Mikola, A.M.K., Vahala, R., Rautiainen, J.A. (2011). "Factors affecting the quality of the plant influent and its suitability for prefermentation and the biological nutrient removal process." J Environ Eng 137 1185. doi:10.1061/(ASCE)EE.1943-7870.0000438.

Factors Affecting the Quality of the Plant Influent and Its Suitability for Prefermentation and the Biological Nutrient Removal Process

A. M. K. Mikola[1]; R. Vahala[2]; and J. A. Rautiainen[3]

Abstract: To understand wastewater quality transformations in the sewer system, a full-scale study focused on the characteristics of the influent wastewater in a middle-sized wastewater-treatment plant receiving only municipal sewage. The objective was to identify conditions in which prefermentation prior to the biological nutrient removal (BNR) process would be useful. Prefermentation aims at increasing the fraction of readily biodegradable organic matter in the wastewater. A correlation between weather conditions and the presence of readily biodegradable organic matter in the feed wastewater was found, but contrary to the expectations, wet weather periods deteriorated the quality of the feed water more than the cold period. Moreover, influent load showed seasonal variation which changes in discharged wastewater could not explain. During the warm water period, significant biological oxidation and nitrogen removal took place in the sewer system, but the plant influent water contained readily biodegradable organic matter and potential for its formation during the warmest period. It was concluded that prefermentation would be mostly needed during the wet weather period. In addition, the study offered valuable information about the seasonal behavior of the sewer network. **DOI: 10.1061/(ASCE)EE.1943-7870.0000438.** *© 2011 American Society of Civil Engineers.*

CE Database subject headings: Sewers; Wastewater management; Biological processes; Water treatment plants; Water treatment.

Author keywords: Sewers; Wastewater management; Biological processes; BNR process; Sewer transformations; Plant influent.

Introduction

For wastewater treatment plants receiving primarily municipal sewage, influent water rarely offers a sufficient readily usable carbon source for biological nutrient removal (BNR). Several studies have shown that biological phosphorus removal and denitrification are dependent on the adequate supply of readily biodegradable chemical oxygen demand (RBCOD) in the feed wastewater (Gonçalves et al. 1994; Brinch et al. 1994; Pitman 1999; de Lucas Martinez et al. 2001). In addition, Crawford et al. (2008) suggested that the availability of volatile fatty acids (VFA) during wintertime is the primary limiting factor for enhanced biological phosphorus removal. Thus, in areas, where seasonal changes in temperature are significant, the lack of carbon in a readily usable form would occur more often during wintertime.

Different kinds of transformations influencing the quality of the wastewater take place in the sewer network. Aerobic conditions will favor hydrolysis and biological oxidation of biodegradable organic material, whereas anaerobic parts of the sewer network will be favorable for VFA production. In large catchments, nitrification may occur in aerobic conditions. Anoxic conditions and thus denitrification have been until recently considered very rare, unless nitrate is added to the sewer network (Abdul-Talib et al. 2002), but new studies suggest that denitrification is also possible in the sewers (Ahnert et al. 2005). Mohanakrishnan et al. (2009) observed that the nitrate uptake rate in the biofilm increased with repeated exposure to nitrate. According to Hvitved-Jacobsen et al. (1998), conditions in gravity sewers can remain aerobic owing to reaeration, although Gudjonsson et al. (2002) showed that dissolved oxygen concentrations in the sewers have strong diurnal variation and depend significantly on the temperature. Because of the natural variability in wastewater composition and the complex transformation and transport processes in the bulk water, biofilms, sediments, and gas phase, the conditions in the sewer network are difficult to predict even in dry weather conditions (Hvitved-Jacobsen et al. 2002; Vollertsen et al. 2005). Because catchments are becoming larger, a concern can also be raised of whether all the readily biodegradable material could, as a result of aerobic sewer reactions, be consumed in the sewers (Sollfrank and Gujer 1991; Siegrist and Tschui 1992).

This paper presents the findings of full-scale research at the Pihlajaniemi wastewater-treatment plant (WWTP) [personal equivalent (PE) 30 000], where the characteristics of the plant influent wastewater and their seasonal variations were studied with the objective of understanding quality transformations in the sewer system. The objective was to understand how sewer transformations and design and weather conditions influence the influent wastewater quality parameters to identify conditions in which prefermentation prior to biological nutrient removal would be useful.

Methods

During the study, the two process trains of the plant were separated and operated as two different treatment processes. The influent wastewater flow was divided in two after sand removal, and the treated water was mixed again before sand filtration. To study the

[1]M. Sc., Aalto Univ. School of Science and Technology, Water Engineering Research Group, P.O. Box 15200 FI-00076, Aalto, Finland (corresponding author). E-mail: anna.mikola@tkk.fi

[2]Prof., Aalto Univ. School of Science and Technology, Water Engineering Research Group. E-mail: riku.vahala@tkk.fi

[3]Managing Director, Kiuru & Rautiainen Ltd., Olavinkatu 24, FI-57130 Savonlinna Finland. E-mail: jyri.rautiainen@kiuru-rautiainen.fi

Note. This manuscript was submitted on September 9, 2010; approved on June 2, 2011; published online on June 4, 2011. Discussion period open until May 1, 2012; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Environmental Engineering***, Vol. 137, No. 12, December 1, 2011. ©ASCE, ISSN 0733-9372/2011/12-1185–1192/$25.00.

suitability of the influent water for prefermentation, one pair of primary clarifiers was modified to in-line low-yield prefermentation basin, which also acted as an equalization basin (Fig. 1). This modified half of the plant was called the equalization/prefermentation line. The volume in the basin was sufficient to store wastewater corresponding to 4–5-h dry-weather average inflow. This was enough to start the hydrolysis of the organic matter. The other pair of primary clarifiers was operated normally, and this unmodified process train was called the primary clarification line. The operation of the equalization/prefermentation process train is described in detail in Mikola et al. (2007).

