WASTEWATER TREATMENT AND RECYCLING WITH MICROALGAE IN COLD CLIMATE

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ABSTRACT (250 WORDS MAX)
Resilient societies need technology with high recycling possibilities, as well as possibilities to treat wastewater with local ecosystem services as dominating driving forces.
Modern wastewater treatment often suffers from the problem of being a linear system, rather than a recycling system. From a recycling point of view the nutrients in the wastewater is of highest interest.
The use of microalgae has been proposed as collection systems for the nutrients, with several potential advantages: 1) they treat the wastewater further from a pathogenic point of view, 2) they produce a sludge of interesting biochemical quality depending on the species present in the treatment ponds, 3) they use the naturally occurring ecosystem services available at the wastewater treatment site in the form of sunlight, wind, and regional biodiversity of phytoplankton.
The academic focus regarding microalgae use for wastewater treatment has to a large extent been on the "sunbelt", between latitudes 35 North and South, respectively. However, a few investigations have been performed on northern and southern latitudes. This paper summarizes experiences from using microalgae for waste water treatment at northern latitudes in Sweden and present suggestions for further research.

Keywords: subarctic climates, phytoplankton, HRAP, ecological engineering, fellingsdams

1 INTRODUCTION

This paper presents experiences regarding the use of microalgae in wastewater treatment in rural areas in northern Sweden. Based on these experiences we discuss potential development of sustainable wastewater treatment in rural areas based on high rate algae ponds (HRAPs) or improved fellingsdams.

Resilient societies need technology with high recycling possibilities, as well as possibilities to treat wastewater using local ecosystem services as dominating driving force. The latter is often accompanied with the need of large land areas, and therefore possible to realize mainly where land is readily available and cost of land is low. This is generally not the case in cities, but often the situation in rural areas. Ponds of different types are used for wastewater treatment in many places from Alaska in the north to New Zealand in the south. In such ponds, microalgae play an important role for the treatment process as long as light is sufficient and temperature high enough. At low temperatures the major function of the ponds are only as sedimentation chambers.

When light and temperature are sufficient microalgae take an active part of the ecosystem function in ponds. Their presence impact pond functions in several ways, for example is oxygen produced through the photosynthesis process, pH increases due to the bicarbonate depletion and giving a shift in the carbon dioxide/carbonic acid balance, etc. [1]. A sunny day, pond water can reach a pH above 10 due to microalgae activity, which have an impact on pathogenic organisms in the wastewater. In traditional oxidation or stabilization ponds the microalgae show a natural stochastic development pattern, with blooms followed by crashes. A more controlled type of ponds for microalgae growth is the so called HRAPs (High Rate Algae Ponds) or HROPs (High Rate Oxidaton Ponds). These ponds are shallow, 0.3-0.5 m, and the wastewater is put to continuous movement, most often by paddle wheels.

The above mentioned situation is well known microalgal behavior from ponds situated within the so called “sunbelt” area, which is defined by Oswald [2] as below latitudes 35 North and South. Further north and south the number of investigations on microalgae behavior and potential is much more limited, but there are some references also fore these climates. Investigations in the south of New Zealand have been made by e.g. Park, et al. [3], [4-6], Craggs, et al. [7], [8, 9], and investigations in the north have been made in Canada by Abdelaziz, et al. [10], Chevalier, et al. [11], Dumas, et al. [12], Tang, et al. [13], Laliberte, et al. [14], De la Noüe and de Pauw [15] and in Sweden by Grönlund, et al. [1], Grönlund [16], [17], Hanæus, et al. [18].

In the following section experiences regarding the use of microalgae in wastewater treatment in the northern parts of Sweden are presented, and in section 3 suggestions for development will be discussed.

