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Simulation study on comparison of algal treatment to conventional biological processes for greywater treatment

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ABSTRACT

The reuse of greywater is a promising strategy to preserve fresh water resources for future generations. The main objective of the present study is to simulate three different biological treatment technologies (high rate algal pond (HRP), conventional activated sludge (AS) treatment and rotating biological contactors (RBC)) at varying pollutant loadings (low, medium and high-strength polluted greywater) and, then, compare the treatment efficiency of HRP treatment with both RBCs and AS process. All of the adopted technologies were found to produce effluents with satisfactory quality. RBC achieved higher removal of nitrate and phosphorus compared to the conventional AS treatment process, whereas sensitivity analyses reveal that the AS process reached the steady state condition faster than the RBC process. The removal efficiency for AS process was 100% for biochemical oxygen demand, while the total suspended solids and *Escherichia coli* concentrations were lower than $5\,mg\,L^{-1}$ and 0.001 MPN $100\text{-}mL^{-1}$, respectively. Algal ponds treatment is effective but highly variable. However, it had additional benefits such as CO_2 assimilation and biomass production. The treatment efficiency of algal system depended mainly on the mass concentrations of algae and flow rates. Algae mass concentration of $700\,g\,m^{-3}$ and flow rate of $40\,m^3\,d^{-1}$ achieved complete removal of the SBOD. The influence of operational parameters on the production of algal biomass was investigated and the higher CO_2 fixation efficiency was achieved with the fraction of photoperiod as 0.8 and mass concentration of algae $1000\,g\,m^{-3}$.

1. Introduction

Water scarcity could present a significant risk to the global sustainability. Though water resources are managed locally, concerns linked to water could be of global origin and can exert impacts at global levels. The treatment and reuse of wastewater is one of the main strategies to protect depleting fresh water resources. It is predicted that in the next 50 years, an acute shortage of water will be faced by an approximate 40% of the inhabitants of the world [1], as the global water demand, over last few decades, increased twice as fast as the world population [2]. Pollution of fresh water resources, increase in population, fast growing economy, rapid industrialization and improper waste management practices further expand the gap between demand and supply of water [3]. Furthermore, disposal of untreated wastewater may result in eutrophication, which is often considered as a serious environmental threat [4]. This situation forced water experts and researchers to search for alternative water sources that can minimize the consumption of fresh water. Greywater, undoubtedly, is a potential resource that can levy the burden on fresh water resources [5]. As it does not include toilet wastewater, it is comparatively less polluted and easy to be treated [6]. The reuse of greywater, as it represents 50–80% of total domestic wastewater, can be considered as one of the most emerging approaches to achieve sustainable and integral water management in different parts of the world where intense water shortage is being faced [7]. Many research studies demonstrated the applicability of treated greywater for domestic purposes such as toilet flushing, gardening, and car washing [7–9]. A wide range of technologies, from simple to sophisticated, have been tested and proved successful in

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Table 1
Initial parameters of greywater for the simulations [31].

Parameters[a]	Low conc.	Medium conc.	High conc.
TCOD	179	347	525
SCOD	89	214	286
SBOD	72	119	182
TSS	28	79	146
Ammonia	0.6	2.2	5.5
Nitrate	0	0	0
Total phosphorus	3.7	9.8	14.6

[a] TCOD: total chemical oxygen demand (mg L^{-1}); SCOD: soluble chemical oxygen demand (mg L^{-1}); SBOD: biochemical oxygen demand (mg L^{-1}); TSS: total suspended solids (mg L^{-1}).

treating greywater [6,10–12], these include activated sludge (AS) treatment, natural systems, rotating biological contactors (RBC), and membrane bioreactor (MBR).