In spite of the fairly small size of the treatment plant, Pihlajaniemi WWTP had practiced extensive weekly process monitoring already before the study. To characterize the influent and the pretreated water, hourly time-proportional composite samples were collected, and chemical oxygen demand with oxidation using dichromate (COD_{Cr}) and biological oxygen demand with an addition of allylthiourea which selectively inhibits ammonia oxidation [BOD_7(ATU)], N_{tot}, NH_4-N, P_{tot}, PO_4-P, and suspended solids (SS) were analyzed weekly. During the 18-month study from November 2002 to March 2004 the standard process monitoring was complemented by soluble COD_{Cr} and soluble BOD_7(ATU) analyses, which had been measured only occasionally preceding the study. Furthermore, to compare the two process trains, all the samples were taken from both process trains. Moreover, four eight-week monitoring campaigns were carried out during different weather conditions (two in wintertime and two in summertime), and 3-h and 24-h time-proportional samples were collected three times per week. During the monitoring campaigns, RBCOD and VFA were measured in addition to the parameters listed previously. The whole process of the plant with sampling points is shown in Fig. 1. The data from the weekly process monitoring from the time preceding and after the study could also be used in this research. The performance of the BNR process was also monitored, and the results concerning the process performance and sludge characteristics have been published previously (Mikola et al. 2007; Mikola et al. 2008).

All the analyses were performed according to standard methods except for RBCOD and VFA analyses. The method used for measuring RBCOD was carried out as proposed by Wentzel et al. (1995) and described in detail in Mikola et al. (2007). RBCOD was measured from grab samples with two duplicates. VFA was analyzed from samples collected for 3 h, then filtered at the plant rapidly after collection and frozen. The frozen samples were sent to the laboratory and analyzed using gas chromatography. The acids analyzed were acetic, propionic, butyric, isobutyric, and isovaleric acid. VFA in this article refers to the sum of these five acids. The method used is described elsewhere in more detail (Aurola 1999). In the first monitoring campaign, VFA was analyzed also from grab samples, but because no significant difference was found between the two sampling procedures, composite samples were collected every 3 h in the following three monitoring campaigns.

Pihlajaniemi Treatment Plant in Savonlinna, Finland

The Pihlajaniemi plant is operated with biological nutrient removal since 1995. After screening and sand removal, the process is divided into two identical lines both consisting of primary clarification (rectangular twin-tanks), biological reactor (plug-flow basins with five compartments separated with walls), and secondary settling (rectangular twin-tanks) followed by flotation filters (Fig. 1). Sludge treatment consists of thickening, dewatering, and composting. Wash water from flotation filters, representing almost 10% of the dry-weather flow, is led to the plant inlet, and it evens out the diurnal flow variation because the filter wash cycle always takes

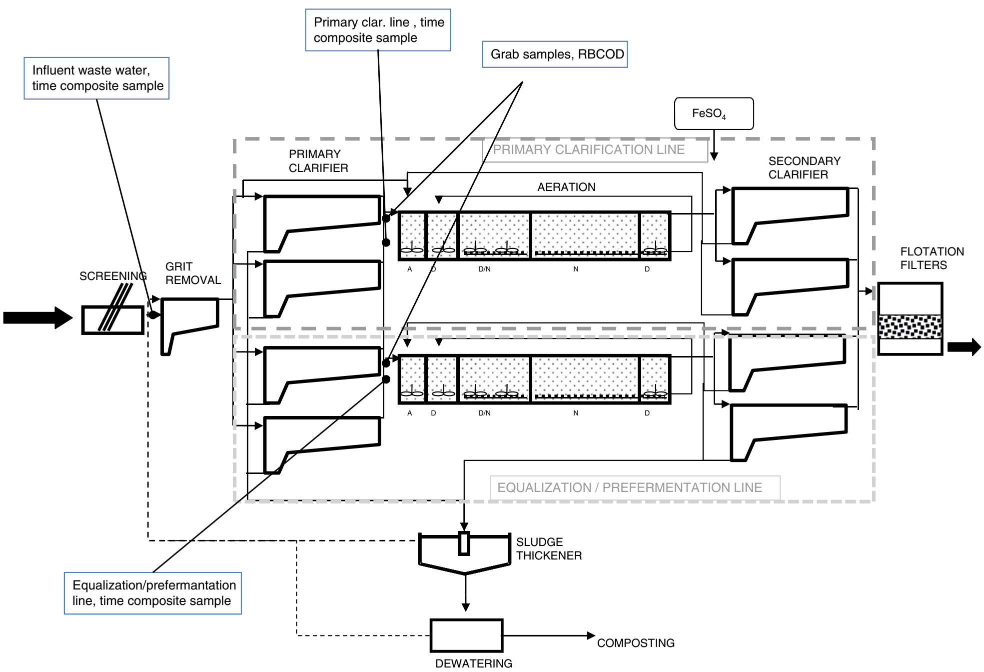

Fig. 1. The treatment process at Pihlajaniemi plant with sampling points

J. Environ. Eng. 2011.137:1185-1192.

place during the night. The reject-water from sludge thickeners and centrifuges is led with no time-control to sand-removal basin. The wash and reject-water flows are introduced at the beginning of the process, and they are distributed equally between the two process trains. More detailed information about the plant can be found in Kiuru and Rautiainen (1998) and in Mikola et al. (2007). The plant receives only municipal sewage and has an average influent flow of 7,500 m^3/d; the normal dry-weather flow is approximately 6,000 m^3/d, and the average concentrations in the influent water are BOD_7(ATU), 200 mg/L; COD_{Cr}, 580 mg/L; N_{tot}, 50 mg/L; and P_{tot}, 9.7 mg/L.

