International Journal of Innovative Studies in Sciences and Engineering Technology (IJISSET)

ISSN 2455-4863 (Online) www.ijisset.org Volume: 5 Issue: 5 | 2019

An Alternative Approach to Wastewater Treatment – A Possible Source of Resources and Two Pathways for an Energy-Saving and Resource Capture Treatment

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Abstract: *There are many threats to a sound development towards a more sustainable future in the world today. Some of these threats are strongly connected with a too short-sighted use of fundamental elements in the industrialized world. The matter is accentuated in the rapid urbanization that "swallows" both arable land and important wetland facilities. Simultaneously, the needed energy supply in many countries is based on fossil sources. Furthermore, the accelerating water pollution in some areas is often neglected by the authorities. This paper highlights possible pathways towards a far more sustainable situation:*

- *By taking advantage of solar cell energy production to fully cover the needed treatment needs for a far-reaching biological treatment of waste water;*
- *To recover both carbon (C) and phosphorus (P) as useful raw materials from municipal sludge. The matter may be accomplished by the Hydrothermal Carbonization process.*

Keywords: *Carbon, phosphorus, Hydrochar, thermal treatment, recovery, solar cells, intermittent biological operation*

A CHANGE OF ENERGY SUPPLY FOR WASTEWATER TREATMENT PLANTS (WWTP)

Rapid urbanization in many parts of the world, especially in sub-tropical and tropical areas, includes some critical challenges with respect to both environment and the use of energy. Within the fields of waste and wastewater management, additional problems are found: On one side a reluctance to handle refuse – based in cultural convictions, and a "new" experience: that the refuse and untreated municipal wastewater treatment plant are both threats to the health and to the physical environment. Numerous examples may be found in the world today, see for instance [1], article found in the June number (2018) of Journal of Water Resource and Protection (JWARP): "Dying Traditional Water Bodies in India Struggling to Survive against Unplanned Development". The paper clearly reveals the concerns in India related to the set-back in wastewater management related to the rapidly growing urbanization. Similar concerns may be found in other identified parts in South Asia(and similar geographical locations) such as in Thailand, although this country has started a pathway to a more sustainable wastewater management for the nation.

Some key issues are raised in these matters: Which are the incentives needed to establish a sustainable wastewater treatment in this part of the tropical world, also including large parts of Africa and Latin America? Some possible pathways may become crucial:

- A traditional, necessary, but insufficient condition is the need for a safe and durable sanitary environment. The matter is often not found attractive enough from a political perspective.
- To provide a safe downstream situation with respect to the needs for a comprehensive re-use of water. This argument is neither found to be sufficient to establish the safe wastewater treatment in many places.
- A contradictive argument is often raised: A safe treatment will become too expensive and resource-consuming. The argument, often identified and even found decisive, is that the needed treatment will end up in extensive operation costs.
- Another problem may be linked to the (normally false) popular conviction that the treatment will cause further environmental inconveniences. There may be questions with respect to the diffusion of odours from the plant, or that the disposal of sludge will become an environmental threat.

Now, would it be possible to overcome these obstacles, by means of arranging positive pathways that tackle these matters in a decisive way? Let us first focus on the water treatment part of a WWTP, and then discuss an option with respect to sludge management. This latter task will focus on recovery of phosphorus and carbon from the sludge emanating from the wastewater treatment facility.

ENERGY SUPPLY FOR THE WATER TREATMENT PART

One important issue that is described in the following is the matter of energy supply. Traditionally the needed electrical energy is supplied from a central distribution system. This in turn is linked to a central (electric) energy production unit. The energy production in both India and Thailand, and other countries as well, is often based on facilities using fossil raw material – carbon or fossil oil. The approach to partly overcome this problem at a wastewater treatment facility has so far been to establish on-site biogas installations by means of anaerobic digestion reactors.

