Global Journals Inc.

Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 14 Issue 6 Version 1.0 Year 2014
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Would it be Possible to Optimize a Municipal Wastewater Treatment Plant?

By Stig Morling & Niclas Åstrand

Abstract- Operation of modern wastewater treatment facilities (in the following: WWTP) are to a very large extent based on different forms of biological treatment. Historically a number of activated sludge models have dominated the market. The model that originally was developed during the second decade of the 20th century is often addressed as a suspended growth system as a contrast to attached growth models, such as trickling filters, rotating biological contactors (RBC:s) and more recently the moving bed biological reactors (MBBR:s). Regardless of the system chosen the biological stage in a modern WWTP represents the major energy consuming stage. The obvious exception for this statement is by convention the anaerobic treatment, especially used when the wastewater is a "high strength" stream, rich in hydrocarbonates. The sharpened demand on biological nutrient removal, especially nitrogen removal has even more highlighted the needs for an efficient process control.

Keywords: bod (biochemical oxygen demand), loading conditions, measurement, nitrogen, nitrification, phosphorus, solids retention time, temperature.

GJSFR-H Classification : FOR Code: 090409

WOULDITBEPOSSIBLETOOPTIMIZEAMUNICIPALWASTEWATERTREATMENTPLANT?

Strictly as per the compliance and regulations of :

Would it be Possible to Optimize a Municipal Wastewater Treatment Plant?

Stig Morling [α] & Niclas Åstrand [σ]

Abstract- Operation of modern wastewater treatment facilities (in the following: WWTP) are to a very large extent based on different forms of biological treatment. Historically a number of activated sludge models have dominated the market. The model that originally was developed during the second decade of the 20th century is often addressed as a suspended growth system as a contrast to attached growth models, such as trickling filters, rotating biological contactors (RBC:s) and more recently the moving bed biological reactors (MBBR:s). Regardless of the system chosen the biological stage in a modern WWTP represents the major energy consuming stage. The obvious exception for this statement is by convention the anaerobic treatment, especially used when the wastewater is a "high strength" stream, rich in hydrocarbonates. The sharpened demand on biological nutrient removal, especially nitrogen removal has even more highlighted the needs for an efficient process control. Four Some different plants with similar but nevertheless distinctive unique conditions have been used to exemplify both the difficulties as well as potential pathways to control a biological reactor:

- A demonstration plant for biological phosphorus removal operated at low temperatures in Northern Sweden;
- Low loaded plant for a combined industrial/municipal wastewater on Sri Lanka;
- A SBR-plant in Southern Poland operated with unexpectedly high chromium loading;
- A midsized plant for advanced nitrogen and phosphorus removal operated with typical weekly variations with respect to loading conditions. This plant was located outside Stockholm, and presents special conditions for plant operation.

The four examples demonstrate empirical findings from most different operation conditions. These findings illustrate some crucial points with respect to operation of biological plants. The insights may be summarized in three major perspectives:

- An understanding of the more or less inevitable load fluctuations that will govern the plant operation during its lifetime. This understanding must be reflected in the fundamental design of the plant. An incorporation of a sufficiently flexible operation mode would be of great value in this respect;
- Needs for a comprehensive process control, based on an extended use of on-line instruments both at the inlet side of the plant, inside the process train, as well as at the discharge point of treated water;
- And last, but not least, a committed and process-oriented operation management at the plant that results in improved operation efficiency.

Author α σ: *Sweco Environment, Stockholm, Sweden.*
e-mail: stig.morling@sweco.se

Keywords: bod (biochemical oxygen demand), loading conditions, measurement, nitrogen, nitrification, phosphorus, solids retention time, temperature.

