DESIGN OF A COMMON EFFLUENT TREATMENT PLANT FOR AN INDUSTRIAL ESTATE

S. RAMPARI1, C. VENKOBACHAR2, R. CHEVANNES3, F. GRANT1, & D. THORNHILL4

1. Undergraduate Students Department of Civil Engineering, UWI, St. Augustine, Trinidad

2. Professor of Environmental Engineering, Department of Civil Engineering, UWI, St. Augustine, Trinidad, W.I. Fax: 868 662-4414 and e-mail: venko@eng.uwi.tt

3. Civil Engineer, West Indies Home Contractors Limited (WIHCON), Jamaica

4. Civil Engineer, Ministry of Environment, Barbados

Abstract

The recent concept of "industrial ecology," in which the waste generated by one industry becomes the raw material for another industry, is an ideal principle in siting industries in an industrial estate. The industrial ecology concept results in minimum net production of industrial pollution to be handled. Ultimately, waste from some industries will have no secondary use and hence must be treated before disposal. On an industrial estate, the use of a common effluent treatment plant reduces the cost to each industry and controls the overall quality of the treated effluent.

In this study, four (4) diverse industries were selected and a Common Wastewater Treatment Plant (CWTP) designed utilizing the concept of industrial ecology. The industries selected were ethylene production, orange juice production, meat processing, and recycling. For each of these industries, the pollution load was calculated based on various production rates with a final effluent BOD target of 50 mg/L.

The industries contributing effluents to the CWTP have varied wastewater characteristics. Therefore, there is a need to pre-treat the effluents from some of these industries prior to their entry into the CWTP. The treatment system involved the use of a number of different pretreatment schemes like an anaerobic treatment system in the form of an Upflow Anaerobic Sludge Blanket (UASB), coagulation and flocculation as well as grease removal by an American Petroleum Institute (API) Separator etc. The effluents from the various pretreatment schemes were then sent to the CWTP for treatment before final disposal.

Two options were investigated for the CWTP. One alternative was of low mechanical content (LMC), consisted of two stabilization ponds in series having a total surface area of 10 hectares. The second design alternative entailed an energy-intensive system and has a high mechanical content (HMC), using extended aeration for CWTP. The effluent from the CWTP was then mixed with the wastewater from the glass recycling. The flow rate of the final effluent was 10,000 m3/d and this effluent had a BOD of 30mg/L and a TSS of 130mg/L, thus satisfying the effluent standards.
INTRODUCTION

An industrial estate is a composition of several different types of industries located in one area, each producing effluent of varying wastewater characteristics. In a scheme of unplanned development, it is common practice for each company on an industrial estate to develop their individual effluent treatment plant. When the industrial estate is considered as a whole, one observes that, because of this practice, valuable resources are wasted on effluent treatment. These resources include capital cost, land space, and maintenance costs.

A common effluent treatment plant and industrial ecology offer an alternative to the practice of having individual effluent treatment systems and makes better overall use of the resources of an industrial estate.

Industrial ecology calls for the waste of one industry to become the raw material of another industry. In this way, there is a net minimum production of industrial pollution to be handled. At some point, however, the waste from some industries will have no secondary and must hence be treated before final disposal.

In a common effluent treatment plant, the effluents from the different industries are treated using one universal treatment system. Common effluent treatment plants eliminate duplicity of treatment systems among the industries on the industrial estate and hence results in a reduction in the total capital required for construction of the industrial estate.

In some cases, wastewater from some industries may require pretreatment before it is allowed to enter may enter the common effluent treatment plant. This may be necessary because of a high pollution concentration produced by a specific industry or perhaps the presence of a specific group of toxins not treated by the common effluent plant.

The benefits of a common effluent treatment plant include reduced land space requirement than that of having individual treatment systems for each industry. This is because, as duplicity is removed, a combined treatment plant allows for additional effluent to be added via a height/depth increase of a treatment system, rather than the construction of an all-new treatment process.

Common effluent treatment plants also allow better monitoring and control of effluent quality. It also reduces the possibility of shock load on the environment. Monitoring of the pretreated influent to the common wastewater treatment plant from each industry and enforce some penalty against any industry with a pollution load exceeding the accepted level. This penalty will force industries to control their pollution level and hence encourage sustainable development.

