PERIODICA POLYTECHNICA SER. CIVIL ENG. VOL. 41, NO. 2, PP. 119-134 (1997)

CHEMICAL UPGRADING OF THE NORTH-BUDAPEST WASTEWATER TREATMENT PLANT

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Received: Jan. 20, 1997

Abstract

In the past decade, the development of chemical technologies has opened the way to use low doses of metal salts (with or without polymers), in wastewater treatment. Then this led to a combination of chemical and biological processes driven by different goals. Available experiences suggest that chemical upgrading is an efficient method to increase the capacity of biological treatment plants (with primary sedimentation).

The specific problem of the North-Budapest Wastewater Treatment Plant (NB-WWTP) is that on the short run the flow to the existing treatment plant can be tripled (which would lead to a 50 – 60% hydraulic overload of the presently under-utilized capacity, 140 000 m^3/d), while on the longer run the flow may reach 400 000 m^3/d. The costs of meeting European Union standards with a proposed advanced biological nutrient removal are extremely high (several hundred million $) and the future flow is uncertain. Since financial resources are scarce, a cost-effective intermediate solution (say for the coming ten years) based on the upgrading of the existing facility should be sought to cope with the increased wastewater flow.

In the frame of the present study, first laboratory jar tests were conducted to study the applicability of chemical enhancement which was followed by a three-week full-scale experiment performed with low chemical dosage during the fall 1993. The experiments showed the ability of chemical upgrading to maintain (or improve) current treatment plant performance under flow increased by at least 50%.

Keywords: wastewater treatment, chemical upgrading, capacity extension, phosphorus removal, Central and Eastern Europe.

Introduction and Problem Formulation

The past development of the water infrastructure in Central and Eastern European (CEE) countries demonstrates a non-sustainable scenario. A data collection program covering Poland, the Czech Republic, Slovakia, Hungary and Bulgaria showed (SOMLYÓDY, 1994) that the overall level of water supply is quite good (about 90%) and, on average, sewerage is adequately developed (74%). However, the level of sewage treatment is poor: less than 50% of the wastewater received secondary treatment at the late eighties (this ratio is even smaller in Hungary). The investment

needs to improve the above situation and to approach Western European levels are tremendous, particularly if we consider the present conditions of economic transition.

In Budapest only about 20% of the wastewater are biologically treated (the generated amount in the dry season is about 1 million m^3/d). The required expenditures are estimated in the order of one thousand million \$. It is clear there is a need to look for cost-effective, double solutions on the short run which can be feasibly further expanded as the economy improves.

The North-Budapest Wastewater Treatment Plant (NB-WWTP) is the larger of the two facilities, and it currently receives sewage from only a part of North-Pest (Újpest). NB-WWTP is a traditional activated sludge plant. Liquid treatment consists of screw pumps, screens, aerated grit chamber, distributor, pre-aeration basins, primary sedimentation tanks, fine-bubble activated sludge process (without nitrification), and final clarifier. Sludge treatment includes chemical conditioning, dewatering, and landfill disposal.

The pre-aeration, primary and biological units are constructed in four parallel trains. The design capacity of each train is 35 000 m^3/d. Discharge is through two outlets to the Danube. Sludge from the biological clarifiers is recycled as return activated sludge. The excess waste activated sludge is recirculated to the head of the primary aeration basins, where together with the primary sludge, it is settled in the primary sedimentation basins (this is partially performed due to the lack of a sludge thickener). The combined primary and biological sludge is then pumped from the primary tanks to the sludge processing unit where it is treated chemically with lime and ferric chloride sulphate before dewatering in a new chamber press. Sludge disposal is to a local landfill which is not an adequate long-term solution.

A flow of about 110 000 m^3/d during the 1980s has decreased after 1990 due to water pricing and industrial structural changes. Currently, the design capacity of 140 000 m^3/d is under-utilized; two or three of the plant's four sections are in use. However, by the end of 1990's, the flow will greatly increase, from a present level of between 70 000 to 80 000 m^3/d to about 220 000 to 250 000 m^3/d; while according to various estimates it may reach 400 000 m^3/d in the long run. After completion of the Angyalföld Pumping Station (planned for 1997) and Pók Pumping Stations (in future) the plant will receive wastewater from the entire North-Pest area (Újpest, Angyalföld, Újpalota, Rákos, Zugló, Mátyásföld, Cinkota), North Buda (Békásmegyer, Csillaghegy, Római fürdö) and other smaller communities.