I. Background

Operation of modern wastewater treatment facilities (in the following: WWTP) are to a very large extent based on different forms of biological treatment. Historically a number of activated sludge models have dominated the market. The model that originally was developed during the second decade of the 20th century is often addressed as a suspended growth system, is a contrast to attached growth models, such as trickling filters, rotating biological contactors (RBC:s) and more recently the moving bed biological reactors (MBBR:s). Regardless of the system chosen the biological stage in a modern WWTP represents the major energy consuming stage. The obvious exception for this statement is by convention anaerobic treatment, especially used when the wastewater is a "high strength" stream, rich in hydrocarbonates. The sharpened demand on biological nutrient removal, especially nitrogen removal has even more highlighted the needs for an efficient process control. This demand has become especially apparent when it comes to different types of activated sludge plants. The by far dominant principal activated sludge configuration is labelled "a one sludge system". This means that the activated sludge process by convention has to host very different populations of micro-organisms in a single stage process. One "classic" problem connected to this mode is the occurrence of an uncontrolled growth of filamentous bacteria. Jenkins et al [1] have addressed this problem in several versions of a comprehensive handbook regarding sludge quality in activated sludge plant performance. A very interesting presentation was made by Leslie Grady (one of the most distinguished scientists in sanitary engineering) in his inauguration speech at the WEFTECH conference in New Orleans in 1999. He referred to side-by-side tests that were done at the Clemson University, South Carolina. Two parallel lab scale reactors were operated for a month at identical conditions. A microbiological analysis of the populations in the two reactors was performed. Professor Grady stated that the two populations had no resemblance at all! He concluded, philosophically: "Perhaps we must realize that we face another example of the Heisenberg thesis of unpredictability, even in our field!" The stipulated enhanced objectives for the treatment will put further questions whether it is possible to arrange strategies and models that will satisfy a really efficient operation. Now the question arises: Will it be justified to talk about a process optimization when you take on board a number of fundamental conditions characterizing a modern biological wastewater treatment plant, such as:

- A treatment plant will be designed for a certain period, often around 20 years. During the plant´s lifetime the load variations will be substantial, the first year´s operation will face an often far lower loading than the design load. In this context it may be relevant to actively question the use of BOD as both a design and consent parameter, see Morling [2];
- The short time variations with respect to loading may be characterized by the evident daily rhythm in flow and pollutants, from the morning and evening peak loads to the obvious minimal loadings during night time. This pattern is most apparent at small to medium sized plants;
- Other variations may be either seasonal, mostly found at resort or typical vacation sites, or a weekly variation found especially at towns with day migrants moving to a larger center to work during daytime. In addition to these problems it is essential to address the chosen sewer system. Especially older systems are based on the "combined concept" meaning that both wastewater and storm water are collected and transported in one pipe. This in turn causes unwanted flow peaks, and thus very diluted inlet water. In addition to the flow peaks also water with unnecessarily low temperatures are to be treated.
- A fourth condition typical for wastewater treatment plants operated in semi-arctic or moderate temperature climates is the water temperature variation during a year. A range from 4 – 5 °C during winter conditions to around 18 °C in late summer may be frequently found in these locations.

These variations will all cause more or less demanding conditions in relation to the question of how to run a treatment plant at efficient conditions. The concept "optimization" will be further scrutinized through the discussion of four examples. A first question to be raised in relation to the concept is however: How do we more specifically define "optimization"? From a more "philosophical" perspective it may be stated that the word optimization has to a very large extent a "quality" implication, while the applied science we practice in waste water engineering is based on "quantifications" based on empirical data. In the following the possibilities and limitations to quantify the concept optimization will be discussed.

II. Materials and Methods

The presented plants in this paper have been in operation for some time and the operation data are to a large extent comprehensive, thus making it possible to illustrate the addressed issue of plant operation efficiency (optimization). These plants have accordingly been chosen as they present different operation conditions that will enlighten the question. It is acknowledged as a basic condition that in all circumstances the ruling effluent standards are met in all circumstances. However, hardly anybody would accept this condition is a sufficient one to qualify a process performance to be "optimized".

The efficiency or optimization of the process must be thoroughly defined and also expressed by some criteria related to measurable values.Among these criteria may be found clear definitions of the load composition, and variations over time. Other conditions to consider are the water temperature influence on the process performance, and other typical water quality issues, such as the alkalinity, pH, conductivity as well as the content of more or less "unwanted" matters, for instance certain heavy metals and complex organic compounds.

