Analysis of the water absorption capacity of reed for use in eco-friendly filters

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Abstract. Reed is able to absorb water, a quality that enables using it as a cartridge filler in eco-friendly filters to address the contamination of waterbodies. Aside from capturing harmful substances and pathogens, such filters actively absorb water. As the filtering medium becomes saturated with a fluid, its absorption capacity degrades, which is why one needs to know the saturation rates if the water purification process is to be effective. This knowledge helps find out how frequently the cartridge filler must be replaced. Absorption rates were sufficient for purification for three hours as shown by experimental laboratory tests using reeds ground to a variety of specific particle sizes without additional processing that would modify its structure physically and chemically. This indicates that cartridges have to be refilled with a new biosorbent at least twice over the daily period of bacterial activity observable from 10 am to 4 pm during daylight hours.

1. Introduction

In light of the alarming environmental situation, especially in industrial areas, efficient technical solutions based on biologically clean sorbents become imperative. These sorbents can purify waterbodies from biogenic contaminants without jeopardizing their ichthyflora and ichthyfauna. This fully applies to the plant-based absorbing structures, including the common reed (Phragmites australis).

Reeds are known to purify waterbodies from a number of harmful substances during vegetation [1-4]. Besides, reed can be collected and dried to use it as an eco-friendly sorbent to trap heavy-metal ions [5-11] or mechanically capture phytoplankton [12,13] that grows rapidly in areas at ecological risk and exacerbates the negative impact that aquatic environments are exposed to.

Cellulose-containing filtering materials, including reed, have a high trapping rate applicable to harmful substances of various hazard classes. Some papers analyze reed as a sorbent and binder for mercury, fluoride, lead, and cadmium [5-11,14]. However, despite being well-studied and proven an effective sorbent, it must be known how long reed can preserve its filtering capacity in an aquatic environment before it can be used in filtering units.

One of the main criteria for maintaining the operating properties of cellulose-containing materials is the time of saturation of the filter structure with a liquid. This is why this research sought to find the water absorption capacity of reeds as a function of its particle size and the duration of the absorption process in an aquatic environment.
2. Materials and methods

The experimenters used reed (Phragmites australis) collected in Voronezh Oblast, Central Federal District, in March this year. It is during this period that reeds have least water: 25% to 30% [15]. Beside bound water, raw reed contains cellulose, hemicellulose, lignin, and sundry organic substances, where the first three components are usually present in a 44-37-15% ratio, respectively [16].

For the purity of experimentation, collected reed was flushed with water to remove dust and sundry unwanted impurities from the surface. Reed was dried over two months under natural conditions at an indoor air temperature of 18±2 ℃, which reduced its humidity to 6-12%.

To find how the fineness could affect the absorption process, the reed stems were cut into 5/10/20/30 mm long parts. Five-liter plastic tanks were used to impregnate reed with water. Before immersion, each particle size-specific sample weighed 400 g.

Studies were carried out by weighting the biomass at an ambient air temperature of 22±2 ℃. The error of weight measurement was 1 g. Water that leaked from the biosorbent pores onto the scale pan was added to the saturated sample weight.

3. Results

Experimentation revealed that water absorption went on at the highest rate during the first hour. 5-mm particles had the largest values. This was due to a significant number of open absorption sites, especially early in the experiment. Then, as shown in Figures 1 and 2, the water absorption capacity degraded to nearly zero over 3 to 4 hours.

![Figure 1](image-url)

**Figure 1.** Reed weight gain due to water absorption as a function of its impregnation time.

The existing water absorption models detailed in [17] use parameters that have little effect on the absorption properties. This approach to finding for how long a material retains its filtering capacity may produce greater error. Relative absorption (Figure 2) calculated per kilogram of the sorbent enable a highly accurate approximation of the process kinetics by the equation

$$g(\tau) = c \frac{e^{(1-\tau)}}{\tau}$$  \hspace{1cm} (1)

where $g(\tau)$ is the relative water absorption, kg/kg of the dry biosorbent; $c$ is the diffusion parameter, h, which is a function of the particle size, see Table 1 for values; $\tau$ is how long reed remained in water (the impregnation time), h.
To run calculations based on the dependency (1), assume time values starting from Hour 1, i.e. the time interval for \( \tau \) is 1 to 8 hours.

