German Water Partnership

Building Partnerships for a ENVIRONMENTAL PROTECTION made in Germany Sustainable Infrastructure

Industrial Water Compendium

A Guide for Decision Makers in Industrial Wastewater Management in India and the MENA Region

Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

On behalf of:

Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety

of the Federal Republic of Germany

Table of contents

Dear readers,

Dear experts in industrial water management, all over the world, industry is having to adapt to the fluctuating availability of water due to climate change. In many regions of the world, availability is dwindling. The substances and materials used in key sectors of industry like the chemical and food industries in India and the mining and textile industries in the MENA region pose additional challenges for the efficient and responsible use of the valuable resource water. For the sake of sustainability, the goal must be to bring cleaned water back into the natural water cycle without posing a threat to living organisms and the environment.

This Industrial Water Compendium provides an impressive illustration of examples from ten key sectors of industry showing how this can be done in an economically and ecologically sound way. The compendium's goal is to support public and private decision-makers in the MENA region (especially in Morocco, Tunisia, Egypt and Jordan) and in India in their efforts to implement solutions for the sustainable and green treatment of industrial wastewater. It analyses the different market characteristics and highlights trends that can be observed in both regions, for example the growing focus on recovering resources or the development of industrial parks for the joint treatment of wastewater flows.

Technical innovations in environmental protection and climate action are more in demand than ever. They also boost the economy as strong drivers of growth. The Export Initiative for Green Technologies, established in 2016 by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, focuses on disseminating and enhancing know-how and deploying environmental and climate technologies and innovative green infrastructure in countries that require support. With the aim of fostering sustainable development and improving living conditions, this compendium has been drawn up as a contribution to the global project by the Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH supporting the Export Initiative for Green Technologies.

We thank GIZ and the German Water Partnership e.V. as publisher for the successful project implementation and the excellent cooperation. The compendium was created with support from the experts at the Federal Environment Agency (UBA). We also thank them for their valuable contribution.

Yours sincerely

Svenja Schulze

Svenja Schulze
Federal Minister for the Environment,
Nature Conservation and Nuclear Safety

Dear readers,

Dear experts in industrial water management,
with water resources dwindling worldwide and water availability fluctuating due to climate change, sustainable water management is becoming increasingly important. Energy-efficient treatment plants, particularly in the emerging economies of Asia and the MENA region, therefore play an important role in achieving the Paris climate goals. On the following pages you can read more about the impressive contribution being made here by German companies in the wastewater sector.

German components and systems for wastewater treatment are already in demand worldwide. In 2019, for example, exports in the fields of water treatment, wastewater and sludge treatment increased by 6.8% compared to the previous year – to a total value of over 1.1 billion euros. The international popularity of German solutions stems from more than just the good reputation of the 'Made in Germany' brand, which promises quality and long lifecycles. More importantly, German companies stand out for their innovative strength and flexibility. After all, being able to offer optimally adapted solutions for a wide array of situations is something that German companies are well-known for. The examples in this compendium illustrate possible approaches to the technical challenges of industrial wastewater treatment within the MENA region and India.

As a strong network with more than 350 members from the German water and wastewater industry, German Water Partnership e.V. is striving to highlight these strengths at the international level. This compendium has been informed by the know-how and extensive experience of the Industrial Water Management Working Group and the India and North Africa/Jordan regional forums.

In producing this Industrial Water Compendium, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety is continuing its long-standing and successful cooperation with the German Water Partnership e.V. under the Environmental Technologies Export Initiative. I would like to thank all of the experts involved as well as the staff of the global project of the Gesellschaft für Internationale Zusammenarbeit (GIZ), through which GIZ is supporting the Environmental Technologies Export Initiative, for their excellent and successful cooperation. Once again, we have thereby been able to create an important building block for the successful international distribution of sustainable technological solutions that are 'Made in Germany' and at the same time contribute to the protection of our environment.

Yours sincerely

Julia Braune

Julia Braune
Managing Director
German Water Partnership e. V.

List of abbreviations

°C	Degrees Celsius
µS	Microsiemens
AOX	Measurement for organically bound halogens
bil.	Billion
BOD5	Biochemical oxygen demand within 5 days
Ca	Calcium
CETP	Common effluent treatment plant
CIP	Cleaning in place
cm	Centimetre
CO_2	Carbon dioxide
COD	Chemical oxygen demand
DOC	Dissolved organic carbon
DWA	Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (German Association for Water, Wastewater and Waste)
EGSB	Expanded granular sludge blanket
FS	Filterable substances
GDP	Gross domestic product
h	Hour
H2S	Hydrogen sulphide
ha	Hectare
ISO	Standard according to the definitions of the International Organization for Standardization, e.g. ISO 14001 (environmental management standard)
kg	Kilogram
km	Kilometre
km^2	Square kilometre
l	Litre
m^3	Cubic metre
MBR	Membrane bioreactor
MENA	Middle East & North Africa; in this compendium, this refers in particular to the MENA countries Egypt, Jordan, Morocco and Tunisia
mg	Milligram
mil.	Million
N	Nitrogen
n.a.	Not available
Na	Sodium
NH4+	Ammonium
NTU	Nephelometric turbidity unit
OPEC	Organization of the Petroleum Exporting Countries
P	Phosphorus
PFAS	Per- and polyfluoroalkyl substances
pH	pH value (potential of hydrogen)
Pt-Co	Platinum-cobalt colour number
t	Ton

TOC	Total organic carbon
TSS	Total suspended solids
UASB	Upflow anaerobic sludge blanket
USD	US dollar
UV radiation	Ultraviolet radiation
VOX	Volatile organic halogens
WHO	World Health Organization
ZLD	Zero liquid discharge

Abstract

Discharges of wastewater from industrial activities represent a global challenge, with developing countries and emerging economies especially vulnerable to their environmental impacts. The aim of this compendium is to support the development and implementation of environmental solutions in India and the MENA region. It is designed to serve as a guide for users, decision-makers and technology providers alike by highlighting the industrial wastewater situation in the partner countries and outlining specific approaches to wastewater treatment. The 2030 Agenda aims to make a contribution to environmental and climate protection in pursuit of the Sustainable Development Goals [1]. The compendium is a contribution to the implementation of Sustainable Development Goal 6, which advocates clean water and access to sanitation for all. It specifically addresses sub-goal 6.3: 'By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.'

For a variety of reasons (such as cost savings, avoiding transportation, consideration of specific local factors), it is to be recommended in many cases that technical plant components be produced and procured within the partner countries. Nonetheless, for some specific challenges, innovative components from specialised German technology providers can make a decisive contribution. This compendium therefore focuses on state-of-the-art technologies for industrial wastewater treatment developed in Germany. In the partner countries, for example, high-added-value industrial sectors with high added value and municipal wastewater treatment plants offer promising fields of application. A key driver for the use of innovative cleaning technologies is the tightening of local regulatory frameworks, as well as the optimisation of supply security and energy efficiency. The expertise available from German technology providers makes it possible to develop customised solutions for specific problems locally – while taking into account the technical, economic, geographical and regulatory conditions involved. Technologies that have proven themselves in industrial wastewater treatment in Germany for many decades are now being augmented by innovative approaches to achieving sustainable and holistic wastewater solutions.

> *The objective of this compendium: to support environmental solutions in India and the MENA region.*

The compendium is divided into 10 chapters that highlight selected industrial sectors in the partner countries. In each case, their economic importance in India and the MENA countries is addressed and the key technical issues involved in the wastewater situation are briefly outlined. These include typical wastewater composition and state-of-the-art solutions as well as current legislative, economic and technical developments. Each chapter concludes with case studies of successful technology implementation by German suppliers in the regions and sectors concerned.

Relevance of individual industries

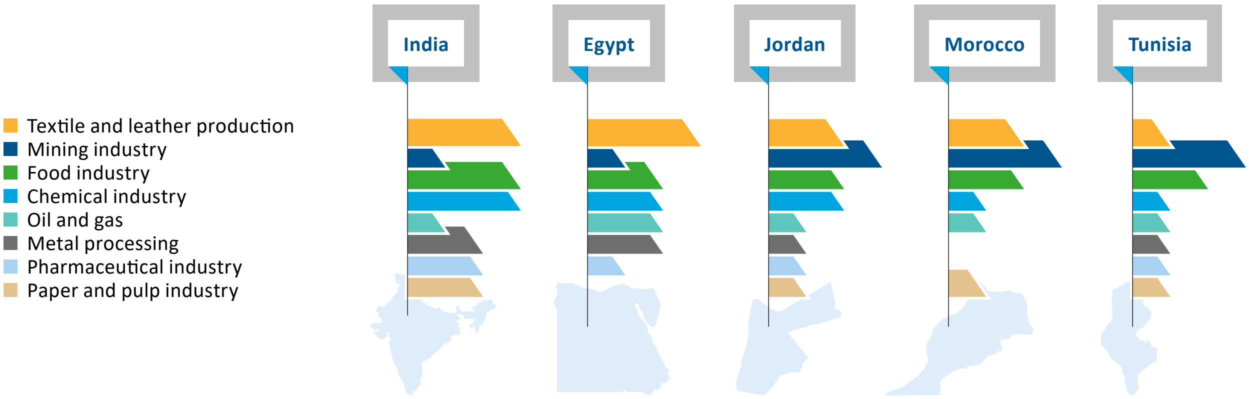


Figure 1: Semi-quantitative assessment of the relevance of individual economic sectors in the regions (2020) (based on [3])

Industrial wastewater in India and the MENA region

India

India's economy, already the sixth-largest in the world, is also one of the fastest growing ones [2]. With 1.35 billion people, India is also the most populous country in the world after China. As an emerging economic power, India has local and international companies represented in almost all relevant sectors of industry (Figure 1). The pressure on companies as a result of stricter environmental regulations and sustainability goals is steadily increasing, and this is prompting a general shift in thinking about how to deal with water as a resource. Key topics are currently the avoidance of wastewater discharges through 'zero liquid discharge' (ZLD) at large companies and the construction of central sewage treatment plants for industrial wastewater.

ZLD is especially relevant for heavily polluted wastewater streams from individual sub-sectors. Currently, ZLD regulations are imposed on a mandatory basis on industries in the Ganges basin and on certain industries in individual states (e.g. textile processing in Tamil Nadu). They are likely to be extended to other industrial areas with a high density of environmentally sensitive industries, such as textile and leather production, the paper industry, the chemical and pharmaceutical industry, the food industry and the metal processing industry [3]. The regulatory regime is also expected to become stricter in the future through increased online monitoring of industrial effluents, as required by the Central Pollution Control Board.

'Common effluent treatment plants' (CETPs) are proliferating with the aim of addressing the wastewater discharge problems of small businesses and industrial centres. There are currently an estimated 200 CETPs in India. Changes in legislation and liability have tightened the requirements for technical environmental protection with regard to CETPs. Site maintenance contracts have changed from covering just one year after commissioning to 15 years for operation and maintenance. This will result in an increased interest in sustainable technologies [4]. Moreover, the increasing development and expansion of industrial parks can be observed, and this will increase the number of available opportunities for the construction of CETPs. The Indian government provides up to 75% of investment funds for CETPs [3].

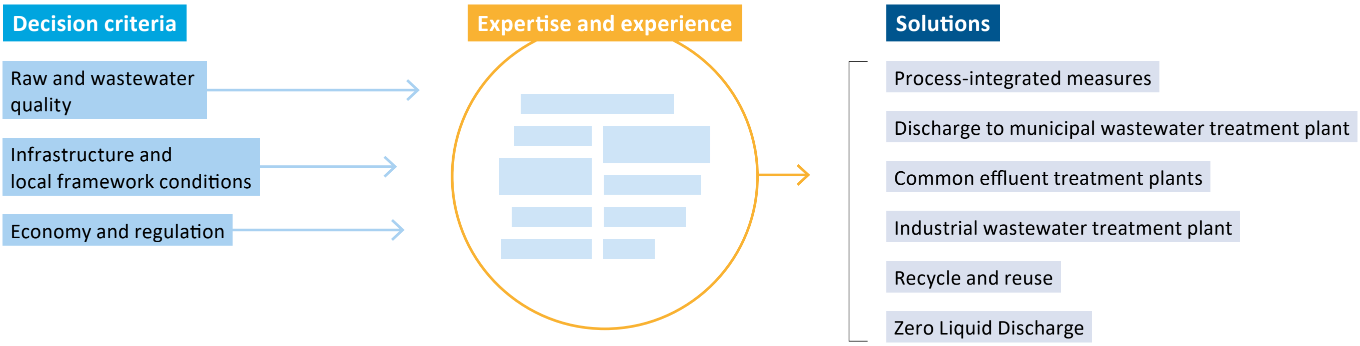


Figure 2: Schematic representation of the processes for identifying technical solutions in industrial wastewater treatment

Decision criteria

Raw and wastewater quality

- Volume
- Temperature
- Pollutants:
  organics,
  nutrients,
  solids,
  salts,
  metals,
  toxic/refractory compounds
- Water/resource recovery potential

Infrastructure and local framework conditions

- Fresh water availability and quality
- Spatial footprint
- Accessibility of municipal wastewater treatment facilities
- Disposal options for waste/sludge
- Closed loop system potential (energy, resources, water)
- Technology availability (local/imported)
- Potential synergies with local industries
- Supply chain security
- Stability of energy supplies
- Availability expertise/ specialists
- Potential for digitisation and automation

Economy and regulation

- Regulation and enforcement
- (National) environmental monitoring schemes
- Available investment capital
- Costs for raw water, treatment, discharge, external wastewater treatment and energy
- Sustainability goals
- Energy/carbon reduction targets

Figure 3: Categorisation and listing of the most key factors and decision-making criteria for identifying technical solutions

MENA region

The countries of Egypt, Jordan, Tunisia and Morocco have a combined population of about 163 million. They constitute very important economic powerhouses for the North Africa and Middle East region [5]. Important economic sectors are the food industry, chemical industry, textile and leather production as well as mining (Figure 1) – in particular the phosphate deposits in Morocco, which are among the largest in the world. A shortage of water resources due to changing climatic conditions and stricter environmental regulations by the responsible governments is having a growing impact on companies in the region.