The sewer network of the city of Savonlinna is widespread. This is partly because of its geographical situation in the lake region in eastern Finland occupying several islands and the lake shore. Moreover, the sewer system has been expanded significantly during previous decades—approximately 10 km of new sewers have been constructed in the city every year. In 1995, the total length of the sewer network of the city of Savonlinna was only approximately 200 km, and in 2007 the sewer system consisted of 280 km of pipes. Furthermore, the Pihlajaniemi plant has received since 1997 sewage from the neighboring town of Punkaharju, approximately 50 km away, and beginning with 2009 from Kerimäki, approximately 30 km away. Fig. 2 shows the sewer network in 2009 and highlights the major expansions. At the time of the study, the transfer main from Kerimäki was not yet in operation. More than 90% of the sewage is pumped to the wastewater treatment plant via three pressure mains (lengths between 1.5 and 6 km), which are underwater constructions beneath Lake Pihlajavesi. A gravity main conducts the wastewater from the western part of the city to the treatment plant. A small part of the sewers are combined. Leakages and storm water account for approximately 30% of the total influent flow. Wastewater from Punkaharju and Kerimäki, representing approximately 6 and 10% of the total influent flow, respectively, is conducted to the treatment plant during the night via a storage tank. Because of the long transfer distances and storage tanks, the retention time in the sewer system can reach several days. Typical retention time in the pressure mains during the daytime in dry weather conditions is between 4–16 h. In the nighttime the retention time is even longer. During a wet-weather period, this retention time drops down to less than 1 h or a couple of hours.

Results and Discussion

Fig. 3 presents influent flow rate and water temperature in the aeration basin during the study and shows that the wastewater temperature was above 12°C only from June to October. Wet-weather periods occurred as usual during the snow melting period in March, but during the study year autumn was exceptionally rainy—the influent flow to the plant from October to December was 20–40% above the long-term average values for these months. Several heavy rain events occurred also during the summer months.

Factors Affecting the Influent Wastewater Quality

In Fig. 4 daily average VFA concentrations from 3-h time-composite samples are plotted against the average influent flow from 24 h prior to sampling. Daily average VFA concentration in the incoming wastewater varied between 0–25 mg/L, whereas in single 3-h composite samples the concentration varied between 0–78 mg/L. The accuracy of the analysis was ± 1 mg/L. The VFA consisted primarily of acetic acid (93%) and represented only a small portion of the soluble COD (between 0 and 29% with 7.5% on average).

The VFA concentration showed significant correlation (Pearson coefficient of correlation $R = 0.72$, $n = 19$, and level of significance $p = 0.01$) with the influent flow rate as shown in Fig. 4. When the flow rate reached roughly two times the normal dry-weather flow of the system, the incoming wastewater contained few VFAs or none at all. The results from RBCOD measurements also supported these findings [Fig. 5(a)]. The value of RBCOD concentration measured in the plant influent water varied between 0 and 42 mg/L, with an analysis accuracy of ± 6 mg/L. A significant correlation ($R = 0.96$; $n = 5$; 0.01) was found between the incoming RBCOD load and the flow rate [Fig. 5(b)]. A strong

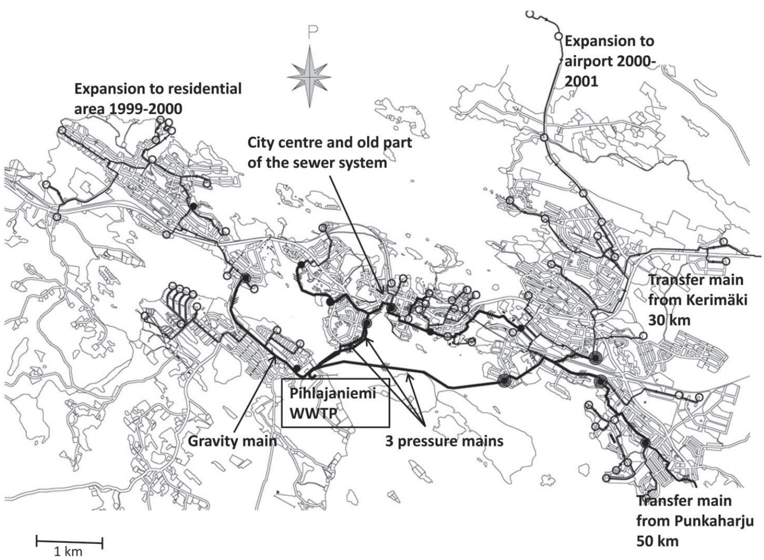

Fig. 2. The sewer network of the city of Savonlinna in 2009; the expansion to Kerimäki was not yet in operation at the time of the study

