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Sewage Treatment Plant Upgrade Applying Wastewater Process Simulation

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ABSTRACT: Cost-effective operation of wastewater treatment plant is a basic need in engineering, but time to time it requires optimisations and re-visiting process parameters since the operational environment constantly changes. Alternation of load, extraneous wastewater sources from industry may lead to instabilities in operation, which could be managed only with full understanding of the actual environment. Process simulation is a helpful tool to predict the effect of future operational mode or reactor setup saving energy and cost. In this study the operation performance of a 2 MLD wastewater treatment plant in Hungary was analysed with the tool of process simulations. First the model was calibrated applying the actual operation and reactor setup, then new alternatives were tested and the model results were compared. As a result of the calculations, in addition to the effluent quality improvement the sludge production could be improved by approximately 20% and the aeration need decreased by 30%.

KEYWORDS: Activated sludge, Operation, Process simulation, Reactor model, Wastewater treatment

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I INTRODUCTION

The goal of wastewater treatment is to discharge treated water that is not harmful for the receiving water body and meet the effluent quality requirement. Most of the cases the processes are focused on reducing the organic matter and facilitate nutrient removal (N and P).

Activated sludge technologies are widely used approaches in sewage treatment. The biomass is in suspended form, homogenised in the reactor. The biomass forms flocs, in which the microorganisms responsible for biodegradation are present [1], [2]. The properties of flocs (e.g. shape, size, stability, diffusion rate) are determined by the fluid flow and also the type of the microorganisms [3]. High shearing makes them small, low mixing energy in the reactor allows to form bigger size of flocs [4]. Aerobic environment is required in organic matter degradation and in the first step of N-removal, in nitrification. Anoxic condition is required for denitrification, where nitrate-nitrogen is converted to gaseous nitrogen. Anaerobic condition is necessary if enhanced biological phosphorous removal (EBPR) is present. In this process the excess inorganic phosphate is removed by so-called luxury phosphate uptake. The process based on the enrichment of polyphosphate accumulating organisms (PAOs), which store phosphate as intra cellular poly-phosphate [5], [6]. The process efficiency is determined by the C/P ratio, which regulate the type of microorganisms presented in the activated sludge culture [7].

The various processes require different conditions; distinct availability of substrate, dissolved oxygen concentration and retention time, thus specific reactor arrangements shall be applied in every cases. For simultaneous organic matter and nitrogen removal the MLE (Modified Ludzack-Ettinger) reactor setup is widely used, where the anoxic zone is followed by an aerobic zone. In anoxic zone the denitrification takes place, which is executed by heterotrophic microorganisms, which require carbon source, but their operation is limited by the presence of dissolved oxygen [8]. Nitrification produces nitrate in aerobic zone, which needs to be directed back to anoxic zone with the help of a so-called internal recirculation (IR). This flow can be from 2 to 5 times the influent flow. The two zones (anoxic and aerobic) are separated from each other, e.g. applying a baffle wall, since the oxygen in aerobic zone might mix back to the anoxic zone adversely affecting the denitrification performance. The denitrification could happen after the aerobic zone (post-denitrification), but this often need external carbon source dosage due to the lack of carbon in that part of the reactor. As a third option, simultaneous denitrification might happen in aerobic zone in the deeper layer of flocs, where the dissolved oxygen cannot reach the inner layer [9]. This requires specific hydrodynamic conditions and the control of the process is unstable. Some part of total nitrogen can be eliminated by this approach, but meeting the strict effluent limit is not achievable.

EBPR requires alternating anaerobic and aerobic conditions, thus A/O (anaerobic, oxic) or A2/O (anaerobic, anoxic, oxic) setups are used. For combined N and P removal there are many other reactor arrangements, from which the UCT (University of Cape Town) is well known since high biological nutrient removal is reported [10]. Combined processes use a sequence of anaerobic, anoxic an aerobic zones connected with internal recycle streams.

Process sizing of a wastewater treatment plant is based on the retention time of biomass (SRT: Sludge Retention Time). Each process requires a minimum value of SRT, which is controlled by the amount of wasted biomass (WAS: Wasted Activated Sludge). In order to maintain the effective concentration of biomass in the biological basin sludge recirculation from the clarifier is applied, this is the recirculated activated sludge stream (RAS) [11].

Optimisation of a sewage treatment plant operation is based on the reduction of sludge production, the aeration requirement, recirculation and chemical dosage. The main operational cost is due to the aeration, but the cost of sludge management is also not negligible. The usage of the appropriate reactor setup the effective oxygen usage, the recirculated flow streams can be optimised. In addition, using a reactor cascade the sludge production also can be reduced [12], [13].

The purpose of this research is to reveal the possibilities of plant upgrade in a specific plant focusing the reduction of operational cost. It can be either by modifications of operational parameters or re-setting the reactor arrangement. The analysis is based on process simulations, where various alternatives are compared.

