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INFLUENT FLOW CONTROL TO INCREASE THE POLLUTION LOAD TREATED DURING RAINY PERIODS

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ABSTRACT

The European Directive of May 1991 concerning urban wastewater treatment points out that sewerage systems must be designed to limit the pollution of receiving watercourses by stormwater discharges. As for the system management, the French Decree of 22 December 1995 states that flows or pollution loads exceeding the reference capacity of the treatment plant may be temporarily admitted. This is especially interesting in the case of separate wastewater sewerage, as inappropriate connections of runoff water and rainfall induced infiltration cause hydraulic overloads in such networks. An automated influent flow control has been implemented on a 8000 population equivalent plant to admit a maximum of twice the dry weather peak flow: the clarifier is then dynamically managed so that neither sludge loss nor degradation through anoxic conditions may occur. A yearly simulation of such a strategy on a smaller treatment plant shows a very significant reduction (90%) of the volume discharged during rainy periods. It can therefore be concluded that a plant with additional hydraulic capacity and good sludge quality can play a significant role in limiting the stormwater discharges from separate sewerage systems. However this operational benefit depends on the inflow composition in the sewerage system (wastewaters, rain and infiltration waters).

KEYWORDS

Activated sludge; control; hydraulic overload; modelling; clarifier; stormwater treatment; wastewater treatment.

INTRODUCTION

The European Directive of May 1991 concerning urban wastewater treatment points out that sewerage systems must be designed to limit the pollution of receiving watercourses by stormwater discharges. As to the system management, the French Decree of 22 December 1995 states that flows or pollution loads exceeding the reference capacity of the treatment plant may be temporarily admitted, unless there is a risk of damage.

Such a possibility has been previously investigated (Joannis *et al.*, 1993), which showed that flowrates equal to twice the peak flow may be treated for 1 to 1.5 hours without appreciable change in treatment efficiency.

Additional load admission on the treatment plant is especially interesting in the case of separate wastewater sewerage, as inappropriate connections of runoff water and rainfall induced infiltration cause hydraulic overloads in such networks (stormwater loads in combined sewers require the treatment of much larger volumes).

MATERIAL AND METHODS

In order to assess the feasibility and the benefit of such an operation to reduce the receiving water pollution by stormwater discharges, a 8000 population equivalent treatment plant has been instrumented since January 1996:

- to draw up the treatment efficiency in standard and in experimental operation (check for a possible change);
- to implement an automated influent flow control to increase the pollution load treated during rainy periods.

Description of the instrumented plant

The instrumented plant is of the extended aeration activated sludge type. The sewerage system is a separate one, the wastewater sewerage being influenced by wet weather infiltrations (wet weather hydraulic load more than twice the dry weather one on a monthly basis), as is often the case. The influent is mainly from domestic origin, with no special industrial influence. Nitrogen reduction is obtained by biological nitrification-denitrification, the aeration being monitored by a redox potential sensor.

The work characteristics of the plant are common, except for a 600 m^3 storm basin, fed with the pre-treated influent, the stored volume of which can be pumped to the aeration basin when the storm is over. The other works are the following:

- a pumping station including three 100 $m^3\ h^{-1}$ pumps, two of which work in standard operation;
- a pre-treatment (screening, grit, oil and grease separator);
- a 1500 m^3 aeration basin with two turbines;
- a 710 m^3 secondary clarifier of the cylindro-conical type, with a 16 m diameter and a 4.1 m depth. The feeding system consists of a well at the center (0.9 m deep), and the effluent withdrawal is at the periphery. A rotating scraper leads the settled sludges to the recycling and withdrawal unit;
- a sludge treatment unit.

In standard operation, a maximum 100 $m^3\ h^{-1}$ flow is admitted to the plant. When a second pump starts because of rainy events, a valve opens to lead half the flow to the storm basin, keeping the admitted flow into the plant to 100 $m^3\ h^{-1}$.

Methodology for the pollution load measurement and the plant operation supervision

The standard measurements (influent and effluent flows and analysis, sludge characterization, aeration control by redox potential) have been completed by:

- flow proportionnal sampling at the inlet and outlet of the plant, to characterize the treatment efficiency during dry and wet weather periods in standard and experimental operations (possible influence on the carbonaceous and nitrogenous pollution elimination);
- discrete (volatile fatty acid) and continuous (redox-pH) return-sludge analysis to test for an evolution resulting from the temporary storage in the secondary clarifier during the experimental operation;
- continuous measurement of water and sludge flows in the plant, and of operation parameters as well:

* water flows and turbidity at the inlet and outlet of the plant; ultra-violet (UV) absorbance at the outlet;

* sludge turbidity in the aeration basin and on the recycling system;
* operation periods of the aerator, recycling and withdrawal pumps;
* depth of the sludge blanket.

