USE OF MODELLING TO DESIGN A HYBRID TREATMENT PROCESS FOR BIOLOGICAL NUTRIENT REMOVAL

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1. Introduction

The Great Billing Sewage Treatment Works (STW) serves the City of Northampton and surrounding villages. The plant has a design loading of 300000 population equivalent (PE) and a design average dry weather flow (ADWF) of 60000 m^3/d. After screening, grit removal and primary sedimentation, the settled sewage flows to secondary treatment. This flow is divided into two parallel trains:

1. Seven activated sludge aeration basins (four new and three old), with two secondary clarifiers per old aeration basin and three clarifiers per new aeration basin.
2. Six biological filter beds, followed by eight humus tanks.

70% of the settled sewage is treated in the activated sludge section, and the remaining 30% is treated on the biological filter beds.

Effluent from the plant discharges into the River Nene, which has been designated a "sensitive area" for phosphorus loading by the National Rivers Authority. Phosphorus removal is therefore required to achieve an annual average of 1 mg/l as P to protect the receiving water from the effects of eutrophication. Current practice at the plant is to remove phosphorus using iron salt addition. Year-round nitrification is also required at the plant to eliminate ammonia toxicity in the effluent.

2. Objectives

The objective of the study was to develop a hybrid BNR process for trial implementation in one aeration lane, that would remove phosphorus from both the activated sludge and the filter bed flow. An important consideration was therefore the amount of filter flow that would be recycled to the activated sludge plant. This hybrid process would:

- remove P biologically from the settled sewage and a portion of the filtered effluent
- reduce oxygen requirements (i.e. save energy) by recovering nitrate-oxygen in the activated sludge basins and from the filter effluent.

Consequently, the optimal combination of settled sewage and filter bed effluent treated in the activated sludge tank needs to be determined.

The following approach was used:

- *outline process design*
- *wastewater characterisation*
- *system modelling*

3. Outline Process Design

The total volume of the activated sludge tank is approximately 4800m^3. A process design was developed using a Modified 3-Stage Bardenpho Process configuration, consisting of four reaction zones in series: pre-anoxic, anaerobic, anoxic and aerobic.

The purpose of the separate zones are:

Pre-anoxic zone:	*Reduce nitrate in return activated sludge (RAS)*
Anaerobic zone:	*Soluble COD uptake and phosphorus*
Anoxic zone:	*Mixed liquor and filtered effluent denitrification*
Aerobic zones:	*Nitrification, phosphorous and carbon uptake*

A potion of the nitrified humus tank effluent was diverted to either the anoxic or last aerobic zone of the process.

A schematic of the proposed hybrid process is shown in Figure 1.

