IMPACT OF A BIOLOGICAL PHOSPHORUS REMOVAL ON BIOGAS RECOVERY

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ABSTRACT
A full-scale investigations supported by laboratory tests on specific operational problems have been described in the paper. Basic mechanism of EBPR i.e. release and uptake of phosphorus are based on growth and decay of microorganisms with the use of easy biodegradable carbon sources. During laboratory tests confirmed with full-scale operation, it was found that an unit amount of a biogas being generated from primary sludge is lower than expected basing on volatile suspended solids removal. The system with mesophilic fermentation of sludge as a stabilization method experienced significant decrease of a biogas production (up to 30 %). Unwanted result was a decrease of an energy recovery potential. Initial explanation of this this problem was proposed based on Wentzel's model of biodegradable matter circulation.

KEY WORDS
Sludge processing, phosphorus removal, nutrient removal, sustainable development, WWTP operation optimization,

INTRODUCTION

Need for SCFA generation in wastewater treatment

Present, modern wastewater treatment plants (WWTPs) are designed based based on concept of enhanced biological nutrient removal (especially a phosphorus removal - EBPR) which in most cases requires higher amount of electron donors than it is usually accessible from raw wastewater. Full scale application of an EBPR technology (i.e. without chemical addition) was accelerated by J. Barnard's concept of short chain fatty acids (SCFAs or more common named VFAs) generation from primary sludge to supplement the treatment train with necessary easy biodegradable carbon sources. (Barnard 1994, 2000). General principle was to perform an acidogenic phase of an anaerobic fermentation in separated facilities and direct obtained SCFA-rich stream of supernatant upstream the multi-phase biological reactor (Moser-Engeler et. al. 1998). These compounds are utilized as an energy source ("electron donors') for two main unit processes responsible for nutrient removal i.e. phosphorus release/uptake and denitrification.
The paper describes results of routine observations supplemented by laboratory dynamic investigations on specific problem when presence generation of SCFAs had been recognized am main cause of decrease of a biogas generation leading to a decrease of an energy recovery potential. As this fact adversely impacts sustainability of the WWTP it was found worth of being investigated.

Methodology
Data regarding wastewater quality (raw, settled, treated) as well as sludge parameters were completed by the Nowy Sącz WWTP laboratory on daily composite samples. Cracow University of Technology laboratory completed tests on fermentation gas production conducted by the CUT were used as a reference (Cimochowicz-Rybicka and Kurbiel 1994, Cimochowicz-Rybicka 1999,2001).

RESULTS AND DISCUSSION

Case study highlights the problem
The problem arose during tests on Nowy Sacz WWTP which is the main test field for authors of this paper regarding EBPR process optimization with an emphasis on energy sources from sludges. As it was described previously (Rybicki and Kurbiel 2000), the Nowy Sącz WWTP has been designed for municipal wastewater treatment, servicing a community of approximately 80000 inhabitants. It is in operation since 1996. Process layout is based on a MUCT system. Sludge processing is of combined type: primary sludge is passing through a fermenter used for VFAs generation to gravity thickener while a WAS is simultaneously stabilized aerobically in the activated sludge reactors then thickened mechanically in drum screen.

Unfavorable proportion of carbon source (expressed as easybiodegradable COD i.e. COD_{EB}) to the total phosphorus P ratio led to incorporation of the SCFA fermentation to the process layout. Figure 1 shows changes of total phosphorus vs time. Figure 2 shows a COD_{EB} to P ratio in eight samples of settled (primary treated with no chemical addition) taken and examined is winter 2003. One can see that this value is slightly higher than presented in year 2001 i.e. 5,6 ppm against 5,15 ppm (Rybicki , 2003). These grab samples were tested for easybiodegradable COD concentration and compared with daily composite sample for a phosphorus concentration. It is visible that additional electron donor are required for most of time.