Mean data over one hour (during dry weather) and over five minute periods (during rainy periods) are recorded locally and tele-transmitted to the laboratory. Good relations can be established between optical and pollution parameters especially for Chemical Oxygen Demand and Suspended Matters (Grange *et al.*, 1987; Marchandise *et al.*, 1990; Ruban *et al.*, 1993).

Settling tank model

A model has been developed:

- to simulate other operation strategies of additional load admission on the treatment plant;
- to assess the long-range benefit of such strategies on rainy period discharges, by simulating meteorological conditions more representative on a yearly basis than those occuring during the experiment.

This model is of the one-dimensional dynamic type, based on the solid flux theory (Kynch, 1952). It simulates the suspended solid concentration vertical profiles in the clarifier. The settling velocity expression as a function of the sludge concentration is the usual exponential formula:

$$v_s = k_1 e^{-k_2 X} \quad (1)$$

with:

k_i = parameters characteristic of the biomass
X = activated sludge concentration
v_s = settling velocity

Several preliminary experiments have been made for a better understanding of how the clarifier works:

- depth measurements of the sludge blanket top have shown that it can be considered as horizontal over the whole surface. Besides, the feeding zone under the well down to the sludge blanket has an approximately cylindrical shape (see Figure 1);
- suspended solid concentration profiles under the feeding well have shown a strong reduction, compared to the feeding concentration from the aeration basin, which can be interpreted as an effect of diffusion and/or dilution due to rotating currents.

For the numerical calculation of the suspended solid concentrations, the clarifier is divided into horizontal layers, which are all completely mixed, as in Laikari (1989). Those 50 layers correspond to 3 zones:

- the upper zone, where the upflow velocity corresponds to the inlet flow Qi;
- the middle zone where the upflow velocity corresponds to Qi plus an additive coefficient k taking into account the rotating current effect mentionned above;
- the lower zone with a downflow velocity corresponding to the recycling flow Qr.

The mass conservation between two layers is made according to Takacs *et al.* (1991), i.e. the settling flux out of layer i is determined as the minimum of the settling flux calculated for that layer and the settling flux for the layer i+1, assuming the layers are numbered from top to bottom. This leads to the condition that the limiting flux at the bottom according to Kynch theory is not exceeded.

$$\delta z.\frac{dX}{dt} = v_h.X_{i-1} - v_h.X_i + \min[v_{s,i-1}.X_{i-1}, v_{s,i}.X_i] - \min[v_{s,i}.X_i, v_{s,i+1}.X_{i+1}] \quad (2)$$

with:

δz	=	layer thickness
$v_{s,i}$	=	settling velocity of layer i with concentration X_i
$v_h = Q_r/A$	=	recycling velocity

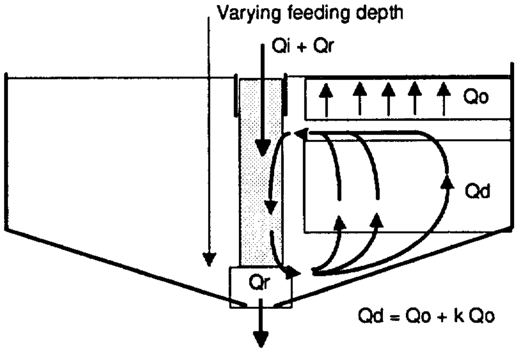

Figure 1. Calculation zones in the clarifier according to the flow conditions.

The feeding point is located at the depth where the layer concentration is equal to the feeding concentration.

EXPERIMENTAL RESULTS AND DISCUSSION

Standard operation characterization of the plant

As shown by the physico-chemical analysis and quality sensor records, the treated water quality complies well with the specifications for the carbonaceous and the nitrogenous pollutions, mainly thanks to the redox potential controlled aeration. The activated sludge is of good quality, with a volume index about 150 ml g^{-1}.

The hydraulic operation analysis on a rather wet period (September 1993 - August 1994: 895 mm total rainfall compared to the 791 mm/year for the last 50 years) confirms the rainfall influence on the flow for a separate wastewater sewerage, and thus the potential benefit of additional load treatment during rainy periods.