2 EXPERIENCES FROM THE NORTH OF SWEDEN

The pioneer in the field of wastewater treatment with microalgae, William J. Oswald [19-22], reported that this practice was appropriate to use in the “sunbelt” area, not further north than latitude 35 [2] due to restrictions in light and temperature. However, in a literature review by Grönlund, et al. [1] it was found that from a cold climate perspective the role of light and temperature was not very clear. In laboratory experiments Grönlund, et al. [23] could show that microalgae collected in the Mid Sweden region could grow readily in wastewater also under cold climatic conditions. During spring and autumn conditions–with temperatures between 5 and 10ºC –the fastest growing cultures in the experiments had doubling times shorter than two days. These doubling times were possible to repeat also in field experiments [24], but could not be proved possible to maintain over longer periods of time. Even though the microalgal growth was slower, Grönlund, et al. [24] concluded that the HRAP technology may be possible to apply successfully from April to October in subarctic climate at latitude 63˚N. These conclusions were based on experiments with high-rate algal ponds (HRAPs) during two seasons, with focus on spring and autumn function.

Grönlund, et al. [25] also investigated the sustainability of a modeled wastewater treatment plant based on HRAP functions, designed for 60˚N. Sustainability was evaluated with a socio-ecological method [26], and with emergy evaluation [27]. The results indicated that the microalgal treatment plant model could be considered having a better position for future sustainable development, compared to a conventional three-step wastewater treatment plant and to a mechanical-chemical plant complemented with a constructed wetland.

So called “fellingsdams” [28], i.e. wastewater stabilization ponds complemented with chemical precipitation and a common wastewater treatment method in northern Sweden, were also investigated from a microalgae perspective. In a case study, two fellingsdam systems were modified by turning off the precipitation during the productive season and the effluent quality measured [18]. In one of the two fellingsdams, the organic matter and phosphorus concentration in the effluent was just slightly above the values that had been reached when using chemical precipitation during previous years. In the second fellingsdam, the performance was not as good. The investigated seasons were characterized by extremely high and low precipitation, respectively, which influenced the flow rates to the fellingsdams significantly and complicated the evaluation. The potential of the biological component replacing the chemical component during the productive period was, however, demonstrated in the experiments. At one of the fellingsdams (Orrviken fellingsdams) a special study was done regarding the microalgal species and genera [29]. This study found that the stabilization ponds did not convert “sewage COD” into “algal COD” to the extent expected. Microalgae were dominant in the effluent COD for only 3-4 weeks out of 12 weeks investigated. The investigation confirmed the traditional “boom and bust” behavior of algae in stabilization ponds, and that species and genera composition varied over the season.

3 DISCUSSION

The experiences described in section 2 above indicate that pond treatment systems based on microalgae have the potential to be a resilient waste water treatment solution in rural areas also in the cold climate of Mid Sweden. The pond treatment systems can be seen as an ecological engineering solution. Ecological engineering is a branch of engineering characterized by an aim to use the available local renewable energies, self-organization and self-design to a large extent, compared to traditional engineering which is still most of the time characterized by imported goods and services as well as engineering design of the components [30, 31]. Wastewater treatment with microalgae fits well into the tradition of ecological engineering with its utilization of the natural occurring ecosystem services available in the form of sunlight, wind, and the regional biodiversity of phytoplankton [17]. We will now discuss potentials for development of pond treatment systems for use in rural communities in northern Sweden.

3.1 Test of more wastewater types

In closed system microalgae cultivation it is possible to choose and decide what species should be cultivated. In open ponds this is almost never possible. The reason is the varying conditions regarding light regime, temperature, nutrient availability and other abiotic factors that occur over the day, the season, and the year. Therefore, the species composition in wastewater ponds will most likely not be stable. The combination of variations in wastewater composition, light, temperature etc. will also be slightly different also between ponds in the same region, which means that every wastewater treatment plant will have its own “fingerprint” of microalgae community. This species composition cannot easily be predicted or modeled but needs to be tested. Therefore, several types of wastewater should be investigated in a region were research is conducted.