Effluent standards applied for the particular stretch of the Danube include COD = 75 mg/l, TSS = 100 mg/l, $NH_4^+ = 6.4$ mg/l, $NO_3^- = 20$ mg/l

and TP = 2 mg/l. The corresponding relaxed values set specifically for the NB-WWTP are 125 mg/l, 50 mg/l, 25 mg/l, 50 mg/l and 5 mg/l which are generally met by the facility (since nitrification does not take place, nitrate is low all the time, while ammonia is close to the limit value).

A long-term solution could be an advanced treatment with nutrient removal to meet the most stringent EU recommendations (although in lack of the planned, new Hungarian legislation it is not clear whether the Danube will be identified to a sensitive region or not) and to treat the predicted flow (of around 400 000 m^3/d). The investment cost requirement is high, about 300 hundred million $ (effluent TN would be 10 mg/l which can be reached by denitrification, while TP = 1 mg/l). However, the future capacity can be estimated only under high uncertainty and thus there is a danger of overexpenditures. For this reason any future strategy requires careful analysis which considers the best utilization of the existing facility (which operates for about ten years and its machinery was completely renewed recently).

In principle three different policies can be followed (and actually are discussed):

(i) To demolish the existing plant and to construct a brand new advanced one taking into account the likely future flow development;
(ii) To build a new advanced plant now according to short-term needs (220 000 – 250 000 m^3/d) only and to stop the operation of the existing plant. Under this scenario the existing plant would start to function again later to cope with further increase in the flow (the flow of this unit would be reduced in comparison to the present value to introduce nitrification and say partial denitrification, depending on water quality goals of the Danube having a high dilution rate); and
(iii) To upgrade chemically the existing facility such that it can handle the short-term increased flow (220 000 – 250 000 m^3/d) under unchanged effluent quality.

The first strategy is irrational since – as noted earlier – the future flow is more than uncertain. Furthermore, effluent and ambient water quality requirements (and their scheduling) are not yet specified and the alternative is very expensive. The second one also would have significant investment requirement right now which though would be associated with improved effluent quality. However, due to high background P and N levels in the river, and the presence of the remaining high portion of untreated wastewater in the capital, a positive impact on ambient water quality could be hardly detected. In fact, it would be advisable to utilize the limited budget available to increase the presently extremely low BOD_5 removal in the entire capital first and to focus on nutrient removal in a multi-

stage development fashion only subsequently (HENZE – ØDEGARD, 1994; SOMLYÓDY, 1994). These are the reasons why we focus here on the third scenario, i.e. on cost-effective capacity extension of the existing plant as an intermediate solution (it is noted that the final decision will also be significantly influenced by space requirement and land availability at the NB-MWWTP in relation to which there is not yet a clear picture).

Chemical Upgrading

Chemical upgrading (CU) offers one such interim solution. CU would extend the capacity of the present facility and would enable it to handle the increased flow expected in short run (without over-building) while meeting present standards. At the same time it would complement any long-term project, which calls for continued use of the existing plant while a new facility is under construction (and perhaps even longer). In addition, the operation of the upgraded plant would allow monitoring of future flow changes and derivation of a much more reliable long-term estimate than what can be obtained at present.

The use of chemicals in wastewater treatment goes back over 100 years. However, at the beginning of the 20th century, with the development of biological treatment, chemical wastewater treatment lost favour in Europe and North America, mainly because of the high doses of lime and other metal salts that were required which resulted in high amount of sludge difficult to dispose. Since the 1980's, there has been a growing recognition that multiple pollution problems (organic matter, nutrients, metals) can be best handled by a combination of chemical and biological methods and this is certainly the future trend in wastewater treatment (HAHN, 1990).

CU is defined subsequently (among a number of options depending on the location of the chemical addition) as the use of low concentrations of metal salts and/or polymers prior to the primary sedimentation basin for capacity expansion (as contrasted to the Scandinavian practice, for instance, where a high dosage is used due to the high P removal required, see e.g. HENZE – ØDEGARD (1994).

Chemical upgrading is particularly effective for a mechanical-biological treatment plant when

(i) the facility is hydraulically or organically overloaded;
(ii) improvements to the existing facility are needed to meet higher effluent standards;
(iii) increased removal of phosphorus is desired;
(iv) wastewater flow fluctuates greatly; and
(v) industrial wastes contribute significantly to the total load of the plant.

