Building-integrated water reuse in combination with urban farming

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Abstract

Building-integrated water recycling is aimed at saving water in office buildings and housing complexes by separate collections and afterwards biological treatment of the various waste water streams. Moreover, the combination with aquaponics and hydroponics allows for the production of fresh food, namely vegetables and fish, whereby water for irrigation purposes as well as transport costs for vegetables will be saved. The presented research work comprises two stages: (1) the development and implementation of combined water treatment systems at laboratory scale particularly for black water treatment, and (2) field tests at a representative huge housing complex. As result of the first research phase a liquid fertilizer could be produced by means of a combined process concluding a hydrolysis step, sedimentation, followed by microfiltration. The intended relation of the nutrients was nearly achieved.

Keywords: water reuse, hydroponics, aquaponics.

1 Introduction

The global water shortage results in an emerging need for novel, more efficient water management systems for both urban regions, where a high amount of fresh drinking water is wasted, and rural areas with a huge consumption of water for field irrigation.

Building-integrated water recycling focusses on water savings in office buildings and housing complexes by separate collection and afterwards biological treatment of the various waste water streams. Moreover, the combination with aquaponics and hydroponics allows producing fresh food, namely vegetables and fish whereby water for irrigation purposes as well as transport costs for vegetables.
will be saved [1–3]. Hydroponics is a kind of plant cultivation where soil is replaced by mineral nutrient solutions. Aquaponics is a food production system that combines aquaculture with hydroponics.

The presented research work refers to the project ROOF WATER-FARM and concentrates on the development of advanced water treatment technologies for black water reuse. Novel combined waste water treatment systems are to be developed to enable the generation of high quality natural liquid fertilizers from black water for use in plant breeding.

2 The project ROOF WATER-FARM

ROOF WATER-FARM demonstrates paths towards innovative city water management and urban food production. Potentials and risks of redesigning across sectors of infrastructure will be explored and communicated.

The research association investigates opportunities for building-integrated water treatment systems to irrigate and fertilize roof-top greenhouses. Technologies for water treatment and aquaponics will be examined at a demonstration and test site in Berlin-Kreuzberg. The research focuses on a hygienically safe usage of rainwater, greywater and blackwater as both a strategy for city water management and a potential for urban food production.

The objectives of ROOF WATER-FARM are as follows:

- developing cultivation technologies of water-based plant and fish production (hydroponics, aquaponics) combined with decentralised water treatment technologies for rainwater, greywater and blackwater;
- testing hygienic safety of the cultivation including significant micro-pollutants (selected pharmaceuticals);
- assessing product quality according to relevant national and European requirements and
- extracting and testing liquid fertilizer (NPK) production.

Furthermore, based on preliminary findings, the transferability of the ROOF WATER-FARM concepts into the urban area will be examined. Structural variants of greenhouse plant and fish production in greenhouses will be projected for the scale of a building unit, and scaled up for urban spaces at large.

Over the course of the project, researchers will develop process-related communication and training tools for building-integrated water treatments and urban food production.

3 Method and materials

The shown research work comprises the development and implementation of combined water treatment systems at laboratory scale, particularly for the production of liquid fertilizer comprising prefiltration, membrane filtration, hydrolysis, advanced oxidation processes and disinfection.
Two testing facilities in laboratory scale has been planned and constructed to experimentally prove the appropriateness of the relevant processes for production of liquid fertilizers (figure 1).

Figure 1:  (a) Experimental setup for hydrolysis and filtration (V = 400 ml), (b) Experimental setup for photocatalysis (TiO2/UV).

The tests have been repeated twice to evaluate the results of the filter flux and the quality of the treated black water at a high fluctuating consistence. The herein presented data results as average value of at least three subsequent tests.

During the whole operating time, the main water parameters like COD (chemical oxygen demand), BOD (biological oxygen demand), TOC (total organic carbon), ammonia, nitrate, and phosphate are measured periodically.

4 Results

First, generally appropriate processes and combinations of processes have been identified for the treatment of black water as liquid fertilizer. The following figure 2 shows the possible process chains for formation of liquid fertilizer and its respective function.

