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Direct water reclamation from sewage using ceramic tight ultra- and nanofiltration

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ABSTRACT

Sewage is a nutrient rich reliable water source that is rather consistent in quality, volume and temperature, and is available in large amounts in urban areas. Decentralised reclamation of water including its constituents from municipal sewage, further referred to as sewer mining, is a concept in which municipal sewage is considered a resource instead of a waste stream.

In this research, water reclamation in the sewer mining concept was studied using ceramic tight ultra- (UF) and ceramic nanofiltration (NF). In our current approach, ceramic membrane filtration is proposed as pre-treatment for reverse osmosis (RO) to produce demineralised water for industries from municipal sewage. The objectives of this research are to study (i) the membrane performance, (ii) the organic matter and ion rejection, and (iii) the biofouling potential of RO using permeate water from the ceramic filtration.

The application of ceramic tight UF and ceramic NF for direct treatment of domestic sewage has been demonstrated in this study. The cross flow ceramic tight UF and NF fed with filtered sewage, can be operated for 1–4 days without any cleaning required. The membrane performance remained high with chemical cleaning with NaClO (0.1%) and HCl (0.1 mol L^{-1}) solutions. On average about 81% of organic matter was rejected by both ceramic tight UF and NF membranes. Finally, the pressure drop increase in the MFS fed with ceramic NF permeate was low during an operation of 14 days. These results were comparable with the increase in pressure drop of an MFS fed with Dutch drinking water.

1. Introduction

Sewer mining is a decentralised water reclamation concept, where municipal sewage is considered a resource instead of a waste stream. In this concept, the sewage flow is fully or partly captured and directly treated for on-site usage, usually for non-potable purposes [4]. There is a growing interest in sewer mining concepts as a possible economic and sustainable alternative for the currently applied decentralised sewage treatment plants (STPs), while recovering nutrients, water and energy from the sewage flows.

Reclamation of treated sewage for drinking water purposes is a much more difficult approach than for non-potable use due to psychological barriers and the perceived health risk [21]. However, sewer mining is considered a breakthrough approach for the production of industrial water, minimising competitive fresh water claims in urban areas. In northern and central Europe, the majority of fresh water supply is used for industrial water [33], whereas for many applications, industrial water requires a low salt concentration and low hardness, i.e. demineralised water [3].

Reverse osmosis (RO) is commonly applied to produce demineralised water, considering its high rejection of impurities, manageable costs, and ease of operation [2,8,21]. However, RO membranes are sensitive to fouling which declines its efficiency, performance and salt rejection. Four types of fouling can be defined; particulate fouling, organic fouling, inorganic fouling (i.e. scaling), and biofouling [17]. Biofouling is caused by biological growth on the membrane and in the feed spacer. Not only the biofilm itself but also the extracellular polymeric substances (EPS) produced by the microorganisms, can deteriorate the membrane performance [9,26,28]. Membrane fouling is directly linked to the feed water quality, therefore extensive pre-treatment of RO-feed water is required [6,17].

Current RO-based water reclamation consists of conventional sewage treatment followed by multimedia filtration (MMF), microfiltration (MF) or ultrafiltration (UF) and RO [2]. In the

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conventional treatment, municipal sewage is usually led through primary settlers, activated sludge process, secondary settlers, whereas the sludge is stabilised in a digester prior to dewatering and disposal (Fig. 1) [25,34]. However, the conventional RO-based water recycle technology requires a large footprint and does not make optimal use of energy, water and nutrient reuse [19,27]. Therefore, alternative treatment concepts are in demand.

Ravazzini et al. [20] and Sayed et al. [24] suggested to disregard the conventional sewage pre-treatment by treating sewage directly with polymeric UF and nanofiltration (NF). However, they found that this process is not economically feasible, due to the duration of the membrane cleaning. The layer of polymeric membranes is very sensitive to chemical cleaning with the use of extreme pH, temperature or chemical concentrations [1,5,13]. Since the concentration of chemicals is directly linked to the duration of the chemical cleaning process, treating the membranes with low chemical concentrations will increase the duration of the chemical cleaning. Sayed et al. [24] found that due to the severe clogging of the membranes using sewage as feed water, chemical cleaning with a duration of 8 h was required after a filtration time of 8 h including hydraulic backwashing. This means that the filtration and relative production downtime are similar.

Forward osmosis (FO) is a new technique that can be used as an alternative water reclamation step in the proposed sewer mining concept [15]. FO is a membrane separation technique based on osmotic pressure; the feed solution is driven through the membrane by a draw solution that has a higher ion concentration than the feed solution. FO consumes much less energy than other membrane techniques, since osmotic pressure is the driving force and no additional pressure is required [14]. The permeate water can be reclaimed with RO, and FO is a suitable pre-treatment step for RO [11,15,35]. However, in order to remove water from sewage, a high ion concentration in the draw solution of FO is required. Due to the high ion concentration, a high pressure RO is necessary, which consumes a lot energy [11]. Furthermore, implementation of the FO is limited by its relatively low flux [18].