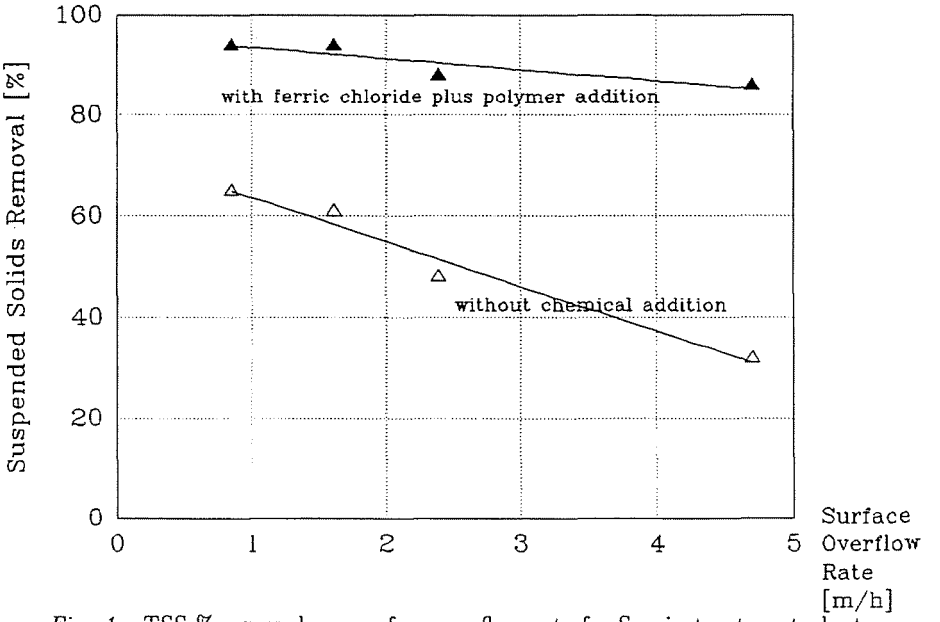

Fig. 1a. TSS % removal vs. surface overflow rate for Sarnia treatment plant

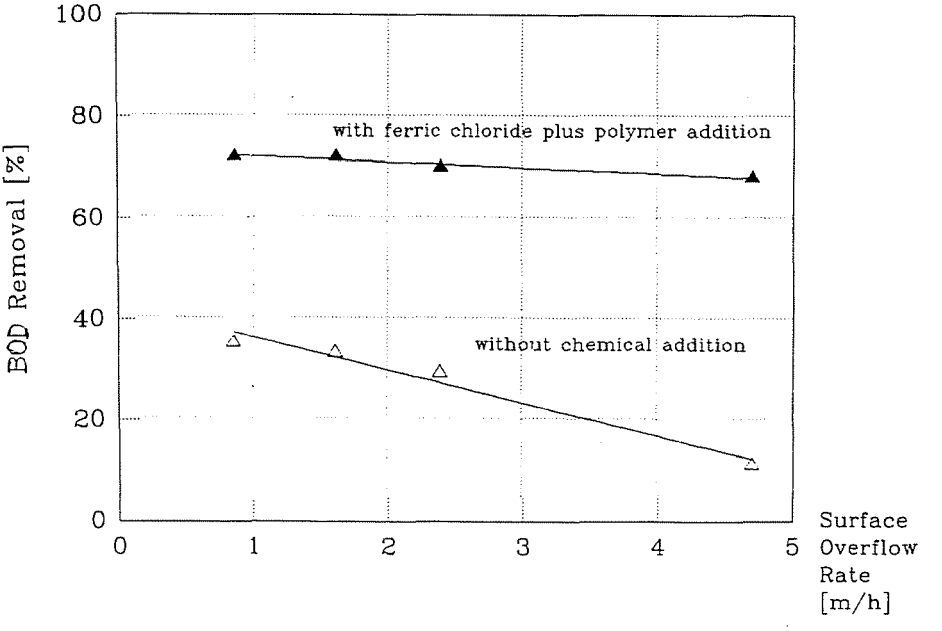

Fig. 1b. BOD % removal vs. surface overflow rate for Sarnia treatment plant

Original work detailing the effect of chemical addition on increasing primary overflow rates was undertaken at the municipal wastewater treatment plant in Sarnia, Canada (HEINKE et al., 1980). *Fig. 1a,* from HEINKE et al., presents TSS % removal versus surface overflow rate. This graph compares the condition of conventional primary treatment to CU using a metal salt and polymer. Without chemical enhancement, we see a decrease in plant performance with increasing overflow rate. At a typical design overflow rate of 1 m/h, about 60% TSS removal can be expected. However, at an overflow rate of 4.5 m/h, TSS removal is only about 30%. With CU, we notice two interesting effects. First, there is an increase in TSS removal across the entire range of primary overflow rates. Second, the curve flattens out. High removal efficiency is obtained at high overflow rates. Increased BOD and phosphorus removal also occur.