3.2 Ponds with storage capacity

From an ecological point of view cold climates are characterized by a bilateral pulse pattern over the year. During the winter time most organisms try to keep their activity as low as possible to survive until the summer period when activity levels in the ecosystems are very high. This pattern is highly relevant for the microalgal growth. Making use of the natural energies available in a northern region therefore suggests mimicking the natural pattern. An approach to do this can be to store the wastewater during the winter season and treat it during the summer season when the biological activity is very high. Grönlund, et al. [24] estimated that HRAPs would function properly from April to October in the mid Sweden region, meaning 5-6 months of operation and 6-7 months of storage. Grönlund (unpublished data) made estimations of the storage capacity needed for a system designed for 5800 m3 of wastewater per day; see Figure 1, 2 and 3. Interestingly, the calculations showed that the area needed for the HRAP was approximately the same as the area needed for the storage pond. With floating HRAPs, described in the next section, the total area demand could be substantially decreased.

3.2 Decreased area use by floating HRAPs

The HRAPs (raceways) used for microalgae culture are area demanding in order to capture the amount of sunlight needed. In most wastewater pond treatment systems, there are often several types of ponds, as for example a collection pond to even out periods of higher loads, and maturation ponds to prolong the detention time in the wastewater treatment plant and ensure pathogen die-off. In theory, it should be possible to have the HRAP floating in another pond (Figure 4). Two positive effects of such a design would be that the pond surface gives the “flat ground” that is needed for the shallow HRAPs and that very little piping will be needed. In mid and northern parts of Sweden, and similar places where ice will cover the ponds during winter time, the HRAPs can be lowered down into the water to avoid freezing problems that could occur if they were located on land. A problem area for this design may be how to balance the paddle wheel, which put an uneven weight to the HRAP. It is intended to further investigate pros and cons of this design.

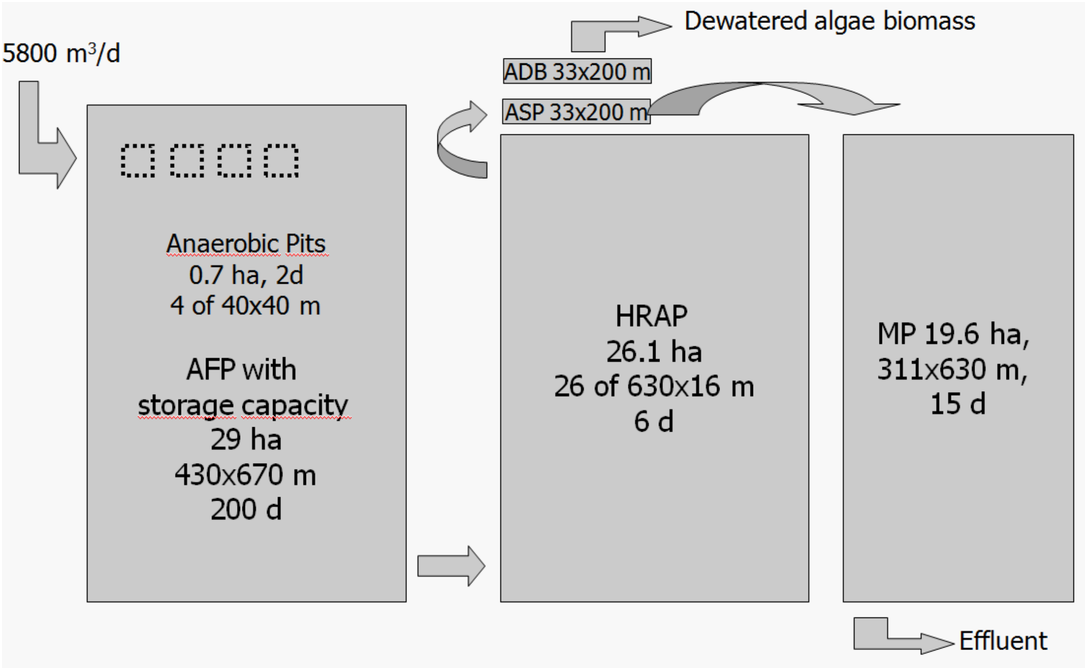

Figure 1. A pond system designed for 5800 m3/d load of wastewater. First an Advanced Facultative Pond (AFP) with storage capacity for 6,5 months (200 days) with a depth of 4 m. During the 5,5 months of summer season the wastewater proceeds to a High Rate Algae Pond (HRAP) with channels of 16 m width and a depth of 0.3 m. The wastewater is set to motion with a series of paddle wheels. The detention time in the HRAP is 6 days. After that the wastewater enters an Algal Settling Pond (ASP), 3 m deep with a detention time of 1.5 days, and finally a Maturation Pond (MP) of 1 m depth and a detention time of 15 days. The algae sludge from the ASP is dewatered on an Algal Dewatering Bed (ADB).