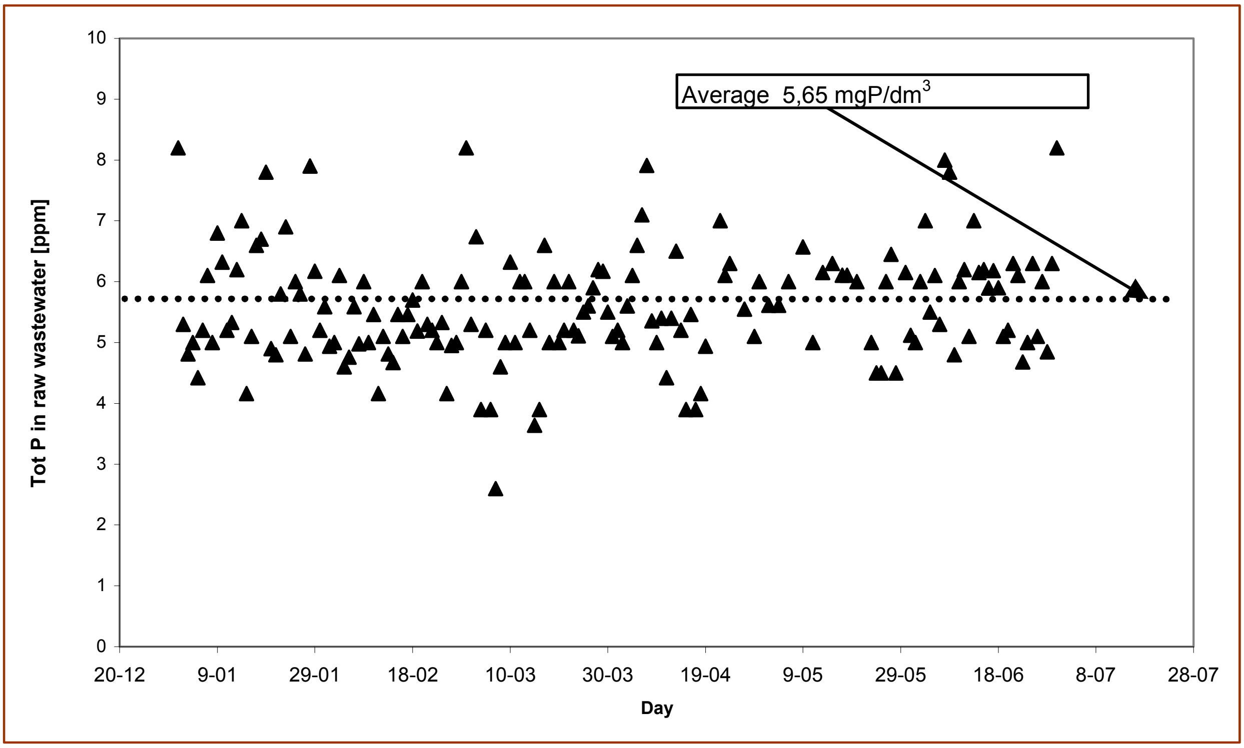

Fig. 1. Total phosphorus vs time – 1st half year 2003 .

Treated wastewater fulfilled required quality standards regarding phosphorus concentration (1,5 ppm) without chemical addition (precipitation).