Later work indicated that chemical addition in the preliminary stages permitted increased primary overflow rates and could approximately double treatment capacity (HARLEMAN et al., 1991). *Fig. 1b* shows a standard curve developed by the Water Pollution Control Federation of expected removal efficiency in terms of TSS (Total Suspended Solids) removal rate versus primary overflow rate (Water Pollution Control Federation, 1985). Juxtaposed against this curve, we see the primary treatment performance of several major chemically upgraded primary and biological treatment plants in North America. Again, we see increased primary treatment performance and at increased overflow rates due to CU.

Recent investigations into the effect of chemical coagulant addition on primary overflow rates (National Research Council, 1993; ALTSHUL et al., 1993) verifies Heinke's finding that polymers improve settling rates and therefore allow increases in overflow rate.

Chemical addition has different impacts depending on the chemical concentration and the type of system. The effect of chemical addition on primary treatment as it was shown is to increase the overflow rate and to improve the removal of suspended solids, biochemical oxygen demand, and phosphorus. The effect of chemical addition on primary plus biological systems is to require less aeration tank volume (or extend existing capacity) and/or to improve nitrification in the aeration tank. However, it is noted that overly high BOD removal can be undesirable if denitrification is needed. Also, pH shifts may be a problem together with the effect on nitrification calling the attention to analyze carefully different consequences of processes introduced.

The sludge production (S) of CU in comparison to a mechanical-biological treatment plant requires special attention. If S (mg/l) is the sum of primary sludge (S_p) and the secondary one (S_s) (see HARLEMAN –

MURCOTT, 1992):

$$S = S_p + S_s\,,$$

where

$$S_p = \mathrm{TSS_{rem}} = \mathrm{TSS_{inf}} - \mathrm{TSS_{eff}}\,,$$

and

$$S_s = Y \cdot \mathrm{BOD_{5rem}} = Y \cdot (\mathrm{BOD_{5inf}} - \mathrm{BOD_{5eff}})\,.$$

Here the indices rem, inf and eff refer to the removed amount of material (TSS and BOD_5), and influent and effluent concentrations, resp. Y is the biological sludge yield (kg solids/kg BOD_5 removed). For a chemically enhanced first stage S_p can be obtained approximately on the basis of stoichiometry of the primary coagulant and the amount of TSS and phosphorus (P) removed (HARLEMAN – MURCOTT, 1992):

$$S_p = TSS_{\mathrm{rem}} + F \cdot \mathrm{P_{rem}} + K \cdot C\,,$$

where F is stoichiometric factor (1.42 for mono and trivalent metals, 2.84 for divalent metals), K is constant (e.g. 0.26 for alum and 0.66 for $FeCl_3$) and C is the concentration of metal salt added.

As can be seen from the above simple equations, the introduction of CU at a biological treatment plant has two opposite impacts:

(i) it increases the primary sludge due to increased TSS and P removal (overall the TSS removal rate grows from about 60% to 80%, and P removal can reach 80%); and
(ii) it decreases the secondary sludge since BOD_5 removal of the first stage increases from about 30% to 55% (or so).

If we assumed average domestic wastewater conditions ($\mathrm{BOD_{5inf}} = \mathrm{TSS_{inf}} = 200$ mg/l, P = 10 mg/l, $Y = 0.8$), as well as trivalent iron salt addition in small dosage (30 mg/l) and removal rates as indicated above, we obtain for a traditional biological plant

$$S = 216 \text{ mg/l}\,,$$

while for CU

$$S = 247 \text{ mg/l}\,.$$

The above simplified calculation shows that the overall specific amount of sludge generated by CU is approximately equal to that of a corresponding conventional biological treatment plant or increases only slightly – 15% in the above example (a high chemical dosage around 200 mg/l would lead to a significant increase in sludge production, to around $S = 350$ mg/l).

Obviously the treatment of more wastewater leads to increased amount of sludge which is the case when upgrading a facility.

As noted, the design of CU of an existing plant requires the systematic analysis of all the process units. On the basis of the explanation given above, generally, the capacity of the primary sedimentation basin and the aeration tank can be roughly doubled (jar test is a useful and simple experiment to test the impact of coagulation and the changed performance of the settling unit). However, the sludge recirculation line and/or the final clarifiers often limit the capacity extension. This problem can be overcome by adding new units, which can be limited by available space (the same applies to the sludge line). Another possibility is to by-pass the biological units above the capacity of the final clarifier and to blend primary and secondary effluents. Such a solution will obviously lead to a poorer effluent quality.