A way to address the question of operation efficiency would be to relate the direct operating costs to the actually achieved purification result. Now you could object that this is not sufficient, also the (annual) capital costs should be included! On the other hand it is somewhat a questionable model, as this one would be related to both the plant age and the chosen depreciation model for the investments.

A practical and interesting model to address the operation efficiency has been developed inter alia in Denmark, where the actual discharge of pollutants has to be paid for. This in turn means that an improved treatment – beyond the consent levels may be found feasible for the operator.

Another more fundamental problem especially in municipal wastewater treatment management in relation to an "optimization" is related to the initial planning and design of the plant.

The occurrence of a major shift to biological nutrient removal systems have by necessity called for a far more deepened knowledge in the microbiological behavior. Today a large number of design manuals, often edited more or less "officially", represent a much needed tool for modern process design, see for instance Standard ATV-DVWK -A 131E [3]. These manuals often clearly point out the needs for safety factors when sizing volumes and process capacities. Sometimes even "built-in" safety-factors are used in the given design outline data, and thus not necessarily explicitly shown.

The introduction of advanced biological nutrient removal has also resulted in a large number of computerized design modelling. These models are by necessity based on a number of so called "default values" that sometimes need to be calibrated for the specific case. One of the most recent ones is BioWin 4.1, Envirosim [4]. However, these models will serve as a most important tool if true sensitivity analyses of different operation situations are to be investigated. This in turn may be at least a good possibility to come closer to an "optimized" operation.

However, the concept "optimization" will be further scrutinized and questioned by presenting the operating conditions and actual performance of four different wastewater treatment plants.

III. Discussion on Four Cases

a) A small plant in operation in northern Sweden operated for biological P-removal at low temperatures

The issue of enhanced and – if possible – a non-chemical phosphorus removal enabled a small northern Swedish community to engage itself into a long-time test operation of a small activated sludge plant as a test unit for enhanced biological phosphorus removal. The work was done in collaboration with the Luleå University of Technology. The full results are presented in [5]. The most important findings from the test operation with respect to operation changes are summarized in the following. The main objective – apart from the "bio-P-removal" as such - was to determine the operation conditions at very low wastewater temperatures between 3 and 10 °C.

The test operation was based on a conversion of a "classic" activated sludge tank into a SBR-basin. The total pilot operation period was around 22 months. The constraints and limitations found in the operation may be seen as typical evidences for a need of improved process control. Again, the question is could the plant have been operated in an "optimized" way? It should however be underlined that some of the limitations found during the test operation were not related to process conditions. Two circumstances in this respect were the relatively small basin size along with its geometrical configuration and the decant system that allowed sometimes an unacceptable level of SS-concentrations in the discharge. It is further worth wile to notice that the main automation system was based on classic relays, mainly controlling the different operation phases.

The presentation of the identified limitations may be defined in relation to strive for a safe and efficient operation; see also Marklund and Morling [5]. On the other hand the study also points out pathways for improved operation modes. The crucial findings may be summarized as follows:

- It was clearly demonstrated that a fast shift in water temperature had a clear influence of both the process reaction rates, and the sludge separation performance. The operation cycle had to be adjusted from 6 to 12 h to meet the temperature change from 10 to 4 °C. In Figure 1 is shown the variation pattern of the water temperature over almost two year´s operation of the pilot plant. It is interesting to observe the sharp change in the temperature both in spring – a rise from 4 to 10 °C, and in fall from 8 to 3 °C.
- To overcome an "unwanted" process performance of the reactor – mainly defined as non-acceptable sludge characteristics - the needed adjustment time was 3 – 4 times the actual SRT (Solids Retention Time).
- The limitations with respect to biological P removal were found to be linked to the low water temperature. Figure 2 illustrates this relation