Here, too, a trend towards the establishment of centralised industrial parks, complete with accompanying centralised wastewater treatment, can be observed [6]. Furthermore, efforts are being made in the region to increase the connection rate of industrial enterprises, as is being promoted in a government initiative in Jordan, for example [7]. The reuse of water and the resources it contains also play a key role in industrial water models. Across the MENA region, there is a particular focus in this regard on the use of plants for irrigation. In this context, legal minimum standards or guidelines for water reuse are intended to minimise the risk of pollutant contamination for humans and the environment. The regulatory framework is most advanced in Jordan, where a ‘Water Substitution and Reuse Policy’ has been in place since 2016. Information on possible treatment processes for various water reuses is summarised in the collection of articles on ‘Non-Potable Reuse’ published by the German Association for Water, Wastewater and Waste (DWA) [8].

Industrial wastewater

Although they are structured very differently in cultural and economic terms, the regions under consideration also have strong overlaps – especially in the relevance of the various industrial sectors, as can be seen in Figure 1.

The main drivers for improving the industrial wastewater situation in India and the MENA region are increasingly strict legal requirements and (regionally) limited freshwater availability. In this context, the optimal implementation of wastewater treatment is highly dependent on the specific technical, geographical, economic and regulatory conditions involved (Figure 2).

The most important basis for the choice of technology is the quantity and composition of the wastewater produced. However, the infrastructural conditions, such as the possibilities for obtaining resources and disposing of waste, must also be taken into account. From an economic point of view, the available capital, cost structures and local expertise play a decisive role. The degree of wastewater treatment and, if necessary, water reuse depends on ecological factors, such as the sensitivity of the receiving watercourse and the general availability of fresh water locally, and of course also on the legal requirements and regulations (Figure 3). All the relevant factors ultimately feed into the technical decision-making process for industrial wastewater treatment. Typically, this involves both the industrial plant operators and technology service providers with the relevant expertise and breadth of experience. The involvement of industry associations and research institutions also facilitates knowledge transfer and innovation (Figure 4).

> *The reuse of water and the resources it contains also plays a key role in industrial water concepts.*

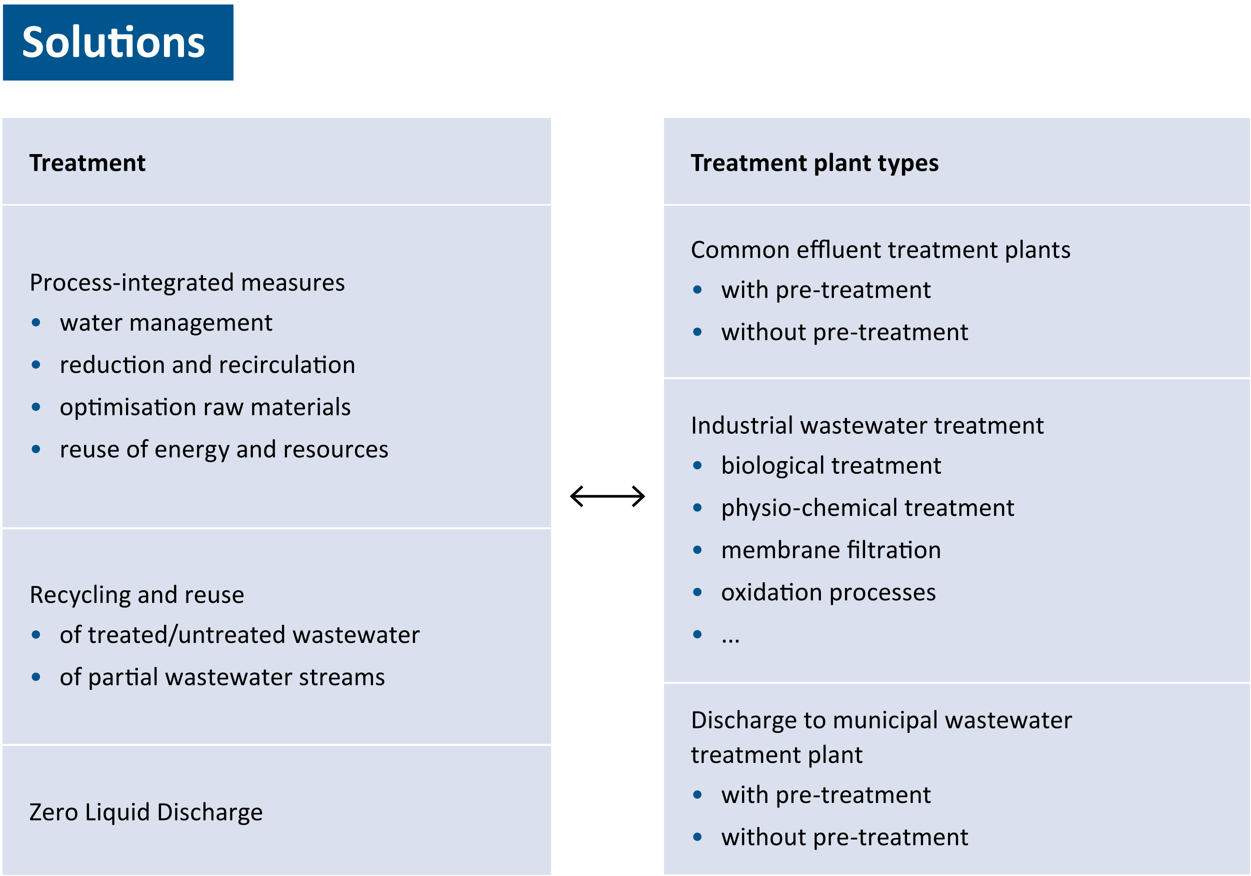
The highest priority in technical decision-making should be the adoption of an integrative approach. The best possible use of the resource water can be ensured by judiciously exploiting synergies between (sub-)processes. A positive example of a holistic technical solution approach is found in the way that wastewater treatment was implemented by Remondis (page reference) at an Indian chemical/plastic electroplating site. Targeted pre-treatment and further purification ensure that 90% of the water there can be reused. Optimum utilisation can also be achieved through the construction of collective industrial effluent treatment plants (CETPs). A trend towards centralised industrial parks and hence centralised wastewater treatment plants can be seen both India and in the MENA countries. However, it is important to carefully weigh the advantages and disadvantages of different treatment scenarios – joint wastewater treatment can be very efficient,

Figure 4: Interaction between the stakeholders whose expertise and breadth of experience is utilised in the identification of technical solutions

especially for companies in similar industries, while in other cases separate (pre-)treatment is often necessary. Depending on the treatment objective and local conditions, the specific technical implementation of wastewater treatment may ultimately involve different treatment stages, such as biological, chemical-physical or membrane processes (Figure 5).

The applicable geographical conditions in the regions under discussion often give rise to considerations on the reuse or further use of wastewater. However, it is also important to take technical factors and legal requirements into account in this context. It should be possible to operate the plant efficiently – not least in terms of energy requirements – and ensure compliance with guideline and – if applicable – limit values. This is particularly applicable to the creation of wastewater-free plants, an approach currently being pursued by government initiatives both in India and in the MENA region.

The technical components that have been developed to meet the challenges mentioned above are now available. However, the properly considered planning and design of a wastewater treatment system first requires a valid set of data on wastewater capacity, composition and the other general conditions involved. Finally, monitoring of plant operation by the operator and of wastewater quality by the competent authorities is essential for reliable compliance with discharge conditions when it comes to protecting aquatic resources. □



Solutions

Treatment

Process-integrated measures
- water management
- reduction and recirculation
- optimisation raw materials
- reuse of energy and resources

Recycling and reuse
- of treated/untreated wastewater
- of partial wastewater streams

Zero Liquid Discharge

⟷

Treatment plant types

Common effluent treatment plants
- with pre-treatment
- without pre-treatment

Industrial wastewater treatment
- biological treatment
- physio-chemical treatment
- membrane filtration
- oxidation processes
- ...

Discharge to municipal wastewater treatment plant
- with pre-treatment
- without pre-treatment

Figure 5: Overview of possible technical solutions for industrial wastewater treatment in line with priorities in individual cases

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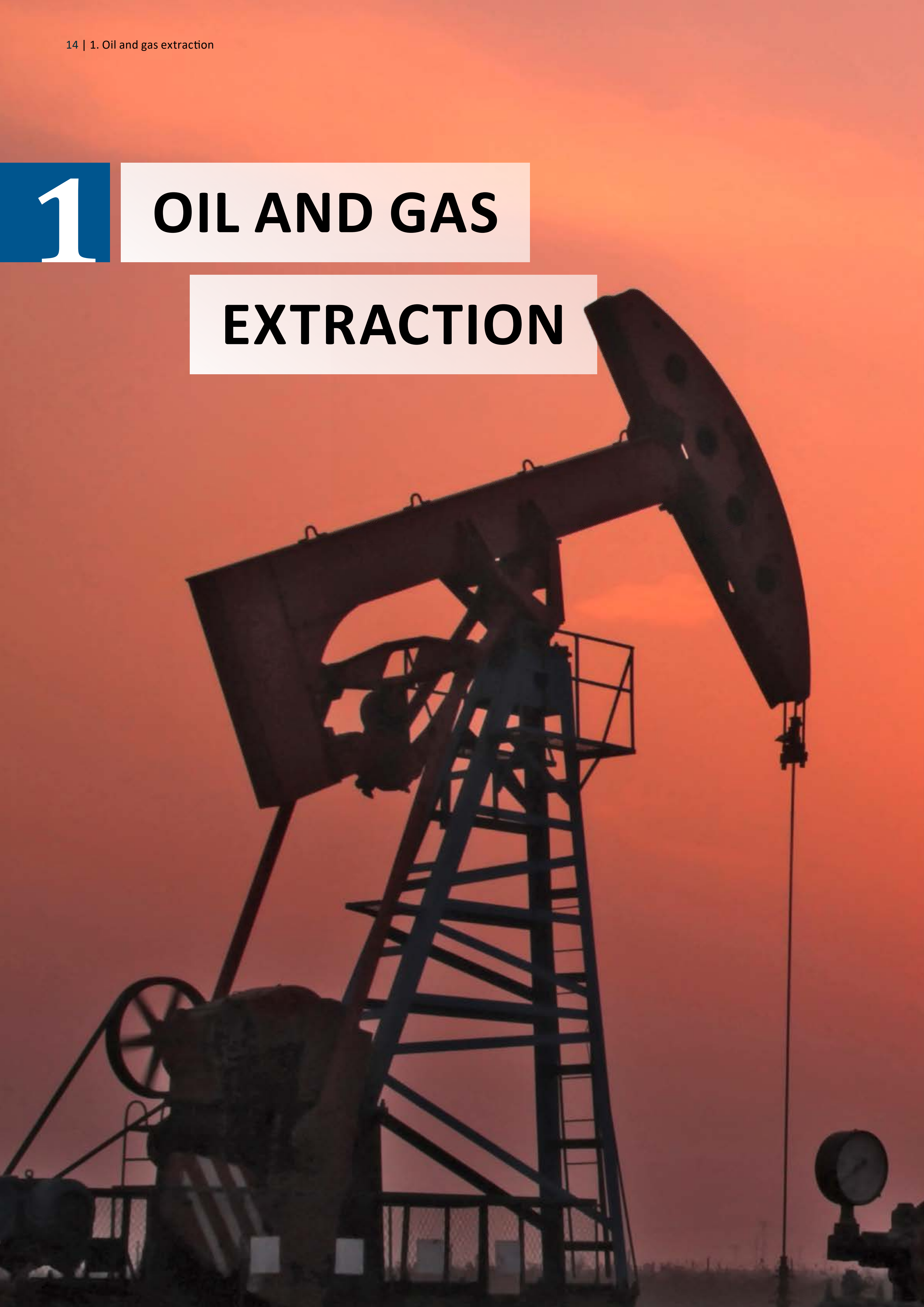
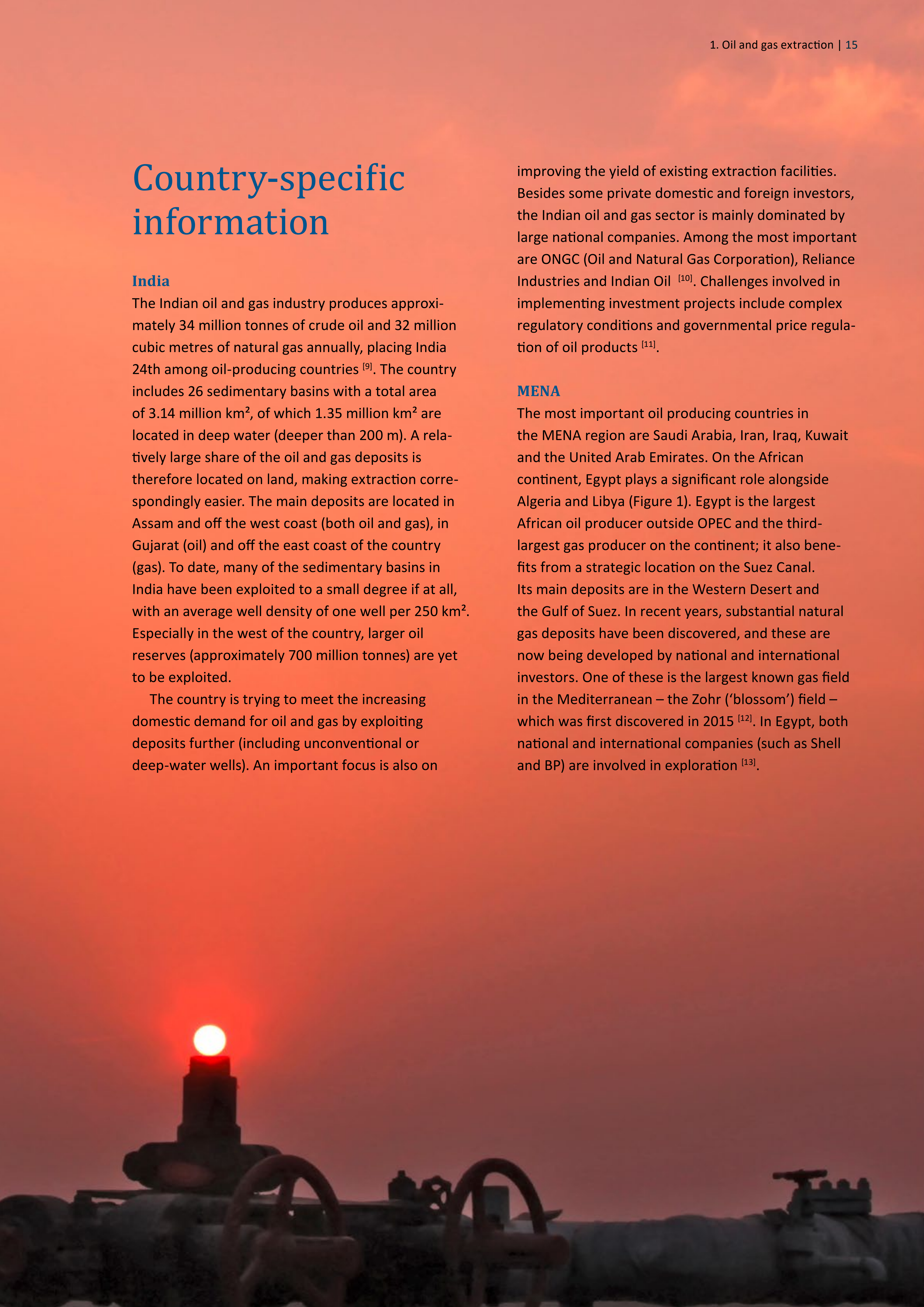
OIL AND GAS EXTRACTION





Country-specific information

India

The Indian oil and gas industry produces approximately 34 million tonnes of crude oil and 32 million cubic metres of natural gas annually, placing India 24th among oil-producing countries [9]. The country includes 26 sedimentary basins with a total area of 3.14 million km^2, of which 1.35 million km^2 are located in deep water (deeper than 200 m). A relatively large share of the oil and gas deposits is therefore located on land, making extraction correspondingly easier. The main deposits are located in Assam and off the west coast (both oil and gas), in Gujarat (oil) and off the east coast of the country (gas). To date, many of the sedimentary basins in India have been exploited to a small degree if at all, with an average well density of one well per 250 km^2. Especially in the west of the country, larger oil reserves (approximately 700 million tonnes) are yet to be exploited.

