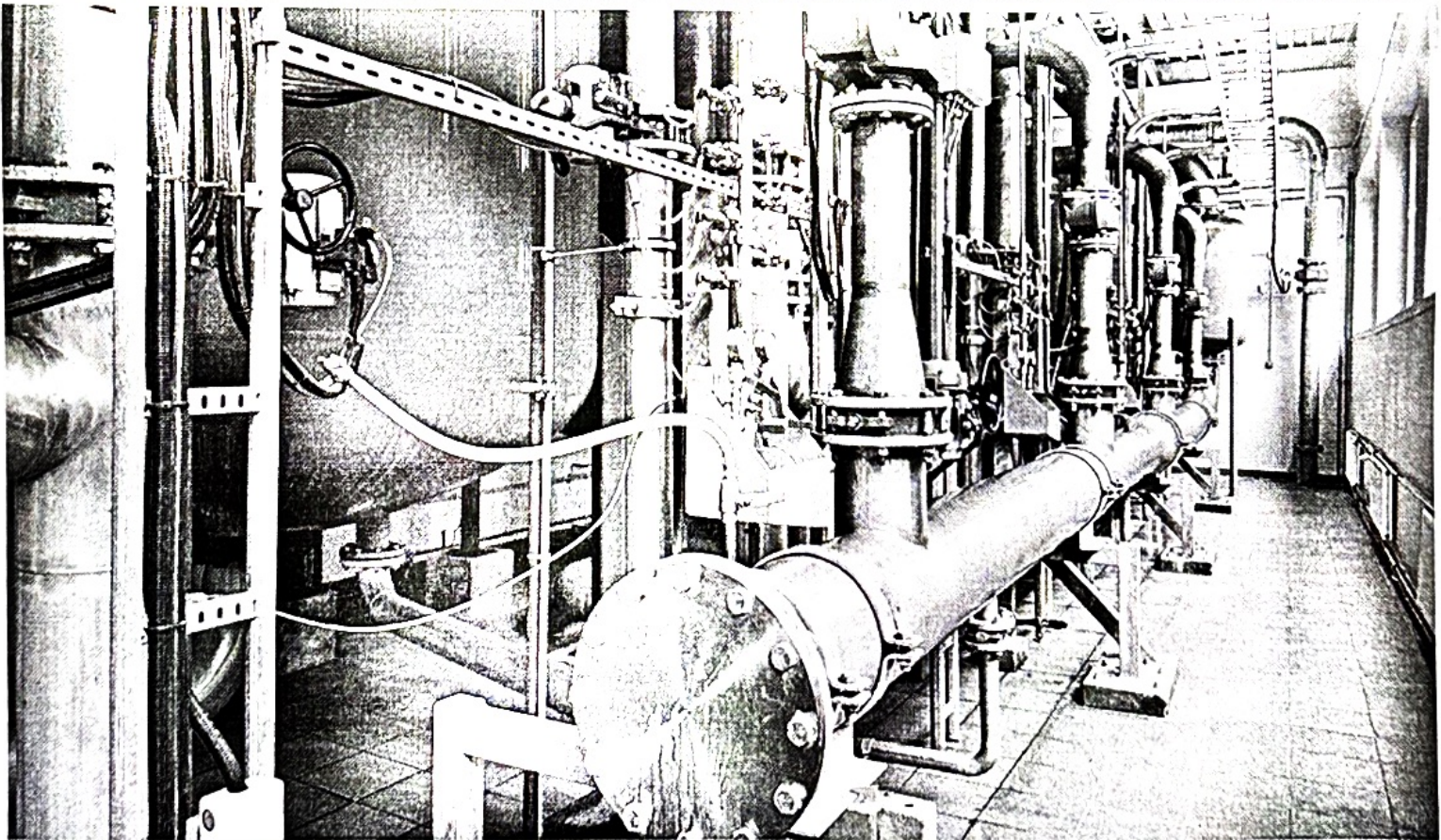


Resource Recovery in  
**INDUSTRIAL WASTE  
WATERS**



*Edited by* **Mika Sillanpää, Ali Khadir, Khum Gurung**



**ELSEVIER**



# Resource Recovery in Industrial Waste Waters

Edited by

**Mika Sillanpää**

Department of Biological and Chemical Engineering,  
Aarhus University, Aarhus, Denmark

