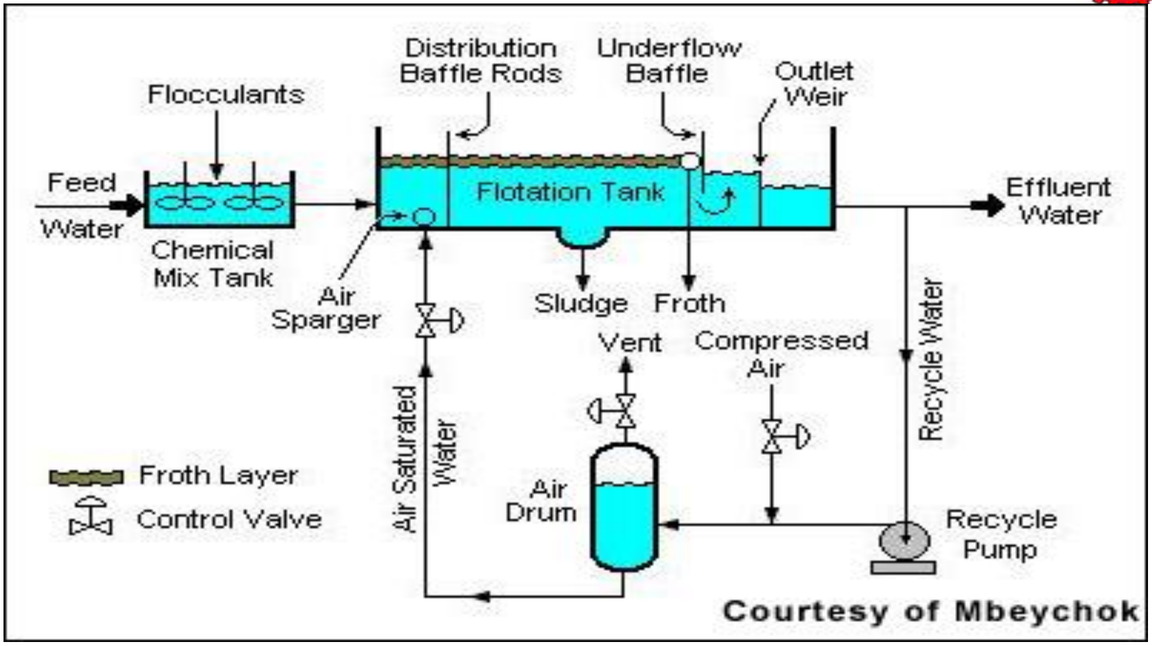

Figure 3.3 *Schematic diagram shows typical flow arrangement for effluent treatment incorporating recycle water fed back via a recycle pump.*

Source: http://www.water-technology.net/projects/tianjinjejuan/tianjinjejuan2.html

3.4 Analytical methods

Ammonia, nitrogen, phosphorus, and Chlorophyll a concentrations were monitored on the samples. Daily samples withdrawn from flasks were centrifuged at 5000–6000 rpm to separate algae. NH_4-N and PO_4-P measurements were carried out in clear supernatant by colorimetric method using phenate and vanadomolybdolo-phosphoric acid with standard deviations of ±0.025 and ±0.08, respectively (Culp et al,1978)

To determine the Chlorophyll a content, 10 ml of algal suspension was centrifuged at 3000 rpm for 30 min and the supernatant was discarded. The algae were suspended in 3 ml of methanol and heated for about 5 min in a water bath. The samples were cooled to room temperature and then the volume was made up to 5 ml by adding methanol. The chl a concentration in the extract was calculated by reading the absorption (A) of the pigment extract in a spectrophotometer at the given wavelength against a solvent blank by using the equation:

Chlorophyll a (mg/L) = $(16.5 \times A_{665}) - (8.3 \times A_{650})$ (Culp et al,1978).

The result of the above experiment showed that batch kinetics coefficients of NH_4-N and PO_4-P removal by C. vulgaris were determined by changing the initial concentrations of corresponding nutrients in the media. The initial Chlorophyll a content was 3.0 ± 0.5 mg l^{-1} at all experimental conditions. Variations of nutrient concentrations were monitored daily and the specific substrate utilization rates were calculated.

4. Discussion of Results

A photo bioreactor was continuously operated at different initial ammonium nitrogen concentrations (NH_4-N_0 = 10-48 mg L^{-1}), hydraulic retention times (HRT = 1.7-5.5 days) and nitrogen/phosphorus ratios (N/P = 4/1-13/1).