The country is trying to meet the increasing domestic demand for oil and gas by exploiting deposits further (including unconventional or deep-water wells). An important focus is also on improving the yield of existing extraction facilities. Besides some private domestic and foreign investors, the Indian oil and gas sector is mainly dominated by large national companies. Among the most important are ONGC (Oil and Natural Gas Corporation), Reliance Industries and Indian Oil [10]. Challenges involved in implementing investment projects include complex regulatory conditions and governmental price regulation of oil products [11].

MENA

The most important oil producing countries in the MENA region are Saudi Arabia, Iran, Iraq, Kuwait and the United Arab Emirates. On the African continent, Egypt plays a significant role alongside Algeria and Libya (Figure 1). Egypt is the largest African oil producer outside OPEC and the third-largest gas producer on the continent; it also benefits from a strategic location on the Suez Canal. Its main deposits are in the Western Desert and the Gulf of Suez. In recent years, substantial natural gas deposits have been discovered, and these are now being developed by national and international investors. One of these is the largest known gas field in the Mediterranean – the Zohr (‘blossom’) field – which was first discovered in 2015 [12]. In Egypt, both national and international companies (such as Shell and BP) are involved in exploration [13].

In direct comparison, Tunisia is only a small oil and gas producer (Figure 1) and the market is dominated by national companies [13]. Its main deposits are the El Borma field, as well as the recently developed Zarat and Miskar fields (in deep water) [14]. In addition, two major shale formations are located in the south of the country, and there are plans to exploit these as unconventional sources in the future [15]. In Jordan and Morocco, the development of oil and gas deposits is still in its infancy (Figure 1). Both countries fulfil most of their energy needs with imports and have so far only produced oil and gas in relatively small quantities. Several domestic companies as well as almost all of the well-known international companies (Shell, BP, ENI and Repsol) are involved in exploration [16]. Shale formations play an important role in both Jordan and Morocco. For example, oil shale is found beneath approximately 70% of Jordan's surface area (about 30 million tonnes of oil, making it the fourth-largest deposit worldwide). However, the resources involved are comparatively difficult to exploit [17, 18].

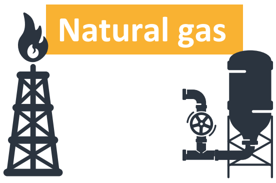
Production volumes and reserves

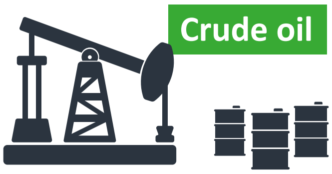
Wastewater generation in the industry

The industrial sector of oil and gas production includes the exploration and development of deposits through exploratory drilling as well as the regular operation of production wells. In addition to conventional oil and gas fields, unconventional sources are increasingly being developed through fracking. Fracking involves pumping fracking fluid into wells at high pressure (typically several hundred bar) to hydraulically fracture the reservoir rock and thereby increase the permeability for oil or gas.

Large quantities of water are used at all stages of oil and gas production, from well-drilling to production operations. As a global average, about 3 m³ of water are needed for every m³ of crude oil extracted – and the trend is rising. In terms of volume, the largest wastewater stream generated

Production volume and reserves





	Natural gas		Crude oil	
	Production volume bcm per year	**Reserves** bcm	**Production volume** billion t per year	**Reserves** million t
Egypt	59.9	1,784.0	33.7	504.0
Tunisia	1.2	65.1	2.1	56.0
Jordan	0.1	5.7	0.02	0.1
Morocco	0.1	1.4	0.01	<0.1

Figure 1: Production volumes and reserves of oil and natural gas in selected MENA countries (2018) [19, 20, 21]

during conventional production is reservoir water. Wastewater also arises from the flooding of ageing wells. In addition, operations can result in a variety of (drilling) muds and cooling waters that need to be treated and disposed of. If oil sand is extracted, consideration will need to be given to tailings ponds as a source of wastewater. Fracking also produces a large proportion of the fracking fluid used as flowback water [22].

Different wastewater streams can only be mixed to a limited extent, as the dissolved minerals and salts can lead to precipitation and deposits in pipes, equipment or wells. Operators can maximise their yield by minimising the loss of oil into wastewater and by recovering saleable oil. Similarly, in regions where water is scarce, the treatment and reuse of wastewater can provide both an environmental and economic benefit [23]. Prior to this, wastewater flows should be analysed with regard to the pollutants they contain; risks to human health, soils, groundwater and plants should be factored in; and appropriate requirements and metrics should be defined.

Wastewater streams and characteristics

Reservoir water

Reservoir water is water stored in geological formations that comes to the surface via production wells. The water contains – and can even be saturated with – a variety of residues from the geological formation in which it is stored, including liquid or gaseous hydrocarbons and other organic substances (e.g. benzene, toluene, ethylbenzene, xylene, naphthalene or phenol) either in dissolved form or floating as free oil. The reservoir water also contains heavy metals and other inorganic residues – some of which are naturally radioactive – which selectively accumulate in the water depending on the geological formation involved (e.g. uranium, radium, radon, lead, arsenic, cadmium and sulphides). Due to its long storage time within deep rock strata, the emerging water may have high temperatures (up to 150°C) and may also be contaminated with production chemicals (e.g. corrosion inhibitors, emulsion breakers, biocides) after passing through the borehole [22, 24].

Parameter	Concentration	Unit
Conductivity	4,200–58,600	µS/cm
pH	4.3–10	-
Total organic carbon (TOC)	0–1,500	mg/l
Solids	1.2–10,623	mg/l
Oil and grease	2–565	mg/l
Ammoniacal nitrogen	10–300	mg/l
Chloride	80–200,000	mg/l
Sulphate	<2–1,650	mg/l

Table 1: Typical quality parameters of reservoir water from petroleum production [26]

In most cases, reservoir water constitutes the largest waste stream in oil and gas production, and the proportion of water extracted increases with the age of the well. The contaminants necessitate careful handling and thorough treatment prior to disposal (Table 1). Nowadays, it is recommended that reservoir water be reused after appropriate treatment, for example as floodwater, in order to protect the environment and to save water resources. Alternatively, the waste stream can be deposited in sink holes or discharged into the environment as wastewater. The best technique available is to treat reservoir water using physico-chemical processes until it is environmentally safe [25]. To meet acceptable quality standards for discharge to surface waters, the water would have a maximum hydrogen carbon content of 10 mg/l, to give one example (Figure 2).

Flowback water

Flowback water is the water-based fracking fluid used in fracking that comes back to the surface through the well after operations have been completed. The amount of flowback water is equivalent to approximately 10–30% of the amount of fracking fluid used and will also depend on the number of fracking phases executed and the reservoir conditions. Flowback water contains a variety of substances, including the chemical additives of the fracking fluid and the contaminants absorbed in the well. Fracking fluid may contain sand, corrosion inhibitors, acids, biocides, lubricants or surfactants, among other things. Frequently found relevant geogenic contaminants from the borehole include aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene, xylene), particulate-bound substances of increased natural radioactivity and volatile mercury compounds [22, 30].

The main disposal methods for flowback water are disposal in injection wells or reuse for secondary or tertiary extraction activities. After appropriate treatment, it may also be possible to dispose of it into the environment. Some contaminants can pose a technical challenge in both reuse and wastewater treatment. For example, polymer gels, solids or precipitates can clog filters, fixed beds and other plant components.

Floodwater

Flood water is used firstly to carry out hydrostatic impermeability and pressure resistance tests of the plants. Secondly, flooding with water is carried out in order to clean boreholes and thereby stimulate the flow of oil. Chemical additives such as corrosion inhibitors, biocides, oxygen binders, acids and, if necessary, tracers are usually added to stabilise the flood water. In addition, the waste-

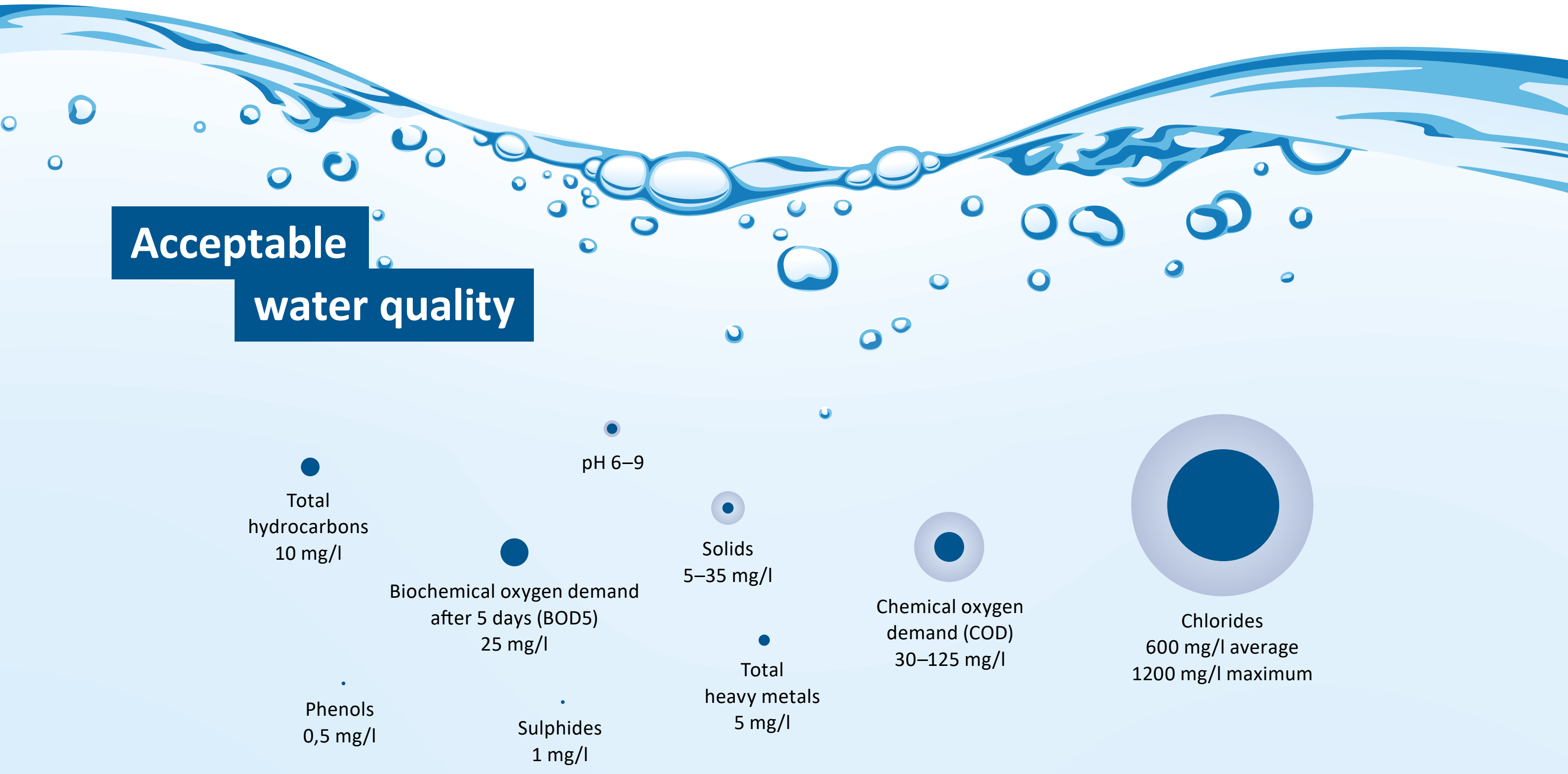


Figure 2: Acceptable water quality for discharge of treated reservoir water to surface waters [27, 28, 29]

water produced after its use is contaminated with substances from the well, such as oils, greases and other hydrocarbons (e.g. benzene, toluene, ethylbenzene, xylene) as well as solids, iron and often chlorine [22]. The best available technique today involves reuse of the floodwater, if necessary after treatment on site or by third parties. If it needs to be disposed of, physico-chemical cleaning along with subsequent quality control will need to be carried out [25].

Treatment processes

Process selection and stages

The choice of wastewater treatment processes depends on its composition, on the specific local geological conditions involved and, if applicable, on the intended reuse or further use of water streams. Usually, the first step consists of pre-treatment using physical and chemical separation processes. These include coarse filtration with screens, filters or fixed-bed filters, or sedimentation in combination with electrical or chemical coagulation to remove suspended solids.

Further treatment by means of biological processes is normally difficult to carry out due to the organic matter in the wastewater, which does not degrade easily. Instead, multiple stages involving more advanced physical and chemical processes are used to perform the following separation tasks [31]:

- Further removal of suspended solids
- Coarse and fine separation of dispersed and undissolved oils and fats
- Separation of other dissolved hydrocarbons in the low concentration range
- Removal of dissolved heavy metals

If a wastewater stream is to be reused or recycled after treatment – for example as floodwater or a component of fracking fluid – the choice of process must meet higher quality criteria. In most cases, desalination must at least be included as an additional step.

