RUHR-UNIVERSITÄT BOCHUM
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Electrocoagulation in the separation process of used bentonite suspensions

Schriftenreihe des Instituts für
Konstruktiven Ingenieurbau, Heft 2020-03

Electrocoagulation in the separation process of used bentonite suspensions

Doctoral Thesis

submitted in fulfilment of the requirements for the degree of Doctor of Engineering (Dr.-Ing.) to the Department of Civil and Environmental Engineering of the Ruhr University Bochum

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Date of submission: 03.03.2020
Date of oral examination: 17.06.2020

Schriftenreihe des Instituts für Konstruktiven Ingenieurbau

Herausgeber:
Geschäftsführender Direktor des
Instituts für Konstruktiven Ingenieurbau
Ruhr-Universität Bochum

Heft 2020-3

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Shaker Verlag
Düren 2020

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.: Bochum, Univ., Diss., 2020

Printed in Germany.

ISBN 978-3-8440-7521-2
ISSN 1614-4384

Shaker Verlag GmbH • Am Langen Graben 15a • 52353 Düren
Phone: 0049/2421/99011-0 • Telefax: 0049/2421/99011-9
Internet: www.shaker.de • e-mail: info@shaker.de

Preface

The present study was developed in my time as research assistant at the Institute for Tunnelling and Construction Management ("TLB") of the Ruhr University Bochum.

My special thanks goes first to Prof. Dr.-Ing. Markus Thewes for his guidance of this thesis. The mutual exchange of ideas and many discussions had a very positive impact on the thesis. Moreover, his support on my way from a non-German speaking intern on the Institute to a research assistant teaching on German was of great importance. Additionally, I would like to thank Dr.-Ing. Britta Schößer for her support, input and guidance of the project, in frame of which this thesis was developed. To Prof. Dr.-Ing. habil. Marc Wichern I would like to thank for his interest in this subject, for our informative discussions and his willingness to be my reviewer. Furthermore, I would like to thank Prof. Dr.-Ing. Annette Hafner for taking the task of a non-specialist examiner.

Big thanks goes to my colleagues for the friendly atmosphere they created at the Institute, in which it was pleasure to work. Their support during research and while writing this thesis was very important to me. I could always rely on each and every one of them, but I would like to mention Anna-Lena Hammer, Annika Jodehl and Peter Hoffmann in particular.

During the experimental part of this research several master theses were written, which I supervised. The obtained experimental data were analysed in depth in this dissertation. For this, many thanks to my former master students Wenyu Jian, Sergey Vishnyakov and Stanislav Bezhenov. Also my former student assistants Marco Schürmanns, Ardit Bektashi and Frederik Klask, including students in summer internships, spent many hours in the laboratory. I am very grateful for their help.

Big thanks goes also on Daniel Lehmann, who was always ready to handle any small malfunction of the experimental equipment. Moreover, he brought the idea to automatically record electricity data and installed the necessary hardware and software. This saved a lot of time and improved the quality of data acquisition by the mid-scale experiments.

Last but not the least; I would like to thank the people from my private life. My parents have always supported me in my desire to either travel around as a tourist or to do internships abroad. The last internship I went to, to the TLB in Bochum, changed my life completely. Here, I also met my girlfriend Yvonne. She deserves special thanks for her support and motivation during the whole time I was writing this thesis.

Herne, in February 2020

Ivan Popovic

Acknowledgements

The research was conducted in co-operation with Herrenknecht AG, GeneSys GmbH, MSE-Filterpressen GmbH and Gebr. Förster GmbH.

Parallel to this thesis, a final research report was written. It includes the most important results of this research. It will presumably be available online on the website of the German Federal Environmental Foundation (DBU), who facilitated this research financially.

Their support is gratefully acknowledged.

Abstract

The separation of fines and the disposal of used bentonite suspensions are important economic and ecological factors in hydroshield tunnelling and the construction of diaphragm walls. To support the separation process of the slurry and to reduce separation time and costs, chemicals like metal salts and polymers are added to the slurry prior to its treatment in a chamber filter press or a centrifuge. However, most of those chemicals are classified as water hazardous substances. If they are not dosed correctly, they end up not only in the dewatered fines but also in the separated water that needs to be disposed. Moreover, addition of polymer solutions to the suspension increases water consumption on the construction site and the total volume of the suspension to be treated.