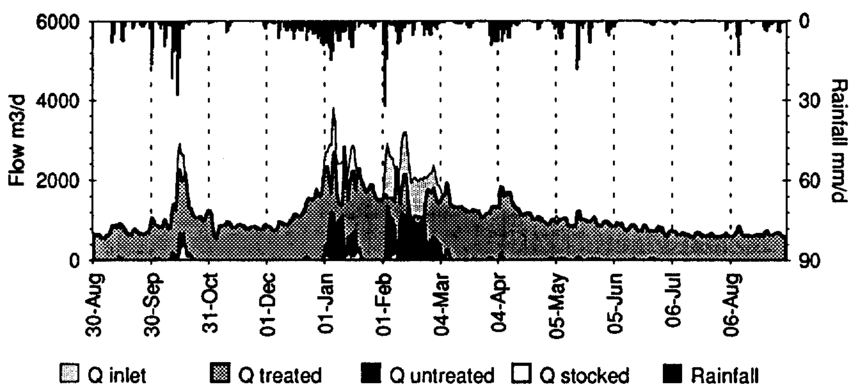

Figure 2. Influent flow versus rainfall - September 1993/August 1994.

Implementation of an automated influent flow control during rainy periods

The tested operation strategy consists in admitting twice the dry weather peak flow (200 $m^3 h^{-1}$) in the plant until:

- the sludge blanket reaches a security level in the secondary clarifier;
- or a maximum time delay for sludge storage in this unit is reached, to prevent any change by anoxic conditions for instance.

The hydraulic capacity to admit twice the dry weather peak flow has been previously verified.

More precisely (see Figure 3) the additional admission starts when the inflow reaches a given value larger than the dry weather peak flow (120 $m^3 h^{-1}$) and when the sludge blanket height is about the standard operation value (< 1 m). A larger sludge blanket height denotes either an incomplete previous automation cycle, or a bad sludge quality, in which latter case it would not be advisable starting the strategy. The storm basin (S.B.) valve opening corresponds to the standard operation during rainy events. When the sludge blanket reaches the security level at top of the clarifier (in fact 0.50 m below the weir) or the sludge storage time exceeds the maximum delay, the admission is stopped. Then the end of the automation cycle happens when the sludge blanket height is again lower than 1 m: if its height decrease is not fast enough, the inflow is limited to 50 $m^3 h^{-1}$, and then possibly to 0 $m^3 h^{-1}$ if the decrease is particularly slow.

Security measures are provided for any fault in the automated operation, in which case the operation returns to its standard status (default state of the instruments or plant equipment, water quality decrease at the outlet).

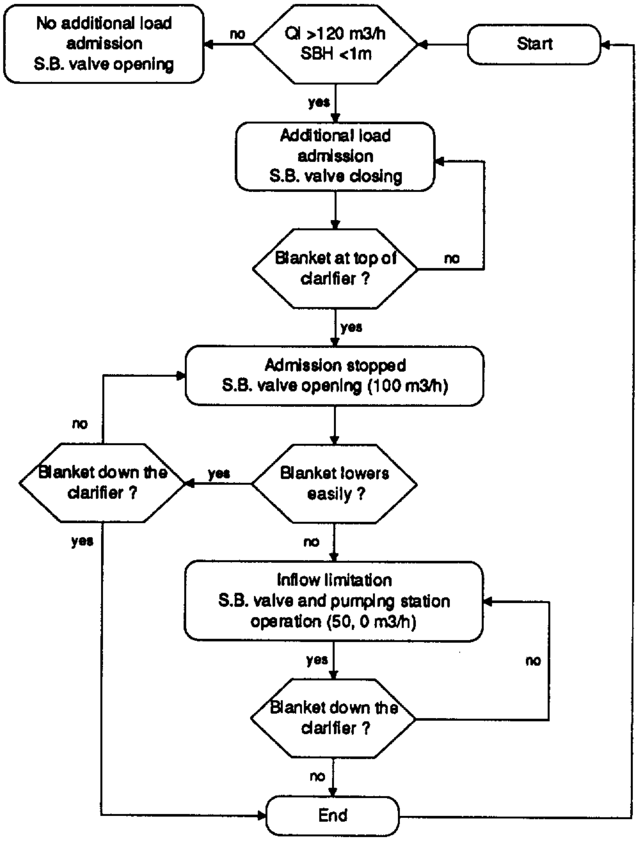

Figure 3. Flow chart of automated influent flow control.