J. Environ. Eng. 2011.137:1185-1192.

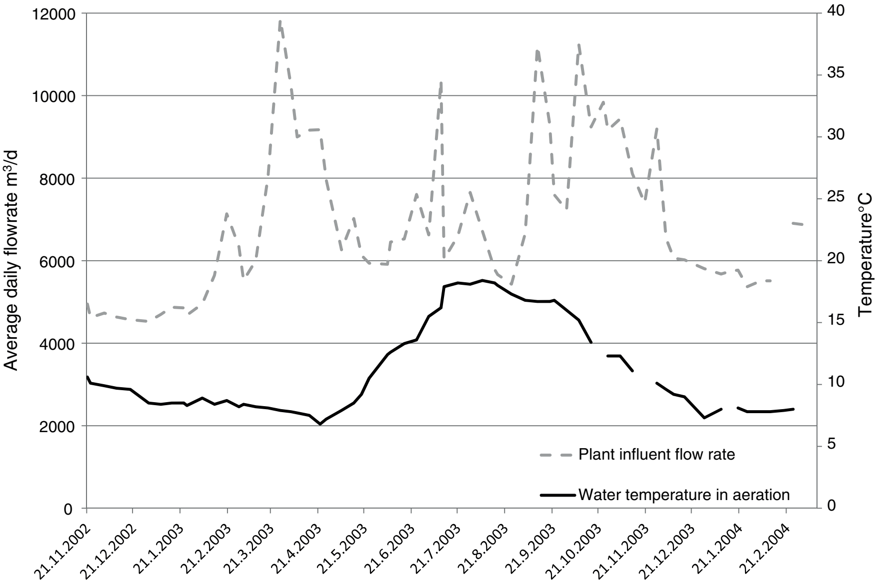

Fig. 3. Influent flow rate and wastewater temperature from weekly samples at Pihlajaniemi plant from November 2002 to March 2004

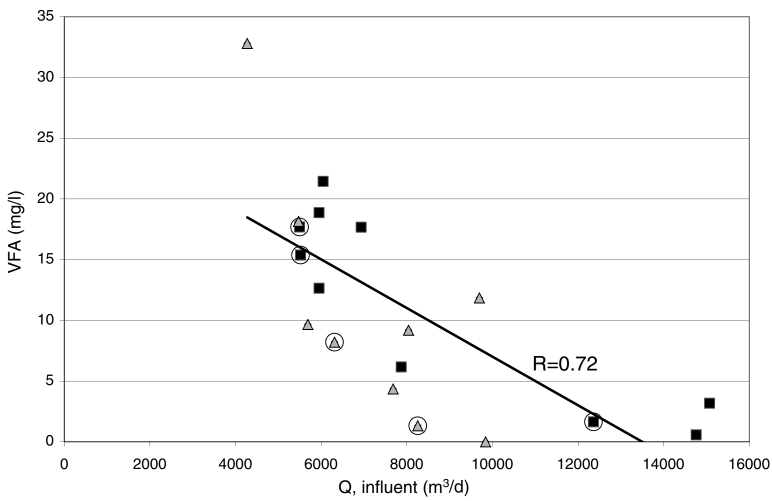

Fig. 4. The daily average VFA content versus the flow rate; VFA concentration in warm (above 12°C) (■) and cold temperatures (below 12°C) (Δ); Sunday samples are marked with (○)

correlation of influent VFA and RBCOD concentrations with the flow rate showed that the solubilization of the organic matter is dependent on the retention time of wastewater in the sewer system. From the two graphs (Figs. 4 and 5) it is shown that only approximately half of the RBCOD in the influent water was VFA. RBCOD was measured from one grab sample at approximately 9:00 a.m., whereas VFA was a daily average of 3-h composite samples. However, the two can be compared, because during most of the days, VFA concentration at 9:00 a.m. was close to the daily average concentration and then increased then during the day and decreased again at night. Also Vollertsen et al. (2006) also detected clearly higher concentrations of RBCOD than VFA in influent wastewater in similar climate conditions. The sewer network of the city of Savonlinna consists primarily of gravity sewers, which are presumably mostly aerobic. The presence of VFA in the plant influent anyhow suggests that anaerobic parts exist in the sewer system. Nielsen et al. (1992) have shown that without an oxygen supply from the air phase, the oxygen is depleted within a few minutes, and it can be assumed that in our case the pressure mains conducting the wastewater to the treatment plant become rapidly anaerobic and thus appropriate for the production of VFAs (Fig. 2). The retention time is also sufficient in dry weather