**Ali Khadir**

Islamic Azad University, Shahre Rey Branch, Tehran, Iran

**Khum Gurung**

AFRY Engineering Consultancy, Pulp and paper industry,  
Jaakonkatu, Vantaa, Finland



ELSEVIER

Elsevier

Radarweg 29, PO Box 211, 1000 AE Amsterdam, Netherlands  
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, United Kingdom  
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States

Copyright © 2023 Elsevier Inc. All rights reserved.

No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher. Details on how to seek permission, further information about the Publisher's permissions policies and our arrangements with organizations such as the Copyright Clearance Center and the Copyright Licensing Agency, can be found at our website: [www.elsevier.com/permissions](http://www.elsevier.com/permissions).

This book and the individual contributions contained in it are protected under copyright by the Publisher (other than as may be noted herein).

#### Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

ISBN: 978-0-323-95327-6

For Information on all Elsevier publications  
visit our website at <https://www.elsevier.com/books-and-journals>

*Publisher:* Candice Janco  
*Senior Acquisitions Editor:* Anita Koch  
*Editorial Project Manager:* Aera Gariguez  
*Production Project Manager:* Bharatwaj Varatharajan  
*Cover Designer:* Christian J. Bilbow

Typeset by MPS Limited, Chennai, India



22. Photocatalytic desalination techniques for industrial wastewater reuse	441
<i>ROHIT PAL, GOUTHAM RANGARAJAN, SHYAM SIVAPRASAD AND RAMIN FARNOOD</i>	
22.1 Introduction	441
22.2 Traditional or conventional desalination techniques and associated bottlenecks	444
22.3 Photocatalysis meets desalination—slurry and immobilized photocatalytic systems	445
22.4 Photocatalytic membrane reactors	452
22.5 Conclusions and future prospects	456
References	457
23. Vanadium in industrial wastewater: a study on methods implicated for their removal and recovery	463
<i>SUMAIYA AKHLAQ, DHANANJAY SINGH, MOHAMMED HARIS SIDDIQUI AND NISHU MITTAL</i>	
Abbreviations	463
23.1 Introduction	464
23.2 Methods (recovery of vanadium from industrial wastewater)	467
23.3 Recent development and research	468
23.4 Research gaps and future perspectives	475
23.5 Conclusion	478
Acknowledgment	479
References	479
24. Recovering industrial wastewater: application of electro dialysis reversal approach	483
<i>DHANANJAY SINGH, MAMTESH KUMARI, MOHAMMED HARIS SIDDIQUI AND NISHU MITTAL</i>	
Abbreviations	483
24.1 Introduction	484
24.2 Methods implicated in recovering industrial wastewater	487

24.3	Recent development and research	491
24.4	Research gaps and future perspectives	494
24.5	Conclusion	494
	Acknowledgment	495
	References	495
25.	Recovery of phosphorus from industrial wastewater through struvite crystallization	499
	<i>SONI KUMARI AND SHEEJA JAGADEVAN</i>	
25.1	Introduction	499
25.2	Methods (data collection)	500
25.3	Recent developments and research	504
25.4	Research gaps and future perspectives	511
25.5	Conclusion	513
	References	513
26.	Biohydrogen recovery from industrial wastewater	521
	<i>ATHIRA KRISHNAN, AMEEN SHA, B.R. SREELEKSHMY AND S.M.A. SHIBLI</i>	
26.1	Introduction	521
26.2	Methods	522
26.3	Factors influencing biohydrogen production	525
26.4	Recent developments and research	537
26.5	Research gaps and future perspectives	539
26.6	Conclusions	540
	References	541
27.	Recovery of critical raw materials from battery industry process and wastewaters	545
	<i>VARSHA SRIVASTAVA, HANNA RUNTTI, SARI TUOMIKOSKI, ANNE HEPONIEMI, TONI KAUPPINEN, PEKKA TYNJÄLÄ AND ULLA LASSI</i>	
	Abbreviations	545
27.1	Introduction	546