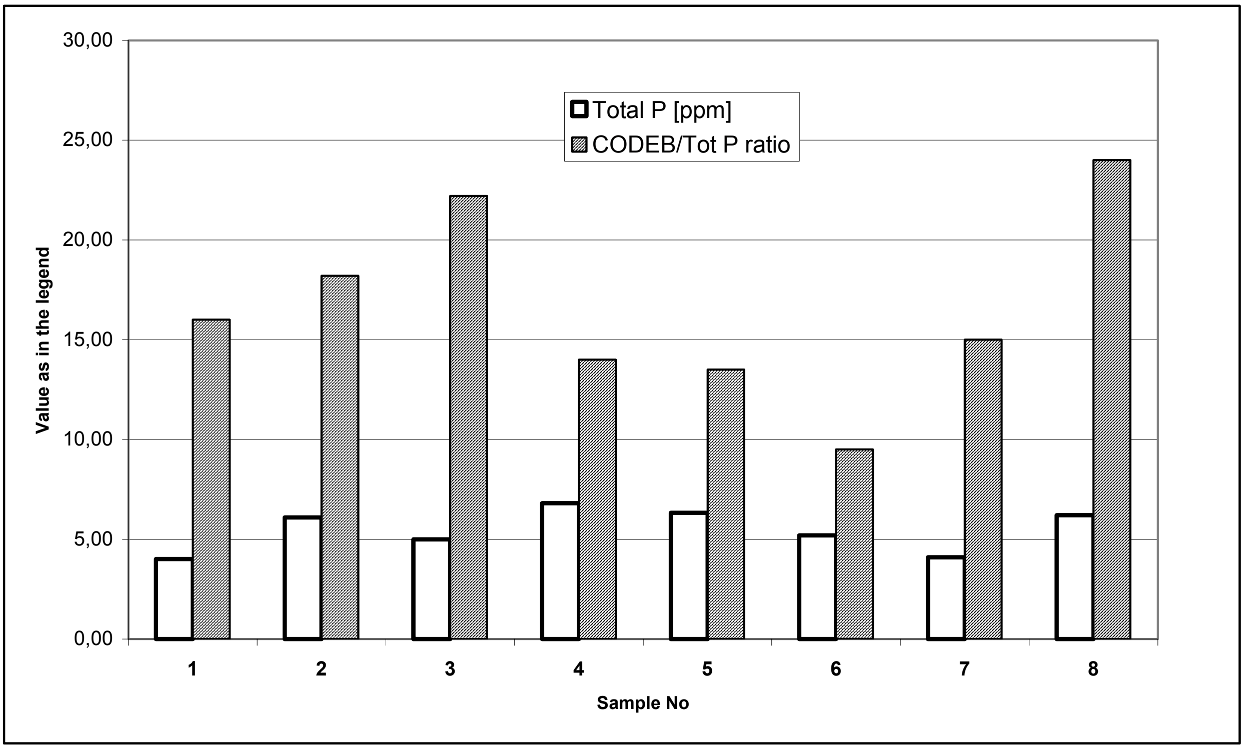

Fig. 2. COD_{EB} to TotP ratio in pretreated (settled) wastewater – 1st half year 2003 .

Adverse impact on a biogas production

Routine gas production observations by the WWTP led to the conclusion that real net unit gas production was lower than it had been expected. These was confirmed by respirometric tests on real sludges from the plant. Unit gas production reflects amount of gas produced, expressed in standard cubic meter per 1 kilogram of volatile suspended solid removed (similar results were obtained when amount of gas being produced per one kilogram of VSS supplied was measured). Results from full scale operation in year 2003 (1st half) has been presented in Fig.3. below as an example of a general situation at the WWTP. One should note than expected value is usually assessed as 0,85 to 1,0 Std m^3 per 1 kg of VSS removed. Observed value were presented as a cumulative curve showing that. This curve shows that in over 80% of daily observation the gas yield was lower than 0,8 std.m/1 kg VSS removed. Observations vs time showed some lower unit gas production in summer months, but this problem cannot be solved with seasonal changes explanation only. Operational check of the plant's operation showed that this might be credited to intensive use of pre-fermenters to decompose some part of an organic matter in raw sludge to less complexed carbon compound, mostly SCFAs which in further step of biological treatment can serve as electron donors for EBPR and biological denitrification processes.

Decrease of unit gas production mentioned above was credited by author to the fact, that extended SCFA production based on feed back control mode combined with limited possibility of sludge discharge control led to two unfavorable results: lack of control of real need for easily biodegradable carbon source for processes also decrease of potential substrate for mesophilic fermentation due to conversion of large load of primary sludge to VFA to be used in a wastewater treatment train.