Ceramic tight UF or ceramic NF is considered a potential alternative of interest for water reclamation in the sewer mining concept [26]. Ceramic membranes, compared to polymeric membranes, are robust; they have a high mechanical strength, a high chemical and thermal resistance, and a homogeneous distribution of narrow pores [32]. The membrane is expected not to be damaged by high pressure, high temperatures or chemicals, enabling high pressure backwash and vigorous chemical cleaning of the membrane. Other benefits are the long life of the membrane (>15 years) and the recyclability of the membrane material. To date, ceramic membranes are less frequently utilised than polymeric membranes due to their higher price per m^2 [26]. In literature, conclusive definitions cannot be found to distinguish ceramic UF from ceramic NF. In this research, the following definitions were used based on the molecular weight cut-off (MWCO) of the membranes: ceramic membranes with a MWCO between 500 and 3000 Da are defined as tight UF membranes, and those with a MWCO smaller than 500 Da as NF membranes.

In this paper, the concept of the production of industrial water from raw sewage in small residential areas using ceramic tight UF or ceramic NF is presented. Fig. 1 gives an overview of the concept in which the conventional RO-based water reclamation process is replaced by a fine sieve, ceramic filtration and RO. This decentralised water treatment can supply demineralised water to nearby located industries, and the resultant cost saving in water transportation can be expected. In our proposed concept, the raw municipal sewage passes firstly through a coarse sieve and grit removal followed by a fine sieve of 1 mm to remove the largest fraction of suspended solids [22]. Then, the pre-treated sewage is directly subjected to ceramic filtration, which serves as the pre-treatment step for RO. The concentrate from the ceramic membrane and the debris from the fine sieve can then be stabilised in anaerobic digester systems in which the organic matter is largely converted into biogas by, for example, an up-flow anaerobic sludge blanket (UASB) reactor. In conventional STPs, a large part of the organic matter is mineralised to CO_2 in the aeration tanks and subsequently released to the atmosphere. By using ceramic filtration combined with anaerobic digestion of the sewage organic matter, energy recovery from the sewage constituents is maximised [16,23,27].

Due to the high foulant load of the sewage, fouling in the ceramic membrane and in the subsequent RO membrane is expected to be the main challenge in this ceramic filtration concept. The aim of this paper is therefore to investigate the feasibility of this concept by determining the (i) performance of ceramic tight UF and ceramic NF in sewage filtration, (ii) rejection of organic matter and ions of the ceramic membrane, and (iii) biofouling potential of the RO with ceramic NF pre-treatment. The energy production from the concentrate of ceramic membranes will be studied in the future stages of research, but is not within the scope of this paper.

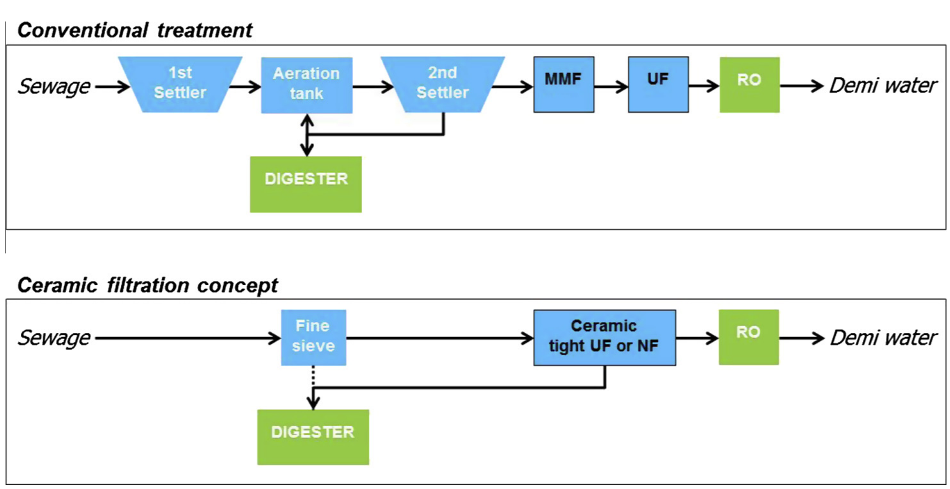

Fig. 1. Production of demineralised (demi) water from sewage using conventional treatment and the ceramic filtration concept. Raw municipal sewage first faces coarse sieve and grit removal before entering the first step of both treatment processes.