Figure 4 shows an example of operation strategy test over 6 hours: the flow increase was obtained by pumping 200 m^3 h^{-1} from the storm basin previously filled with wastewater. The sludge blanket rises as soon as the inflow increases, then returns to its initial level 10 hours after the overload end. The second rising is due to a natural rainy event. The outlet Chemical Oxygen Demand (C.O.D) increases to almost 100 mg l^{-1}, then returns to its initial value after the rainy event. The C.O.D. increase may result from a shorter retention time of the influent whitin the plant. In the case of a real load caused by a rainy event, C.O.D. increase could also possibly result from the resuspended deposits of the sewage, as they are less readily biodegradable than 'fresh' wastewaters. The suspended solid (S.S.) values remain low.

It must be noted that for the five operation strategy tests performed, neither the volatile fatty acid nor the continuous redox analysis showed any return-sludge degradation through anoxic conditions after its temporary storage in the clarifier.

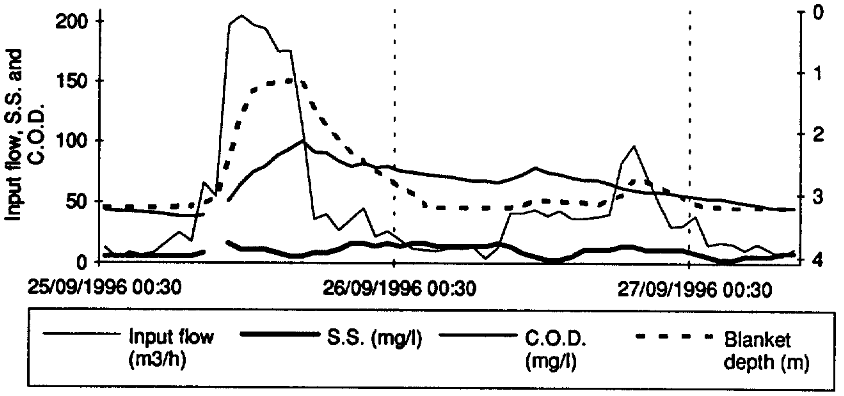

Figure 4. Example of operation strategy test - rainy event on 26 February 1996.

Settling tank model - simulation results

Model calibration. The settling model described above was fitted to the data of an overload experiment, for which concentration profiles were sampled. Figure 5 shows that the simulation of the upwards and downwards movements of the interface between the sludge blanket and the supernatant liquor (BDsim) is in close agreement with the measured values (BDmeas). The over-estimate of the blanket height at lower levels is merely due to the fact that the sensor does not measure deeper than 3.2 m.

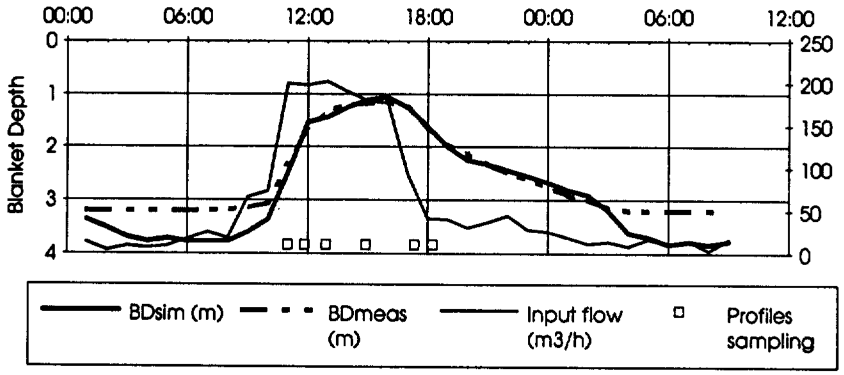

Figure 5. Simulated and measured blanket depth (BD) in the clarifier.

The simulated suspended solid concentrations fit well to the (near) hourly profiles (see Figure 6).

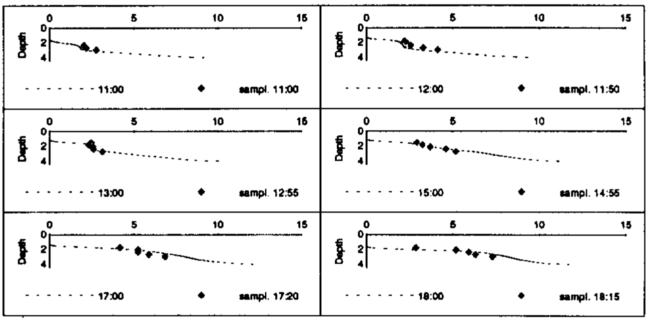

Figure 6. Simulated and measured suspended solids concentrations versus depth in the clarifier.