Further treatment

To separate solids and oils, subsequent treatment mainly involves physical separation processes, which exploit the difference in density of the different phases. The separation of fine suspended particles can be aided by the dosing of flocculants, while demulsifiers can be dosed to separate dispersed oils. Specifically, the following technologies can be considered [25, 32]:

- Gravity separators
- Hydrocyclones
- Skimmers
- Centrifuges
- Gas flotation

Following phase separation, the wastewater still contains organic and inorganic contaminants in dissolved form, usually hydrocarbons and heavy metals. In most cases, these are removed from the wastewater by chemical separation processes but, depending on the application, special filtration processes or thermal processes may also be used. The most common basic operations are [25]:

- Membrane filtration
- Adsorption
- Polymer extraction
- Steam stripping

Reuse

Wastewater that is to be reused in oil and gas production usually requires additional desalination [33]. Both cations (e.g. sodium, calcium, magnesium, potassium) and anions (e.g. chloride, nitrate, sulphate) are removed in this context. Typically, the following processes are used:

- Ion exchange
- Membrane process
- Distillation □

CASE STUDY: Petroleum refinery wastewater treatment in Shandong Province, China

Industrial membrane bioreactor (MBR) modules

Background

Crude-oil refining is a major industry worldwide, including in India and North Africa. Biological treatment of wastewater from petroleum refineries often involves problems in meeting prescribed effluent levels due to the complex composition of the wastewater and its relatively high oil content. One of the challenges that arise in this context is the sometimes poor settling behaviour of the activated sludge in the final sedimentation stage of biological treatment and the formation of floating sludge, which cannot be contained in the final sedimentation stage. For this reason, technologies that offer a high degree of operational reliability are used in wastewater treatment in this area. In the project in Shandong Province / China, membrane bioreactor technology (MBR) was therefore selected for the treatment of the wastewater.

Parameter	Feed	Discharge	Required
COD [mg/l]	700	≤ 60	≤ 70
BOD [mg/l]	200	≤ 15	≤ 20
Total nitrogen [mg/l]	100	8	≤ 15
Total phosphorus [mg/l]	3	0	≤ 1
TSS [mg/l]	230	≤ 10	≤ 10
Oil [mg/l]	25	0	≤ 5
Turbidity (NTU)	-	≤ 0.5	≤ 1

Table 1: Feed and discharge parameters

Special challenge/problem

The wastewater to be treated originates from the refining of crude oil and, in addition to high COD and BOD values, has a high oil and solvent content. To comply with the legally prescribed effluent values (Tab. 1) after wastewater treatment, an appropriate process control system was selected. Solvents, oils and the tar substances present in crude oil, in particular, can cause problems in plant operation. Reliable BOD and COD degradation can only be achieved in the biological stage if these substances are separated in advance. Furthermore, attention must be paid to ensuring that, even if the sludge has poor sedimentation properties in the biological stage and floating sludge is formed, there is no possibility of an increased solids content and therefore increased COD and BOD values in the effluent from the wastewater treatment plant. This aspect in particular makes a membrane-supported hybrid process ideal for achieving the lowest possible solids concentrations in the effluent from the biological stage.

Solution

In response to unsatisfactory performance levels, a petroleum refinery wastewater treatment plant in Shandong Province, China, was refitted with an MBR solution including MICRODYN BIO-CEL® XL modules. In the wastewater treatment plant, 14 BIO-CEL XL modules were deployed, providing a total membrane area of

Figure 1: Submerged membrane modules after installation (left) and in operation (right)

26,880 m². The modules are arranged in two separate filtration lines in a single basin. The maximum and average flow rates are 13,500 and 9,600 m³/day, respectively. The treatment system processes also include:

- Oil separator
- CAF (cavitation air flotation) treatment
- DAF (dissolved air flotation) treatment
- Equalisation tank
- Anoxic primary tank
- Sedimentation tank
- Secondary anoxic tank
- Filtration tank (MBR)

Results

The results of this MBR system summarised in Tab. 1 demonstrate that MICRODYN BIO-CEL® XL modules can successfully treat wastewater from petroleum refineries and consistently meet the environmental authorisation requirements for wastewater. As shown in Tab. 1, the MBR system fulfilled the TSS wastewater requirement of 10 mg/l. The COD, BOD, total nitrogen, total phosphorus, oil and turbidity levels were drastically reduced and surpassed the client's wastewater requirements. The membrane filtration system is monitored by continuously measuring flow, transmembrane pressure and turbidity.

Contribution of the technology provided

The installation of an MBR system enables stable operation with almost complete separation of solids even under challenging conditions (e.g. floating sludge). The self-supporting MICRODYN modules used here offer a very high packing density and comparatively energy-efficient operation. □

2

CHEMICAL INDUSTRY

Country-specific information

India

The chemical industry, one of India's oldest economic sectors, makes a significant contribution to the country's economic development. Most of the chemical manufacturing companies are based in Gujarat, followed by Maharashtra and other less significant regions. The government supports this important pillar of the economy by allowing 100% foreign direct investment and licence-free production of most chemical products (except hazardous substances). In the last national five-year plan (2012–2017), a budget of the equivalent of USD 83 million was allocated, in addition to a wide range of support measures, to improve the environmental performance of the industry. The industry is expected to grow at an estimated rate of 13–14% for 2020–2025, with petrochemicals in particular growing by 8–9% [34]. The sector includes both national and large international companies. Some of the major chemical producers in India are Aarti Industries, Atul, BASF, Evonik, Pidlite Industries, Tata Chemicals and UPL [35].

The most important segments of the chemical industry in India are [34]:

- Petrochemicals and basic organic chemicals
- Basic inorganic chemicals, especially fertiliser and chlor-alkali industries
- Polymers
- Fine chemicals and speciality chemicals, especially dyes and pigments
- Pharmaceutical industry

Major sectors and contribution to GDP

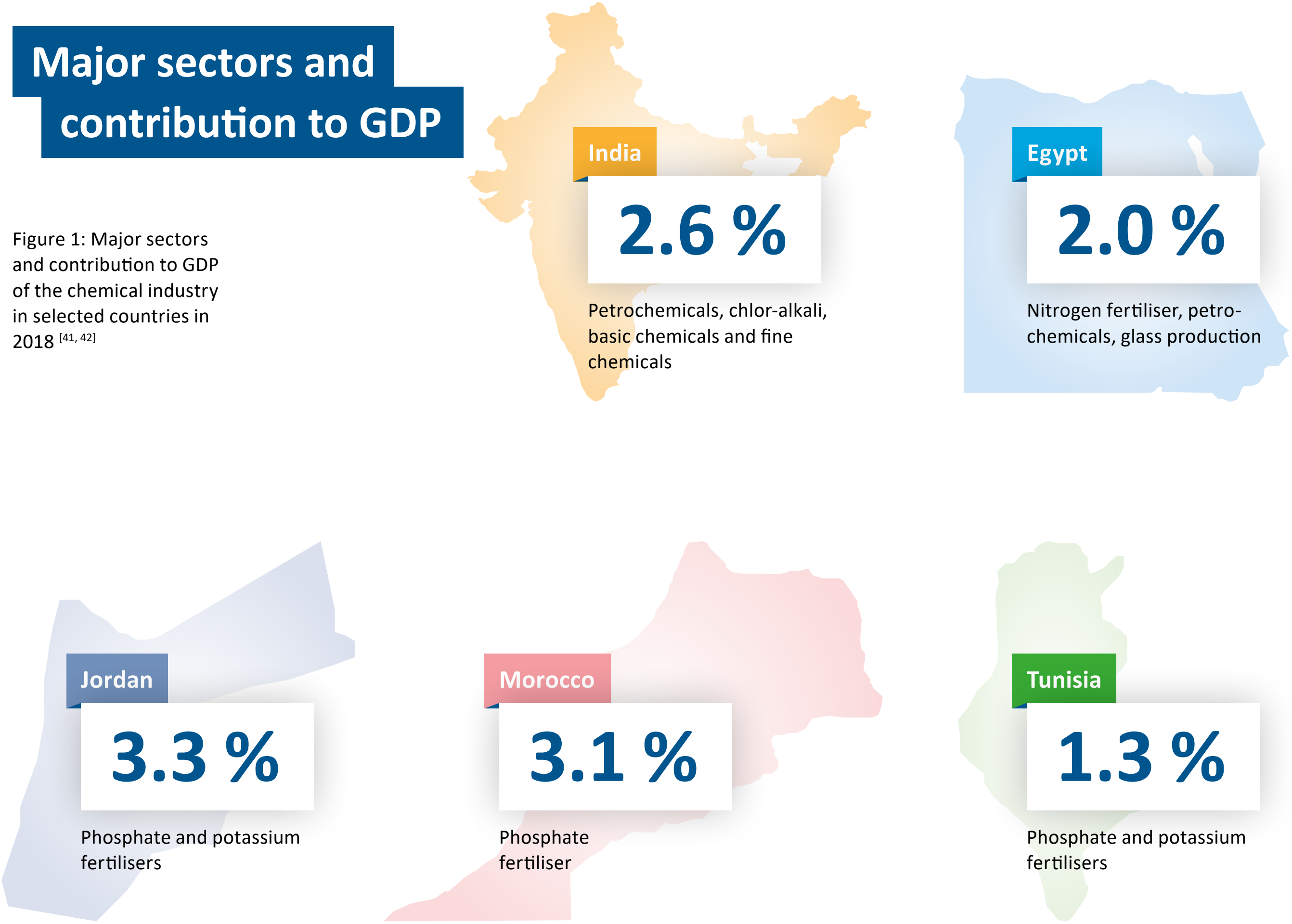


Figure 1: Major sectors and contribution to GDP of the chemical industry in selected countries in 2018 [41, 42]

MENA

Within the MENA region, the growth of the chemical industry has strongly correlated with the available resources; in other words, the processing of oil, gas and mineral raw materials has played the most significant role (Figure 1).

Fertiliser production is the most important and fastest growing sector in many MENA countries. Egypt produces about 2 million tonnes of fertiliser annually – a figure that is increasing – and is the region's largest producer of nitrogen fertiliser (ammonium/urea). The market is dominated by local companies such as Abu Qir Fertilizers and Alexandria Fertilizers [36]. Other relevant industries are petrochemicals and polymer production, especially in the industrialised regions of Cairo, Alexandria and Helwan. The country is also pursuing a 20-year plan to expand its production capacities for (poly)ethylene and other olefins [37].

Other significant resources in the region include phosphate and potash minerals. Jordan and Tunisia have deposits of these minerals and mainly produce phosphorus and potassium fertilisers from them [38]. Morocco is home to more than 70% of global phosphate reserves; as a result, the processing of phosphates into fertilisers and phosphoric acid is by some way the largest branch of the chemical industry there [39, 40]. The leading companies in the Moroccan and Jordanian fertiliser industry are closely linked to the respective national governments through partnerships or financing models.

Wastewater generation in the industry

The chemical industry incorporates a very wide variety of products and production processes. The processes used differ depending on the sub-sector and product, for example with regard to the synthesis method, catalysis and process control method involved. The petrochemical industry includes petroleum refining, the production of basic organic chemicals, for example by thermal or catalytic cracking, and, based on this, the production of polymers including synthetic fibres. In the fertiliser industry, meanwhile, mineral raw materials, such as potash or phosphate rock, are often processed. As a basic material for nitrogen fertilisers, ammonia is produced by means of the energy-intensive Haber-Bosch process. The chlor-alkali industry produces caustic soda, caustic potash, chlorine and, as a by-product, hydrogen. These are important raw materials for the production of basic inorganic chemicals, fine chemicals and consumer goods. Inorganic substances are produced from aqueous solutions of the initial raw materials mainly by means of crystallisation, filtration and drying [22, 43].

The wide variety of sub-sectors and production processes involved in the chemical industry yields very heterogeneous wastewater streams. The wastewater contains only a small amount of the starting materials or target products; to a greater extent, it contains the by-products of various reactions. These contaminants arise when reactions take place in the aqueous phase (water as a solvent), when material flows are washed with aqueous solutions, or in the event of condensation reactions [22, 44].

Wastewater streams and characteristics

Petrochemicals and basic organic chemicals

Steam is used in almost all refineries for distillation and separation processes. In such situations, it comes into direct contact with the hydrocarbons to be refined and, in condensed form, creates the most significant wastewater stream in the petrochemical industry: acidic water with contaminants of ammonia, hydrogen sulphide and hydrocarbons. This stream can also contain residues of metals, salts and other inorganics [22, 45].

When crude oil is processed into basic organic chemicals and finally into polymers, the most significant wastewater streams occur as reaction water or as washing water during (intermediate) product washing. High organic loads are often present in the form of organic acids or alkalis. In some cases, however, oils, (heavy) metals and other toxic and/or refractory compounds are also found in the wastewater as residues of catalysts and auxiliary materials that have been used [46, 47, 48].

Fertiliser production

In addition to catalysed oxidation processes, fertiliser production involves mainly filtration, crystallisation and smelting processes. In addition to the actual products manufactured, relevant by-product streams are also generated, such as sulphuric and phosphoric acid in phosphate processing or urea and nitric acid in ammonia processing. Both products and by-products are sometimes found in appreciable concentrations in the wastewater, which is mainly produced in the waste gas scrubbing process but also arises as a spent cooling medium or solvent. The wastewater streams are generally often acidic and contain a variety of inorganic contaminants [49, 50].

Chlor-alkali industry and other basic inorganic chemicals

Chlor-alkali plants produce chlorine and alkali in the form of sodium hydroxide or potassium hydroxide through electrolysis of a salt solution. This gives rise to both acidic and alkaline waters with high concentrations of dissolved salts and metals. Many of the water streams involved are very highly concentrated; because of this, the recovery of by-products, recirculation of auxiliary materials, or evaporation and disposal often make both ecological and economic sense. Of particular importance among the auxiliary materials are mercury (in the mercury process) and asbestos (in the diaphragm process), which are used in traditional chlor-alkali plants. However, these two processes are no longer considered as the best available techniques today and are increasingly being replaced by the modern membrane cell process, which results in less contaminated wastewater [51, 52].

In general, wastewater streams from the production of inorganic basic chemicals often contain chlorides, sulphates, phosphates, fluorides and other inorganic compounds. Ammonia and high solids contents can also play an important role here [50, 53]. Wastewater from sodium carbonate production often has a high pH value and high solids content, while wastewater containing sulphuric acid is produced during chlorine gas scrubbing.