Effluent NH_4-N concentrations varied between 2.1 ± 0.5 mg L^{-1} and 26 ± 1.2 mg L^{-1} with increasing initial NH_4-N concentrations from 10 ± 0.6 mg L^{-1} to 48 ± 1.8 mg L^{-1} at θ_H = 2.7 days. The maximum removal efficiency was obtained as 79 ± 4.5% at 10 mg L^{-1} NH_4-N concentration.

Operating the system for longer HRT improved the effluent quality, and the percentage removal increased from 35 ± 2.4% to 93 ± 0.2% for 20 mg L^{-1} initial NH_4-N concentration.

The N/P ratio had a substantial effect on removal and the optimum ratio was determined as N/P = 8/1.

Saturation value constant, and maximum substrate utilization rate constant of the Stover-Kincannon model for ammonium nitrogen removal by *C. vulgaris* were determined as $K_B = 10.3$ mg L^{-1} d^{-1}, $U_{max} =$ 13.0 mg L^{-1} day^{-1}, respectively.

Experimental results indicated that C. vulgaris can completely remove up to 21.2 mg l^{-1} ammonia-nitrogen concentration. However the tolerance to PO_4-P was lower.

The culture was able to remove only 7.7 mg l^{-1} initial PO_4-P concentration with 78% efficiency. The main reason for low removal performance at high nutrient concentrations could be the light limitation because of excess Chlorophyll *a* concentrations in this study.

In addition, the optimization of other parameters such as N/P ratio and light–dark cycle may enhance the nutrient removal capability of C. vulgaris at high nitrogen and phosphorus concentrations.

4.1 NH_4-N and PO_4-P removal

The variation of NH_4-N concentration with time at different initial NH_4-N concentration for 10 days of batch operation was obtained. The NH_4-N was completely removed from the media when the initial concentration was between 13.2 and 21.2 mg l^{-1}.

However, the NH_4-N removal efficiency was around 50% for $(NH_4\text{-}N)_o = 41.8–92.8$ mg l^{-1} and it further decreased to less than 24% when the NH_4-N concentration was higher than 129 mg l^{-1}.

Since the pH was kept constant around pH 7, no significant ammonia removal was observed in control experiments. The final phosphorus concentration was around 1.7 mg l^{-1} with 78% removal efficiency for $(PO_4\text{-}P)_o = 7.7$ mg l^{-1}.

The higher concentrations resulted in mostly less than 30% removal. Although nitrogen and phosphorus uptake by algae did not provide efficient removal of these nutrients from the synthetic media at high concentrations of nutrients, final chl *a* content of the culture significantly increased from 10.7 mg l^{-1} to 27.3 mg l^{-1} with the increase in $(NH_4\text{-}N)_0 = 13.2$ mg $l^{-1}$to $(NH_4\text{-}N)_0 = 410$ mg l^{-1}.

The light limitation due to excess amount of Chlorophyll *a* could be one of the reasons for low removal efficiencies at high nutrient concentrations. These results indicate that *C. vulgaris* is very effective in removing nutrient concentrations as $NH_4\text{-}N_0 < 22$ mg l^{-1} and $PO_4\text{-}P_0 < 7.7$ mg l^{-1}.

4.2 Determination of batch kinetic coefficients

The Michaelis–Menten kinetic relationship was used in determination of kinetic coefficients, K_m, saturation constant, k, and reaction rate constant. The substrate concentration corresponds to half reaction rate gives the saturation constant.

Based on the experimental data, batch kinetic coefficients of ammonia nitrogen removal by C. vulgaris were determined as k = 1.5 mg NH_4-N mg^{-1}, Chlorophyll *a* d^{-1} and $K_m = 31.5$ mg l^{-1}.

Similarly, kinetic coefficients for PO_4-P removal were found as k = 0.5 mg PO_4-P mg^{-1} Chlorophyll *a* d^{-1} and $K_m = 10.5$ mg l^{-1}. So, ammonia nitrogen removal rate is higher than that of phosphorus.

Yield coefficient for NH_4-N was $Y_N = 0.15$ mg chl a mg^{-1} NH_4-N and $Y_P = 0.14$ mg Chlorophyll *a* mg^{-1} PO_4-P for phosphorus. This result indicates that almost the same amounts of Chlorophyll *a* a are produced from phosphorus and nitrogen in C. vulgaris.