II MATERIAL AND METHODS

For plant performance simulation ASM2d model approach was used, which belongs to the ASM (Activated Sludge Model) family describing most of the biokinetic processes in wastewater treatment including biomass build-up for heterotrophic and autotrophic microorganisms, degradation of organic material and nutrients, aeration and chemical processes. ASM2d takes into account 21 processes. Stoichiometric and conversional parameters are a priori set in simulation software, changing the default values are only acceptable if proper measurement campaign is carried out and the results suggest any modifications. The parameters are yields for the mass of various microorganisms, half saturation rates, maximum growth rates, hydrolysis rates, decay and conversional rates described more in detail in literature [14-16].

In this research a small wastewater treatment plant was analysed with a 2,000 m^3/d (2 MLD) capacity treating sewage from municipal source. The plant has a possibility to receive 50 m^3 septage daily, but so far there were no need for such treatment. The raw wastewater is directed to the pre-treatment units, which includes a mechanical screen with openings of 3 mm and a vortex type grit chamber. The pre-treated wastewater then flows to one train of biological treatment. In the plant there is an additional train - basically equipped with manual elements – for unforeseen circumstances (e.g. unexpected load, accidentally washout of biomass) or maintenance of the main train. The first unit of the biological treatment is an anaerobic reactor with a reactor volume of 120 m^3, which could function as pre-selector, but due to the present under-loading of the plant this reactor is not used and the wastewater goes directly to the second unit, which is an anoxic reactor with a reactor volume of 140 m^3. Process scheme of the plant can be seen in Fig. 1. This reactor also receives the IR flow with a discharge of 3,500-4000 m^3/d and centrate and filtrate from sludge management. Aerobic reactor has a volume of 400 m^3 and depth aeration is applied maintaining 2.5-3.0 dissolved oxygen concentration.

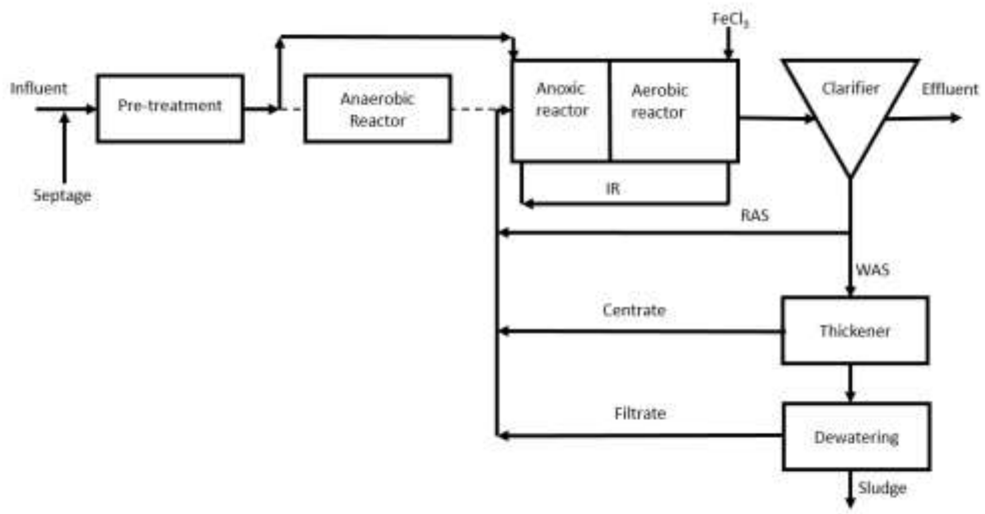

Fig.1: Process scheme of the wastewater treatment plant –actual operation

The biomass concentration is 4.0 g/L in the biological reactors. Phase separation takes place in Dorr-type secondary clarifier, RAS is 80% of the influent flow. Since the observed inefficiencies in biological excess P removal, chemical (ferric-chloride) is dosed to the last part of the aerobic basin, where coagulation and flocculation takes place and make the phosphorous precipitate. This sludge is taken out from the system with the WAS flow. Sludge management consists of thickening and dewatering with a centrifuge. Polyelectrolyte addition helps in reduction of sludge volume.

GPS-X 6.5 simulation software environment was used for the calculations. As a first step the plant layout was built. After the selection of the process units the connectivity was set. Raw influent wastewater data were determined. The non-measured parameters were determined by influent characterization, where primarily the COD fractions were calculated. These fractions (soluble inert, fermentable readily biodegradable particulate inert, slowly biodegradable) were adjusted to meet the measured BOD_5 value. The results of the fractionation can be seen in Table I. Steady-state simulations were performed, therefore the input data were also constant during the simulations, representing the 50%ile of a 5-year period of data series. First plausibility check was performed on the data set, neglecting the values that does not fit to the rest of the values, then the basic ratios were calculated. If the ratios were not in the acceptable range, these were omitted. For example, the volatile suspended solid concentration (VSS) is always smaller than total suspended solid concentration (TSS) and falls within the range of $0.6<VSS/TSS<0.9$. The VSS/TSS ratio was 0.75 and the particulate COD/VSS ratio was 1.9 mg/L.