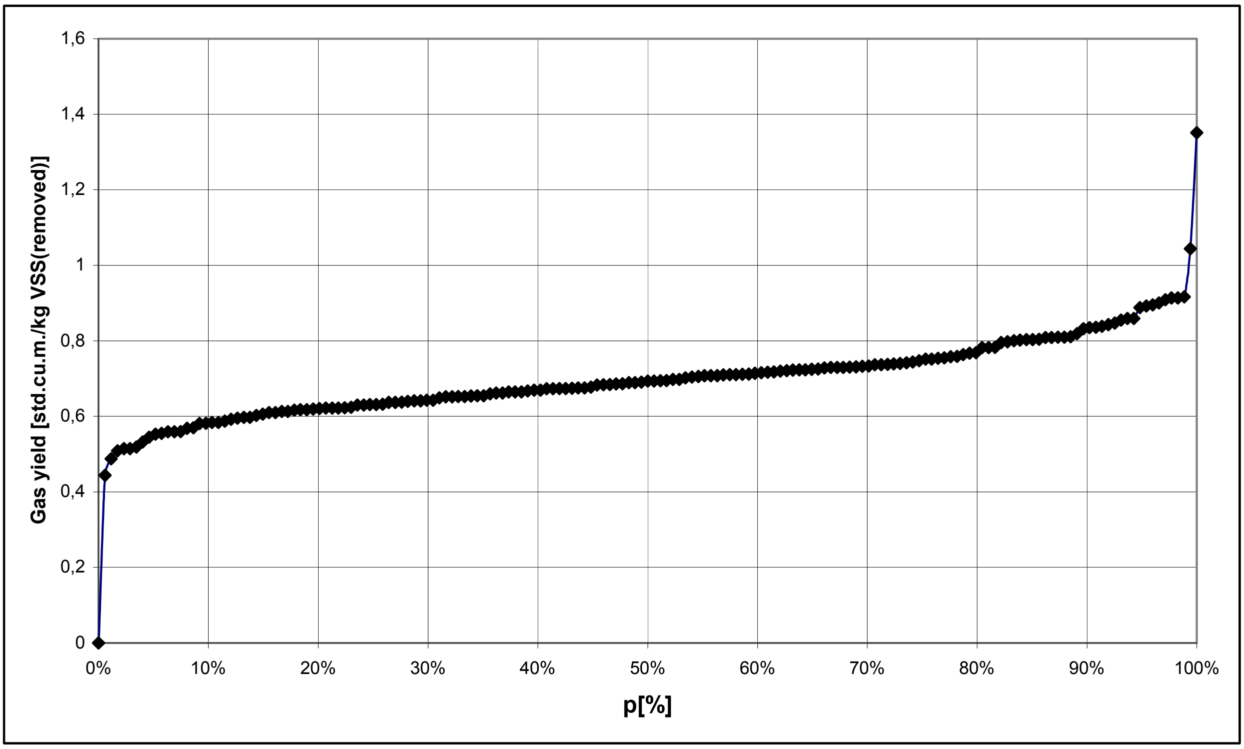

Figure 3. Gas yield cumulative curve - Nowy Sacz case study .

Assessment of decrease of fermentation products available

Product of mesophilic fermentation of wastewater sludges i.e. methane rich gas called a 'Biogas' can be utilized as fuel for boilers and gas generators. In general term stoichiometry of this process can be simplified as in Equation (1):

$$C_nH_aO_bN_c + (2n + c - b - 9sd/20 - ed/4)\ H_2O \rightarrow de/8\ CH_4 + (n - c\ sd/5 - de/8)\ CO_2 + sd/20\ C_5H_7O_2N + (c - sd/20)\ NH_4^+ + (c - sd/20)\ HCO_3^- \quad (1)$$

where: $d = 4n + a - 2b - 3c$,

s = fraction of waste converted to cells,

e = fraction of waste converted to methane for energy ($s + e = 1$),

$C_nH_aO_bN$ = empirical formula of waste being digested,.

Obtained volume of a biogas generated during a mesophilic digestion phase as well as the methane content in the biogas can vary depending on the nature of the substrates delivered with raw (in this very case - primary) sludge. So it might be influenced by an conduction of an acetogenic phasis. The laboratory method selected for this study was the respirometric batch tests (Cimochowicz-Rybicka 1999, 2001). It appears to be the most precise method for determination of digestion parameters. The method focuses on batch test on a biogas generation, which remains proportional to organic matter decomposition. As particulate matter cannot transfer through the microorganisms' cell it is required that organic and inorganic substrates are in soluble form. Conversion of an organic matter into methane and carbon dioxide leads to decrease of degradable organic matter content in sludge.

Fermentation is being characterized (simplified) bya first order process with respect to fermentable components (Moser-Engeler et al., 1998), where the hydrolysis constant, at pH dependence being neglectible can be expressed as:

$r_{acid} = k_{acid}*X_{acid}$

Where:

r_{acid} – acid production rate

k_{acid} – hydrolysis constant

X_{acid} – fermentable fraction of a COD, usually assumed 30% of total COD.

For operational conditions similar to those at the Nowy Sącz WWTP, Moser-Engeler (ibidem) proved that a hydrolysis constant equals to 0,152 d^{-1}. This led us to general assumption that in operational personnel of the Nowy Sącz plant tends to increase the SRT in pre-fermentation so real value of this parameter is higher than 2 d as in the design calculations. It would probably led to produce and 'use' higher part of easybiodegradable matter.

Table 1 summarizes calculations of probable decrease of fermentable products in primary sludge directed to digestion chambers. It was assumed that easybiodegradable matter concentration is proportional to easybiodegradable matter (which may be rough estimation) also 12% efficiacy of fermentation after 2 days was assumed. SRT data were calculated from the operation log, COD decrease observations were done on grab samples. SRT values are for pre-fermenter and sludge thickener together. Lowest line of the table shows a SFM value . It is a "Surplus fermentation" module which shows relative amount of fermentation products quantity as related to the dimension value expressed as:

$$\text{SFM} = \frac{\%of\ fermented COD - 12\%}{12\%}$$

Table 1.Calculation of a SFM value

Sample No	**1**	**2**	**3**	**4**	**5**	**6**	**7**
SRT [days]	3,1	3,2	2,8	4,1	6,5	5,8	4,8
% of fermented COD	15	15	14	17	19	18	16
SFM	25%	25%	17%	42%	58%	50%	33%
Part of COD_{EB} directed to digestion	50%	50%	52%	43%	37%	40%	47%