J. Environ. Eng. 2011.137:1185-1192.

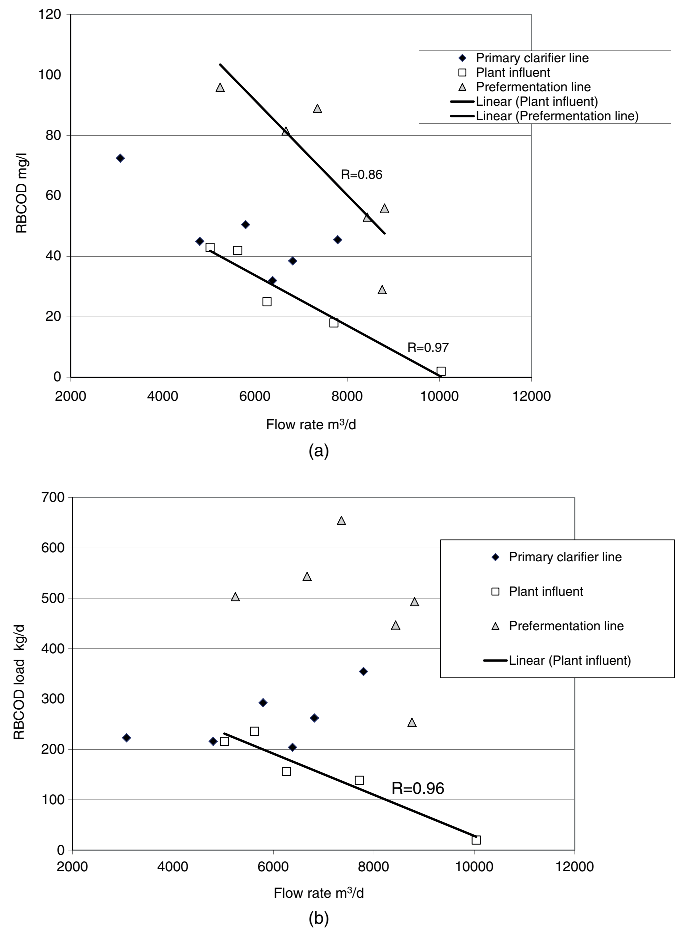

Fig. 5. (a) The RBCOD concentration in the plant influent, after the equalization/prefermentation basin and after the primary clarification; (b) the RBCOD load in the plant influent, after the equalization/prefermentation basin and after the primary clarification

conditions. In addition, the parts of the gravity sewers with low slope may also become anaerobic (Hvitved-Jacobsen et al. 2002). The disappearance of VFAs at high flow rates can be explained by the fact, that in addition to the shortened retention time in the pressure mains, the high flow rate presumably altered the oxygen status in the sewers toward more aerobic because the high flow rates primarily resulted from rain water intrusion containing oxygen. Moreover, the reaeration probably played a larger role as flow rates increased, as proposed by Huisman et al. (2004).

Cold temperature has been reported to decrease the VFA formation in the sewer system, leading to low VFA concentrations in the plant influent wastewater (Crawford et al. 2008). Fig. 4 shows that in cold temperatures influent water contained less VFA than in warm temperatures (11.5 mg/L on average during a warm period and 8.6 mg/L during a cold period), but no statistical correlation was found. The influence of temperature on RBCOD could not be seen because of the small number of samples. The less significant effect of temperature in comparison with the flow rate and thus the retention time in the sewers can be explained by the fact that temperature had both positive and negative effects on the production of VFA. While VFA production was facilitated by the high temperature in the downstream anaerobic parts, the readily biodegradable organic matter was also used more rapidly in the upstream aerobic parts, decreasing the amount of VFA potential arriving at the anaerobic part.

The fairly large vertical scatter in Fig. 4 suggests that there are other factors affecting the influent VFA concentration, such as daily load variation of wastewater discharges. For example, five samples were collected during the weekends, and the average of those samples was 8.8 mg/L, whereas the average of the samples collected during the week was 10.7 mg/L. During the entire study (18 months), the average BOD load in the influent during weekends was only 86% of the average BOD load during weekdays. These results suggest that the lower organic load during weekends also resulted in lower VFA concentrations, although the number of samples collected during the weekend was too small to draw any final conclusions. The highest value (32.8 mg VFA/L) was the only sample collected on a Monday. Clearly, wastewater composition has a high magnitude of variability, some of which, e.g., weekly repeated patterns, can be explained.

J. Environ. Eng. 2011.137:1185-1192.

The influent soluble COD (filtered sample) load also showed significant correlation with the flow rate, but the correlation with temperature was not significant. The RBCOD, VFA , soluble COD, and total COD concentrations were also compared. The VFA and RBCOD concentrations showed significant correlation with the soluble COD concentration (VFA: $n = 186$, $R = 0.73$, 0.0001; RBCOD: $n = 17$, $R = 0.62$, 0.01), but no correlation was found with total COD.

To estimate the effect of aerobic processes in the sewer system and the risk of running out of RBCOD in the plant influent water, the seasonal changes in the influent loads were studied. The loads of organic matter, phosphorus, and SS showed significant positive correlation with the influent flow rate, and the highest values of load occurred during the snow-melting period in March, but because of extreme flow conditions, these values also include the load from sediments and detached biofilm. Ammonia and nitrogen load did not show any correlation with flow rate. Table 1 shows average loads of organic matter, nitrogen, phosphorus, and SS during the 12 months from January 2001 preceding the study and during the study (altogether 30 months) from periods when the water temperature was above and below 12°C. During the storm water flows, some load may have been lost because of sewer overflows; on the other hand, increased scour in the sewers may have increased the load. The results from the days when the influent flow rate was more than double the normal dry-weather flow were omitted. Nevertheless, in this case the load from the stormwater events did not alter the results. Organic matter and nitrogen loads to the plant were significantly (t-test values in Table 1) less when the water temperature was above 12°C. For phosphorus and SS loads, on the other hand, no statistically significant difference was found. These observations can't be explained by seasonal changes in discharges; the wastewater was from domestic sources, and although part of the population left the city during the holiday season, tourists and visitors compensated for this loss. Moreover, a decrease in discharged wastewater would presumably have resulted in a decrease of load of all the parameters. The flow rates in the studied periods did not differ significantly either. On the contrary, the observed decrease in organic and nitrogen loads at warm temperatures can be attributed to the biological oxidation and to heterotrophic assimilation and nitrification and denitrification taking place in the sewers.