With the concepts of industrial ecology and common effluent treatment plants in mind, the objectives of this study are:

. The examination of possible industries to be placed on the industrial estate.

. To estimate production rates for the industries selected and hence determine each industry's wastewater characteristics

. To determine an appropriate pretreatment scheme for the industries as necessary
To determine an appropriate treatment system for the combined treatment plant.

INDUSTRY SELECTION

The selection of industries to be placed on the estate was evaluated by the various criteria. These include: 1) They should, as far as possible, be downstream industries of the products at the Point Lisas Industrial Estate; 2) The industries should be different to from those currently at the Point Lisas Industrial Estate 3) The industries should be viable in Trinidad and Tobago.

From the above criteria, the following industries were selected: a) Ethylene Production; b) The recycling of paper, glass and plastic c) Orange Juice Manufacturing; d) Meat Processing. It was also decided that there would be a workshop on the estate.

INDUSTRY PROFILE AND WASTEWATER CHARACTERISTICS.

Table 1 gives the computed pollution load and expected production rate for the various industries. The production rates were set based upon what can be expected from some small and medium-scaled
industries in Trinidad. The treated effluent should meet the requirements of the Trinidad and Tobago Bureau of Standards as presented in Table 2.

It can be seen that the effluents from the industries require variable treatment as their wastewater characteristics are also variable - a true representation of what one may expect to find upon investigation of any industrial estate.

PRETREATMENT SCHEMES

There are several factors that determine if the effluent requires pretreatment or if it can be sent directly to the common effluent plant. These factors include concentration of the effluent, constituent elements of effluent and the capabilities of the common treatment plant. For the common effluent treatment plant, a BOD5 value of around 800mg/l or less was considered acceptable, with a TSS value less than 200 mg/L. If the values for BOD5 and TSS are greater than this, then pretreatment becomes necessary. These factors were considered and table 1 shows the significant constituents of the effluent upon which his design is based.

Petro Chemical Industry: Ethylene Production

From Table 1, the major pollutants from ethylene production are fats, oils and grease and COD. Therefore, one must look at a pretreatment system that will deal with both these pollutants.

The solution involves the use of two methods of pretreatment - grease separation using an American Petroleum Institute (A.P.I.) Separator, followed by COD removal using Activated Carbon treatment. Figure 1 shows a diagram of the API Separator.

![Figure 1. American Petroleum Institute (API) Separator](image-url)
The API separator depends upon the difference in specific gravity oil and water. The API Separator will not separate substances in solution or break emulsions. It is a large rectangular tank designed to slow wastewater flow rate so that oil droplets can rise to the surface over the length of the tank. There is a scraper that moves oil that has floated to the surface of the tank into drums located on the downstream end of the tank. On its return to the upstream end, it goes to the bottom of the tank and scraped sludge into a collection trough.

The design criteria for this design were: 1) the critical (slowest rising) oil droplet had a velocity of $1.011 \times 10^{-3} \text{ m/s}$; 2) the depth of flow was limited between 0.91 - 2.44m; 3) The width of the separator was limited between 1.83 and 6.1m; 4) the depth-to-width ratio was between 0.35 and 0.5; 5) an oil retention baffle should be located no less than 0.3m downstream from a skimming device and should have a maximum submergence height 55% of the water depth.

The dimensions of the designed API separator were length: 10m; width 3m; height 1.5m A properly designed API separator will produce effluent concentrations of less than 50mg/L. The next step in the treatment process is to remove organics especially COD using fixed-bed granular activated carbon adsorption. Figure 2 shows diagram of a fixed-bed granular activated carbon adsorption process.

![Figure 2. Granular Activated Carbon](image)

Activated carbon serves as a major treatment process in a physiochemical treatment system. The carbon is prepared by making char from materials such as almond, coconut hull, woods and coal. The char is then activated (oxidized) at higher temperatures to create a very porous structure. A fixed-bed cylindrical column is used as a means of contacting granular activated carbon with the wastewater. The water is applied at the top of the column and withdrawn at the bottom allowing enough residence time (a minimum of 30 minutes) for completion of the adsorption process. An oxidizing agent, usually steam, is then applied at a slightly higher temperature to remove the residue and reactivate the carbon. The effluent is then sent to the common effluent treatment plant for further treatment.