A parameter study, comprising a multitude of experiments at varying process parameters (pH value 1 to 4, pressure 1 to 3 bar), revealed as beneficial pretreatment a process combination of 1) hydrolysis, 2) sedimentation (removal of coarse particles) and 3) filtration (removal of fine particles). For filtration, specially adapted nickel microsieves with isopores for black water treatment had been produced with a pore diameter of 9 or 12 µm and a surface of 15 x 15 cm². The sieve production was carried out by means of a micro electroplating process. The following tab. 1 shows results of the optimized black water treatment in terms of characteristic organic sum parameters and relevant nutrients, which has been obtained by this process chain.
Figure 2: Possible process combination for production of liquid fertilizer out of black water.

Table 1: Consistency of treated black water after hydrolysis (pH 2.4), sedimentation and filtration by microsieves (pore diameter 9 µm) (TOC: total organic carbon, COD: chemical oxygen demand).

<table>
<thead>
<tr>
<th></th>
<th>BW</th>
<th>Hydroly.</th>
<th>Sed.</th>
<th>MF</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8,28</td>
<td>2,43</td>
<td>2,47</td>
<td>2,47</td>
</tr>
<tr>
<td>TOC [mg/L]</td>
<td>684</td>
<td>5910</td>
<td>815</td>
<td>800</td>
</tr>
<tr>
<td>COD [mg/L]</td>
<td>974</td>
<td>9970</td>
<td>957</td>
<td>922</td>
</tr>
<tr>
<td>potassium [mg/L]</td>
<td>74,1</td>
<td>122</td>
<td>116</td>
<td>118</td>
</tr>
<tr>
<td>orthophosphate [mg/L]</td>
<td>48,2</td>
<td>101</td>
<td>101</td>
<td>104</td>
</tr>
<tr>
<td>nitrate [mg/L]</td>
<td>20,3</td>
<td>1010</td>
<td>992</td>
<td>1020</td>
</tr>
<tr>
<td>ammonia [mg/L]</td>
<td>112</td>
<td>90,3</td>
<td>85,2</td>
<td>87,5</td>
</tr>
<tr>
<td>ratio</td>
<td>NO₃⁻</td>
<td>NH₄⁺</td>
<td>PO₄³⁻</td>
<td>K</td>
</tr>
<tr>
<td>BW</td>
<td>1</td>
<td>0,09</td>
<td>0,10</td>
<td>0,12</td>
</tr>
<tr>
<td>fertilizer</td>
<td>1</td>
<td>0,10</td>
<td>0,10</td>
<td>0,56</td>
</tr>
</tbody>
</table>

During the hydrolysis the amount of phosphate and potassium were raised by 110 and 64%, respectively. However, aside the intended increase of nutrient concentration, hydrolysis also effects the undesired accumulation of COD and TOC. COD-active substances will be degraded by oxygenic exhaustion and synthesis of partially phytotoxic material resulting in significant damages to plants.

The sedimentation reduces the COD after hydrolysis to a value of 957 mg/L, which lies obviously below the critical upper limit of 2000 mg/L. It is assumed that the majority of COD-active organic substances was adsorbed on particles and removed with the sediment after the settling process.
The microfiltration is applied as a post-treatment step in order to remove the remained particles and bacteria and does not affect the concentration of the organic components and the nutrients as well.

The relative high concentration of nitrate results from the hydrolysis where nitric acid is employed for the pH control. Nitric acid is an ideal reagent for the acidification since its salt, nitrate, is a very valuable compound for fluid fertilizers. Compared to treated black water, the relation of nutrients in a commercial liquid fertilizer has been met well at three of the relevant nutrients.

Further experiments for the treatment of blackwater by photocatalysis were stopped since the high turbidity strongly diminished the light intensity that is necessary for the efficacy of the catalytic particles.

5 Outlook

In general black water can be reused as liquid fertilizer for plant breeding.

As a relevant share of the black water gets lost during the sedimentation process and therefore lacks at the production of liquid fertilizer, alternatives such as band filtration will be tested. Further investigations focus on membrane filtration, such as ultrafiltration and hygienization of the liquid fertilizer. First concepts for a pilot plant are being developed.

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References