Table I: Raw wastewater characteristics

Raw wastewater	mg/L
Chemical oxygen demand (COD)	495
Soluble inert COD (S_i)	25
Fermentable readily biodegradable COD (S_s)	145
Particulate inert COD (X_i)	60
Slowly biodegradable COD (X_s)	265
Biological oxygen demand (BOD_5)	252
Total Suspended Solid (TSS)	230
Total Kjeldahl Nitrogen (TKN)	66
Total Phosphorous (TP) mg/l	10.6

The following model scenarios were calculated:

- actual reactor arrangement without anaerobic volume – calibration
- UCT setup by using anaerobic volume
- extended MLE process by conversion the anaerobic to anoxic zone

III. RESULTS AND DISCUSSION

A. Model calibration – actual reactor arrangement

Current operation of the plant was simulated by applying the anoxic and aerobic zones. The model used the same SRT as in the actual plant. Based on actual data it was a little short, 7.2 days at 18°C. As Table II shows it was enough for nitrification, the calculated total nitrogen is somewhat higher compared to measured value. It might have been caused the incomplete denitrification. Since in the anoxic reactor the nitrate-nitrogen concentration was 5.2 mg/l the limiting factor could be the anoxic volume and not the IR. The calculated composite values for organic removal showed good agreement with field experiment, therefore the default parameters built in GPS-X were used. Phosphorus uptake rate was much lower in the calculations. EBPR is working in the full scale plant at low rate, which is not given back by the model. The reason could be that the model assumes completely stirred tank reactor, where there is no spatial difference in dissolved oxygen concentration, whereas in real life scenario dead-zones, low mixing zones could appear, where anaerobic conditions are built.

Table II: Raw wastewater characteristics

Parameter	Measured concentration	Calculated concentration
COD	37 mg/l	47 mg/l
BOD_5	12 mg/l	9.4 mg/l
TN	15 mg/l	20 mg/l
NH_4-N	2.2 mg/l	1.2 mg/l
TP	4.7 mg/l	7 mg/l

B. UCT arrangement and extended MLE

In GPS-X various model layouts were created to test model alternatives described in previous sections. The influent data were the same just the reactors and their connectivity were modified. The output data were the effluent quality, the aeration need and the sludge production, which are compared in Table III in each scenario.

Table II: Effect of reactor arrangement on operational parameters

	Current setup (MLE)	UCT	Extended MLE
Reactor volumes	140 m^3 Anoxic 400 m^3 Aerobic	120 m^3 Anaerobic 140 m^3 Anoxic 400 m^3 Aerobic	260 m^3 Anoxic 400 m^3 Aerobic
Sludge production	397 kgTS/d	369 kgTS/d	323 kgTS/d
Total air demand	788 m^3/d	772 m^3/d	570 m^3/d
Effluent quality	COD 47 mg/l BOD_5 9.4 mg/l TN 20 mg/l NH_4-N 1.2 mg/l TP 7 mg/l	COD 46 mg/l BOD_5 8.5 mg/l TN 16 mg/l NH_4-N 2.3 mg/l TP 2.8 mg/l	COD 46 mg/l BOD_5 8.7 mg/l TN 14 mg/l NH_4-N 0.5 mg/l TP 2.5 mg/l

If anaerobic volume is used by introducing an internal recycle from the end of the anoxic volume back to the anaerobic zone, the phosphorous uptake could be enhanced and less ferric-chloride is needed for precipitation of phosphate. Furthermore, the usage of nitrate means less external oxygen needed. Table III also shows that effluent TP reduced significantly.

In extended MLE process the first biological reactor is converted to anoxic zone by modifying IR stream from the aerobic reactor to the first reactor (and not to the second as it is in the current operation). That alternative clearly shows the further reduction of oxygen needed and sludge produced. Overall 28% of aeration need and 19% of sludge amount produced could be spared by only changing the IR stream end point.

Additional alternative could be the technology changes from activated sludge plant to a hybrid biofilm system, where the biomass amount could be enhanced. This could be easily implemented by introducing MBBR carriers to the reactors providing surface for attached growth process.

IV. CONCLUSIONS

The operation of a 2 MLD plant was analyzed with the help of process simulations. The plant data were gathered and reconciled then these were applied in influent characterization feeding the model with input data necessary. The model was calibrated with the current operational parameters and reactor arrangement, which showed satisfactory agreement with the measurements and revealed the possibility for further improvements. UCT and MLE process with larger reactor volume verified as a good option for plant upgrade. Not only the treated wastewater effluent quality improved, but also the operation of the plant could be cost effective reducing the air demand and the sludge amount. Attached growth process or hybrid systems will be examined as next step of the research.

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