Treatment processes

Process selection and stages

The heterogeneous wastewater streams of the chemical industry, which contain a variety of contaminants, often require complex treatment schemes, the specific implementation of which will depend on the composition of the wastewater involved. Many wastewater streams contain high organic loads with good biodegradability. In these cases, biological

	Neutralisation	Precipitation	Adsorption	Ion exchange	Extraction	Stripping	Oxidation
Petrochemicals and basic organic chemicals	✓	✓	✓		✓	✓	✓
Fertiliser production	✓			✓		✓	
Chlor-alkali industry and other basic inorganic chemicals	✓	✓	✓	✓			✓

Table 1: Wastewater pre-treatment processes commonly used in the chemical industry with the respective sub-sectors in which they are applied (based on [22, 46, 48, 50, 53, 54])

cleaning forms the core of wastewater treatment. However, if the wastewater is additionally contaminated with harmful substances, it must first be subjected to pre-treatment, the objectives of which include [22]:

- Neutralisation, in order to create optimal conditions for biological degradation
- Removal of substances with a toxic effect on biology
- Increasing the biodegradability of the wastewater (for example, through oxidation)
- Removal of non-biodegradable contaminants
- Load reduction of chemical oxygen demand (COD) or nitrogen in line with the capacity of the biological system

In the chemical industry, the treatment of water streams is difficult to separate from production and production-support processes, for example as regards the recirculation of solvents or washing waters. As the technical possibilities expand, potentials for the treatment, recycling and further use of auxiliary materials and by-products from aqueous solutions are also developing. The treatment of process water before it is used in the actual process also plays an important role.

Pre-treatment of wastewater

Almost all industrial wastewaters need to be pre-treated before being biologically cleaned. To achieve the above-mentioned objectives, chemical-physical or thermal treatment processes are mainly used (Table 1). The most common of these are [22, 46, 48, 50, 53, 54]:

- Neutralisation
- Precipitation
- Adsorption
- Ion exchange
- Extraction
- Steam stripping
- Oxidation

Biological cleaning

Wastewater streams from the chemical industry have very different physical and chemical characteristics. Many wastewater streams from the chemical industry have properties that are conducive to biological cleaning processes, i.e. high organic loads and moderate temperatures. Biological cleaning involves two stages:

- Carbon degradation via the aerobic activated sludge process
- Nitrogen elimination via nitrification and denitrification

The plants can be designed as multi-stage systems with varying combinations of the individual process stages. Aeration is typically carried out via robust injector systems that enable efficient oxygen input. In some cases, treatment of the waste gas from the first biological stage is necessary to prevent the discharge of volatile substances.

However, inlet and concentration fluctuations, unwanted contaminants and high salt content levels (>20 g/l) can impair the operation of a biological cleaning system. Moreover, wastewater from the petrochemical industry often only contains small amounts of usable phosphorus compounds, necessitating an additional dosage of phosphates or phosphoric acid for biological cleaning [22, 55].

Further treatment

The recovery and reuse of auxiliary materials associated with or integrated into the production process, such as the recirculation of condensates or the recovery of solvents by means of distillation, is a traditionally established practice that is indispensable for high plant efficiency. If water needs to be recovered and reused, this is normally done by means of ultrafiltration and reverse osmosis. The increasing concentration of manufacturing companies in industrial parks is also making it easier to create local circular economies for materials through the recover and reuse of (by-)products. Most importantly, however, industrial parks now also allow highly complex forms of wastewater in the chemical industry to be treated in an efficient way [44]. □

CASE STUDY: Chemical/plastic electroplating in India

Design and operation of a zero liquid discharge (ZLD) plant

Background

In 2017, a new production plant for coating plastic parts for the automotive industry was built near New Delhi (India) by Euro American Plastic Products (EAP). REMONDIS was commissioned by EAP to build, finance and operate the wastewater plant as part of a BOOT contract.

Special challenge/problem

The wastewater composition is typical for this type of galvanic coating. Table 1 shows the mean values in November–December 2017. Because of increasing industrialisation and the ensuing water demand combined with limited water availability, the local licensing authorities both prescribed ZLD technology for wastewater treatment and limited the allocation of water quantities for production. As the plant had to be integrated into an existing building, this imposed significant constraints on available construction space, especially with regard to the buffer and equalisation basins.

Parameter	Value
Quantity [m³/day]	200
pH	4–6
Lf [µS/cm]	12,000
COD [mg/l]	113
Cr total [mg/l]	1,418
Ni [mg/l]	54
Cu [mg/l]	67
Fe [mg/l]	9

Table 1: Composition of mixed wastewater

Solution

The wastewater treatment starts with partial flow treatment for chromium (VI) wastewater and for effluents with a high complexing agent content. The former is reduced using sodium bisulphite and sulphuric acid, while the wastewater containing complexing agents is pre-treated in a separate batch process. This is followed by the mixing of all partial streams and heavy metal precipitation. Solids are separated by parallel plate separators, gravel filters and a chamber filter press. This treatment corresponds to the usual process even without ZLD technology. To reuse the wastewater, the salts introduced in the production process also have to be separated by means of two-stage reverse osmosis (RO), with the stages achieving a permeate yield of 80% and 70% respectively. The RO feed is pre-treated by ultrafiltration to prevent the RO membrane from being blocked with particulate matter. The structure of the membrane stage is shown in Fig. 1.

Results

The treatment stages described enable about 90% of the wastewater to be reused, while salts and organic residues remain in the concentrate stream (Tab. 2). These concentrates are evaporated, and the brine is disposed of together with the filter cake. The condensate obtained is returned to the process water circuit.

Treatment stage	Conductivity [µS/cm]
Permeate first RO stage	220
Concentrate first RO stage	38,500
Permeate second RO stage	30
Concentrate second RO stage	3,700

Table 2: Quality of process water produced

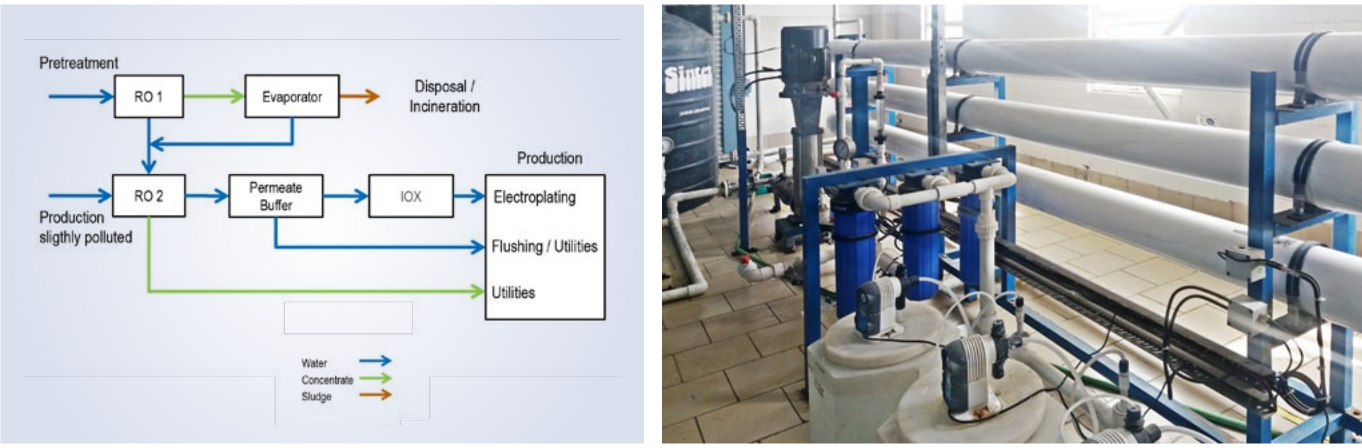


Figure 1: Structure of membrane stage using ZLD technology in plastic electroplating (left) Photograph of RO stage 1 (right)

To optimise treatment costs, a distinction is made between three different quality levels when returning the treated water to production. The concentrate of the second RO stage is still of sufficient quality for simple rinsing processes and other process water applications. The permeate from this stage can either be used directly in the electroplating bath or, in the case of particularly stringent quality requirements, it is purified again via a mixed-bed exchanger.

The most challenging tasks during commissioning were the generation of a uniform wastewater quality in the feed to the RO stages and the development of a cleaning regime for all of the membrane stages. The first stage of the RO plant is subject to particularly high loads and requires a correspondingly high cleaning frequency. For membrane cleaning operations, the optimum balance between yield and cleaning effort was found to be the cleaning regime described in Table 3.

Contribution of the technology provided

Remondis supplied a complete treatment system for wastewater treatment and process water treatment in accordance with the ZLD model. The efficient operation of the plant depends on robust pre-treatment using ultrafiltration, high resistance to fouling and efficient cleaning in the RO stages, and expedient interconnection and reuse of the resulting water flows. □

Stage	Frequency	Cleaning chemicals
UF	monthly	NaOCl and citric acid
first RO stage	every 7 to 10 days	HCl and NaOH
Second RO stage	monthly	HCl and NaOH

Table 3: Cleaning scheme for membrane stages

Parameter	Feed
Quantity [m³/day]	200
pH	4–6
Conductivity [µS/cm]	12,000
COD [mg/l]	113
Cr total [mg/l]	1,418
Ni [mg/l]	54
Cu [mg/l]	67
Fe [mg/l]	9

Table 4: Overview of water treatment influent values – mean values of the commissioning period Nov.–Dec. 2017. Effluent values are not relevant in this case, as it is a ZLD plant.

CASE STUDY: **Optimised process water treatment for fertiliser production in Egypt**

Optimised process water treatment using reverse osmosis and ion exchangers

Background

Alexandria Fertilizers Co. (Alexfert) is one of Egypt's largest fertiliser manufacturers, established as a joint stock company in 2003. To manufacture fertilisers, large quantities of high-quality process water are required. This is mainly extracted from a Nile canal. Due to seasonal fluctuations, treatment is particularly challenging, as consistently high water quality is required along with a high yield (Table 1).

Special challenge/problem

The Alexandria plant generates a process water flow of about 5,750 m^3/day and, for pre-treatment purposes, uses flocculation to reduce organic substances and a cold lime softening process. To achieve the desired quality for use, among other things, as boiler feed water, a combination of different ion exchange processes (strongly acidic cation (SAC), weakly basic anion (WBA), strongly basic

Figure 1: Process water treatment with reverse osmosis and ion exchangers

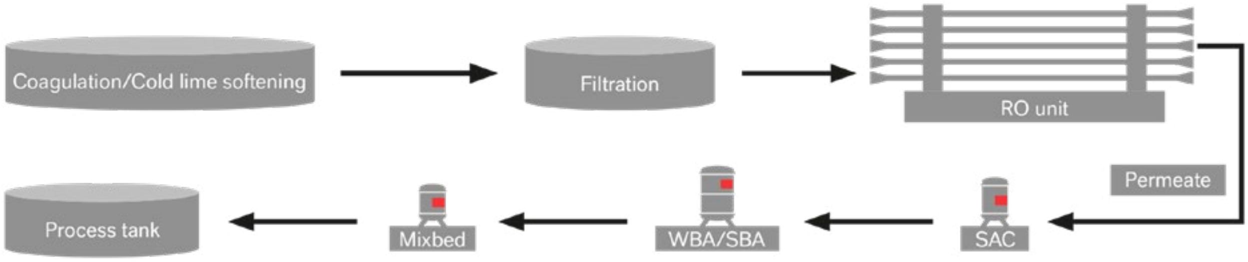


Figure 2: Water treatment of Alexfert fertiliser production using a reverse osmosis system

anion (SBA) and a mixed bed) was used for demineralisation. However, as the canal water has a salt content of 300–550 mg/l depending on the season, the ion exchangers had to be regenerated regularly with acid and alkali. Also, the presence of silica shortened the working life of the ion exchangers.

Solution

If ion exchangers can only be operated inefficiently under difficult conditions with short service lives and high regeneration agent use, pre-treatment may be necessary. The plant described above was expanded in 2016 to include reverse osmosis, which reduces the salt load upstream of the ion exchangers (Figs. 1, 2). Since the canal water has a low water quality despite pre-treatment, the Lewabrane B400 FR reverse osmosis elements from LANXESS* were used, as they are particularly suitable for the quality levels involved. The plant consists of two lines, each with two concentrate stages. The permeate yield from the reverse osmosis is 74%. For demineralisation with ion exchangers, monodisperse Lewatit resins are used to further optimise the use of chemicals.

Capacity	5,750 m^3/day
Yield	Approx. 74%
Water type	Canal water from the Nile
Inlet salt content	300–550 mg/l
Effluent salt content	<0.01 mg/l
Installation	February 2016

Table 1: Summary of the plant parameters in the water treatment at Alexfert, Alexandria

Results

The highly cross-linked polyamide membrane can remove over 99.7% of the salts. The conductivity after reverse osmosis is 3–5 µS/cm, with a conductivity in the feed of 700–1,100 µS/cm. Since this achieves a four-fold increase in the service life of the ion exchangers, 60% of the regeneration chemicals are saved. A conductivity of 0.08 µS/cm of the production water could be achieved in the effluent from the Lewatit ion exchangers, with a final silica concentration of 2 ppb.

Contribution of the technology provided

LANXESS provided a particularly robust reverse osmosis system that ensures consistently high permeate quality even at low feed quality. The special design of the feed spacers significantly reduces membrane fouling – and thus also any drop in pressure within the module. The process integration increases the service life of the ion exchangers and reduces the quantity of regeneration chemicals needed. □

*The membrane business of Lanxess Deutschland GmbH was taken over by SUEZ WTS Germany GmbH in Ratingen after the time of writing.

3

PHARMACEUTICAL INDUSTRY

Country-specific information

India

India’s pharmaceutical industry – as a sub-sector of the chemical industry – is of great national and international importance. India is the largest producer of generic drugs worldwide and produces more than 80% of the AIDS (Acquired Immune Deficiency Syndrome) drugs in use. India is also the leading producer of paracetamol, while more than 50% of vaccines used globally come from India. The industry grew by 9.8% in 2019, while its biotechnology sub-sectors are estimated to be growing by around 30% annually [56]. The highly diversified market is home to both Indian companies (such as Sun Pharma and Dr. Reddy’s) and most if the international pharmaceutical companies (such as Pfizer, GSK, Sanofi, Merck and Roche) [57].