Now, may we find even better options for the energy supply? Yes, indeed! Combining the developed solar cell system with the fundamental understanding of the biological treatment conditions may create a pathway to a smart model to totally avoid the dependence of fossil-based energy. In addition to this advantage it may substitute the complex and rather expensive model to convert the carbon content into methane gas. The set back with respect to solar cells has been the time limitation – the sun is "absent" at night. However, two ways are evident to overcome this limitation:

The knowledge that suspended growth biological reactor systems, typically an activated sludge plant, may be aerated in an intermittent way. Several studies and full-scale operations support this statement, see [2], [3], [4] and, [5], In this context, an interesting example may be highlighted from Sweden. A full-scale study was performed for the community of Mora in the central part of Sweden. The main WWTP facility treating wastewater from around 15 000person equivalents is based on a classic treatment plant configuration. The treatment process chain is the following, see ***Figure 1***.

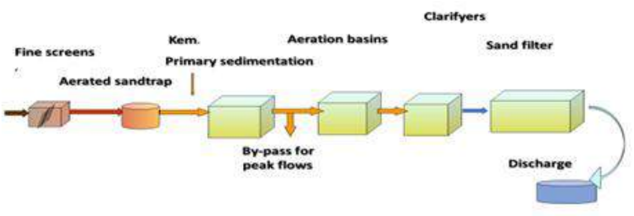

Figure 1.*Simplified flow process chain over the Mora WWTP*

The Mora plant performance as recorded during the test periods are summarized in ***Table 1.***

Table 1 *Performance results during 2015 at Mora main WWTP, periods before and after the introduction of intermittent operation, source [4]*

Period Jan to mid-March	pH	Total P	BOD	COD	SS	Q
		mg/l	mg/l	mg/l	mg/l	m³/d
Number of obs	6	6	6	6	6	14
Max value	7.8	1	35	98	48	8 629
Mean value		0.41	21	67	24	6 283
Median value	7.4	0.34	22	73	21.5	6 321
Min Value	7.10	0.10	8	39	12	4 261
Period early June early Nov						
Number of obs	11	11	11	11	11	11
Max value	7.6	0.28	13	53	11	8 748
Mean value		0.15	6	38	5	6 031
Median value	7.5	0.14	6	36	3.6	5 685
Min Value	7	0.10	3	30	2	4 247

The results as presented from these two periods may be summarized as follows:

- A comparison of a continuous aeration mode with an intermittent mode demonstrated savings in the aeration supply of around 42% when the intermittent mode was established;
- The plant performance in an overall perspective was improved. The most striking result was the discharge of suspended solids, going down from more than 20 ppm as average value to less than 5 ppm.
- Accordingly, the phosphorus and organic levels were lowered by around 50 to almost 70%, as compared with the continuous operation mode.

1. The option to operate a low-load biological system with aeration during daytime, and with an "idle" period during night-time will allow the combination of an energy supply from solar cells during daytime hours.
2. In the developed perspective an improved capacity to store the energy by "smart" batteries will further increase the attractive use of the solar cell energy supply concept.

As intermediate conclusions, the following may be stated:

The treatment model with biological treatment, based on intermittent aeration, will allow a simple operation, with versatile treatment objectives. A main advantage will be the potential to avoid methane gas production, due to transformation of organic

ISSN 2455-4863 (Online) www.ijisset.org Volume: 5 Issue: 5 | 2019

carbon (methane gas is 28 times more reacting with respect to climate change than the carbon dioxide).

Even rather high-rate activated sludge plants may be operated with an energy-saving strategy, by closely observing the process key variables. Typical variables are the free oxygen level in the aeration reactor as well as the suspended solids concentration, to control the biological status on-line.

AN EXAMPLE OF AN ALTERNATIVE CONFIGURATION OF A WWTP FOR WARM CLIMATE CONDITIONS

The following example represents a typical situation in many sub-tropical and tropical countries. An outline of conditions for a needed municipal WWTP may be found as follows:

A community that hosts 30 000 inhabitants, with no treatment facility, but with an expanding sewer system connected to the discharge point and thus will represent an uncontrolled discharge of raw wastewater;

- The water environment is in many aspects threatened and downstream re-use of the water is not possible;
- The power supply by electricity is based on an energy facility using fossil fuel as the input;
- A reliable and as simple as possible treatment model is needed.

Three further conditions are imperative for the alternative WWTP.

- The mental and intellectual understanding of the needs for an improvement is at hand.
- Dedicated staff to handle the management and day-by-day operation of a wastewater treatment facility.