Experiments in the North Budapest Wastewater Treatment Plant (NB-WWTP)

Based on preliminary analyses, the flow of the primary sedimentation tanks can be roughly tripled. However, the corresponding increased amount of organic material load could not adequately be handled by the activated sludge process due to insufficient residence time, sludge age and F/M ratio. Simplified technological calculations demonstrated that about 220 000 m^3/d could safely be treated (under the present influent BOD_5 conditions). This flow (and load) is probably also acceptable from the viewpoint of the final clarifiers; thus effluent quality should remain practically unchanged. The expansion of the sludge line obviously cannot be avoided. The verification of the above assumptions requires both laboratory and full-scale experiments.

Jar Tests

In the summer and fall of 1993, jar tests were performed at the NB-WWTP laboratory to determine the viability of chemically upgrading this facility (SOMLYÓDY et al., 1995). The principal goal was to analyze whether metal salts (alone or in combination with a polymer) could be used to increase capacity of the existing plant. Because local sources of metal salts would likely be the most cost-effective, the metal salt ferric chloride sulfate ($FeClSO_4$) also known by the product name 'ongroflock', and already in use in sludge conditioning at the NB-WWTP became a candidate for inves-

tigation. In addition to testing $FeClSO_4$, other metal salts and polymers were also studied.

Mixing time and speed has a considerable impact on the efficiency of coagulation. For this reason, two mixing procedures were used: a standard and a specific one. The mixing speeds were the same for both procedures, but the mixing time varied. The standard mixing procedure is a protocol for a 'generic' wastewater treatment plant. The NB-WWTP mixing procedure was determined based on conditions (detention and settling time as well as velocity gradient) specific to the Budapest treatment plant.

Adjustment of the mixing procedure to the NB-WWTP specifics was made based on the plant specific detention and travel times and previous research (MORRISSEY – HARLEMAN, 1991). The main difference is the longer rapid mixing time of the specific procedure which accounts for the long detention time prior to primary sedimentation and the short flocculation time (approximately the travel time from the pre-aeration basin to the primary settling tanks).

Samples were analyzed on a daily basis for (among others) COD. BOD_5, TSS and TP. Three sample sites were used for the jar tests. From the point of view of the full-scale test the most representative was the site grit chamber effluent, because the $FeClSO_4$ for the full-scale experiment was added just a few meters downstream of this site.

We compared the results from the two different mixing regimes (see SOMLYÓDY et al., 1995 for details). The NB-WWTP jar test procedure gives less effective COD removal than the standard procedure. We also examined the effect of different $FeClSO_4$ concentrations and the polymer addition on the COD removal. The use of a polymer significantly improves COD removal. Other jar test experiments showed that the addition of polymer increased floc size and the speed of floc formation. Such flocs settled faster. This is likely a reason for improved COD removal with polymer dosage.

Application of different settling times was corresponding with the possible overflow rates of the whole plant. The results showed significant improvement in COD removal and increased overflow rate. There is at least a twofold increase in the latter when only $FeClSO_4$ is added (without anionic polymer).

Principal conclusions from the jar test at NB-WWTP include the following:

- Locally available $FeClSO_4$ which is used at the plant for sludge dewatering is effective in increasing the removal of pollutants (in jar tests);

- COD removal (from post-grit chamber water) using 25 to 50 mg/l $FeClSO_4$ improved COD removal by 12 to 20% (relative to zero chemical removal of 36%);
- A drastic improvement in overflow rate (from about 1 m/h to 3 – 4 m/h) is obtained when only $FeClSO_4$ is added. Use of an anionic polymer improves performance even further;
- $FeClSO_4$ in a concentration range of 25 to 50 mg/l (as $FeClSO_4$) is recommended for full-scale testing because of its performance, availability, cost, and the familiarity of the NB-WWTP personnel with this chemical;
- A high molecular weight anionic polymer dose of 0.2 mg/l would double the chemical cost of implementing CU at NB-WWTP. Depending on the results of using $FeClSO_4$ alone, the application of a polymer can be considered at a later stage.