Drug manufacturing in India relies heavily on imported active pharmaceutical ingredients, most of which come from China. Accordingly, promoting the production of active pharmaceutical ingredients within the country represents an important medium-term goal for strengthening the industry domestically. As recommended by the Katoch Committee, industrial parks, equipped with the appropriate infrastructure and bundled services (energy supply, wastewater treatment, storage facilities, testing laboratories, etc.), are therefore being set up throughout the country to provide incentives specifically for manufacturers of active pharmaceutical ingredients and medicines. In late 2019, a decision was made to establish an industrial park of this type in Hyderabad and provide corresponding government funding (‘Hyderabad Pharma City’) [58].

Environmental and particularly water-related aspects of production are regulated in India by the ‘Central Pollution Control Board’. One of its roles is to set discharge conditions for pharmaceutical wastewater. The discharge of antibiotic residues from production plants, which has been shown to result in the spread of antibiotic-resistant germs within Indian surface waters, is currently the subject of critical discussion. A draft law for stricter regulation and control of antibiotic concentrations in industrial wastewater streams has been in consultation since early 2020 and could significantly increase the requirements for pharmaceutical wastewater treatment in India in the future [59].

MENA

The pharmaceutical industries of the MENA countries are, relatively speaking, not very export-oriented and are focused instead on meeting domestic requirements. This makes them heavily dependent on the national health systems of the particular countries involved [60].

The main drug manufacturer in the region is Egypt, where the sector is growing by approximately 8% annually. Both privatised companies (Novartis, GSK and Sanofi) and state-owned companies contribute to the production of pharmaceuticals, fulfilling 90% of domestic demand for medicines (mainly through generics). Overall, the industry is considered stable and sustainable, even though government control of drug prices and the heavy dependence on imported raw materials (approximately 90%) pose challenges for production in the country [61, 62].

Morocco's pharmaceutical industry is the second-ranking chemical industry in the country (after phosphates) and the second-largest in Africa (after Egypt). The industry is growing by 6.7% annually, with Sanofi as the leading producer, followed by local companies Cooper and Bottu SA [63]. In 2015, the country was able to meet approximately 65% of the national demand for medicines with drugs produced internally. [64]. Tunisia achieves a similar ratio, with 60% of medicines being produced domestically [65]. Drug production also plays an important role in Jordan's national economy. Some of its pharmaceuticals, most of which are manufactured in industrial zones around Amman, are exported to neighbouring countries [66].

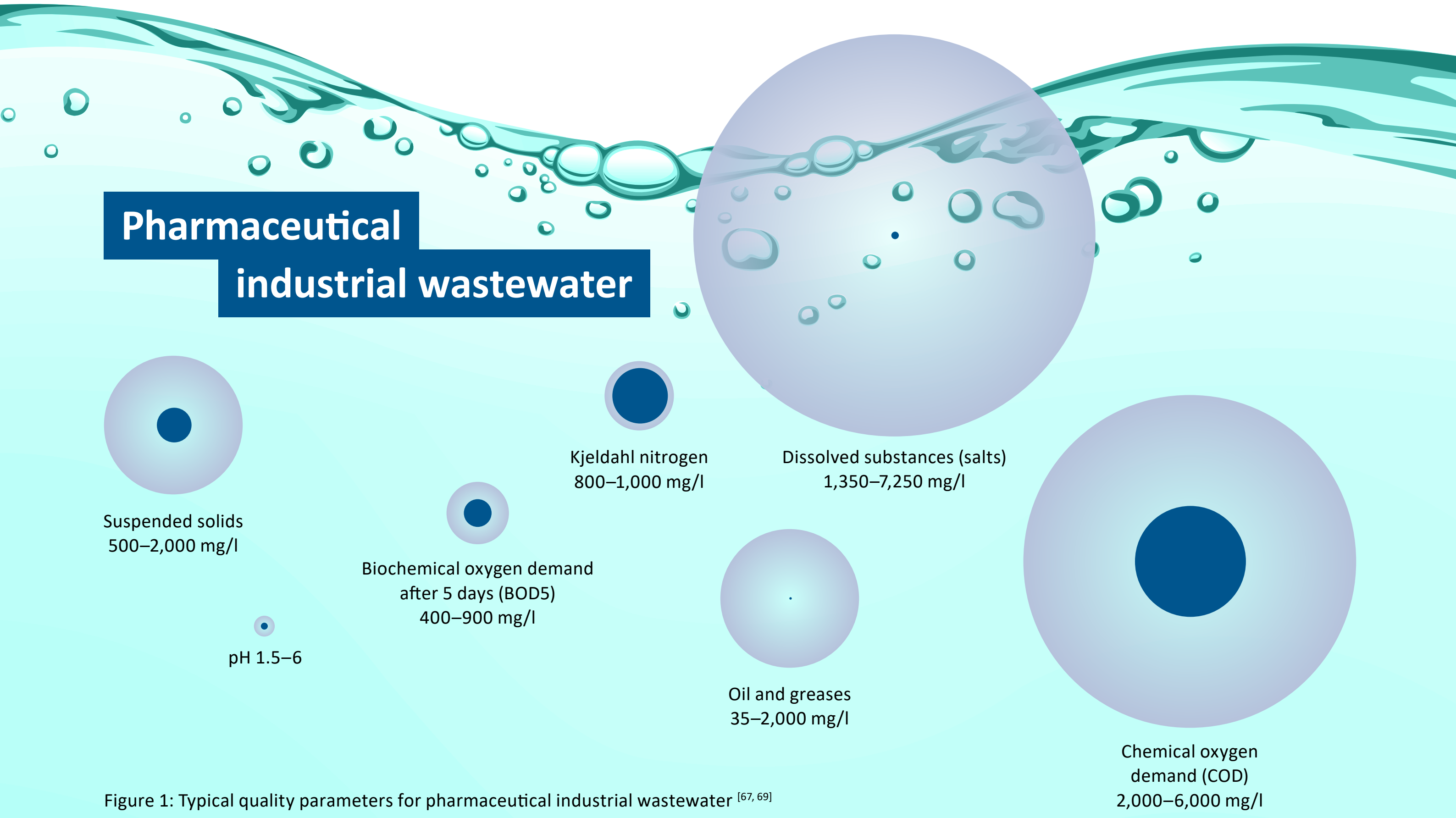


Figure 1: Typical quality parameters for pharmaceutical industrial wastewater [67, 69]

Industry and wastewater generation

The pharmaceutical industry includes the production, extraction, processing, purification and packaging of chemical or biological substances used in medicines and cosmetics. The industry encompasses a wide variety of products and production processes. The most common process steps in the pharmaceutical industry are:

- Synthesis of organic chemicals
- Biotechnological processes
- Extraction of natural substances
- Product formulation and filling

The pharmaceutical industry differs from other sectors mainly in the frequent batch and product changes involved. Individual production steps are often performed one after the other in semi-continuous or batch production mode within multi-purpose reactors. Large quantities of rinse water are produced during each intermediate cleaning stage, and these make up the bulk of industrial wastewater produced. Among other things, rinse water can contain appreciable concentrations of pharmaceutically active substances and must therefore be thoroughly cleaned. Moreover, regeneration solutions and concentrates are generated by the usually very complex (raw) water treatment process, along with clarification water from the cooling towers. The largest quantities of wastewater in the pharmaceutical industry are derived from the chemical synthesis and fermentation processes [22].

Synthesis

Synthesis refers to the production of active pharmaceutical ingredients from organic and inorganic starting materials in a series of chemical reactions. This typically results in the formation of numerous intermediate products and by-products. The end products are finally separated by separation processes (e.g. liquid-liquid extraction, crystallisation or filtration). The different chemical reactions result in very heterogeneous synthesis effluents that contain starting materials, pharmaceutically active products and by-products, as well as a variety of excipients. Solvents, acids, bases, nitrates, sulphates and cyanides are used as auxiliary substances. With pH values of 1–11, the chemical and biological oxygen demand of these effluents is typically high [67].

Fermentation

Biotechnological processes involve the propagation, cultivation and fermentation of microorganisms such as fungi and bacteria. During fermentation, nutrients, inorganic salts and other substances are dosed, after which the final products are separated from the fermentation broth (for example, by precipitation and filtration). Major fermentation products include antibiotics, steroids and vitamins. Fermentation broths constitute the most important wastewater stream from fermentation processes. They contain unspent raw materials and nutrients as well as the remains of microorganisms. Auxiliary substances such as buffers, chelates and disinfectants as well as solvents and precipitants such as metal salts and halogens can also be found in the wastewater [67].

Wastewater streams and characteristics

Typical contaminants

Pharmaceutical wastewater has a high biological and chemical oxygen demand, and contains volatile organic compounds and, in some cases, highly active or toxic substances. These include many of the starting materials and catalysts used in production and, of course, the active pharmaceutical ingredients themselves [68] (Figure 1). The occurrence of active pharmaceutical ingredients in wastewater is problematic firstly because of their high environmental toxicity; secondly, these pollutants play a role in the spread of microbial antibiotic resistance. Spent solvents (such as benzene, phenol or toluene) are another major source of contamination. These are used as reaction and cleaning media in production processes and are discharged into the wastewater via solvent recovery systems. In general, the pharmaceutical industry is facing a challenge due to the great variation in the quantity and characteristics of the individual production wastewaters involved, as well as the extreme persistence and poor biodegradability of many contaminants [22, 69].

Treatment processes

Biological cleaning

Wastewater treatment in the pharmaceutical industry is traditionally carried out by means of biological cleaning processes. The wastewater often contains a readily biodegradable organic load. However, there are often substances in the wastewater that have poor biodegradability or can even have a toxic effect on the biological agents. This is a challenge for numerous biological cleaning processes. The biodegradability of a chemical compound depends mainly on its stereochemistry, toxicity and concentration levels. From an operational point of view, the suitability of the particular microbial strain involved, the degradation conditions and the time spent in the biological stage play an important role [66].

Aerobic processes are most commonly used in the pharmaceutical industry for wastewater treatment, as they are very robust in operation. Activated sludge processes including sedimentation and long sludge retention times are often the means of choice, although membrane bioreactors are also increasingly utilised to achieve a high effluent quality. Aerobic processes have proven successful for the degradation of many active pharmaceutical ingredients (e.g. ibuprofen, naproxen, bezafibrate and oestrogens), but they have their limits, especially with sulphonamides (e.g. sulphamethoxazole, clopamide and sotalol). Anaerobic processes are less commonly used because, on a comparative basis, they are susceptible to a number of pharmaceutically active substances and disinfectants [67].

In recent decades, increasing attention has also been paid to active pharmaceutical ingredients in wastewater. Although these substances occur in comparatively low concentrations, they are difficult to remove and have a high level of environmental toxicity. The removal of these active substances as close as possible to their source (i.e., on a decentralised basis within the wastewater stream involved) serves the following goals, among others:

- Removal of substances with a toxic effect on biology
- Increasing the biodegradability of the water
- Removal of non-biodegradable contaminants

Depending on the general conditions and the wastewater matrix, it may also make sense to further purify the wastewater stream following biological cleaning. In both cases, the removal of persistent active pharmaceutical ingredients is achieved by advanced physico-chemical cleaning processes. The most commonly used processes are [67, 69]:

- Coagulation and flocculation
- Precipitation
- Adsorption
- Oxidation
- Membrane filtration

Even though, in many locations, there are still no binding limits in place for the discharge of certain active pharmaceutical ingredients, advanced purification is already widespread in many pharmaceutical production plants. One reason for this is that companies operating globally often set high operational quality standards that have to be met regardless of local regulations.

The reuse of treated wastewater in the pharmaceutical industry is only considered, if at all, for non-production applications. This is because of the very stringent quality standards imposed at an international level on the use of pure water streams for production and cleaning purposes. Discharge into the environment is also problematic due to contaminants. In contrast, there is more potential in the recovery and reuse of other raw materials, such as solvents, acids and individual active ingredients. These recovery approaches often rely on the operation of an efficient and decentralised secondary wastewater treatment system [22].

Oxidation

A number of chemical compounds that have poor biodegradability and are difficult to remove from wastewater by adsorption can be successfully eliminated by oxidation processes. Oxidation products are formed from the original molecules as a result of reaction with oxygen. It is often observed that these oxidation products are more easily degradable in a subsequent biological stage than the original substances. However, it should also be noted that the resulting reaction products are not fundamentally harmless and, in some cases, may even be more toxic than the original substances.

The most frequently used oxidation process in industrial wastewater treatment is treatment with gaseous ozone. The ozone molecules react selectively with certain functional groups of the wastewater matrix but they also decompose to form hydroxyl radicals, which oxidise wastewater components less selectively and have a higher oxidation potential. Ozone processes are widely used in the pharmaceutical industry, for example for the targeted removal of antibiotics from wastewater streams [70].

As an alternative to ozonation, advanced oxidation processes are increasingly being used. These are mainly aimed at the formation of non-selectively reacting hydroxyl radicals and are intended to reduce the formation of problematic oxidation products. There is a wide range of tried-and-tested processes available, from homogeneous to heterogeneously catalysed reactions. The catalysts used are usually transition metals, while an external energy source, such as UV radiation, can also be deployed. Common advanced oxidation processes for wastewater treatment include [71, 72]:

- Combination of ozone and hydrogen peroxide
- (Photo) Fenton process with iron salt as catalyst
- Electro-oxidation
- TiO2 photocatalysis (currently at pilot scale) □

CASE STUDY: Pharmaceutical industry in India

Membrane filtration for recirculation of biopharmaceutical wastewater up to zero liquid discharge (ZLD) standards

Background

A global biotechnology company was looking for a reliable and efficient wastewater treatment system for its newly constructed industrial enzyme and microorganism manufacturing plant near Mumbai, India.

Special challenge/problem

Wastewater from biotechnological production processes usually has a high, easily degradable organic load and may also contain auxiliary substances (e.g. precipitants, solvents or chemical inactivators). For this reason, the plant operator initially considered biological treatment for the purification of its wastewater streams, followed by two-stage membrane filtration (ultrafiltration and reverse osmosis). However, given the specific conditions on site, this process option was likely to cause the following operational problems:

- Sludge discharge from the biological stage and correspondingly costly pre-treatment for the ultrafiltration, especially if suspended solids are present
- The need for large quantities of backwash water for the membrane systems and the additional hydraulic load on the system associated with the backwash water
- High consumption of chemicals and high space requirements for the combination of processes

In view of these challenges, the operator was interested in identifying a wastewater treatment solution that was as fit for purpose and cost-effective as possible. The most important goal was to comprehensively treat all wastewater streams in order to comply with the zero liquid discharge (ZLD) model often required in India and to completely recycle or reuse treated water.