The design criteria used here are: 1) the depth of the carbon bed is usually 2 to 3m; 2) The flow rate usually varies between 0.08 to 0.4 m$^3$/m$^2$.minute and contact periods are between 10 to 50 minutes, based on empty tank cross section and volume; 3) Typical contact periods are from 30 minutes and more; 4) The diameter of the cylindrical tank is dependant on the flow to be treated and the required
contact time. However, maximum diameter is limited by cost considerations and practical design problems and rarely exceeds 2 m; 5) downtime of up to 40% should be included in the fixed-bed design system with 5 to 10% makeup carbon being provided after each regeneration cycle.

Therefore the dimensions of the designed fixed-bed granular activated carbon system are: 1) diameter of tank is 1.5m; 2) depth of tank is 5m; 3) depth of carbon bed is 3m; 4) contact time is 35-40 minutes.

Food and Agro Industries - Orange Juice Production & Meat Processing

Upon examination of Table 1, we see that the major pollutant parameters for the meat processing industry are BOD5 and Fats Oils and Grease. In the case of the orange juice industry, the major pollutants are BOD5 and TSS. Therefore, the pretreatment system would be most efficient if the effluents were combined so that all the biological treatment could be applied together with the oil removal for the meat processing effluent taking place separately.

An API separator was used in the grease separation, the principle of operation being described previously. For the biological treatment, an extremely efficient treatment process was required. An Upflow Anaerobic Sludge Blanket (U.A.S.B.) was chosen as the method of treatment that would be used. A schematic diagram of the UASB is shown in figure 3.

![Figure 3. Upflow Anaerobic Sludge Blanket](image)

The UASB is a large rectangular tank about 4 m high with inlets at the bottom of the tank. The first 2 meters of the tank from the base of the tank is a sludge blanket containing bacteria that feed
anaerobically. At the top of the tank are phase separators that, as the name suggests, separates the phases into solids, liquids and gasses. The influent enters from the bottom of the tank and is passed through the sludge blanket where the bacteria in the sludge blanket feed on the effluent and produce methane gas. The flowrate through the sludge blanket is controlled so as to achieve a feed rate of about one meter per hour. When the effluent reaches the top of the sludge blanket, 80% of the BOD5 would be removed achieving a BOD5 level of about 294 mg/L, which is now acceptable to the combined treatment plant.

An important advantage of the UASB is that this treatment method produces methane gas that can be used to generate electricity and run the pumps on the treatment plant. For the treatment system designed, one can expect around 50kw of constant power from the Methane gas assuming the use of a 30% efficient methane gas generator.

**Paper Recycling**

For the paper recycling industry, the major pollutant parameters are COD and TSS. Therefore, from Table 1, the treatment system must have a high removal rate for suspended solids. The pretreatment system used for this industry was coagulation and flocculation and sedimentation. This is shown below in figure 4.

![Diagram of coagulation and flocculation](image)

**Figure 4. Coagulation and Flocculation**

This treatment process includes several different operations. Each of these operations is important because they each have different considerations. Firstly, the particles of the suspended solids are of such a size that they will not naturally agglomerate. Hence, chemical coagulation of these suspended...
solids was used in order to allow agglomeration of these particles to take place. The chemicals added were alum and lime so that surface water with turbidity resulting from colloidal particles can be clarified by creating colloids in cluster, or flocs that are large enough to be removed by gravity settling. The wastewater is then mixed (rapid mix) as to ensure that the chemicals are equally distributed in the water (so that it can be well treated). During or after mixing, certain chemicals reactions occur. Some of the reaction products are insoluble and will begin to precipitate as solid particles. The term coagulation is sometimes used to refer specifically to these chemical reactions, which begins the formation of floc.

The next step in the process is flocculation, which refers to gentle agitation of the treated water for a period of time (slow mix). This favors the collision of the small floc particles with each other with the other suspended particles in the water. This causes them to stick together, or agglomerate, and grow into large, readily settleable masses. Again, the word flocculation may have two slightly different meanings. Theoretically it may mean the growth of the floc particles. In practice, it more often refers to the gentle agitation of the water, which brings about this growth.