We estimated the amount of organic matter removed in the sewer system by comparing the load during the cold and the warm periods. A bit less than 10% of COD and BOD were removed in the sewer system during the warm period. These removal rates are close to those proposed by Ahnert et al. (2005) who showed that on the basis of the analysis of the plant influent data that approximately 20% of COD and 15% of total Kjeldahl nitrogen were removed in the sewer system. Chen et al. (2001) observed that 14% of the dissolved organic carbon (DOC) was removed in the sewer line with a hydraulic retention time of only 18 min. In our case, the calculation was made on the basis of the assumption that below 12°C no COD degradation and no nitrification occurred, although presumably some biological activity occurred also below this temperature. Similarly, by comparing the average nitrogen load during the cold period of 333 kg/d and during the warm period of 296 kg/d, during the warm water period an average of 37 kg of nitrogen (11%) was removed per day as a consequence of biological activity in the sewer network. This means that ammonia was nitrified in the aerobic parts of the sewers, and nitrates were denitrified in the anoxic parts. In addition, a part of the ammonia would have assimilated by heterotrophic bacteria. Abdul-Talib et al. (2002) demonstrated that significant denitrification rates occurred in the bulk water in the sewer network and that all added nitrate was reduced to nitrogen with the accumulation of nitrites. Nevertheless, the observed removal of organic matter (10%) seems low in comparison with nitrogen removal (11%), considering that a part of the organic matter should be readily biodegradable. Moreover, 8.6 mg of COD is needed for the reduction of 1 mg of nitrate to N_2 gas (Cuevas-Rodrigues et al. 1998). This observation could be explained by the fact that more organic matter entered the sewers with rain and ground water intrusion during warm period and lessened the observed COD removal. The hypothesis should anyhow be verified by monitoring the seasonal changes in rain and groundwater intrusion. If, indeed, the COD load to the plant remained higher owing to the load from combined sewerage, the potential modifications in the sewer system may still lead to the risk of too low of an organic load.

Table 1. Average Loads of Organic Matter, Nitrogen, Phosphorus, and Suspended Solids to the Plant from Cold and Warm Periods during 30 Months

Parameter	Unit	Temp. > 12°C average 15.9°C $n = 38$	Temp. < 12°C 8.5°C $n = 69$	t-test
BOD_7(ATU)	kg/d	1238	1361	0.04[a]
COD_{Cr}	kg/d	3546	3820	0.03[a]
NH_4-N	kg/d	227	245	0.002[a]
N_{tot}	kg/d	296	333	0.00000009[a]
P_{tot}	kg/d	62	60	0.44
SS	kg/d	2218	2120	0.44
Inflow	m^3/d	6084	6459	0.20

[a]Significant difference according to t-test.

Response of Pretreatment to the Influent Characteristics

In Figs. 5 and 6, RBCOD and VFA concentrations in the influent water, after equalization/prefermentation and after primary clarification, are plotted against the average flow rate of 24 h prior to sampling. Because of the limited number of composite samplers and RBCOD equipment, all three samples were not taken on the same day but were taken on consecutive days in similar conditions. The RBCOD concentration slightly increased in the primary clarifiers, but in the equalization/prefermentation basin the RBCOD concentrations were more than doubled. The value of VFA concentration in both the equalization/prefermentation basin and the primary clarifiers were significantly more than in the influent wastewater (t-test: 0.002). No significant difference in VFA concentration could be seen between primary clarification and equalization/prefermentation basin, although soluble COD and BOD were approximately 15% more in the prefermented water. It is, nevertheless, noteworthy that VFA was also produced in the primary clarification basin. The VFA and RBCOD concentrations in the equalization/prefermentation line showed significant correlation with flow rate (RBCOD: $R = 0.86$, $n = 6$, $p = 0.05$; VFA: $R = 0.64$, $n = 16$, $p = 0.02$) and thus, were affected by the retention time in the pretreatment basin, as expected in the case of in-line prefermentation [Figs. 5(a) and 6(a)]. The graphs with RBCOD and VFA load against flow rate [Figs. 5(b) and 6(b)] illustrate that the quantity of VFA and RBCOD produced was really affected by flow rate and that the changes recorded in the concentration were not solely because of the dilution of the wastewater. Surprisingly, the concentration in the primary clarification line was not dependent on the flow rate. During the wet-weather flows, the fermentation process may have also deteriorated because the sludge loss from the pretreatment basins, although large amounts of sludge were not lost.

J. Environ. Eng. 2011.137:1185-1192.

The VFA and RBCOD concentrations after the pretreatment did not show any correlation with temperature. On the other h and, in cold water the prefermentation basin gave a better yield, suggesting that VFA potential was decreased during the summertime. The VFA yield in the prefermentation basin was studied in three-day periods during dry weather in summertime and in wintertime. The average VFA yield in very similar flow conditions in the cold period was higher (1.93 mg VFA/L/h, average of composite samples from three days) compared with the warm period (1.56 mg VFA/L/h, average of composite samples from 3 days). The temperature during the cold period was 7.9°C, and during the warm period it was 15.8°C. The Pihlajaniemi plant has a large catchment with long retention time in the sewers and has a potential risk of not having enough readily biodegradable matter in the plant influent. Nevertheless, our results show that in spite of the proved biological oxidation in the sewer network during the warm period, the influent wastewater still contained readily biodegradable organic matter and VFA potential, which was demonstrated with the VFA production in the prefermentation basin (Fig. 6).