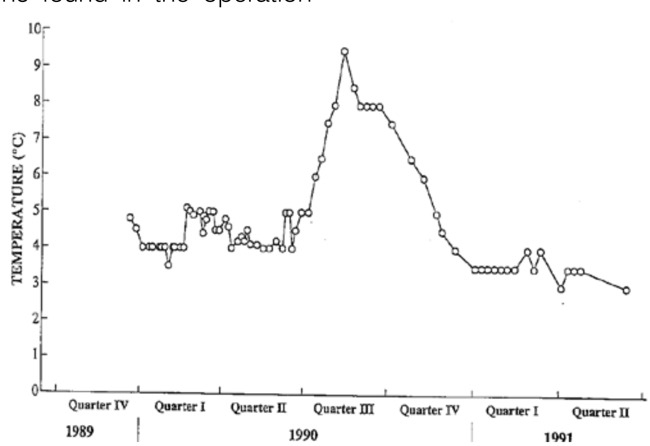

Figure 1 : Wastewater temperature variation at the Dokkas pilot plant operation during 7 quarters, after Marklund and Morling [5]

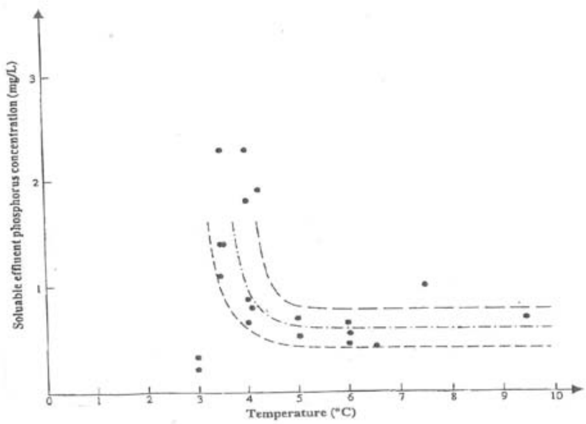

Figure 2 : Outlet soluble phosphorus levels versus reactor temperature during the period August 1990 to June 1991 (n =21), after Marklund and Morling [5]

As a summary: The pilot operation project enlightened some shortcomings with respect to the "optimization" possibilities, even though the objectives for the study were not focusing on these perspectives:

1. A biological treatment at low water temperatures are by nature retarded. The needs for a more active and efficient control and process adjustment call for rapid on-line information of the main process variables. The retarded information from an off-site laboratory will only provide "historic" data. The needs for swift change of the operation mode are then not satisfied.
2. In this case the intermittent operation anyhow was an efficient way to at least partly overcome the classic problems with the small plants to meet an improved performance (on the way versus an "optimization").
3. It is also more than likely that a more comprehensive on-line control instruments along with a more "intelligent" PC – operation control would be a further step towards a much better process control, and eventually coming closer to an "optimized" plant operation.

b) An industrial-municipal WWTP in Sri-Lanka

The second example with respect to operation efficiency is taken from in more or less opposite conditions as the first one: A nutrient removing plant located in a tropical climate. The industrial-municipal WWTP at Ja Ela/Ekala, north of Colombo, in Sri Lanka. The main issue in this case is the very low loads during the first year of operation. In this respect the plant performance enlighten a more or less classic situation for many plant operators: How to find an efficient and operating cost saving mode of operation. The case has been presented by Berg and Morling [6]. The paper presents a focus on mainly a way to improve the operation with respect to energy costs for aeration. Some of the obvious performance results are cited in the following.

The issue of operation of an under-loaded activated sludge treatment facility has been addressed and the basic problem has been identified as an excessive use of energy for the aeration. The way to mitigate this problem showed to be a very simple one—to operate the aeration basin at an intermittent mode. In this specific case it has been possible to implement this model; however, some important limitations have been identified at the same time. The most striking results are quoted in the following:

- *"It is found imperative that the on-line measurement of operation variables are viable and maintained on a regular basis;*
- *The automation mode must allow for a flexible intermittent operation. This is a consideration that should be reflected already in the design work;*
- *An additional removal strategy for the waste activated sludge may be needed: To withdraw the sludge from the intermittent reactor;*
- *The current mode of intermittent operation has been successful also thanks to an extended hydraulic retention time in the aerobic reactor. This matter must be addressed closely when applying the strategy; at shorter hydraulic retention times there is a risk that amounts of not nitrified ammonia will pass through the system;*
- *The outcome of the operation modification has been by large very satisfying, with a sustained biological performance with respect to organic removal (expressed as BOD and COD), an improved removal of total nitrogen thanks to an enhanced denitrification efficiency and finally but not least striking: An efficient biological phosphorus removal has been established in the vicinity of 80% to 90%.*