Full-Scale Experiment

The applicability of chemical upgrading was tested full-scale as a next step during September to October, 1993 (SOMLYÓDY et al., 1995). The experiment was comprised of three test periods of eight days each and of a final 24-hour period of extremely intensive overloading. The first period was devoted to composite and point sampling and the analysis of numerous parameters with no chemical addition (i.e. normal operation). In the second period chemical addition was started under unchanged flow conditions, i.e. flow was equally distributed between two trains operated at that time. In the third period one of the trains was overloaded, while the other underloaded. This period tested the ability of capacity expansion.

Seven point sample sites and three composite sample sites were applied measuring the influent and effluent parameters at the grit chamber, at the primary sedimentation tanks, at the biological aeration basins, and at the secondary sedimentation tanks. *Fig. 2* shows the schematic of the full-scale test. Point samples were taken twice per day (at 10 a.m. and 11 p.m.). Daily composite samples were also taken by automatic equipment (there was no possibility of performing flow proportional sampling).

The water quality parameters analysed incorporated pH, COD, COD_{filt}, BOD_5, TSS, total P, P_{filt}, nitrogen components, total Cr, and total Fe. In addition, dissolved oxygen was monitored in the aeration basins. Sludge volume index and sludge production were also measured and visual observations of different units were made regularly.

Reaction between the applied metal salt and the wastewater occurs within a time span of less than 0.1 seconds (KEMIRA, 1990). In order to

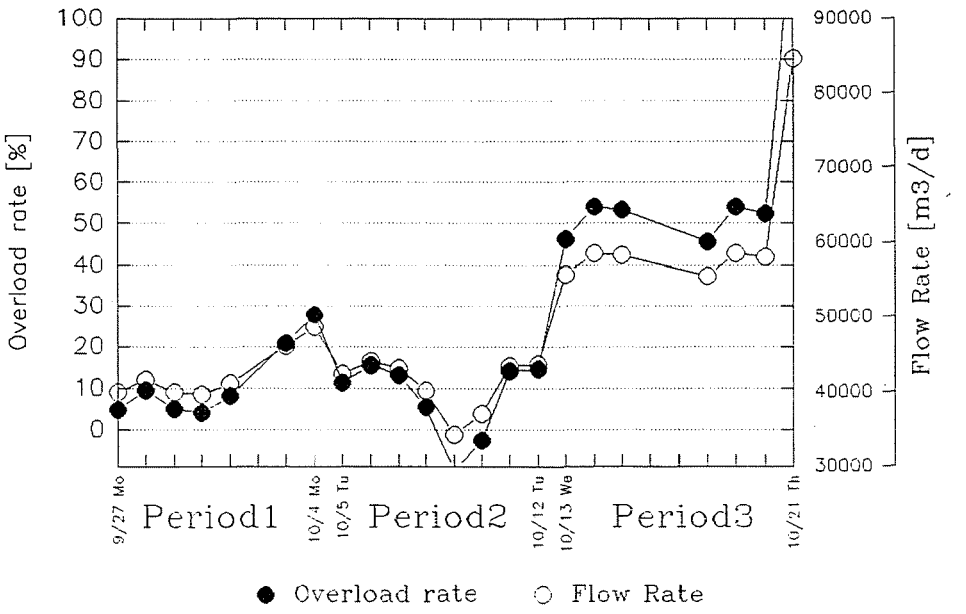

Fig. 2. Overload rate (compared to 1993 average) and flow rate for the experimental train

obtain efficient mixing chemical addition was placed in the Parshall flume. Several diffusers were developed and tested, but none of them operated as anticipated and this facility remained a weak element of the experiment.

A 25 mg/l chemical starting dose was selected on the basis of jar test results. The chemical dose was adjusted to the flow two times per day. The chemical feed pump was calibrated first by using tap water. Subsequently the calibration was performed with ongroflock and during the full-scale test we repeated it periodically and was found to be reliable. The continuous chemical dosage was somewhat distorted due to breakdowns of the chemical feed pump (which was caused by the lack of a filter). In the third period due to

(i) underfeeding of the chemical on account of multiple breakdowns of the chemical feed pump and
(ii) the smaller than anticipated size of floc formation, the chemical dose was increased to 35 mg/l.

We could adjust and measure the flow rate of the two operating trains in the distribution structure. From here the incoming wastewater flows separately into the two trains. The distribution is controlled by a weir and an adjustable gate. The calibration curve was produced for the weir

of the overloaded train. During the calibration the other gate was locked and the different incoming flow rates were measured at the Parshall flume. We set different incoming flow rates in the necessary range by a bypass at the very beginning of the plant. The water levels were measured over the weir. From these data the distribution weir calibration curve was derived. Based on that curve we adjusted the gate for the underloaded train to set the flow rate in the third period of the full scale test.