The thesis presents an alternative support method for fine separation processes by means of electrocoagulation. This electrochemical process causes coagulation and destabilisation of the suspension by applying an electrical current. It has a similar effect on the subsequent fine separation as the addition of chemicals, but offers the advantage that no water hazardous substances are required and the water consumption on the construction site decreases.

In order to determine the extent to which electrocoagulation can support the separation of used slurries, a standard for a used suspension was defined, which was subjected to parametric studies. First studies were performed with laboratory-size electrocoagulation cells which had a volume of 2 to 4 l. Based on the results, the technology was scaled up to a mid-scale cell with a volume of 320 l. This equipment, together with a laboratory chamber filter press, enabled a practice-oriented investigation of the influence of the electrocoagulation treatment on the separation of fines. The results were validated with a used suspension from a tunnelling construction site.

The studies have shown that electrocoagulation could reduce the required filter press capacity by up to 20 % and could save at least 0.2 m³ water per 1 m³ of used slurry.

An ecological comparison between electrocoagulation and conventional conditioning showed that the electrocoagulation is ecologically beneficial. An economical comparison has shown for electricity prices in Germany that the costs were in the same order of magnitude. However, it is important to note that the operational cost of EC depends to a great extent on electricity price at the site, which differs significantly between countries. Therefore, electrocoagulation could be more economically beneficial in countries with lower electricity prices than Germany.

The thesis includes design recommendations for a real-scale prototype as well as ideas for further research. The experimental procedure and analysis developed in this thesis allow the investigation of any given used suspension. The next steps should be the investigation of further used suspensions from construction sites and determining the electricity consumption during electrocoagulation depending on the used suspension properties.

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List of Abbreviations

%	Percent
($Al_2(SO_4)_3$)	Aluminium sulfate
AbfAblV	Abfallablagerungsverordnung (• Waste Disposal Ordinance)
AC	Alternating current
AG	Aktien Gesellschaft
Al	Aluminium
$Al(OH)_3$	Aluminium hydroxide
$Al(OH)_{4-}$	Tetrahydroxoaluminat-ion
approx..	Approximately
ASTM	American Society for Testing and Materials
AwSV	Verordnung über Anlagen zum Umgang mit wassergefährdenden Stoffen (Ordinance on facilities for handling substances that are hazardous to water)
BP	Bipolar electrodes
CA	Conditioning agents
ccc	Critical coagulation concentration
CFP	Chamber filter press
Cl	Chlor
cm	Centimetre
Cr	Chromium
DC	Direct current
DepV	Verordnung über Deponien und Langzeitlager (Deponieverordnung), Deponierverordnung (• Landfill Ordinance)
DIN	Deutsches Institut für Normungen (German Institute for Standardization
DK	Deposition class
DLVO	Derjaguin-Landau-Verwey-Overbeek-Theorie
e.g	For example
EC	Electrocoagulation
Eq	Equation
exp	Experiment
Fe	Iron
$Fe(OH)_2$	Iron (II)-hydroxid
$Fe(OH)_3$	Iron (III)-hydroxide
$FeCl_3$	Ferric chloride
FW	Filtrate water
GmbH	Gesellschaft mit beschränkter Haftung (Company with limited liability)
i.e.	lat. id est, meaning
IEP	Isoelectric point
kg	Kilogram