However, it may still be questioned whether the plant operation is really optimized. Over a certain period of time it is evident that the plant efficiency has been improved substantially. On the other hand it is not proven that the day-by-day performance is found to be really optimized.

c) An "over-loaded" WWTP in Poland

The third example is taken from a plant built in southern Poland. The city of Nowy Targ was one of the first to accept and perform a modern wastewater treatment plant after the fall of the communist era. Taken into operation in 1995 the plant that was built as a three reactor SBR-plant soon experienced an unforeseen heavy industrial load from a large number of tanneries (both legal and illegal). This in turn caused a from time to time substantial overloading of the plant. This has been described more in detail by Morling [7] and [8]. The experiences from the operation may in this context serve as illustrations of possibilities and limitations with respect to optimization of the operating conditions. The plant was operated with consistently very good removal efficiencies, even during the unexpected peak-load conditions. This fact may be attributed as an indication of an important factor to sustain the following statement: Improved plant operation efficiency, aiming for optimization calls for a committed and process-oriented operation management at the plant.

The plant operators adopted an "optimization" strategy for the SBR operation. These include the following main actions:

1. To operate the plant with SBR cycles of about 5.5 hours. This means that the start of "fill" for reactor number one (as an example) will not occur at the same time from day to day. A clear advantage was found with this operation mode: A regular peak load occurring at about 09.00 hours each day was directed to different reactors following a systematic main cycle mode.
2. The loading variations on the SBR units were met by altering the aerated time by three different modes as shown in Table 1:

Table 1 : Variation of the SBR-cycle related to the load conditions, total cycle length about 5.5 h

Cycle phase	Normal operation	High load operation	Peak load operation
Fill/mix	1 h 30 min	1 h	30 min
Fill/react	30 min	1 h	1 h 30 min
React	2 h	2 h	2 h
Settle	1 h	1 h	1 h

Compared with the initial operation mode, the aerated time of the cycle during "normal" operation has been shortened by one hour. This alteration does not illustrate a true optimization of the plant, but could be seen as a step towards a needed, better energy efficiency.

The plant operators were carefully recording a number of important process variables. By investigating these it has been possible to enlighten the obvious difficulties to really create an optimized operation mode. The figures 3 and 4 illustrate the nitrification capacity linked to on one side nitrogen loading and on the other hand the ratio COD/N.

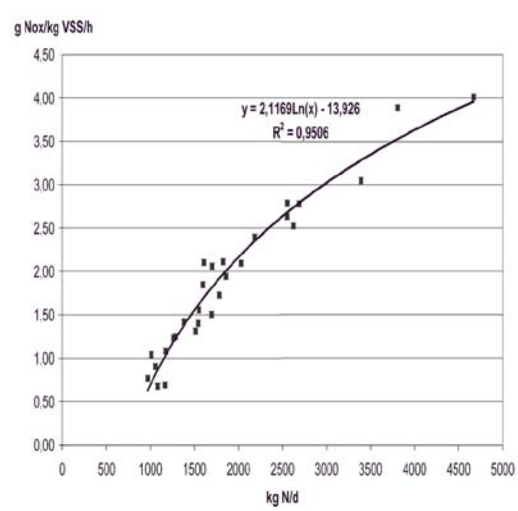

Figure 4 : Nitrification rate versus inlet nitrogen load at Nowy Targ, first quarter 2005, based on 29 observations, after Morling [8]