The daily average flow during the chemical experiment was about 12% higher than the assumed 72 000 m^3/d. The daily pattern of the flow was also different from our assumptions. First the night-time flow was higher than assumed on the basis of preceding observations. Second, the underloaded train received more wastewater. In spite of these disturbances we could keep the overflow in the third period at the desired level.

The fluctuation in the influent concentrations was significant (although not unusual). The likely extent of diurnal changes is also reflected by the deviation of the 10 a.m. observations and the daily composite (average) values. The correlation between the composite sample and point sample(s) concentrations is rather poor, which in spite of problems related to composite sample observations further justifies the role of diurnal alterations and the fact that short-term dynamics are not properly captured by the present monitoring (one or two daily samples).

Results

Fig. 2 illustrates the flow of the experimental train. As can be seen, it was kept rather constant during the first two periods, though somewhat above the nominal value. The plot demonstrates the extreme overload exceeding 100% during the last day. Excluding this day, the flow of Period 3 was above the design by about 50%.

Fig. 3 shows the influent and final effluent (after blending the effluents of the two trains) time series of TSS. This parameter gives a general representation for the operation of the plant. To show the role of different treatment units in removing pollutants, primary and biological effluent concentrations of the experimental train are also plotted for TSS. For the purpose of comparison we indicated standards specific for the NB-WWTP (abbreviated as efflim-s) and general standards (efflim-g). The final effluent TSS remained at the normal level during the full scale test, despite the accidentally increased inflow concentrations and the intentionally increased overflow rate.

Table 1 contains the summary results for the removal rates of the most important parameters. Since monitoring in 1993 was performed sys-

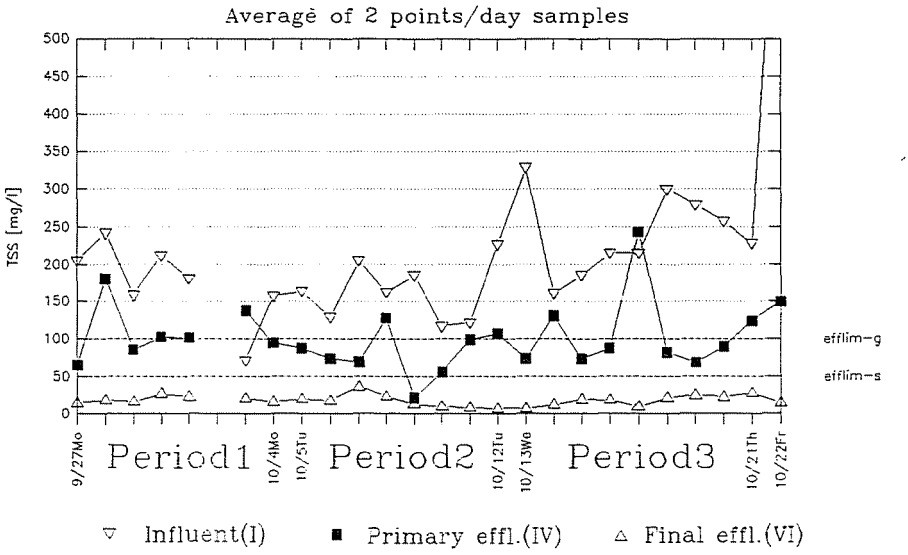

Fig. 3. TSS for the full-scale test

Table 1
Mean and standard deviation of removal rate for the plant

	Period 2 + Period 3	Period 3	September 1993 (22 days)	1993 (191 days)
COD [%I]	86	85	81	86
	4	6	7	7
BOD_5 [%]	95	95	88	92
	4	5	5	7
TSS [%]	93	94	86	93
	4	3	14	6
TP [%]	79	81	28	33
	13	16	38	106
NH_4^+ [%]	34	29	41	21
	29	38	18	28

Upper number: mean
Lower number: standard deviation

tematically at 10 a.m. (only), the 10 a.m. measurements are given for all the parameters.

For the purpose of comparison we indicated average values for the first nine months of 1993 (191 days) and for the previous month (September 1993). Full comparison was not possible, because for these two periods

data were available only for weekdays. For the experimental periods only BOD_5 was not measured on weekends, for the other parameters weekend data are also included. The most remarkable from the table is, that while the removal rate for all the parameters did not change significantly during the experimental period, phosphorus removal was increased from 30% to about 80%.