Our findings show that high amounts of VFA can be produced in the sewers even in cold temperature as long as flow rates are at dry-weather level. This would suggest that the periods with highest likelihood for lack of VFAs are, in fact, the wet seasons, not so much the cold seasons, although the two might coincide. The lack of VFA proved most severe during wet-weather flows, but the performance of the in-line prefermentation used in our study also deteriorated because of the shortened retention time. A side-stream

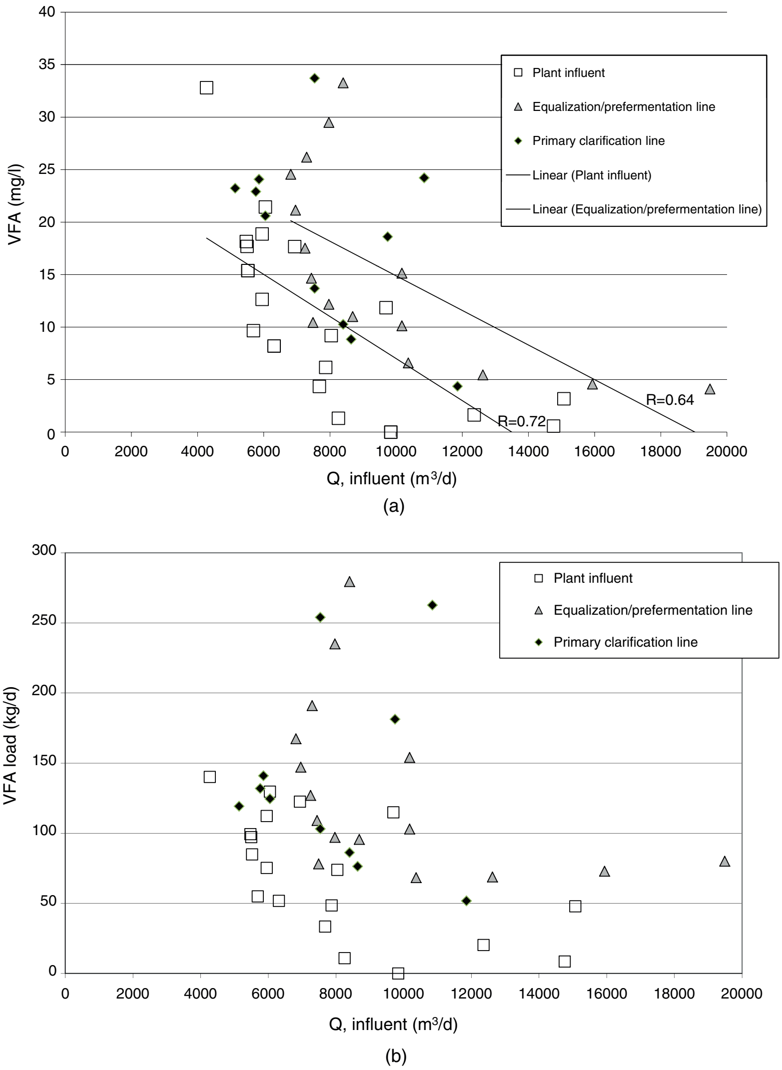

Fig. 6. (a) The VFA concentration in the plant influent, after the equalization/prefermentation basin and after the primary clarification; (b) the VFA load in the plant influent after the equalization/prefermentation basin and after the primary clarification

J. Environ. Eng. 2011.137:1185-1192.

prefermentation might have been able to supply the necessary VFA even during wet periods.

We believe that a thorough long-term (18–30 months in our case) analysis of the influent water can offer relevant information concerning sewer processes. By studying the measured parameters from the influent wastewater, assumptions on the sewer conditions were made. The advantage of this approach was that it did not necessitate measurements in the sewer network. In the case of Savonlinna there would have been almost 400 km of sewers to be monitored in changing conditions.

Conclusions

The plant influent wastewater quality was monitored in an attempt to understand the sewer transformations and their effect on prefermentation and the BNR process. It was evidenced that a significant amount of VFA was produced in the sewer network also during the wintertime, when the flow rate was at normal dry-weather flow, but VFA production was susceptible to changes in sewer conditions. At high flow rates very little or no VFA production was detected, assumingly because of shortened anaerobic retention time in the sewer network. High flow rate also decreased VFA production in the prefermentation basin. RBCOD results supported the findings with VFA analysis. It was also observed that during the warm water period, the load of organic matter and nitrogen to the treatment plant decreased, but this decrease could not be explained by any changes in the discharged wastewater. It is suggested that the decrease was caused by the biological activity taking place in the sewer network. In spite of the detected biological activity in the aerobic part of the sewers, suitable organic matter was available for producing VFAs in the anaerobic part of the sewers and in the prefermentation step. Nevertheless, some evidence was found that VFA potential of the plant influent wastewater was better during wintertime. Moreover, the organic load entering through rain water intrusion is not known. It can be concluded from these results, that large sewer systems can be useful in the production of suitable feed for the BNR process, but during wet weather periods VFA production drops down drastically. Thus, to profit from the fermentation capacity of the sewer network, rain water in the sewers should be minimized, i.e., leakages should be minimized and separate sewers should be favored. Furthermore, prefermentation would be needed mostly during the wet weather period and could be profitable during the cold period, whereas during the warm period, with dry weather conditions, prefermentation occurring in the sewer system might be enough.