Sedimentation generally follows flocculation, but it is usually considered a separate process and not a part of chemical coagulation and refers to the removal of the floc from water by settling in basins especially designed for the purpose.

For coagulation, the recommended solution strength is 1 kg to 16.67L of water or solution strength of 6%. The lime dosage required per day is 30mg/L. Rapid Mixing requires a hydraulic retention time of 2 minutes and a 15/s velocity gradient. Slow mixing requires a hydraulic retention time of 30 minutes and a 30/s velocity gradient. For sedimentation we assume a sidewall depth of 3m and a surface-loading rate of 30m/d.

The resulting dimensions of the treatment system are: 1) for the rapid mixing tanks are length is 5m; width is 5m and diameter is 1m.

The dimensions for the slow mix tank are length is10m, width is10m and diameter is 3m and the required power input is 0.3075kW.

The dimensions for the settling tank are a diameter of 16m and a depth of tank of 3m.

**COMBINED TREATMENT PLANT APPROACH AND DESIGN**

In the design of a suitable combined treatment system for this project, two alternatives were considered. These were:

- Oxidation/Stabilization Ponds
- Extended Aeration Treatment System
Oxidation/Stabilization Ponds

Oxidation ponds are termed land intensive wastewater treatment systems, as they require the provision of large land areas. These are generally placed where land acquisition is not a constraint and it is cheap. Some advantages of these systems are: 1) Equipment costs are almost non-existent; 2) Operation and maintenance is minimal compared to the Extended Aeration Treatment system; 3) Skilled workers are not required 4) They function very well in tropical climates 6) Costs of construction materials are low ; 7) Low mechanical content(LMC) ;8) They effectively treat a wide range of wastes; 9) they are able to withstand organic and hydraulic shock loads and10) The degree of treatment can be readily altered.

Some limitations of the pond systems are: 1) Not suitable for built up areas due to large land requirements; 2) The nuisance of flies and offensive odours. For this project the type of pond system utilized is the facultative pond system as shown in figure 5.

![Facultative Pond](fig5.png)

Facultative ponds are usually between 0.6 and 2.44 meters deep. They consist of three sections: 1) an anaerobic lower zone; 2) a facultative middle zone and 3) an aerobic upper zone maintained by photosynthesis and surface re-aeration.

The specific advantages of this system are: 1). They have long retention times, which handles large fluctuations in wastewater flow and strength; 2) they have a low capital cost and maintenance cost, compared with the extended aeration.
The design criteria for the pond include 1) for minimum temperature of 20°C, BOD reaction rate constant, K_{20°C} = 0.25d^{-1}, The maximum pond BOD5 (S_e) max, consistent with aerobic conditions is given by:

\[ (S_e)_{max} = \frac{700}{0.6d + 8} \]

Where d represents the pond depth in feet; the number of ponds required was determined by the use of enough ponds in a series arrangement for 90% BOD removal. Two ponds were used in series, with a depth of 2m and a surface area of 6.0 hectares with each pond having a retention time of 22.7 days.

In the design of the facultative pond system, the ponds were arranged in series and the flow of influent into the treatment system was split between two series of ponds. This was done in order that necessary repairs may be carried out without a complete shutdown of the operation. It is also suggested that the ponds be desludged every 10 years.

This treatment scheme is shown in figure 6.

![Figure 6. Schematic Flow Pattern Showing Series Pond Arrangement](image)

**Extended Aeration Treatment System**

Extended Aeration systems are one of the most widely used treatment systems. This popularity is due to its small size and construction cost. In extended aeration, the effluent is screened and then pumped into an extended aeration tank. Here, there are mechanical aerators present that increase the oxygen of the system. The biomass in the aeration tank is auto-oxidized and hence there is no need for sludge digestion that results in a reduction in land utilization and initial construction cost. The sludge is sent then sent to the sludge drying beds.
The advantages of the system are 1) The capital cost is relatively low; 2) Land requirement is much less than that of a pond system; 3) The availability of cheap energy in Trinidad makes this available option. In contrast to the pond design, it is a system with a High Mechanical Content (HMC).