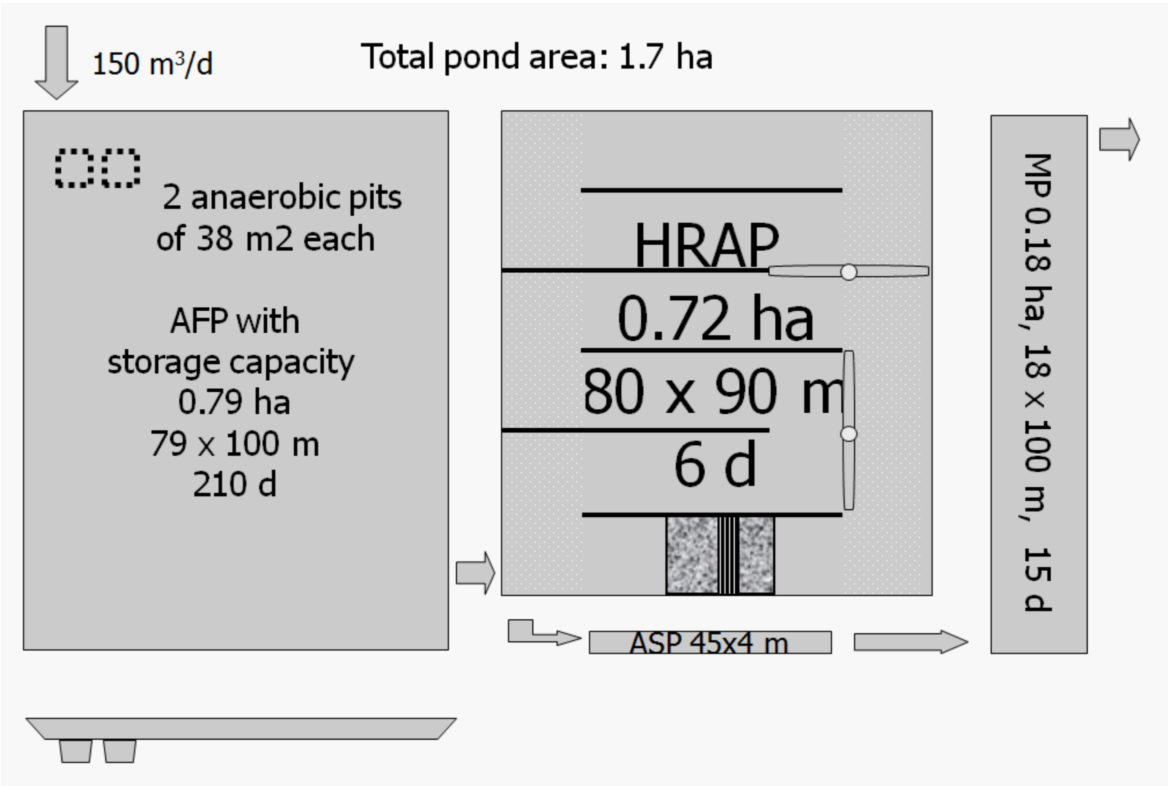

Figure 2. A pond system designed for 150 m3/d load of wastewater, and a storage time of 7 months, 210 days, meaning that the High Rate Algae Pond (HRAP) is only active for 5 months during the summer period. The HRAP has a paddlewheel with concrete reinforcement in the bottom down in the picture. To the right it also has swinging walls, enabling flexibility in the HRP volume. Other abbreviations, se Figure 1.