Long term assessment of the benefit of additional load admission. The lack of rainy events since the model calibration did not allow its validation on adequate data sets. We shall then consider the results obtained under analogous conditions on a smaller treatment plant (1000 population equivalents). A clarifier model was developed like the one described above (one-dimensional dynamic type, based on the solid flux theory), but in that case the clarifier was conical (6.7 m diameter, 4.55 m depth). As long period simulations require large calculation time, a simplified model was developed and validated using the complete one. This reservoir type model reproduces the upwards and downwards movements of the sludge blanket with good precision.

The simulation data set consisted of hourly flows over one year. The inflow included on average 45% wastewaters, 44% infiltration (long term infiltration, depending on the ground water level) and 11% rainwater (inappropriate connections of runoff water and rainfall induced infiltration): those values are representative of what happens on many sites.

The tested strategy was the same as described above: admission of twice the dry weather peak flow (40 m^3 h^{-1}) in the plant until:

- either the sludge blanket reaches a security level in the secondary clarifier;
- or a maximum time delay for sludge storage in this unit is reached, to prevent any change through anoxic conditions. In fact the additional load stops when Dmax is reached, but the whole sludge storage time depends on the time the sludge blanket needs to return to the standard operation level. During this step, the inflow is limited to the dry weather peak flow (20 m^3 h^{-1}).

Table 1 shows the results of the simulations: compared to the volume discharged in the case of standard operation (1237 m^3 for inflow limited to dry weather peak flow), the benefit is very significant: respectively 89 and 90% reduction for a 135 and 126 m^3 discharge. This very good result may be explained mainly by the two following reasons:

- given the hydraulic configuration of the aeration basin, no biomass transfer to the clarifier occurs for the experienced flows when the turbine is already at rest. When it works, the transfer concentration is logically enough equal to the aeration basin concentration. When the turbine stops, the transfer concentration decreases during about 20 minutes then drops down to about 20% its initial value. Then this concentration depends on the hydraulic configuration of the considered plant and on the sludge settling quality as well.

- the aeration period frequency is 22%, with several hours between two consecutive periods, during which rainy events may occur, resulting in no biomass transfer as explained above. This would not be the case for a diffused bubble aeration which works continuously.

The small difference between the sludge storage times for Dmax equal to 0.5 and 1.0 h confirms that for twice the dry weather peak flow, half an hour is sufficient to admit the majority of the additional load. Then increasing Dmax only plays a minor role.

Table 1. Simulation results of additional load admission

Dmax (hour)	0.5	1
Average sludge storage time (mn)	21	23
Maximum sludge storage time (mn)	74	79
Volume discharged (m^3)	135	126

Concerning the effluent quality, the additional influent load goes through the plant instead of being discharged to the receiving waters. It is pre-treated and its particulate pollution is kept, although the dissolved pollution is not treated as well as in dry weather periods because of the limited retention time.

It must be stressed that this very good result depends strongly on the inflow composition, namely the respective parts of wastewaters, rain and infiltration waters. An 'unfavorable' repartition between these various origins may notably reduce the benefit of such hydraulic strategies.

CONCLUSIONS

The inflow characterization of a 8000 population equivalent plant has confirmed the potential benefit of an additional load admission to reduce on a yearly basis the pollution discharges from a separate sewerage system during rainy periods.

Admitting twice the dry weather peak flow in that case is hydraulically feasible: the sludge volume stored in the clarifier is then dynamically managed, so that neither sludge loss nor degradation through anoxic conditions may occur. Five tests of such a strategy have been performed which have confirmed its viability.

A long term simulation - one year - of additional load admission under analogous conditions on a smaller treatment plant (1000 population equivalents) shows a very significant reduction (90%) of the volume discharged during rainy periods, compared to standard operation.

It can then be concluded that a plant with additional hydraulic capacity (with regard to the dry weather peak flow) and good sludge quality can play a significant role limiting the stormwater discharges from separate sewerage systems. In case of 'unfavourable' inflow composition (respective part of wastewaters, rain and infiltration waters), other measures such as pipe restoration, storm basin, etc ..., can be taken.

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