References

Abdul-Talib, S., Hvitved-Jacobsen, T., Vollertsen, J., and Ujang, Z. (2002). "Anoxic transformations of wastewater organic matter in sewers—process kinetics, model concept and wastewater treatment potential." *Water Sci. Technol.*, 45(3), 53–60.

Ahnert, M., Kuehn, V., and Krebs, P. (2005). "Identification of overall degradation in sewer systems from long-term measurements and consequences for WWTP simulations." *Water Sci. Technol.*, 52(3), 153–161.

Aurola, A.-M. (1999). "Organic matter and polyhydroxyalkanoates in biological phosphate removal from municipal wastewater." Licenciate's thesis, Helsinki Univ. of Technology, Helsinki, Finland.

Brinch, P. P., Rindel, K., and Kalb, K. (1994). "Upgrading to nutrient removal by means of internal carbon from sludge hydrolysis." *Water Sci. Technol.*, 29(12), 31–40.

Chen, G.-H., Leung, D. H.-W., and Huang, J.-C. (2001). "Removal of dissolved organic carbon in sanitary gravity sewer." *J. Environ. Eng.*, 127(4), 295–301.

Crawford, G., Daigger, G., Fisher, J., Blair, S., and Lewis, R. (2008). "Phosphorus removal performance of the Traverse City MBR." *Proc., IWA World Water Congress and Exhibition* (CD-ROM), IWA Publishing, London.

de Lucas, Martinez A., Cañizares, P., Mayor, L. R., and Camacho, J. V. (2001). "Short-term effects of wastewater biodegradability on biological phosphorus removal." *J. Environ. Eng.*, 127(3), 259–265.

Cuevas-Rodrigues, G., Gonzalaz-Barcelo, O., and Gonzalaz-Martinez, S. (1998). "Wastewater fermentation and nutrient removal in sequencing batch reactors." *Wat. Sci. Technol.*, 38(1), 255–264.

Gonçalves, R. F., Charlier, A. C., and Sammut, F. (1994). "Primary fermentation of soluble and particulate organic matter for wastewater treatment." *Water Sci. Technol.*, 30(6), 53–62.

Gudjonsson, G., Vollertsen, J., and Hvitved-Jacobsen, T. (2002). "Dissolved oxygen in gravity sewers—measurement and simulation." *Water Sci. Technol.*, 45(3), 35–44.

Huisman, J. L., Weber, N., and Gujer, W. (2004). "Reaeration in sewers." *Water Res.*, 38(5), 1089–1100.

Hvitved-Jacobsen, T., Vollertsen, J., and Tahaka, N. (1998). "A process and model concept for microbial wastewater transformations in gravity sewers." *Water Sci. Technol.*, 37(1), 233–241.

Hvitved-Jacobsen, T., Vollertsen, J., and Matos, J. S. (2002). "The sewer as a bioreactor—a dry weather approach." *Water Sci. Technol.*, 45(3), 11–24.

Kiuru, H. J., and Rautiainen, J. A. (1998). "Biological nutrient removal at a very low-loaded activated sludge plant with high biomass concentrations." *Water Sci. Technol.*, 38(1), 63–70.

Mikola, A., Rautiainen, J., and Kiuru, H. (2007). "Diurnal flow equalization and prefermentation using primary clarifiers in a BNR plant." *Water Pract.*, 1(5), 1–13.

Mikola, A., Rautiainen, J., and Kiuru, H. (2008). "The effect of flow equalization and prefermentation on the sludge production and sludge characteristics in a BNR plant." *Water Sci. Technol.*, 57(12), 2023–2029.

Mohanakrishnan, J., et al. (2009). "Impact of nitrate addition on biofilm properties and activities in rising main sewers." *Water Res.*, 43(17), 4225–4237.

Nielsen, P. H., Raunkjer, K., Norsker, N. H., Jensen, N. A., and Hvitved-Jacobsen, T. (1992). "Transformation of wastewater in sewer systems—a review." *Wat. Sci. Technol.*, 25(6), 17–31.

Pitman, A. R. (1999). "Management of biological nutrient removal plant sludges—change the paradigms?." *Water Res.*, 33(5), 1141–1146.

Siegrist, H., and Tschui, M. (1992). "Interpretation of experimental data with regard to the activated sludge model No.1 and calibration of the model for municipal wastewater treatment plants." *Water Sci. Technol.*, 25(6), 167–183.

Sollfrank, U., and Gujer, W. (1991). "Characterisation of domestic wastewater for mathematical modelling of the activated sludge process." *Water Sci. Technol.*, 23(4), 1057–1066.

Vollertsen, J., Nielsen, A. H., Yang, W., and Hvitved-Jacobsen, T. (2005). "Effects of in-sewer processes: a stochastic model approach." *Water Sci. Technol.*, 52(3), 171–180.

Vollertsen, J., Petersen, G., and Borregaard, V. R. (2006). "Hydrolysis and fermentation of activated sludge to enhance biological phosphorus removal." *Water Sci. Technol.*, 53(12), 55–64.

Wentzel, M. C., Mbewe, A., and Ekama, G. A. (1995). "Batch test for measurement of readily biodegradable COD and active organism concentrations in municipal waste waters." *Water SA*, 21(2), 117–124.

J. Environ. Eng. 2011.137:1185-1192.