The chemical upgrading test has a number of other accomplishments as follows. Overflow rates could be significantly increased (including also the final clarifier). The plant became less vulnerable to sudden changes in influent loads. No change in the specific sludge production was detected by the inadequate monitoring system due to chemical dosage (our calculations using particular data of the NB-WWTP indicated a 13% increase in comparison to the existing system). Average TSS removal, in the primary stage during the chemical test improved from about 35 per cent (a rather poor value clearly indicating the negative impact of storing secondary sludge in the primary sedimentation tank) to 51 per cent and 62 per cent (for Periods 2 and 3, respectively). The increase in COD removal was smaller than anticipated (about 10 per cent).

There were a few areas in which the chemical upgrading test did not attain its full potential (or further improvements could be achieved): floc formation was not optimal due to industrial discharges; initial chemical mixing was poor due to the diffuser problem; excessive turbulence in the pre-aeration basin caused floc break-up, etc. As noted, removal rates of the primary clarifier seem to be smaller than suggested by the literature. The likely reasons are the composition of raw wastewater, lack of sludge thickening and associated sludge storage in the primary sedimentation basin, and sludge recirculation to the primary sedimentation tank. Thus, the fixing of the sludge line would lead to further improvement of the performance of the plant (and additional capacity increase).

Investment cost for chemical upgrading (including also improvements needed anyway such as upgrading of the sludge line and monitoring) would be about a few (say around 5) million USD. The principal increase in operation, maintenance and repair (OMR) costs over the current level would be for the usage of additional ongroflock. Extra labor costs are not anticipated because technically trained and competent chemists and engineers familiar with the CU process are already on staff at the NB-WWTP.

Assuming 220 000 m^3/d future flow and 25 mg/l dose, about 10 m^3/d or 14 wet tons per day ongroflock would be needed. The cost is 9500 Ft/wet ton (excluding transportation from about 200 km which is provided by the NB-WWTP even today) which leads to about 0.8 Ft/m^3 (including also transportation – 1993 price estimates). The daily ongroflock need for the

sludge dewatering would be 6 – 7 wet tons per day, leading to 20 wet t/d for the entire treatment process.

Conclusions

Based on the results obtained and analyses performed, we draw conclusions as follows.

(1) Technological calculations, jar tests, and full-scale experimental results indicate that a capacity increase from the present level to 220 000 to 250 000 m^3/d at the existing NB-WWTP is realistic by applying locally available $FeClSO_4$ in a small dosage (around 25 mg/l). Present levels of effluent quality would be maintained for TSS, COD, BOD_5, NH_4–N, pH, etc., while P removal increases from about 30% to 80%.

(2) An increase in specific sludge production is a consequence of chemical addition. Under the present small dosage, however, this increase could not be detected (although calculations suggested approximately a 13% growth): it was matched by operational conditions and uncertainty of data monitored.

(3) Removal rates of the primary stage are poorer at present than literature data would suggest. This is due to the sludge stored in the primary clarifier. The improvement of the sludge line would lead to an improved performance of the plant and additional capacity increase.

(4) Floc formation was less than optimal. This can be improved by employing a better-developed diffuser and enhancing initial mixing. Polymer addition also would have a positive impact on the performance of the primary clarifier (though operational costs would increase).

(5) The investment cost requirement of the upgrading would not be more than a few (about 5) million USD, including improvements which are necessary regardless of chemical enhancement. Improved monitoring (and automatic flow proportional sampling) cannot be disregarded for evaluating the performance of the plant and its units under significant fluctuations in wastewater flow and composition. Similarly, the improvement of sludge thickening is also strongly recommended.

(6) Operational costs would increase by about 6% (per unit cubic meter of wastewater treated) if just ongroflock is employed.

(7) On the basis of the above findings, chemical upgrading is recommended as an intermediate technology that is easy and cost-effective to implement and would satisfy short-term needs. A long-term plan should be developed on the basis of future flow changes, the adequate solution of sludge management, available financial resources, water quality requirements of the Danube, and new, forthcoming legislation.

Acknowledgements

The present study was funded by the Budapest Sewer Work, the International Institute for Applied Systems Analysis, IIASA and Kemira Kemwater. The work was undertaken by a team which included Susan Murcott (Massachusetts Institute of Technology, MIT), Géza Ritter and László Vass (Budapest Sewer Works), and György Botond (DHV Hungary Ltd.) in addition to the authors of the paper. Their excellent contribution is acknowledged here. The authors also appreciate the professional support of György Garai (Budapest Sewer Works). Special thanks are due to Éva Török and her colleagues for ably conducting the second jar test experiments and for the large number of analyses they performed.

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