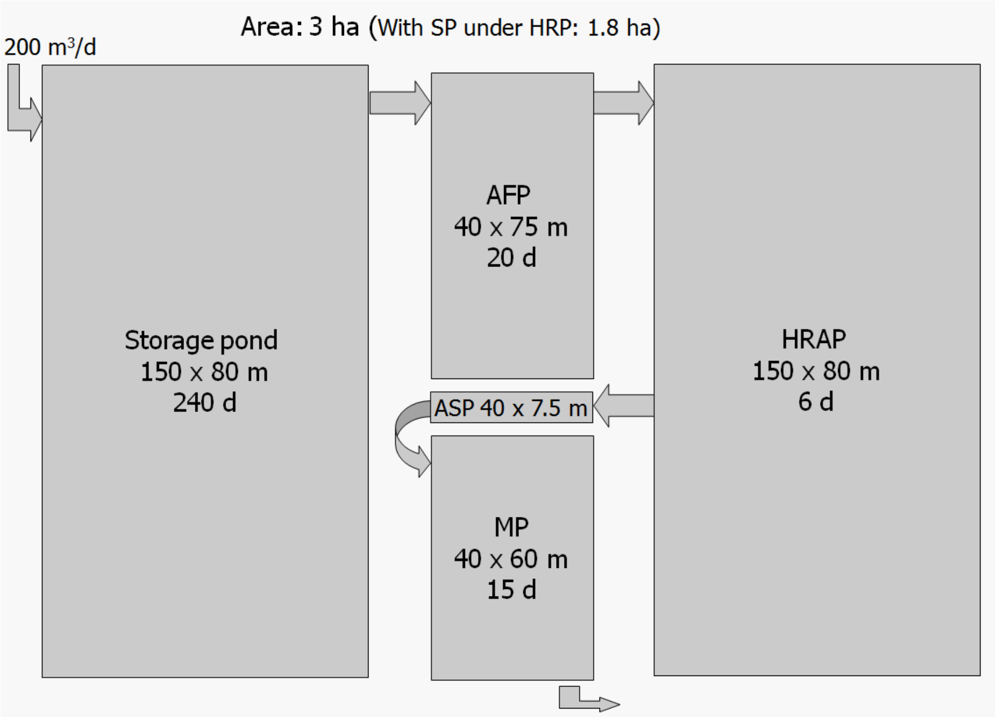

Figure 3. A pond system designed for 200 m3/d load of wastewater, and a storage time of 8 months, 240 days, meaning that the High Rate Algae Pond (HRAP) is only active for 4 months during the summer period. Other abbreviations, se Figure 1.

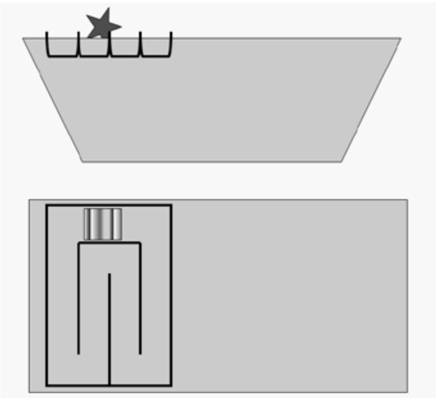

Figure 4. Floating HRAPs (raceways) in top of a stabilization pond or maturation pond.

3.2 Anaerobic tank

In a series of ponds for waste water treatment, an anaerobic pond is often the first pond [32]. Problems connected with this pond are frequent occasions of bad smell and that methane can escape to the atmosphere contributing to climate change. Oswald and co-workers developed and patented a series of ponds, which they called AIWPS (Advanced Integrated Ponding System) [33]. The first pond in this system contain anaerobic pits; for example [34, 35] addressed the design of this part of the system. The idea with this design is that any bad smelling gases coming from the anaerobic pits should be captured in oxygen rich layers of water above the pit and oxidized into other, less smelling compounds. It would also be possible to recirculate oxygen rich water from the HRAP pond to ensure a favorable oxygen condition in this top layer water. Instead of the pit design it would be interesting to investigate what can be achieved with a submerged anaerobic tank, see Figure 5. It must be mentioned though, that anaerobic bacteria are well-known for their low activity during cold conditions.