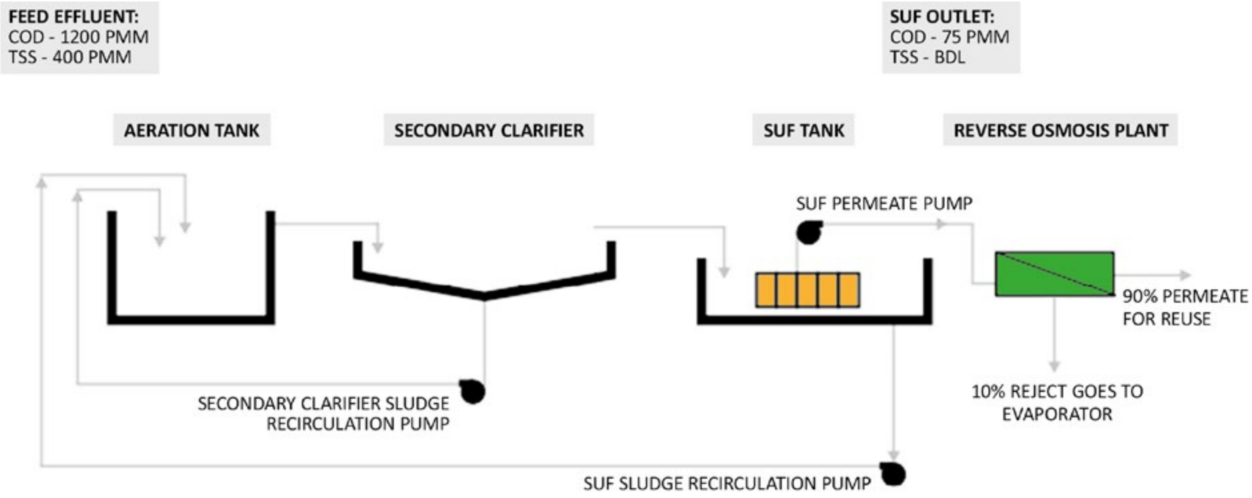


Figure 1: Schematic representation of the process flow for the SUFRO® process

Figure 2: 8.3 m³/h SUFRO® plant near Mumbai, India – Biological cleaning (left) Reverse osmosis (centre) Secondary clarifier and ultrafiltration tank (right)

Solution

A.T.E. HUBER Envirotech (AHET) worked closely with the client to develop and propose the following technological solution: its biological treatment system using SUFRO® technology. The system includes Biomem membrane filtration from HUBER SE – a submerged and negative pressure ultrafiltration membrane laminate with a pore size of 38 nm rather than conventional positive-pressure ultrafiltration – followed by a reverse osmosis system (Fig 1).

Results

A biological wastewater treatment plant based on SUFRO® technology with a capacity equivalent to 8.3 m³/h was planned, installed and commissioned by AHET.

Its design and mode of operation make Biomem membrane filtration much more robust with regard to increased levels of suspended solids in the feed than conventional pressure ultrafiltration. Customary pre-treatment by means of pressure sand filters, activated carbon filters or basket filters is therefore not required. The biomass in the secondary sedimentation overflow is effectively retained in the membrane tank and returned to the aeration tank, preventing the biomass from being washed out. The hydraulic load of the biological treatment is not increased by the occurrence of backwash water, as this is collected in the membrane tank. Membrane backwashing also uses fewer chemicals and water than conventional processes. The ultrafiltration permeate is fed directly into a three-stage reverse osmosis process without additional pre-treatment. With the process combination, the COD content can be reduced from up to 1,200 mg/l to below 75 mg/l, while suspended solids are simultaneously brought to a non-detectable level (Fig. 1). The high quality of the treated wastewater makes it possible to reuse up to 90% of it as cooling water in the production plant.

Contribution of the technology provided

The plant that has been constructed is particularly robust (for example, in dealing with high concentrations of solids) and easy to operate. The fact that additional pre-treatment steps are not needed makes the system a very compact solution for water reuse up to zero liquid discharge (ZLD) levels. The highly efficient membrane cleaning minimises the quantities of water and chemicals required. □

4 MINING

Country-specific information

India

India has extensive mineral deposits and a correspondingly well-developed mining industry. This has established itself primarily in the north-east of the country (states of Jharkhand, West Bengal and Orissa). The main resources involved consist of coal as an energy source, iron ore for steel production, and bauxite, from which aluminium is extracted (Figure 1). India’s mining sector grew by 3.6% in 2019. Its growth is closely linked to the development of downstream industries. The fastest-growing sector is the extraction of iron ore, which is used in the construction, infrastructure and automotive industries.

85% of the Indian mining industry is state-owned (for example, by the National Mineral Development Corporation, Vedanta, Hinalco Industries), especially in the coal mining sector. However, national and international private companies are also active in the extraction of metallic resources [75]. Depending on the sector, the state permits up to 100% foreign investment without further review and grants leases with a term of 20–30 years. The National Mineral Policy adopted in 2019 is also aimed at ensuring regulation, transparency and sustainability in India’s mining sector. The national environmental guidelines do not specifically mention mining but call for the development and implementation of progressive plans for orderly mine closures [73, 76].

MENA

The mining industry within the MENA region is dominated by the extraction of non-metallic resources. The main raw material involved is undoubtedly phosphate rock, which is in high demand worldwide for fertiliser production. The main phosphate producer in the region is Morocco. The country is the world's third-largest producer and around 75% of global phosphorus reserves are located within the country. The phosphate mines are operated by the state-owned company OCP (Office Chérifien des Phosphates). Depending on the estimates used, the sector represents approximately 7% of Morocco's GDP [77] Phosphate mineral is also the most important resource mined in Tunisia (by the state-owned 'Chimique de Tunisie' company) and Jordan (by the partly privatised 'Jordan Phosphate Mines'), alongside other non-metallic raw materials, such as potassium salts and gypsum. However, mining is not one of the strongest industries in these countries overall [78].

The Egyptian mining industry is concentrated in the Eastern Desert and the Sinai Peninsula, where coal and metal ores are the main resources mined. As well as gold, tantalite is a major raw material (Egypt being the fourth-largest producer worldwide). This metal is used as a storage medium in the electronics industry. As shown by its relaxation of the conditions for foreign investors in early 2020, the government aims to encourage further development and exploitation of the resources [79].

Industry and wastewater generation

The mining industry includes the development, extraction and processing of mineral resources, such as metallic raw materials, fossil fuels and minerals. Raw materials can be extracted by means of opencast mining (e.g. phosphate, gold, iron ore) or by deep mining (e.g. coal). In most cases, the extracted rock is first mechanically crushed and the final material is then separated either mechanically (by flotation or magnetic separation) or chemically (by leaching and precipitation). Environmental relevance is a global issue in this field. In addition to the large amount of land required, key factors in this regard include the large quantities of water used and the potential release of environmentally harmful substances into the air and water.

In mining, fresh water is mainly used for the following purposes:

- For conveying raw materials in the form of slurries or suspensions
- For process steps of comminution or separation in the water phase, such as grinding or flotation
- Targeted acidic or basic extraction of metals from ores and soils

Coal	Iron ore	Bauxite	Chromite	
729 million t (2020)	**206** million t (2020)	**2,909** million t (2019)	**4.2** million t (2019)	Annual production
Third-largest producer worldwide	Fourth-largest producer worldwide	Seventh-largest reserve worldwide	Second-largest producer in Asia	Rank

Figure 1: Principal mineral resources in the Indian mining industry [73, 74]

These water streams are referred to as process water and, after appropriate treatment, can to a large extent be reused. Excess process water is generated as wastewater. However, the majority of contaminated wastewater in mining does not derive from process water, but from run-off and infiltration of rainwater. As it passes through pits and spoil heaps, rainwater accumulates mineral contaminants and can also trigger acidification reactions. As (acidic) leachate, it represents the most problematic and, in terms of volume, the largest wastewater stream in mining [80].

Wastewater streams and characteristics

Process water

In mining, process water is produced under comparatively controlled conditions and its composition is directly influenced by the particular process control method deployed. Water used for conveying, crushing or mechanically separating raw materials is generally contaminated with solids and mineral contaminants. Water streams following acid leaching are more critical: Strong acids (sulphuric or phosphoric acid) are needed for the widespread extraction of phosphate from apatite, a mineral with very poor solubility. To improve solubility or complex formation, chemicals, such as cyanides or sulphates, are sometimes added and these also accumulate in the water [81, 82].

Leachate

Ores that are normally bound in rock layers in anaerobic conditions are crushed during the mining process and exposed to oxidising environments. The contact with ambient air and rainwater triggers chemical reactions, depending on how soluble, hydrolysable or adsorbable the particular raw material is. The resulting leachate is often very acidic, dissolving metals and sulphates from the rock in high concentrations, for example. Typical properties of leachate are pH values <6 (sometimes also up to pH 9) and high sulphate concentrations in the 1–10 g/l range [80].

Contaminant	Concentration in wastewater before treatment	after treatment
pH [-]	5–10	6–9
Solutes [mg/l]	n.a.	<1,000
Solids [mg/l]	10–500	5–35
Sulphate [mg/l]	5,000–10,000	50–2,000
Nitrogen compounds [mg/l]		
- Nitrite	0.1–1	0.01–1
- Nitrate	1–100	0.1–50
- Ammonium	1–50	0.1–10
Phosphorus [mg/l]	0.1–10	0.01–2
Chlorine [mg/l]	n.a.	20–200
Chemical oxygen demand (COD) [mg/l]	n.a.	15–100
Metals [mg/l]		
- Arsenic	0.1–5	0.01–0.05
- Cadmium	0.005–0.5	0.002–0.02
- Chromium	0.005–0.05	0.002–0.02
- Copper	0.02–0.2	0.0002–0.1
- Iron	2–50	0.02–2.5
- Lead	0.05–5	0.01–0.05
- Nickel	0.1–0.5	0.01–0.2
- Zinc	0.5–5	0.01–0.5
Cyanide [mg/l]	n.a.	<0.1

Table 1: Typical contaminants in process waters from mining [80]

Typical contaminants

Wastewater streams generated in mining operations are often very acidic and are contaminated by high concentrations of metals, semi-metals and sometimes salts (Table 1). Most of the contaminants in the wastewater originate directly from the geological formations involved, although some of them are also auxiliary substances from raw material processing. The most important contaminants are [80, 81, 83, 84]:

- pH value
  Is influenced by the composition of the extracted rock. In addition, acidic or alkaline extraction agents can play a role in dissolving metals, for example, in the extraction of gold, aluminium or uranium.

- Solutes and solids
  The content of solutes depends on the properties of the raw material. Potash salt extraction produces effluents with particularly high salt contents. High concentrations of suspended solids occur mainly in coal mining.

- Nutrients
  Nitrogen is usually introduced via explosives for extracting rock and is usually present in the form of nitrite, nitrate or ammonium. In phosphate mining, high residual concentrations of phosphorus are often found in wastewater. However, phosphorus from the recultivation of tailings (for instance through soil erosion or from fertilisers) can also enter wastewater in other sectors. Phosphorus predominantly occurs in wastewater in the form of phosphate.

- Others
  Depending on the composition of the raw material extracted, the wastewater may contain relevant concentrations of chlorine and sulphates. These contaminants are particularly significant in the potash salt industry. Similarly, residues of metals from the rock can contaminate the wastewater, such as arsenic in gold mining or cadmium in phosphate mining. Some metals and cyanides are also used as auxiliary substances, especially for the extraction of gold in alkaline solutions.

Treatment processes

Process selection and stages

Particularly in dry regions, water reuse plays an important role in reducing the demand for fresh water. Nowadays, process water is collected separately in most mining operations and is treated and, for the most part, reused in the particular process step involved. This can also enable the efficient recovery of valuable raw materials from the water streams. However, due to the accumulation of excess process water and additional large quantities of leachate, mining is still a long way from the goal of 'zero liquid discharge' in practice.

Wastewater is usually treated using physico-chemical processes that are designed to perform the following tasks:

- Separation of solids
- Removal of dissolved salts, nutrients and metals
- Extensive neutralisation

With regard to the choice of process, active processes are sometimes used. These are also widespread in other industries and enable wastewater streams to be treated in a targeted way by using energy and/or auxiliary materials. Passive processes, which are self-sustaining over longer periods of time (10–30 years) and do not involve significant operating costs, can also be considered as alternative or supplementary options. These are essentially biological or physical processes that can be used primarily with low water flows (<50 l/s) and low loads (acid load <10 kg/day or <800 mg/l). Frequently used passive processes include treatment ponds and (artificially created) aerobic or anaerobic wetlands [80, 83].

Physico-chemical treatment

To separate solids from wastewater, gravity-driven processes are usually used, often with the addition of flocculants. However, depending on the volumetric flow and properties of the suspended solids, filtration processes are also used. The following processes are considered the best available techniques [80]:

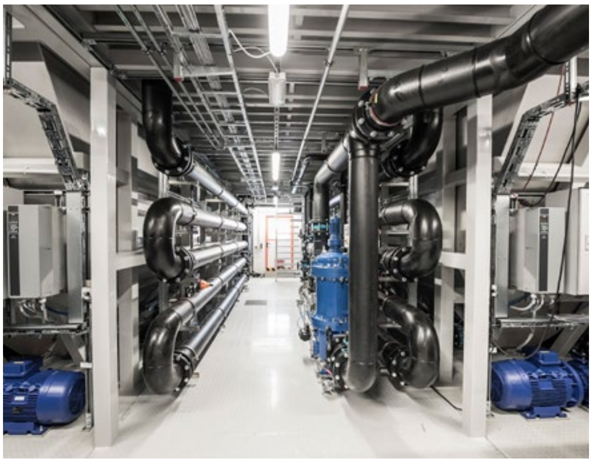
- Sedimentation in gravity separators or clarification ponds
- Gas flotation
- Centrifugation
- Surface or space filtration

Clarification ponds are man-made basins that can hold up to several 100,000 m³ of wastewater.
The water flows through them at a shallow gradient, and an impermeable base seal prevents water from escaping. Two processes run in parallel here, namely the evaporation of clean water (provided that the wastewater does not contain any volatile components) and the sedimentation of solids, such as precipitation products [80, 81].

