



Universiteit
Leiden
The Netherlands

Real-Time Substrate Feed Optimization of Anaerobic Co-Digestion Plants

Gaida, D.

Citation

Gaida, D. (2014, October 22). *Real-Time Substrate Feed Optimization of Anaerobic Co-Digestion Plants*. Retrieved from <https://hdl.handle.net/1887/29085>

Version: Corrected Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/29085>

Note: To cite this publication please use the final published version (if applicable).

Cover Page



Universiteit Leiden



The handle <http://hdl.handle.net/1887/29085> holds various files of this Leiden University dissertation

Author: Gaida, Daniel

Title: Dynamic real-time substrate feed optimization of anaerobic co-digestion plants

Issue Date: 2014-10-22

Dynamic Real-Time Substrate Feed Optimization of Anaerobic Co-Digestion Plants

Proefschrift

ter verkrijging van
de graad van Doctor aan de Universiteit Leiden,
op gezag van Rector Magnificus prof. mr. C.J.J.M. Stolker,
volgens besluit van het College voor Promoties
te verdedigen op woensdag 22 oktober 2014
klokke 11:15 uur

door

Daniel Gaida
geboren te Radevormwald, Duitsland
in 1983

Promotiecommissie

Promotor: Prof. Dr. T.H.W. Bäck
Prof. Dr. M. Bongards (Cologne University of Applied Sciences)

Voorzitter: Prof. Dr. J.N. Kok

Overige leden: Prof. Dr. U. Jumar (University of Magdeburg)
Prof. Dr. A. Plaat
Dr. M.T.M. Emmerich
Dr. E.A. Schultes

Cover design: Martin Baljan, B.Sc.

ISBN: 978-94-6259-288-9

Contents

1	Introduction	5
1.1	Aim and Objectives	7
1.2	Main Contributions of this Thesis	8
1.3	Outline of this Thesis	9
I	Dynamic Real-Time Optimization	11
2	Multi-Objective Nonlinear Model Predictive Control	15
2.1	Case I: Number of Objectives $n_o = 1$	17
2.2	Multi-Objective Optimization	21
2.3	Case II: Number of Objectives $n_o > 1$	23
2.4	Summary and Discussion	24
3	Multi-Objective Optimization Algorithms	25
3.1	Hypervolume-based Evolutionary Algorithm	25
3.2	SMS-EGO	29
4	State Estimation	33
4.1	State Estimation using Software Sensors	34
4.2	Hybrid Extended Kalman Filter	38
4.3	Moving Horizon Estimation	40
4.4	Application to an Anaerobic Digestion Process	42
4.5	Summary and Discussion	49
II	Substrate Feed Control for Biogas Plants	51
5	The Anaerobic Digestion Process	55
5.1	Process Description	55
5.2	Important Process Values	56
5.3	Important Definitions and Terms	57
5.4	Typical Reactors	61

6 State of the Art of Biogas Plant Feed Control	65
6.1 Classical Control	67
6.2 Expert Systems	67
6.3 Linearizing Control	68
6.4 Discontinuous Control	69
6.5 Other Advanced Controls	69
6.6 Summary and Discussion	69
6.7 Tables	72
7 Modeling Biogas Plants	85
7.1 The Anaerobic Digestion Model No. 1 (ADM1)	86
7.2 The Substrate Feed	92
7.3 Performance Indicators of Biogas Plants	96
7.4 Model Implementation of an Agricultural Biogas Plant	109
7.5 Model Calibration and Validation	110
7.6 Summary and Discussion	117
III Simulation & Optimization Studies	119
8 State Estimation of the Anaerobic Digestion Process	123
8.1 Introduction	123
8.2 State Estimation using Software Sensors	124
8.3 Summary and Discussion	127
9 Dynamic Real-Time Substrate Feed Optimization of a Biogas Plant	129
9.1 Introduction	129
9.2 Control Structure	130
9.3 Performance Experiments	133
9.4 Summary and Discussion	167
10 Conclusion	173
10.1 Summary	173
10.2 Outlook	176
Bibliography	179
A Anaerobic Digestion Model (Simple)	205
B Biogas Toolbox in MATLAB[®]	209

C ADM1: Petersen Matrix and Model Parameters	213
D Symbols and Abbreviations	219
Samenvatting (Dutch)	231
Curriculum Vitae	233