Enabling sustainability in wastewater treatment facilities requires finding solutions that are appropriate in the present and are capable of accommodating changes in the future [13]. The use of algae cultivation for wastewater treatment and for the generation of revenue through biomass production offers a possibility for sustainable approaches [14]. Algae systems can be used to treat domestic wastewater [15], textile industrial wastewater [16], agro-industrial wastewater [17], food processing industry effluents [18], wastewater containing toxic metals [19] and wastewater from other sources [20,21]. Furthermore, algae wastewater treatment systems can be integrated with power plants [22], by which carbon source in the form of CO_2 can be obtained at low cost [23]. This, in turn, increases the treatment efficiency and lipid production for the generation of high-value-added products. Domestic wastewaters are a rich source of nutrients and organics. Interestingly, microalgae can grow well in nitrogen and phosphorus rich wastewater with a strong potential to remove them [24]. In a traditional wastewater treatment process the CO_2 is produced from the degradation of organic compounds while in algal cultures the algae converts nutrient rich wastewater to cellular structures, by using CO_2 and sunlight, through photosynthesis [25]. In addition, it is possible to include algal system in traditional wastewater treatment for tertiary treatment to improve water quality while the generated biomass can be used for co-digestion with AS to generate biofuels and/or high-value products [26,27].

Simulation of biological treatment of wastewater offers a feasible pathway for engineers to operate a treatment plant efficiently, by gaining better understanding of biological mechanisms and improving treatability [28]. To keep the system performance very close to optimal operating conditions, a reliable modeling technique is essential. Moreover, modeling serves as a tool to identify any needed process modifications and helps execute corrective actions before precarious situations arise [29]. Hitherto, two different approaches have been used to simulate the wastewater treatment. The first one is based on the physical phenomena whereas the second one uses statistical processing of data. The trade-off between these two viewpoints is the 'grey-box' model, which is based on a simplified hypothesis on system's operation and fundamental equations [30]. The deterministic models, though successful, are multi-dimensional and contain large number of stoichiometric and kinetic parameters that do not fit in every situation of model application. It should be noted that the behavior of wastewater treatment facilities depends on the influent loads, temperature and microbial activities.

Even though considerable experimental research has been carried out on the treatment of greywater, to the best of our knowledge, very limited or even negligible number of simulation studies has been reported. In the present study, an attempt has been made to simulate three different biological treatment technologies namely AS treatment, RBC and high rate pond containing algae-bacteria consortium, and compare the efficiency of high-rate algal ponds with the other well-established treatment technologies in treating greywater with three different levels of pollutant concentrations.

2. Methodology

2.1. Simulated greywater

Simulated greywater parameters (Table 1) were chosen from a previous study about the treatment of real greywater [31], which were in accordance with other studies [32,33]. The inlet flow for the simulated treatments studied were selected based on the volume of greywater generated in different countries as liters per capita and per day (Lpcd), which varies between 16 and 225 Lpcd [34–36]. These values were used as a reference and were converted to $m^3 h^{-1}$ to work in the simulation. Considering the highest value as a family with four members, the flow of greywater in a single house would be 0.0375 $m^3 h^{-1}$. This value was the minimum flow to treat, considering an individual house, and 3.75 $m^3 h^{-1}$ was the maximum flow to treat, considering a community with 100 homes. An initial value of 1 $m^3 h^{-1}$ was used during simulations.

2.2. Simulation of treatment units

The conventional AS treatment and RBC treatment were simulated using a wastewater modeling software, STOAT 5.0 [37]. The treatment train, including all the techniques used to treat the greywater, was

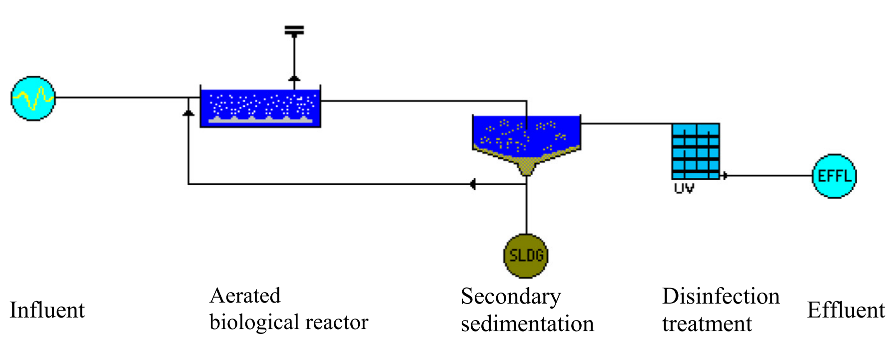

Fig. 1. Scheme of the treatment train of greywater based on AS treatment.