Typical effluent standards may tentatively be adopted as follows, see ***Table 2.***

Table 2 *Indicative consent values for a 30 000 person-equivalent WWTP for the semitropical and tropical world*

Variable	Level	Value
BOD_5	<15	mg/l
(COD, indicative)	<80	mg/l
SS	<20	mg/l
Total nitrogen	<15	mg/l
Ammonia nitrogen	<4	mg/l
Total phosphorus	<1.5	mg/l
pH range	6 - 9	
Water temperature	<35	^{o}C

REALISTIC RESULTS FOR THE OPTION

Physical conditions, such as design flow and design pollution load for the example is shown in ***Figure 2*** over the treatment process chain. The figure also includes expected discharge levels at an integrated operation model.

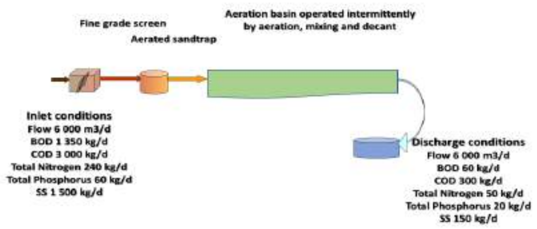

Figure 2. *Simplified balance model for a typical low-load WWTP, adopted for medium sized communities, loads and anticipated results.*

Some indicative power demands for the treatment process are calculated from the classical process engineering outlines found in most updated design programs and manuals. In this case, as the model foresees a power supply based on solar cells, and thus an intermittent operation, the fundamental considerations that were found for instance in the SBR-system, the Oxidation Ditch model and the Biode Nitro options are relevant.

The power demands may be divided into two situations at design load conditions, daylight operation and night-time conditions.

Power consumption during aeration: 145 kWh/h, to be based on solar cell energy, and related to the design capacity.

Power consumption during night-time: 10 kWh/h, to be based on battery power emanating from the solar cell energy generation, for an intermittent night-time operation.

Safety peak capacity factor for daytime operation 1.3.

DISCUSSION

Some fundamental points are to be kept in mind in relation to this solution on a wastewater treatment based on a fossil-free energy supply:

I. The necessity to upgrade and maintain a sustainable water protection, but also to provide a discharge quality that may allow a re-use of the treated water, such as for irrigation;

II. To arrange an energy supply based on a local production by means of solar cells and batteries, thus independent from a central energy production;

III. By the solar-cells energy production modules, a "carbon sink" model is provided;

IV. Finally the model may be used as a demonstration that handling and protecting the environment may be an attractive and thus popular model for further development.

OPTION TO RECOVER PHOSPHORUS AND CARBON FROM MUNICIPAL SLUDGE

Traditionally the reuse of phosphorus from municipal sludge has focused on using the sludge as a fertilizer on farming land. However, recent in-depth studies regarding the sludge contents and potential risks connected to the sludge management has been put in focus. This matter has in turn pointed out urgent needs to find better ways to reuse especially the phosphorus content in the sludge from the municipal wastewater treatment plants. The phosphorus removal at most Swedish plants now exceeds 95% of the incoming amounts, see for instance [6]. Thus, the potentials for phosphorus reuse from separated sludge is an important task. The demands for a high-quality phosphorus product within the food production industry will become a strong driving incentive. An adopted model for phosphorous recovery is based on the struvite crystallization option, see for instance a summary from 2012 presented at the annual 'WEFTECH conference proceedings [7].

The following discussion revolves around the Hydro Thermal Carbonization treatment model, in the following referred as HTC. The findings go back to studies performed during the 1990s by inter alia Markus Antonietti, at the Max Planck Institute of Colloids and Interfaces. The fundamentals of the process have been described in many scientific papers. A recent study [8] performed by Michaela Lucian and Luca Fiori describes comprehensibly the fundamental elements of the process. A description of the process is presented as follows:

- Organic rich matter, such as refuse streams, containing organic carbon is treated by means of heat and pressure during a limited time.
- The process will disintegrate complex organic matter with a polymer structure into short chain carbon substances.
- The disintegration is by convention exothermic, thus in theory liberating energy as heat.
- Typical treatment models are found in the market as either batch mode operated reactors, or continuous reactors in a cascade model.
- Basic design outlines for the operation are the following: process temperature 180 – 220 °C; operation pressure 16 – 22 bars and an efficient reactor time of 2 – 4 hours.
- Some of the important findings from tests with the technology are the following:

  # A concentrate – called the hydrochar – with high carbon content and a high phosphorus capture.

  # The hydrochar is easily dewatered to between 50 and 65% dry solids.

Although the versatile potential use of the HTCis described in the scientific literature, the following discussion will concentrate on the application on municipal sludge and the possibilities to extract phosphate from the concentrate.