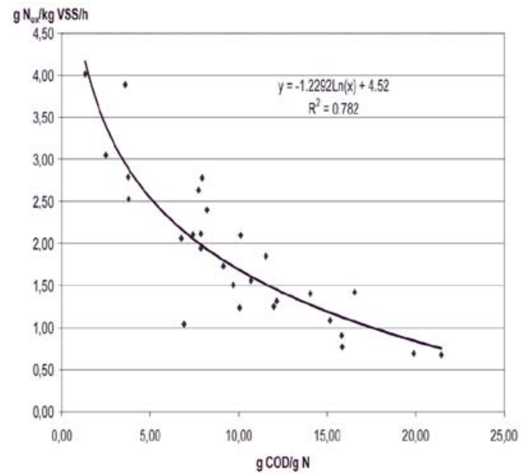

Figure 5 : Nitrification rate versus inlet ratio COD/N at Nowy Targ, first quarter 2005, based on 29 observations, after Morling [8]

The two figures illustrate that the nitrification rate is not only related to water temperature, but also to the actual nitrogen loading and the ratio COD/nitrogen in the incoming wastewater. The two figures illustrate a more or less normal, and very dynamic load situation at many WWTP:s. That in turn puts the question forth: is it really possible to find an operation pathway that may be called "optimized"? The more or less continuously changing conditions, would call for an automation control and operation system of really comprehensive capacities.

The classic and relevant way to assess any WWTP performance is to study an extended operation period, still with rather uniform conditions. The two figures 4 and 5 are based on a low water temperature situation at the plant. Of special interest at this plant was the nitrogen removal performance, both with respect to the seasonally low water temperatures, and the high Cr content in the crude wastewater. The "overloading" situation was terminated in 2008, when the tanneries in Nowy Targ to a very large extent were closed due to the change in market conditions. This in turn has made it possible to compare the plant performance during the "overloading" situation, with a later more normal load situation, the latter based mainly on municipal wastewater, see Table 2:

Table 2 : Comparison of discharge wastewater quality at the Nowy Targ plant, year 2004- 2005 (with high nitrogen and Cr load) and year 2009, mainly municipal wastewater

Period	Year 2004 - 2005	Year 2009
Nitrogen, consent level, mg N/l	20	20
Mean value mg N/l	15.5	9.5
Median value, mg N/l	15.0	6.6
Phosphorus, consent level, mg P/	0.5	0.5
Mean value mg P/l	0.49	0.38
Median value, mg P/l	0.40	0.17

When addressing these discharge figures you may assume that a substantial improvement has been achieved with respect to operation efficiency. This assumption may however be somewhat premature. There are a number of detailed information details missing that would be indispensable to correctly asses the performance. An improvement with respect to the effluent levels is evident, but is it really an improvement with respect to the efficiency? The basic answer is: More information is needed.

d) A plant operated with a typical weekly load variation outside Stockholm, Sweden

The last example represents a more or less classic problem found at many municipal WWTP outside Stockholm. The plant is built as a two-reactor SBR-facility, followed by a polishing chemical precipitation.

- A low load situation during the first years of operation;
- A load variation due to a daily work migration during weekdays.

The second problem could be defined as an insufficient amount of organic matter in relation to the nutrient load. However, the limited load resulted in an extended solids retention time (SRT). An initial SRT during the first half year operation was estimated at close to 40 days. This in turn resulted in a complete nitrification, but a rather limited denitrification, but foremost an unexpected high discharge level of phosphorus. This discharge was suggested to be caused by a secondary release of polyphosphate. The mitigation method was to add septic sludge as an organic carbon source. This action proved to be efficient. Shown in Table 3 are the annual mean values of the relevant pollution variables in the wastewater into the biological reactors. The removal of all pollution variables was improved. The discharge values over three years are presented in Table 4.

Table 3 : Comparison of inlet concentrations and pollution ratios during year 1997 and 1998/1999, (after Morling [9])

Period	Year 1997	Year 1998/1999
Inlet concentrations		
COD, mg/l	353	650
BOD_7, mg/l	121	194
BOD_5, mg/l	105	169
Tot-N, mg/l	26.5	26.2
Tot-P, mg/l	7.9	9.7
Ratios		
COD: BOD_5	3.36:1	3.85:1
BOD_5: Tot-N	3.96:1	6.45:1
BOD_5, Tot-P	13.29:1	17.4:1

Table 4 : Summary of discharge figures at the Tjustvik WWTP from 1998 through 2000 (72 obs.), all values in mg/l, (after Morling [9])