Unlike the existing models, the exponent function (1) is proven to provide highly accurate approximation of the water absorption capacity for reed growing in the climate of Voronezh Oblast. However, the proposed equation is similarly applicable to the materials collected in the Central Federal District; and since that region is a cluster of industrial centers, biological filters with ground reed-filled cartridges could be effectively used to improve the quality of water there.

![Figure 2. Water mass absorbed to dry weight ratio, g/g.](image)

| Actual values depending on the particle size, mm | Recommended values for calculations depending on the particle size, mm |
|-----------------------------------------------|----------------------------------------------------------|
| 5 10 20 30 < 7 > 7                          | 1 0.7 0.65 0.6 0.9 0.65                                    |

Collected data (Figures 1 and 2) can be used to find the hydrophobicity of the material by the formula

\[
B = \frac{m_g - m}{m} \cdot 100\%  \tag{2}
\]

where \( m_g, m \) is the water-impregnated/dry mass, respectively, kg.

Although finer grinding increases reed hydrophobicity, as shown in Table 2, use of \(<5 \) mm biosorbents is not recommendable. This filter structure will induce a greater hydraulic resistance from the unit, and the surface will quickly become clogged before being saturated with harmful substances.

At the same time, the size of the crushed reed in the range of \(5 \) mm will allow not only to carry out the process of filtration of water with a high degree of purification and to retain more phytoplankton in the porous structure, but also to carry out the subsequent effective disposal of organic material by anaerobic fermentation. A sufficiently fine organic structure will be subject to deeper biological conversion due to the greatest availability of nutrients for processing microorganisms.

As a result of the organization of such a recycling scheme, fertilizer and associated biogas will be ready for introduction into the soil. According to the data of studies [18,19] with 1 kg of dry weight of algae at a temperature of 32 °C, a gas mixture with a volume of 0.8-1 m3 is obtained, which includes 65% methane (CH\(_4\)), up to 30% carbon dioxide (CO\(_2\)) and an average of 1% of the following
components $\text{H}_2$, $\text{H}_2\text{S}$, $\text{O}_2$ and $\text{N}_2$. It should be noted that for the process of anaerobic fermentation of phytoplankton-saturated reeds, city treatment plant anaerobic digesters can be used. Such a solution will avoid significant costs for the creation of biogas stations for these purposes, which will subsequently be loaded at full capacity only in the summer and autumn seasons.

Table 2. Sorbent hydrophobicity as a function of the water impregnation time.

| Water impregnation time, h | $\text{B}_2$, % |
|----------------------------|----------------|
|                            | 5 mm particle size | 10 mm particle size | 20 mm particle size | 30 mm particle size |
| 1                          | 100             | 70              | 65              | 60              |
| 2                          | 10             | 9               | 6               | 3               |
| 3                          | 0              | 3               | 6               | 15              |
| 4                          | 7              | 0               | 5               | 8               |
| 5                          | 0              | 3               | 0               | 0               |
| 6                          | 4              | 0               | 0               | 0               |
| 7                          | 0              | 5               | 0               | 0               |
| 8                          | 2              | 0               | 0               | 2               |

4. Conclusions

Experimental research proves that reed is most optimally used as a sorbent over 3 to 4 hours regardless of the particle size.

The smaller organic structure has a greater water absorption capacity and therefore a sorbing effect. In addition, the organization of subsequent disposal of such material by anaerobic fermentation will provide a deeper environmentally sound biological conversion. With all these positive factors, filling the filter cartridge with a reed with a fraction size of less than 5 mm is not advisable due to significant hydraulic resistance and rapid clogging of the surface.

Note that $<5$ mm reed is a promising solution for situations that call for quick surface cleaning, i.e. liquid hydrocarbons spills [20-21]. 10-30 mm particles are suitable for filtering out heavy metals and trapping pathogens, i.e. for addressing the wastewater effluents of treatment facilities. Given that phytoplankton is most active from 10 am to 4 pm, and its concentration peaks near water surface [20,22], waterbodies must be treated over this timeframe with the cartridges being replaced at least twice.

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