Nutrient removal in wastewater using microalgae

Bei der zuständigen Fakultät für Ingenieurwissenschaften Abteilung Bauwissenschaften der Universität Duisburg-Essen vorgelegte Dissertation zum Erwerb des Grades Doktor Ingenieur (Dr.-Ing.)

Von Carlo Pozza, M. Sc.
geboren am 11 Februar 1985 in Valdagno (Italien)

Die mündliche Prüfung wurde am 26.02.2014
mit den Gutachtern:

Prof. Dr.-Ing. R. Widmann
Prof. Dr.-Ing. K. Kuchta

abgehalten.

Forum Siedlungswasserwirtschaft und Abfallwirtschaft
Universität Duisburg-Essen

Heft 43

Carlo Pozza

Nutrient removal in wastewater using microalgae

Shaker Verlag
Aachen 2014

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: Duisburg-Essen, Univ., Diss., 2014

Printed in Germany.

ISBN 978-3-8440-2754-9
ISSN 1616-6035

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen
Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9
Internet: www.shaker.de • e-mail: info@shaker.de

Abstract

The removal of nutrients is one of the most difficult and high-energy intensive processes in urban wastewater treatment. It is usually achieved with biological systems such as activated sludge. Microalgae have been proposed as an alternative biomass: since they are phototrophic microorganisms, they do not need an organic carbon source and consequently they are able to grow and assimilate nitrogen and phosphorous especially in wastewater with low carbon to nitrogen ratio, contrary to active sludge bacteria.

In a laboratory scale, different methods for the selection of microalgae were evaluated: autochthonic microalgae and cultivation media with high concentrations of ammonium were found to increase the nitrogen removal rate and microalgae growth rate in wastewater. The combination of microalgae with active sludge has shown to increase organic carbon removal and nitrification rates.

Larger scale tests were executed on an urban wastewater treatment plant, where different photobioreactors treated the centrate of the sludge thickening while microalgae growth rate, nutrient removal and operational and external conditions were evaluated. Moreover, experiments have been conducted on separation of microalgae using a flocculation microflotation system and on biogas production using microalgae as a substrate.

The results suggest, that the microalgae are effective in the removal of nitrogen, especially in a tubular reactor design. The use of flocculation microflotation is a cost effective alternative for the separation and microalgae can be used as substrate for biogas production if correctly pretreated and co-digested.

Abstrakt

Der Abbau von Nährstoffen ist einer der komplexesten und energieintensivsten Verfahrensschritte der kommunalen Abwasserbehandlung. Traditionell wird dieser Prozessschritt mit Hilfe von biologischen Systemen (z.B. Belebtschlamm) realisiert. Mikroalgen wurden in der Fachliteratur bereits als alternative Biomasse für den Stickstoff- und Phosphorabbau vorgeschlagen. Da Algen phototrope Mikroorganismen sind, benötigen sie für ihren Stoffwechsel keine organische Kohlenstoffquelle, was ihren Einsatz besonders in Abwässern mit geringem Kohlenstoff zu Stickstoff Verhältnis interessant macht.

Die vorliegende Arbeit beschreibt vor diesem Hintergrund durchgeführte Experimente im Labor- und halbtechnischem Maßstab. Bei der Anreicherung von Mikroalgen haben insbesondere sowohl autochthone Mikroalgen, als auch solche, die in einem Kulturmedium mit hohen Ammoniumkonzentrationen gezüchtet wurden, erhöhte Wachstumsgeschwindigkeiten mit einhergehenden gesteigerten Stickstoffabbauraten im Abwasser aufgewiesen. Durch die Kombination von Mikroalgen und Belebtschlamm konnten der organische Kohlenstoffabbau sowie die Nitrifikationsrate deutlich gesteigert werden.

Drei halb-technische Anlagen wurden auf dem Gelände einer Kläranlage installiert und betrieben. Insbesondere wurden die Wachstumsgeschwindigkeit der Mikroalgen, die Stickstoffabbaurate und der Einfluss verschiedener Betriebsparameter auf die Behandlung von dem Zentrat der Schlammeindickung evaluiert. Darüber hinaus wurde die Algenabtrennung durch ein Mikroflotationsverfahren mit Flockung und das Biogaspotential der Algen überprüft. Die Ergebnisse zeigten, dass die Mikroalgen Stickstoff effektiv reduzieren, insbesondere unter Verwendung eines röhrenförmigen Reaktordesigns. Das Mikroflotationsverfahren ist eine kosteneffektive Alternative für die Separation der Mikroalgen. Mit vorausgehender Vorbehandlung können die Mikroalgen besonders als Ko-Substrat zur Biogasgewinnung eingesetzt werden.

Acknowledgments

This work is the result of three years of Marie Curie scholarship in the framework of the ATWARM program (Advanced Technologies for Water Resource Management) at the Department Municipal Water- and Waste Management (University of Duisburg Essen, DE).

In the first place, I would like to thank Prof. Renatus Widmann not only for his advice and support during these years but also to have scared me every time he silently entered in my office.

My thanks go to Thorsten Mietzel and Sebastian Schmuck for their help, support and encouragement.

I extend my gratitude to all the members of the department of Municipal Water- and Waste Management. Among them, a special thanks goes to my office mate Benjamin Brinkmann for his help and sympathy another one to Ilka for our book exchange. I would like to thank also Alfred and Erika for the nice Espresso breaks and I will always remember Benjamin Keser for his self-confidence: “Don’t worry, I won’t get lost in Venice”.

I thank all the bachelor and master thesis students that realized too late what they were going into: Tanja, Reyhan, Rofia, Matthias and Bahie. A special thank goes to Jens and Pascal, first because they insisted to bet against me about a certain football match and then they were forced to make me discover the Dampf Brauerei.

My gratitude goes to all the workers of the Wastewater Treatment Plant at Dorsten for their support, assistance and congeniality. I will always remember their incredible hunger during a barbecue.

I thank Francesco Ometto and Raffaella Villa from Cranfield University (UK) for their collaboration, support and friendship. Francesco, How can I forget all our adventures between Italy, Germany, Greece, Ireland, England and China?

I thank to all the ATWARM students and staff for these three years of meeting, summer schools and dinners (renamed in the end FATwarm).

I would like to thank Giacomo Bertini for his friendship and ideas during these long three years away from our homeland. “Why they haven’t build Germany in Tuscany?” still remains an open question. I thank Eva Hofer for “Der kleine Hobbit”, probably the most difficult book I’ve read, and to Jan Frösler for our small black market of materials and chemicals used in the experiments.

A special thank go to Anna and Leon for the patience in trying to correct my English (made in Greece) and an extra thank to Liliana for delivering in Essen: wine, pasta, beans and once also a mother. I thank my parents, Gaspare and Rosa, for their support during all these University years between Italy, Greece and Germany.

A deep thank to Oliver and Nora for the company, the music, the cookies, the different biers, the Doppelkopf lessons and the time spend together. I extend my thanks to all the people of Onckenstraße: Oliver, Nora, Anne, Diane, Michael, Lena, Till, Holger, Daniel, Sebastian, Marvin and why not, Antonio too;)

Last but not least, the most beautiful discovery of these three years, Maren, grazie.

This research was funded by the European Union in the framework of the Marie Curie Initial Training Network, (ATWARM, Advanced Technologies for Water Resource Management). Emschergenossenschaft/Lipperverband also funded the experiments held in the wastewater treatment plant at Dorsten (DE).

Index