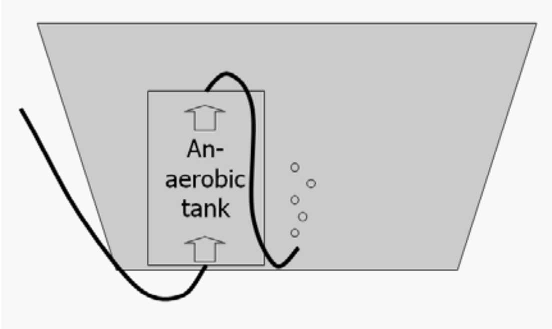

Figure 5. An anaerobic tank submerged in a facultative pond.

3.5 Microalgae for Bio-CCS

Another approach for utilization of microalgae and waste water could be to use the algae to absorb CO_2 from flue gases with the waste water having the function of nutrient source for the algae growth (and being treated at the same time). The latest IPCC report points out a need to capture CO_2 also from biofueled power plants to be able to minimize climate impacts in future. The HRAP technology is probably not best suited for this since the flue gases from the chimney are supposed to pass the water column. Instead vertical cylinders will perform better. Experiments with such systems have been made primarily in areas with more evenly distributed yearly sunlight compared to the short period of daylight wintertime in the Mid Sweden region; performance should be tested also in this region.

3.6 Use of the microalgae sludge

Above has been described how microalgae contribute to the treatment of wastewater or flue gases. A secondary effect (or a first effect depending on your initial intentions) is that microalgae produce a sludge of interesting biochemical quality depending on the species present in the treatment facility and how the wastewater treatment plant is designed. Possible products from the microalgae can for example be feed for aquaculture or in feedlots, extraction of pigments, enzymes, and oils of different kinds for fuel or industrial use. Grönlund, et al. [1] noted that less than one per mille of the world algal species are sufficiently explored concerning biochemical contents.

In HRAPs the sludge constitute almost fully of microalgae. In fellingsdams the chemical precipitation constitute a major part of the sludge.

For a Bio-CCS facility it would be beneficial if the sludge or product from the sludge retained the captured CO2 for a substantial time. One possible use of the microalgae for carbon storage purposes can be as insulation material. It should be investigated further what are beneficial use of the generated algae biomass in different situations.

Sludge from waste water treatment contains resources in form of both nutrients and energy. Some studies have investigated if it is more interesting to utilize the energy contents or the nutrient contents of such sludge [36, 37]. If it is possible to utilize the energy in the sludge to efficiently replaces fossil fuels, the energy resource value of the sludge was shown to be of the same magnitude or even larger compared to the nutrient recourse value when replacing artificial fertilizers. In situations where available technologies for energy utilization are not feasible, e.g. due to small scale, or when renewable energy sources have become dominant so it is not fossil fuels that can be replaced, the nutrients gain higher value as recourse. The most interesting situation would of course be to simultaneously utilize both the energy and the nutrient resource value while decomposing harmful substances and polish the water from pathogenic micro organisms.

4 CONCLUSIONS

Resilient societies need technology with high recycling possibilities, as well as possibilities to treat wastewater with local ecosystem services as dominating driving forces.
Modern wastewater treatment often suffers from the problem of being a linear system, rather than a recycling system. From a recycling point of view the nutrients in the wastewater is of highest interest.

Using microalgae as a collection system for the nutrients has several advantages: 1) they treat the wastewater further from a pathogenic point of view, 2) they produce a sludge of interesting biochemical quality depending on the species present in the treatment facility, 3) they use the natural occurring ecosystem services available in the form of sunlight, wind, and regional biodiversity of phytoplankton.

Experiences from the mid Sweden mountain regions suggests that an microalgae based type of ponds, so called HRAPs (High Rate Algae Ponds), can be used 5-6 month during the summer period. The rest of the year a storage pond is used. For coming research it is suggested to test more types of wastewater, since the species composition is depending on this; to test floating HRAPs, preferably located on the storage ponds; to test if anaerobic tanks is a possible way forward; and to use microalgae for Bio-CCS, collecting flue gases from a biofuel based power plant in the region.

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