For the extended aeration system, the governing equation is:

\[ V = \frac{Q(S_0 - S_e)}{K_d \cdot X} \]

Where: 
- \( V \) = Volume of reactor, m³
- \( Q \) = Flow rate, m³/d
- \( S_0 \) = Influent BOD5, mg/L
- \( S_e \) = Effluent, mg/L
- \( X \) = Biomass concentration, mg/L
- \( K_d \) = Decay constant, t⁻¹

The resulting dimensions of the extended aeration tank are:

Using 2 tanks
- Length = 20m
- Width = 20m
- Depth of tank = 5m
Resulting Scheme

Figure 8 below show the combined scheme when the stabilization pond is used for the common effluent plant

**SERVICES**
- Q = 1200 m³/d
- Waste Oil = 756 mg/L
- Metal Filings = 50 mg/L

**ELECTROPLATING**
- Q = 120 m³/d
- Nickel = 3.3 mg/L
- Sulphate = 4.4 mg/L
- Chromium = 4.3 mg/L

**PAPER RECYCLING**
- Q = 1200 m³/d
- BOD = 300 mg/L
- TSS = 350 mg/L
- COD = 750 mg/L
- COC = 30 mg/L

**PLASTIC RECYCLING**
- Q = 2125 m³/d
- BOD = 800 mg/L
- TSS = 120 mg/L

**ETHYLENE PRODUCTION**
- Q = 360 m³/d
- BOD = 100 mg/L
- COD = 3200 mg/L
- TSS = 300 mg/L
- Fats oil and Grease = 400 mg/L

**ORANGE JUICE PRODUCTION**
- Q = 40 m³/d
- TSS = 1411 mg/L

**MEAT PROCESSING**
- Q = 1420 m³/d
- BOD = 2000 mg/L
- TSS = 500 mg/L
- N = 200 mg/L
- P = 20 mg/L
- Oil and Grease = 617 mg/L

**DOMESTIC WASTE**
- Q = 42 m³/d
- BOD = 195 mg/L
- COD = 143 mg/L

**API OIL AND GREASE SEPARATOR**

**PRETREATMENT**

**ACTIVATED CARBON**

**CHARACTERISTICS**
- Ethylene
  - Q = 960 m³/d
  - BOD = 100 mg/L
  - COD = 3200 mg/L

**OIL AND GREASE SEPARATOR**

**COAGULATION & FLOCCULATION**

**GLASS RECYCLING**
- Q = 480 m³/d
- BOD = 14 mg/L
- TSS = 32 mg/L
- HEM = 37 mg/L
- Phosphorous = 35 mg/L
- COD = 4 mg/L
- Iron = 115 mg/L

**Combined Treatment**

**STABILIZATION POND**

**TREATMENT - PRECIPITATION FOLLOWED BY DISPOSAL**

**Final Effluent Characteristics**
- Q = 10000 m³/d
- BOD = 10 mg/L
- TSS = 130 mg/L

**To costal disposal**

Figure 8. Schematic of Entire Treatment System
CONCLUSION

Through this project, it has been shown that it is feasible to have a common effluent treatment plant for an industrial estate.

It has also been shown that wastewater from particular industries can be treated using a combination of pretreatment followed by treatment in a common effluent plant. These pretreatment schemes are: 1) for the petro-chemical industry, oil separation in an AIP separator followed by COD reduction using Fixed-bed Granular Activated Carbon; 2) for the meat processing industry, grease separation using an AIP separator followed by biological treatment using a UASB; 3) for the paper recycling of paper, coagulation, flocculation and sedimentation were used as the pretreatment methods.

Some of the wastewater generated on the estate required less or no treatment than those listed above. For example, wastewater from the recycling of plastics and domestic wastewater required no pretreatment and these were sent directly to the common effluent plant while waste from the recycling of glass required no pretreatment.

For the common treatment plant, it was shown that there were two alternatives. One alternative was an oxidation pond that is a land intensive treatment system with a low mechanical content. The other is an extended aeration system that is an energy intensive system with a high mechanical content.