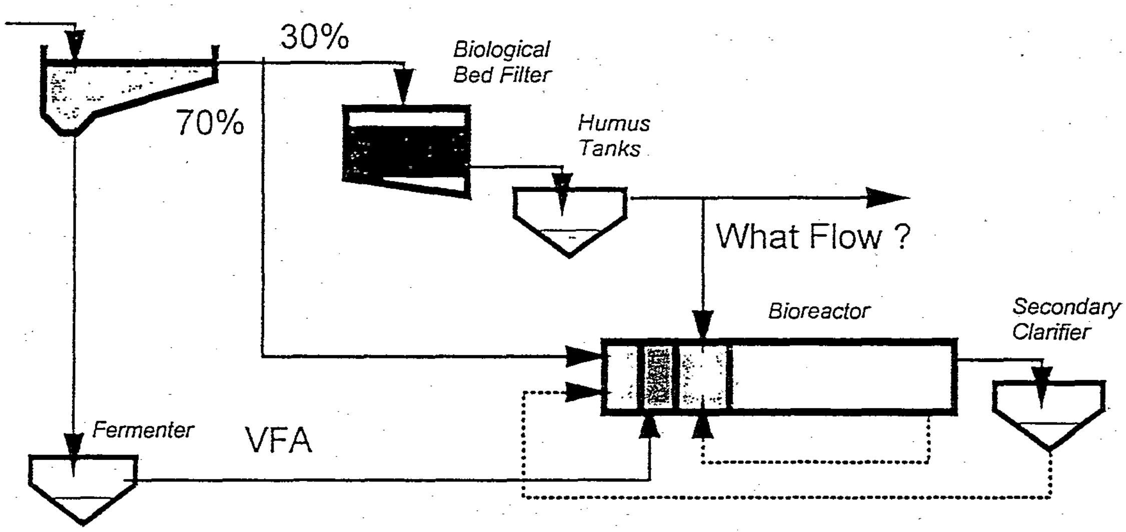

Figure 1: Process Layout

4. Wastewater Characterisation

The settled sewage at the plant was characterised to develop typical diurnal flow patterns for conventional monitoring parameters such as COD, NH_3 and Total Phosphorus to be used as input for the process modelling. Additional settled sewage characteristics such as the readily biodegradable and inert COD fractions were also determined. The humus tank effluent quality was assumed on the basis of operating experience at the plant.

The total settled sewage dry weather flow entering one aeration lane is estimated to be 10000 m^3/day. Table 1 lists the average wastewater characteristics for the settled sewage, filter effluent and the fermenter supernatant.

Table 1: Settled Sewage, Trickling Filter Effluent and Fermenter Characteristics

	Design Settled Sewage Characteristics	Filter Effluent	Fermenter Supernatant
Flow (m^3/day)	10000	See Table 2	500 (5% of flow)
COD (mg/l)	475	100	500
NH_3-N (mg/l)	28	4	-
TKN-N (mg/l)	35	8	50
NO_3-N	0	18	0
Total Phosphorus (mg/l)	9.5	5	10
ISS (mg/l)	5	5	5

5. Process Modelling

Process modelling was carried out using the BioWin process model. BioWin uses a modified version of the IAWPRC Activated Sludge Model No. 1 and was developed by Envirosim Associates Ltd (Canada) in association with Reid Crowther. It is capable of simulating all suspended growth processes under steady-state and dynamic loading conditions and incorporates carbonaceous removal, nitrification, denitrification and biological excess phosphorus removal (BEPR). The model was used to consider both steady state and dynamic conditions.

5.1 Steady State Modelling

5.1.1 Configuration and Loading

A series of steady-state model runs were carried out under summer and winter operating conditions assuming mixed liquor temperatures of 17°C and 12°C respectively. Various ratios of activated sludge process and biological filter flows were used to determine the limits for the plant operation. These are shown in Table 2.

Table 2: Steady State Simulation Cases

Flow (m^3/day)	Settled Sewage to Pre-Anoxic Zone	Filter Effluent to Anoxic Zone	Total Flow Treated by BNR Process
Case 1	10000	0	10000
Case 2	9000	3000	12000
Case 3	8000	6000	14000
Case 4	7000	9000	16000

Settled sewage and RAS enter the bioreactor at the inlet to the pre-anoxic zone. The fermenter supernatant, when the primary sludge fermenter was assumed to be in service, was discharged to the anaerobic zone at a constant rate of 500 m^3/day. The biological filter effluent (BFE), when directed to the activated sludge bioreactor, was normally discharged to the anoxic zone of the process. An alternative operating mode with the discharge of the BFE to the final aerobic cell was also investigated. The RAS flow rate was maintained at a constant rate of 10000 m^3/d, or ADWF. The nitrified mixed liquor recycle rate was 20000 m^3/d, or 2*ADWF.

5.1.2 Effect of Loading Pattern on Biological Phosphorous Removal

The increased loading from the biological filter effluent resulted in a significant increase in the effluent phosphorus concentration. Under summer and winter operating conditions, the effluent P objective of below 1.0 mg/l was achieved in Loading Cases 1 and 2 with primary sludge fermentation. Without primary sludge fermentation, only Loading Case 1 (i.e. no biological filter effluent) met the effluent P objective during the summer months only. The principal reason for the deterioration in effluent quality with regard to the phosphorus concentration is that the increased phosphorus loading exceeded the P removal capacity of the BNR process, particularly without the use of primary sludge fermentation.

5.1.3 Effect of Sludge Age on Nitrification and Biological Phosphorous Removal

The sludge age of the activated sludge process was varied between 10 days and 22 days to determine its effect on nitrification and biological phosphorus removal.