Variable	COD	BOD_7	Total P	Total N	NH_4-N
Consent level	(< 70)	< 10	< 0.3	< 15	< 4
Max value	168	10	0.4	18	14
75 % level	32	< 3	0.24	9.3	3.2
50 % level	< 30	< 3	0.15	5.9	0.27
Min value	< 30	< 3	0.05	2.4	0.01

This process alteration may be characterized as a substantial improvement of operation efficiency. On the other hand was it really an optimization of the plant? Still it is difficult to answer this question accurately, as the main objective for the process modification was first of all to safeguard the consent values for the pant. On the other hand rather than representing a "true" optimization of the plant operation, it does exemplify a necessary step towards an optimization.

IV. Conclusions

The four examples demonstrate empirical findings from wastewater treatment plants with most different operation conditions. These findings illustrate some crucial points with respect to operation of biological plants. The insights may be summarized in four major perspectives:

- The needs for an understanding of the more or less inevitable load fluctuations that will govern the plant operation during its lifetime. This understanding must be reflected in the fundamental design of the plant. An incorporation of a sufficiently flexible operation mode would be of great value in this respect;
- Needs for a comprehensive process control, based on an extended use of on-line instruments both at the inlet side of the plant, inside the process train, as well as at the discharge point of treated water. Only an active process control by means of more or less instantaneous "feed-back" on changing conditions may justify the expression "optimized operation ";
- A separation of the storm water collection from the sewers that inevitably will result in improved

operation conditions especially for a biological treatment installation;

- And last, but not least, a committed and process oriented operation management working at the plant. Or, in other words: The day-by-day operation of a wastewater treatment plant may be seen as an ongoing very large, full-scale scientific work. The need of interest and curiosity shown from the plant staff may be illustrated by a metaphor from one of the short stories by Sir Arthur Conan Doyle [10]. Sherlock Holmes says: *"We approached the case, you remember, with an absolutely blank mind, which is always an advantage."*

V. Acknowledgments

The paper has been commented by Ms Åsa Westlund, head of the Sweco Environment Process department from technical aspects. Mr Guy Taylor has corrected linguistic errors. Thank you both.

References Références Referencias

1. Jenkins. D, Daigger, G. T. and Richard M. G. (2003) "Manual on Solving Activated Sludge Bulking, Foaming, and Other Solids Separation Problems" 3rd (Third) edition Spiral-bound – June 28, 2003.
2. Morling, S (2014) "Problems in Water Environmental Control—Sense and Nonsense in Measurement of Water Protection" Journal of Water Resource and Protection, 2014, 6, **-**Published Online November 2014 in SciRes. http://www.scirp.org/journal/jwarp doi.
3. Standard ATV-DVWK -A 131E: Dimensioning of Single-Stage Activated Sludge Slants.
4. BioWin 4.1, Envirosim.
5. Marklund, S. and Morling, S (1994)"Biological phosphorus removal at temperatures from 3 to 10 oC - a full scale study of a sequencing batch reactor unit", Canadian Journal of Civil Engineering, 21, pp 81-88.
6. Berg, J. and Morling, S. (2013) "Process Adaption and Modifications of a Nutrient Removing Wastewater Treatment Plant in Sri Lanka Operated at Low Loading Conditions", Materials Sciences and Applications, 2013, 4, pp 299-306.
7. Morling, S. (2007) "Plant performance of an Sequencing Batch Reactor in Poland, operated with high Chromium load, reaching advanced nutrient removal" Proceeding at the Vienna conference on Large Wastewater Treatment Plants, September.
8. Morling, S. (2008) "Nitrogen removal efficiency and nitrification rates at the Sequencing Batch Reactor in Nowy Targ, Poland" VATTEN 2, pp 121- 128.
9. Morling, S. (2001) "Performance of an SBR-plant for advanced nutrient removal, using septic sludge as a carbon source" Water, Science and Technology Volume 43 No 3 pp 131 – 138.
10. Conan Doyle, A. (1893) *"The Cardboard Box",* from "The Memoirs of Sherlock Holmes", published in ISBN 0 907486 86 X.