- Difference between percentage of fermented products directed to digestion, calculated based on real SRT and a design value i.e.12% of fermented primary sludge to be directed to the digestion chamber shows the last line of Table 1. It is clearly visible that in this specific case approximately half of design load of fermentation products reaches digestion chambers. That may be an explanation of lower-than-expected biogas generation. Longer SRT in digestion chamber might be a countermeasure – to some extent. Also longer SRT sometimes leads to mass overload of a pre-fermentation unit causing problems with a mass balance

Basing on real SRT values calculations were made to compare real biogas production with possible daily amount if design parameters are kept. These simplified calculations are presented in the Fig.4. which shows that a biogas production is approx. 20% lower than expected .

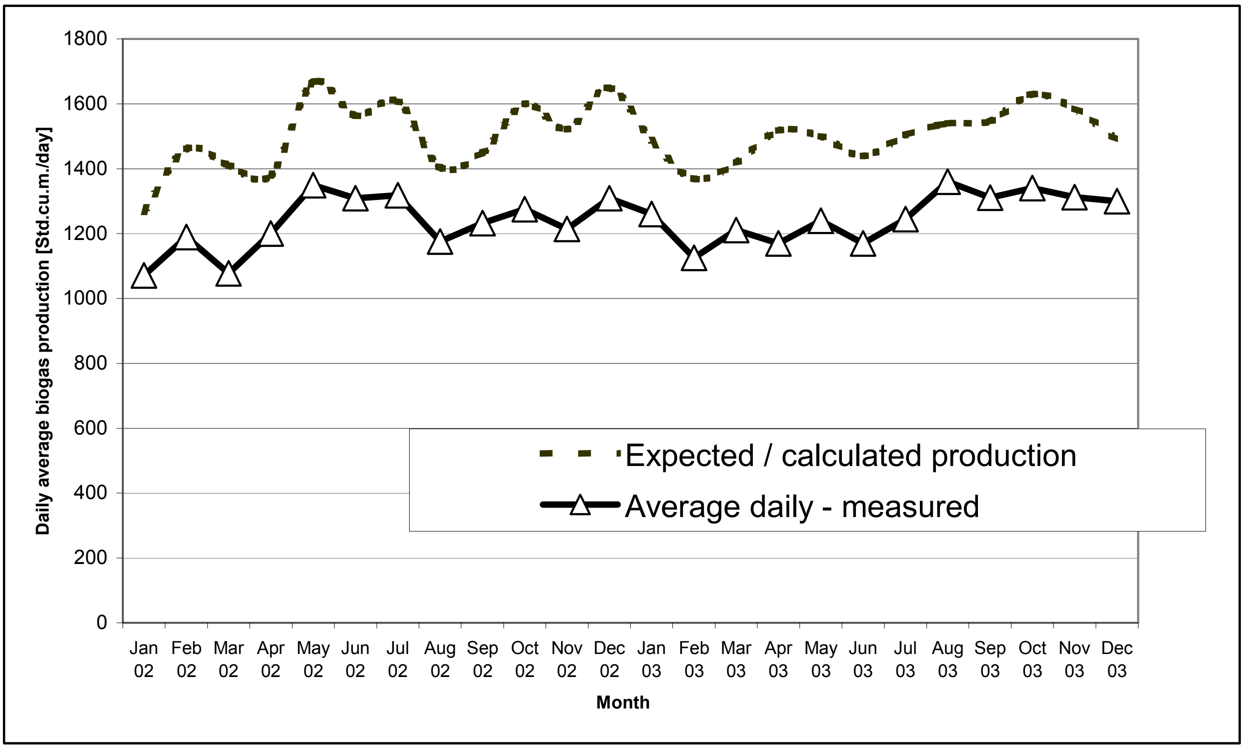

Figure.4. Measured and expected daily biogas production – calculated on real data.

CONCLUSIONS

The paper describes results of investigations on impact of biological phosphorus removal on a biogas production; it has been observed that SCFA generation may in longer period adversely impacts a fermentated products concentration in sludge

SCFA generation of primary sludge delivers required amount of an electron donors and the MUCT type treatment plant however it may lead to decrease a biogas volume production and finally may influence economical characteristics of entire plant

Overloading of pre-fermentation unit may adversely affect not only biological reactor itself, but also may create operational problems in other part of a WWTP for example it may significantly decrease energy recovery.

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