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学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

High rate algal pond for greywater treatment in arid and semi-arid areas
(乾燥地域及び半乾燥地域における高速藻類池の研究)

In recent years, large scale algal production has received lot of consideration due to the ability of algae to grow extremely rapidly and to accumulate a high quantity of lipid in their cells for biofuel production. For this purpose, algal photosynthetic growth is required and finding an economical and reliable method to produce and harvest algae feedstock remains a challenge. Thereby, apart from closed reactors used for algal production, the use of open ponds also known as high rate algal ponds which integrate wastewater treatment is nowadays emerging. For large scale biofuel production, HRAPs treating wastewater are recognized to be low-cost than closed photobioreactors due to the easy operation and cost-effective construction.

While the concern of algal biofuel production and wastewater treatment is currently increasing, this thesis focuses on the ability of HRAP to treat greywater and produce resources for agricultural activities in urban and peri-urban areas of arid and semi-arid countries. To tackle the increasingly severe issues related to water scarcity and domestic wastewater treatment in these areas, a greywater treatment system based on high rate algal pond (HRAP) was developed. As the conventional ponds, this technology is low cost, simple to build and operate. The HRAP is able to provide efficient wastewater treatment because of the assimilation of the wastewater nutrients into the algal biomass. Resources like biomass and energy can be recovered from the wastewater treatment for beneficial use. However, some negative points regarding the implementation of HRAP concern the large land area requirements and the washout of algae from ponds which increases the total suspended solids (TSS) concentration in the effluent. For an efficient wastewater treatment and recovery of resources usable in agriculture, the main purpose of this work consists to find operating strategies of HRAP leading to effective production and harvest of high settleable algal biomass.

At a laboratory scale and under tropical conditions, several reactors simulating HRAP were set and various operated parameters based on the hydraulic retention time (HRT), solid retention time (SRT) and algal recycling were applied. In both reactors, the temperature was kept at 30±2 degrees Celsius, the mixing of the reactor was performed to avoid algae sedimentation and LED lamps gave photosynthetic photon density varying from 430-550±ol-2s-1 at the surface of the pond. The water qualities of synthetic greywater with their average values ±SD were: pH (6.76±0.45); T-N (12.41±3 mg/L); T-P (5.26±0.4 mg/L); TOC (22.69 mg/L). Samples withdrawn from influent tanks, HRAP, SBRs, CFRs and corresponding effluents tanks were collected once to twice per week and immediately analysed. Total suspended solids (TSS) together with settleable solids were determined. Nitrogen and phosphorus species such as ammonium- nitrogen, nitrite, nitrate, total nitrogen, soluble reactive phosphorus and total phosphorus (T-P) were measured. As the treated effluent will serve for irrigation purpose, inactivation of E.coli in the system was also investigated.

Chapter 1

A review of the wastewater and greywater management in urban areas of arid and semi-arid areas was made followed by an analysis of greywater treatment options in urban areas of arid and semi-arid countries. Based on the results of the situation assessment, a treatment option using high rate algal pond technology was proposed.

Chapter 2

The configuration of the greywater treatment system used in this section consists of a HRAP which is a photosynthetic reactor followed by an algal settling pond (ASP). In this system, an HRT of 8 days and various SRT of 10, 15 and 20 days were set. The SRT and the recirculation of algae had an effect on the self-granulation and settleability of the algae. In fact, by recirculating the algae, the dominant algal species could be maintained and higher settleability and removal efficiency of the algae could be achieved. Further, operating long SRT of 20 days

has increased the TSS concentration in HRAP due to the low TSS concentration caused by the mixture washout during long SRT. For operation under a short SRT of 10 days, efficient algal removal (86 %) together with NH4 ±N and PO4 3–P removal (84 % and 55 % respectively) were achieved. In the ASP, at SRT of 10 days, settleable algae were dominant and the selection has occurred by simple gravity sedimentation.

Chapter 3

To investigate the selection mechanism of self-flocculated algae, the experiments were carried out by using 3 replications of sequencing batch reactors (SBR) and 3 other replications of continuous flow reactors (CFR). The three SBRs which simulated HRAP with algae recirculation were operated at a HRT of 10 days and SRT of 20 days. In the three other CFRs which simulated HRAP without algae recirculation, experiments were carried out using same HRT and SRT of 20 days. Moreover, the effects of the algae recirculation, HRT and SRT control were investigated. Despite operation with the same solid retention time (SRT) and the similarity of the algal growth rate found in both SBRs and CFRs, the algal productivity was higher in the SBRs owing to the short HRT of 10 days in these reactors. Further, in contrast to CFR, the operation of HRAP under batch mode has enhanced the selection of settleable algae through the sedimentation process. It was also found that under similar operating and physical conditions in the SBRs and CFRs, the control of the algal productivity and independent control of HRT and SRT were achieved. The comparison of SBRs and CFRs on their performance to remove the ammonium-nitrogen and T-N has shown that the SBRs presented greater capacity of removal efficiency during all the experimental period. In both reactors, more nitrogen than phosphorus was removed and the concentrations of dissolved phosphorus in the effluents from SBRs were lower. The operation of short HRT and the effect of sedimentation applied in SBRs resulted in a higher algal concentration and thus promoted nitrogen and phosphorus removal by assimilation into algal biomass and sedimentation processes.

Chapter 4

This chapter focuses mainly on the production of resources from the high rate algal pond (HRAP) to serve the agriculture in arid and semi-arid areas. Furthermore, operating strategies for the application of HRAP were indicated. Experiments were achieved by using the systems described in Chapters 2 and 3.

The nitrogen and phosphorus balance were established during the period when the algal growth in the reactors was not subject to change. Contrary to the CFRs where HRT and SRT were similar, in the SBRs, the contribution of the excess algae withdrawn from the reactors has led to the increase of nitrogen exiting the system. Operating strategies of HRAP to produce settleable algae and treated water for irrigation were suggested. It was proposed that for urban agricultural irrigation, the selection of appropriate hydraulic conditions (long HRT and long SRT) can be implemented to meet different needs. In contrast, the operation of short HRT and short SRT provide effluent with a lower nutrient concentration which can be discharged into reservoirs. The recovered algal biomass from the HRAP could be used either as fertilizer or used as a livestock feed supplement. Focusing on conventional HRAPs, this method might be applied to achieve efficient productivity or removal of the algal biomass.

Chapter 5

The reuse of the greywater for irrigation purpose presents many challenges, including the risk of pathogen infection. In HRAP, algae play an essential role in the process of pathogen removal by raising the pH and dissolved oxygen concentration which favour inactivation of bacteria. The main objective in this chapter was to investigate the possibility of greywater treatment in HRAP for irrigation purpose. Thus, the target of disinfection of the greywater was set to 2 log unit reduction for the E.coli. Under a tropical climate, series of batch experiments were set up to investigate the potential of algal sedimentation and other pathways of inactivation were investigated. It was found that the natural decay of bacteria was dominant and UV irradiation was effective. However the recovery of light-damaged cells at night should be considered.

Chapter 6

This chapter discusses the conclusions drawn in this thesis and reports on areas that need further research.