4.3 Groundwater Remediation, Odour And Vapour Control

It is common knowledge that nitrogen is essential for all living things, but high levels of nitrate-nitrogen in waters destined for portable drinking purpose can pose serious health risk, especially for infants and pregnant women. Novel treatment approaches developed for wastewater treatment are capable of recovering nutrients like phosphorous, nitrogen and organics. Hence treatment of ground water for the removal of organics may vary based on the intended uses. Therefore novel applications have been developed to meet the increasing technological demands for wastewater treatment.

With respect to the case study developed for investigating the behaviour and occurrence of natural estrogens and synthetic contraceptives in municipal STPs. This study became necessary due to the observation relating to the feminization of male fishes within a municipal sewage treatment plant. It was discovered that the natural hormones excreted by humans and flushed into the sewers had an effect on the aquatic life style; hence extraction was necessary.

In most cases even trace elements of the contaminants require some level of extraction to meet drinking water standard or makeup the water quality requirements.

4.4 A Case Study – Pharmaceutical Industry

A characteristic of the pharmaceutical industries is the diversity of their process operations, which gives rise to a wide variation in liquid wastes. There is little similarity between effluents from different factories and individual effluents may alter continually as a result of process changes. This lack of homogeneity leads to a difficulty in categorising wastes of this type, preventing any real standardisation of treatment methods and necessitating a detailed and individual approach to effluent assessment. Many individual effluents arise from insufficient processes or spillages and thus the initial site investigation work is aimed at recovery methods to reduce the volume of effluent to be treated. (Callely et al, 1977).

As a result of the complexity of many of the pharmaceutical wastes, the resultant treatment plants may be multi – stage and in some cases may consist of two or more completely separate plants situated on the same works, with a complicated collection and balancing system (Callely et al, 1977).

4.4.1 Waste Characteristics

The majority of organic chemical which may be found in any significant amount in many of these process waste are readily biodegradable. Certain waste constituents often present in small amounts are extremely toxic to bacteria and may be produced as biocides. Due to the considerable difference between works effluents, it is impossible to describe each type of waste which may be encountered individually. It is therefore most beneficial to discuss the major trends in waste stream characteristics and apply these collectively to specific applications (Callely et al, 1977).

4.4.2 Carbohydrate Products

Sterile products. These effluents contain mainly dextrose and salt solutions. A sterile area with container washing shows a flow of 1-8m3/h with a BOD of 12 – 85 mg/l and suspended solids level of 16 – 2400mg/l.

4.4.3 Production of pastilles

These contain sugar and starch washed from equipment and Starch moulds Contain 2250mg/l BOD and 150mg/l suspended solids level.

4.4.4 Acid and Alkali Effluents.

These contain little or no organic matter and pollutants load in terms of BOD may be negligible.

i. Dissolved salts. The most predominate one are sulphates and chlorides, which may be found in concentrations of 25 000 – 30 000 mg/l
ii. General process liquors
iii. Strong process liquors
iv. Emulsions

4.4.5Waste Assessment

i. Site survey
ii. Chemical Analysis: Effluent composition
iii. Treatability Studies

4.4.6 Waste Treatment Processes

i. Segregation and Balancing
ii. Neutralisation and Pre – treatment

5. Conclusion

Useful conclusions obtained from studies of treatment processes show that integrated wastewater treatment processes can be considered as an alternative to single stage algal pond systems to improve algal separation and nutrient removal. Combination of *C. vulgaris* with water hyacinth *Eichhornia crassipes* resulted in 23% more nitrogen removal.

With the novel approach, *C. vulgaris* was co-immobilized with the growth promoting bacterium *Azospirillum brasilense* in small alginate beads and enhanced ammonia and phosphorus removal were obtained.

Results also indicated that the algae-immobilized photo bioreactor system had an effective nitrogen removal capacity when the operating conditions were optimized. The optimal conditions for the immobilized photo bioreactor system used in this study can be summarized as HRT = 5.5 days, N/P = 8 and NH_4-N_0 = 20 mg L^{-1} initial nitrogen concentration to obtain removal efficiency greater than 90%.

Advantages

a. The advantages of using algae for that purpose include: the low cost of the operation,
b. The possibility of recycling assimilated nitrogen and phosphorus into algae biomass as a fertilizer avoiding a sludge handling problem.
c. The discharge of oxygenated effluent into the water body. In addition, the process has no carbon requirement for nitrogen and phosphorus removal, which is attractive for the treatment of secondary effluents

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Acknowledgement

The authors would like to thank the research group Environmental and Energy Engineering (Alpha consultants 2010) University of Sheffield, United Kingdom for the team spirit and effort in carrying out this research and for their assistance in the preparation of this paper.