# Recovering industrial wastewater: application of electro dialysis reversal approach

Dhananjay Singh<sup>1,\*</sup>, Mamtesh Kumari<sup>2,\*</sup>,  
Mohammed Haris Siddiqui<sup>3</sup>, Nishu Mittal<sup>4</sup>

<sup>1</sup>DEPARTMENT OF BIOSCIENCES, INTEGRAL UNIVERSITY, LUCKNOW, UTTAR PRADESH, INDIA <sup>2</sup>DEPARTMENT OF BIOSCIENCES AND BIOENGINEERING, INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE, UTTARAKHAND, INDIA <sup>3</sup>DEPARTMENT OF BIOENGINEERING, INTEGRAL UNIVERSITY, LUCKNOW, UTTAR PRADESH, INDIA <sup>4</sup>INSTITUTE OF BIOSCIENCES AND BIOTECHNOLOGY, SHRI RAMSWAROOP MEMORIAL UNIVERSITY, BARABANKI, UTTAR PRADESH, INDIA

## Abbreviations

AM	anion-selective membrane
BOD	biological oxygen demand
Ca <sup>2+</sup>	calcium ions
CM	cation-selective membrane
COD	chemical oxygen demand
DC	direct current
ED	electrodialysis
EDR	electrodialysis reversal
gpd	gallon per day
MF	microfiltration
mg/L	microgram per liter
Mg <sup>2+</sup>	magnesium ions
mgd	million gallons per day
min	minute
NF	nanofiltration
RO	reverse osmosis
SDG	sustainable development goal
UF	ultrafiltration
µm	micrometer

\* Both authors have contributed equally.

## 24.1 Introduction

Water is a major contributing factor to the development of a country: it is necessary for the production and preservation of a host of benefits and services for people and ecosystems. But hasty industrialization on urbanization has increased very sharply and led to the generation of large amounts of wastewater worldwide. Half of the freshwater is used in agricultural activities worldwide, while the remaining half is discharged into the surrounding as wastewater generated from industry and household activities thus causing serious effects on aquatic life, human health, and economic productivity (Smol et al., 2020; Voulvoulis, 2018). In developed countries like North America and Europe, the rate of water consumption at the industrial level is higher as compared to developing nations, that is, 50% and 4%–12%, respectively.

The waste from water can be reduced in three different ways including regeneration, reuse, and recycling. During the reuse process, wastewater can be converted into usable form, while in the regeneration process, pollutants are removed by some treatment. In the regeneration recycling process, the contaminated water is often regenerated to separate pollutants to recycle it.

### 24.1.1 Background

In recent years, the increase in the utilization of natural resources and increase in mining activities lead to an increase in the frequency of metals discharge into the environment. Therefore, the management of wastewater discharged from industries becomes an important concern all over the world. Several studies and research have been presented so far to treat wastewater using different processes (Abbas et al., 2016; Rajasulochana and Preethy, 2016; Azimi et al., 2017; Alalwan et al., 2020; Babincev et al., 2020; Mustafa and Asmatulu, 2020). The World Economic Forum classified water shortage and its effects as the major environmental risk at the world level (World Economic Forum, 2014). Distinguishing the growing challenge of water shortage, wastewater management has also found recognition in one of the 17 Sustainable Development Goals, namely, SDG 6, which aims to, among others, substantially increase water use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater by 2030 (Masi et al., 2018; UN General assembly, 2015).

### 24.1.2 Types of different wastes in industrial wastewater

The contamination level of industrial wastewater depends upon the level of technical processing in each industry sector and can be reduced steadily with the upgradation of industrial technologies. The aggregate rate of industrial wastewater is higher in developing countries as compared to developed ones.

The type of wastewater effluent from different industries is listed in the table given below (Table 24–1). As the characteristic features of each type of wastewater are different, the treatment of industrial wastewater should be drawn particularly for the specific type of