The principal effect of sludge age is on the ability of the process to nitrify. During the winter months nitrification fails at sludge ages below 15 days. The failure of nitrification is more dramatic with the increased hydraulic loading to the plant, (e.g. Cases 3 and 4). During the summer months, nitrification does not fail at sludge ages greater than 10 days.

Under both summer and winter conditions, the phosphorus removal improved with the shorter sludge ages. In most cases, the effluent phosphorus concentration increased by between 0.1 and 0.15 mg/l for each day that the sludge age was increased. This is primarily the result of the decreased mass of phosphorus removed from the process in the surplus activated sludge at the longer sludge ages.

5.1.4 Effect of Biological Filter Effluent Discharge Point on Process Performance

Summer and winter runs were carried out with the effluent from the biological filters being discharged to the anoxic zone of the bioreactor. The discharge of the biological filter effluent to the final aerobic reactor (Aerobic 4) was also simulated. This technique is known as "step feeding" and allows a higher bioreactor MLSS inventory to be maintained in the activated sludge process without increasing the flux loading to the secondary clarifiers.

In all winter loading cases modelled, the discharge of the biological filter effluent to the final aerobic cell reduced the effluent phosphorus concentration by approximately 0.5 mg/l. The reason for this improvement was not established, but it is thought that the model used assumes that phosphorus uptake is more efficient under aerobic conditions than under anoxic conditions. Compared with the anoxic discharge point cases, the effluent TKN concentration did not appreciably change at the longer sludge ages.

5.2 *Dynamic Modelling*

The proposed hybrid BNR configuration was modelled under dynamic loading conditions with summer and winter operating conditions.

5.2.1 Winter and Summer Conditions with Biological Filter Effluent to Anoxic Zone

The results of the winter dynamic simulations confirm the finding of the steady-state simulations with respect to biological phosphorus removal, i.e. that the effluent consent value of 1 mg/l of phosphorous is only achievable in Loading Case 1, and possibly 2 if primary sludge fermentation is incorporated into the process design. The effluent consent with respect to phosphorus cannot be achieved in any of the loading cases without fermentation. The plant achieved complete nitrification in all loading with relatively small ammonia peaks of up to 3 mg/l during the daily high-flow period.

The results of the summer dynamic simulations also confirm that the effluent consent value of 1 mg/l phosphorous is only achievable in Loading Cases 1&2 if primary sludge fermentation is incorporated into the process design. The plant achieved complete nitrification with relatively small ammonia peaks of up to 2 mg/l during the daily high-flow period.

5.2.2 Winter Conditions with Biological Filter Effluent to Final Aerobic Cell

The only cases that met the effluent P limitation were Cases 1&2 with primary sludge fermentation. The plant achieved complete nitrification under all loadings with relatively small ammonia peaks of up to 3 mg/l during the daily high-flow period. The alternative discharge point also affected the solids loading on the secondary clarifiers. For example, the last aerobic cell's MLSS concentration under Case 2 loading was reduced by 10% by introducing the filter effluent into the last aerobic cell.

6. Conclusions

- The use of a Modified 3-Stage Bardenpho Process configuration, consisting of pre-anoxic, anaerobic, anoxic and aerobic zones is recommended as the basis for retrofitting an aeration lane to carry out a demonstration-scale study.
- Inclusion of a primary sludge fermenter supernatant stream into the process gave a significant improvement in phosphorus removal in all cases.
- The sludge age should be maintained at 10 to 12 days during the summer months and 16 to 18 days during the winter months.
- It is estimated that the module can treat between 8000 and 10000 m^3/d of settled sewage. The discharging of biological filter effluent to the bioreactor will have to be offset by a reduction in the settled sewage flow to the plant.
- The solids loading rate to the secondary clarifiers can be reduced by discharging the biological filter effluent to the final aerobic zone without compromising the nutrient removal characteristics of the process.

Active Effluent Control (Case Study)
S Mathews ,YWS & D Parker Hull CC

Question Peter Whalley NRA
Do you need to look at the effect on the river
Answer
Yes do need to develop further into UPM, but I do not think that there would be any adverse effect given the better treatment achieved.

Question John Turner Leeds City Council
Holistic management in urban environment is mentioned, need to bear in mind the effects on CSO's.
Answer
Yes but this was a dry weather flow study. I agree you cannot control what the trader does just because it is raining . It wall all be much more complex in the urban situation.