LAGA	Länderarbeitsgemeinschaft Abfall, Bund/Länder-Arbeitsgemeinschaft Abfall (Federal / State Working Group on Waste)
LCFP	Laboratory chamber filter press
LEL	Lower explosive limit
Li	Lithium
Mg	Magnesium
mm	Millimetre
MP-P	Monopolar electrodes in parallel connection
MP-S	Monopolar electrodes in serial
NaCl	Sodium chloride
pH	potentia hydrogenii
prEN	European standard - draft
PZC	Point of zero charge
PZD	Negative logarithm of the Fe(x) concentration, Predominance-zone diagram
SUS	Standard used suspension
t	Time
TDS	Total dissolved solids
TOT layer	Tetrahedral-octahedral-tetrahedral layer
UEL	Upper explosive limit
VwVwS	Verwaltungsvorschrift wassergefährdende Stoffe (Administrative Regulation on Water-Polluting Substances)
WGK	Water hazard class
WHG	Wasserhaushaltsgesetz (Water Resources Act)
Zn	Zinc

List of Symbols

ΔFt_{EC}	[-]	Change of filtration time after EC
ΔFV_{EC}	[-]	Change of filtration volume after EC
ΔFW	[%]	Increase of the filtrate water release
$\Delta\rho$	[%]	Decrease of the remaining suspension density
A	[cm²]	Electrode surface area
A	[m²]	Cross section area
B	[g]	Dry weight of coagulated bentonite
B_0	[g]	Dry weight of bentonite particles in suspension
B_{kt}	[%]	Percentage of coagulated bentonite
C_e	[%]	Current efficiency
c_{el}	[nM]	Concentration of electrolytes
F	[As/mol]	Faraday constant = 96485
F%	[-]	Time ratio of a filtration process in one filtration cycle
FV	[-]	Factor for decrease of filtration volume due to EC
FW_o	[ml]	Filter water release of the suspension before EC treatment (obtained using the API filter press)
FW_r	[ml]	Filter water release of the remaining suspension (obtained using the API filter press)
FW_{rel}	[l]	Filtrate water release at the end of the filtration (obtained using the laboratory chamber filter press)
I	[A]	Electrical current
K	[$W^{-1}m^{-1}$]	Specific electricial conductivity
L	[m]	Length
M	[g/mol]	Molar mass
$m_{d,cm}$	[kg]	Dry weight of coagulated material
$m_{d,cm}$	[kg]	Dry weight of filter cakes
$m_{w,cm}$	[kg]	Wet weight of coagulated material
$m_{w,cm}$	[kg]	Wet weight of filter cakes
P	[kWh]	Power consumption
P_{cfp}	[-]	Factor for change of productivity of chamber filter press with EC
P_{sep}	[-]	Factor for productivity of separation process when replacing CA with EC
R	[Jmol-1K-1]	Ideal gas constant = 8.314
R	[Ω]	Resistance
R_{cfp}	[-]	Factor for calculation of required chamber filter press capacity when replacing CA with EC
RM_{cm}	[-]	Residual moisture of coagulated material
RM_{fc}	[-]	Residual moisture of the filter cake
T	[K]	Absolute temperature of the produced gas
t	[h]	Time
$t_{FW,CA}$	[h]	Filtration time after CA
$t_{FW,EC}$	[h]	Filtration time after EC
U	[V]	Voltage

V	[l]	Volume of the produced gas
V_a	[J]	Van der Waals attractive energy
V_b	[J]	Barrier to redispersion
V_{CA}	[m³]	Volume of CA added to used suspension prior to filtration (per m³ used suspension)
V_{cfp}	[m³]	Volume of chamber filter press
V_{CM}	[m³]	Volume of coagulated material
$V_{FW,CA}$	[m³]	Filtrate water discharge with CA
$V_{FW,EC}$	[m³]	Filtrate water discharge after EC
V_m	[J]	Maximal energy barrier
V_r	[J]	Interparticle double layer repulsion energy
$V_{S,CM}$	[m³]	Volume of soil in coagulated material
V_t	[J]	Total interaction energy
$V_{W,CM}$	[m³]	Volume of water in coagulated material per m³ suspension
Z	[-]	Valence of ions of the substance
δ_S	[t/m³]	Grain density
δ_{SUS}	[t/m³]	Suspension density
Z	[mV]	Zeta potential
µm	[1µm]	Micrometre
ρ_o	[g/cm³]	Density of suspension before the EC treatment
ρ_r	[g/cm³]	Remaining suspension density
ρ_w	[g/cm³]	Water density