In a study Heilmann, S. and others [9] present a "Phosphorus Reclamation through a Hydro Thermal Carbonization (HTC) process of Animal Manures". The findings are important with respect to the possible application on municipal sludge. With respect to the phosphate capture, the following quotation from the study is important:"Phosphate-*recovery was achieved in the yields of 80-90% by subsequent acid treatment of the hydrochars, addition of base to acid extracts to achieve a pH of 9, and filtration of principally calcium phosphate."*

The study also concludes that there is no specific advantage of the pathway to struvite formation over the way to the enrichment by calcium phosphate.

A study for Kohtla-Järve Vesi, Estonia concerning the main WWTP included a test study on the HTC-process regarding the potential for various technical improvements of the wastewater treatment facility, reference [10]. The study confirmed the potential of phosphorus capture up to 90% in the hydrochar. The study did not go further to test acidic leaching of the phosphate for further extraction.

However, in a recent study for the Swedish Energy Authority, Björkman et al [11] have presented results from an experimental study. This study concerns the potentials of phosphorus recovery from an HTC process. The presented model in this study also includes an interesting option to recover the carbon for a versatile use, rather than to only produce methane gas through anaerobic digestion. The study refers to laboratory pilot tests suggesting a recovery of phosphorus and carbon of > 90% for different recycling use. A development in Germany on the HTC-process is now advancing the technology to full-scale applications. There are now pathways to arrange continuous HTC-treatment models, incorporating three to four reactors either operated in a true plug-flow model, or as a cascade model, refence given by Terra Nova Energy GmbH, in Germany, see further reference [12]. The obvious alternative is to operate the model in a batch mode that is under a parallel development both in Sweden and Germany.

An additional concern with respect to the reuse of sludge from municipal plants has been presented recently in Germany, see reference [13]. The study points out deep concerns regarding the remains of pharmaceuticals in the digested sludge. The German authorities foresee a total prohibition for sludge deposits on arable land and other deposit actions in nature. Thus, there are incentives for alternative actions by necessity.

SOME VIEWPOINTS ON AN ADVANCED RECOVERY OF CARBON AND PHOSPHORUS

As pointed out above, the technology for recovery of both carbon and phosphorus is now advancing and will become available within the foreseeable future. The focus on recycling the phosphorus from municipal wastewater is facing a rapidly growing interest.

Although the HTC technology seems to include some promising and attractive options, there are still important questions to be raised and clarified in further studies. The important points that need further investigations are inter alia:

- To clarify how a clean phosphate may be extracted in a refinery process. Such a study is now underway at the Royal Institute of Technology, Stockholm;
- To further clarify the quality of reject water from the hydrochar, with respect to residual pollutants;
- To find out to what extent the process may cause the formation of dioxins, as the process itself provides at least two of the three necessary components: heat and organic carbon.
- To evaluate to what extent the HTC process may become a feasible way to disintegrate pharmaceutical remains found in municipal sludge.

Nevertheless, the process will allow for some very promising pathways within the future municipal sludge management. Some advantages may be stated already at this stage:

- The process will incorporate both sludge stabilization and hygienization by convention;
- The option to recover both phosphorus and carbon as potential valuable raw materials;
- The far better dewatering results in comparison with conventional sludge treatment systems.

Acknowledgements

Malte Lilliestråhle, Svenska Biokol AB for valuable support, Dr Eva Björkman and Benjamin Wirth and A Clemens for excellent studies on the phosphorus extraction mode.

MsSophie Taintor at Sweco International for linguistic scrutinization of the text.

Thank you all!

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