Solutes are typically removed from wastewater by means of physico-chemical processes. The following processes are among those used for this purpose:

- Precipitation
- Adsorption
- Ion exchange
- Membrane process

Depending on the composition of the wastewater, different chemical conditions can lead to the precipitation of contaminants. Some metals undergo a reduction in their solubility under oxidative conditions (either artificially aerated or as a result of active biological aeration), while in other metals this is due to reduction under anaerobic conditions. Many metals can also be precipitated and separated as hydroxide or carbonate compounds during neutralisation [80, 83]. □



CASE STUDY: Gold mining in South Africa

Pumps dewater flooded mines in South Africa

Background

The mining of precious metals is a highly relevant industry in India, and parallels to the situation there can potentially be drawn from the following example in South Africa. The city of Johannesburg was established in the wake of the Witwatersrand gold rush in 1886. Since then, 40,000 tonnes – 30% of the world's gold – have been extracted from the mines there. Numerous abandoned shafts and mines under the city still bear witness to this gold rush today. However, these pose an increasing risk to people and the environment. Due to the infiltration of rainwater into these shafts, a lake has formed under the city that contains highly polluted acidic water in places and is expanding steadily. During mining operations, the infiltrating groundwater was pumped out of the mines by the existing infrastructure. However, with the closure of many of the mines, this process was halted. The Western Basin filled up and began to empty in 2002. Pumping stopped in the Central Basin in 2008 and in the Eastern Basin in early 2011.

Special challenge/problem

The pumping away of mine water poses some challenges, particularly because of its chemical composition. The metamorphic rock of the mine tunnels contains the mineral pyrite, which reacts with oxygenated rainwater or groundwater, leading to increased sulphate concentrations and ultimately low pH values. At pH values of two, sulphuric acid dissolves aluminium, potentially toxic metals and uranium from the rock and produces iron oxide as a by-product when the pH value increases. As a result, the pH in the water can reach levels that make it a danger to humans and the environment. Mine drainage has therefore become an ecological issue and a challenge.

Figure 1:
ANDRITZ submersible motor pump
from the HDM (Heavy Duty Mining) series

Solution

All options should be exploited in the decommissioning of mining sites to protect surface and groundwater, for instance by sealing mine shafts as completely as possible or with the aid of long-term passive treatment of the resulting mine water. Reliable pump technologies can make an important contribution here. International technology Group ANDRITZ offers a pump series specially designed for the difficult conditions inherent in mining activity – the Heavy Duty Mining (HDM) series (Fig. 1). This pump type has two submersible motor pumps arranged one above the other in opposite directions, driven by a continuous pump shaft. The suction areas of the two pumps are located at the ends of the HDM. Each of the two pumps transports half the flow rate at full pressure to the centre of the pump. There, a diversionary stage directs the flow via external housing channels into the pressure line. The double-flow design completely neutralises the axial thrust, with loads on the unit reduced to a minimum.

Figure 2: Installation of one of the ANDRITZ pumps

To use these pumps for pumping acid mine water, certain components had to be protected against the aggressive acid. For this purpose, the submersible motors were encapsulated in such a way that the internal pressure exceeds the external pressure. This prevents water from penetrating and attacking the components inside the motor. To ensure high durability of the materials in contact with the medium, several material options were chosen and qualifying tests were carried out. From the materials considered, those with the best mechanical properties were selected for the components of the pump unit in order to allow for a compact design. The variable total head of the selected pumps is between 300–500 m with a flow rate up to 1500 m^3/h. The motor size is 2400 kw.

Results

All the pump units are identical and have the same hydraulics. At least one complete pump unit is stored on site in a disassembled condition; this ensures that a spare pump is available right away. In addition, a number of selected spare parts are also stored on site. The two pumps – weighing 21 t, and each 15 m long and 1 m in diameter – have been in operation since June 2014 (Fig. 2). Freely suspended from 430 m-long tubes made of duplex steel, they pump the acid mine water to the surface and then to a neighbouring treatment plant. Here, the addition of lime raises the pH and neutralises the acidity, and the heavy metals dissolved in the water are precipitated as hydroxides.

The authorities are building two more pumping stations to the west and east of Johannesburg with the long-term goal of lowering the water level in the flooded mines from the current level of about 200 metres to a depth of 1,000 metres. With this step, the operator also aims to regain access to the higher levels in order to resume the mining of gold and gold ores there. ANDRITZ supplied a total of seven pumps, which were installed in these two pumping stations.

Contribution of the technology provided

The advantages of the pump technology provided are its high durability and maintenance-free operation at very high flow rates under highly corrosive conditions. Firstly, this is ensured by the targeted selection of chemically and mechanically highly stable material; secondly, the special encapsulation with increased internal pressure protects the critical system components. □

5

FOOD INDUSTRY

Country-specific information

India

The Indian food industry is built on a stable national agricultural sector with large areas of farmland and favourable climatic conditions. Due to growing prosperity, increasing urbanisation and changing dietary habits, food processing is also playing an increasingly important role in the country. Today, the capital value of the food processing industry represents approximately 30% of the Indian food industry and therefore equates to around 188 billion USD [85, 86].

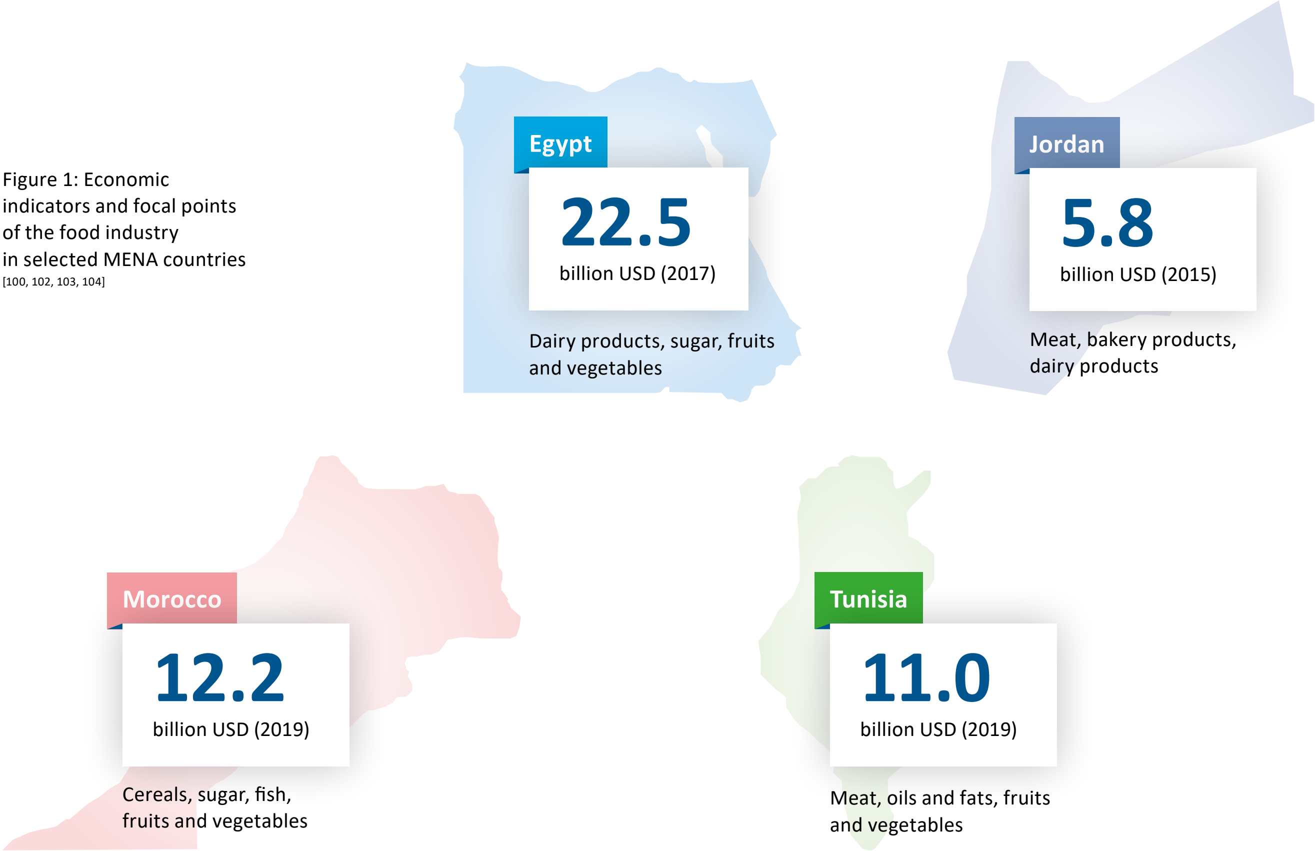
Horticulture (fruits and vegetables) is the most profitable agricultural sector in India, the world’ s second-largest producer of fruits and vegetables (Table 1). However, only about 2% of the produce is processed in India, a relatively low figure by international standards (USA: 65%, Philippines: 78%, China: 23%). The processing rates for rice and wheat are somewhat higher. The country is self-sufficient with regard to rice and wheat. India has about 10 million active dairy farmers, making it the largest global dairy producer. Approximately 35% of the produce sold is used in food processing to produce milk powder, butter, cheese and other dairy products. This makes the dairy industry a major player in the country’s economy, with the sector dominated

Product	Annual production	Annual turnover	Annual growth	Main regions
Fruit and vegetables	282 million t (2017–18)	USD 42 billion (2017–18)	4.2% (2017–18)	Maharashtra, Andhra Pradesh, Uttar Pradesh, West Bengal, Bihar
Milk	176 million t (2017–18)	USD 72 billion (2016)	15% (2010–15)	Delhi, Punjab, Gujarat, Surat, Lucknow, Bihar, Hyderabad
Rice	113 million t (2017–18)	USD 53 billion (2020)	6.5% (2020)	Punjab, Haryana, West Bengal, Uttar Pradesh, Tamil Nadu, Orissa, Andhra Pradesh
Wheat	107 million t (2020)	USD 61 billion (2020 exports)	3.5% (2020)	Punjab, Haryana, Uttar Pradesh, Madhya Pradesh
Fish (domestic)	9 million t (2017–18)	USD 3.5 billion (2012–13)	6% (2012–13)	West Bengal, Andhra Pradesh, Gujarat, Kerala
Meat	7.7 million t (2017–18)	USD 16.5 billion (2020)	8% (2020)	Uttar Pradesh, West Bengal, Andhra Pradesh, Haryana, Tamil Nadu

Table 1: Comparison of the key sectors of the Indian food industry [87, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98]

Focal points of the food industry

Figure 1: Economic indicators and focal points of the food industry in selected MENA countries [100, 102, 103, 104]



by large local corporations. The production of fish (second-largest producer worldwide) and meat (sixth-largest producer worldwide) also plays a role, even if the products are essentially only sold in packaged and chilled or frozen form [87].

Currently, the food industry in India is still confronted with high product losses (especially in horticulture), unclear regulatory conditions and insufficiently developed supply chains. In the future, it will become increasingly important for the sector to adhere to strict quality and hygiene standards and align itself technologically with international best practices. For this reason, the Ministry of Food Processing Industries is specifically promoting a programme of modernisation and investment (including 100% foreign investments) in the sector [86, 87].

Technological developments in Indian food processing (including in environmental technology) are driven mainly by internationally operating groups, through the adoption of global benchmarks and sustainability targets. Such developments include the cleaning of organically highly polluted waste-water by means of biological processes and increased reclamation of water to compensate for seasonal fluctuations in raw water availability [88].

MENA

The development of the food industry is often closely linked to the agricultural resources in the particular country. Due to their relatively hot and dry climate, agriculture in many MENA countries is focused on intensive animal husbandry for milk and meat production and on the cultivation of suitable fruit, vegetable and grain varieties. Accordingly, the most important segments of the food processing industry are dairies and the processing of meat, fish and cereals (Figure 1). In general, due to the spread of 'western' dietary habits, an increasing demand for convenience products such as powdered milk, instant noodles and frozen products can be observed, which is leading to an increase in food processing.

The dairy industry is a traditional element of the economy in many countries and is currently experiencing strong growth (for example, 32% annual growth in Jordan). In the MENA region, the most prominent products include pasteurised milk, yoghurt and various types of cheese [99, 100]. In Tunisia and Jordan, meat production also plays an important role, with poultry being by far the largest contributor. A major local player here is the highly diversified Poulina group of companies. Processing activities are focused on the preservation and production of various prepared meat products [101, 100]. In the horticultural sector, tomatoes, citrus fruits and dates are cultivated; these are only rarely processed before being sold or exported. In Tunisia, olive production is also an important economic sector and underlies the industrial production and refining of olive oil. (The main producer is the local 'Société de conditionnement des huiles d'olive'). Morocco, with its coastline of 3,500 km, is believed to be the largest fish producer in Africa.

Due to its close links with agricultural activities, the water consumption of the food processing industry is not always clear-cut. In Jordan, however, it is estimated to represent around 10% of total industrial water consumption [101], to give one example. Efforts are being made in many places to promote industrial wastewater treatment and water reuse to protect freshwater resources. Multinational corporations and meat processing companies, in particular, often already comply with ISO 14001 and other voluntary standards. However, the high proportion of largely unstructured small and medium-sized enterprises in the food sector makes it difficult in many cases to implement environmental protection measures across the board [100, 101].

Industry and wastewater generation

In the food industry, agricultural products are processed for human consumption using raw materials, labour and technology. The sectors of the industry are categorised according to the input products used in each case:

- Milk
  Cooling and pasteurisation of milk, production of cheese, butter, yoghurt and other dairy products, and milk powder

- Fruit and vegetables
  Washing and chopping, production and processing of juice, concentrate and puree to final products (e.g. ketchup, jam or crisps)

- Grain
  Milling and processing of flour up to the end product (e.g. pasta, bakery products), as well as extraction of starch, glucose and malt

- Meat and fish
  Cooling and cutting, preservation (for instance by freezing or smoking) or preparation of finished products (for instance by pre-cooking or deep-frying)

Within each sector, the degree of processing can vary; from light processing (sorting, washing or packaging) to intensive processing (of fermentation products or baked goods). The production of beverages and ready meals can generally be assigned to one or more of the sectors mentioned but is sometimes also listed as a separate sector.

In the food industry, fresh water is used for washing raw materials, cleaning equipment or directly in the production process. Due to the compliance with tough hygiene regulations at the production stage, cleaning waters constitute by far the largest proportion of industrial wastewater [105, 106].

Wastewater from the food processing industry

Industry	Total suspended solids (TSS) [g/l]	COD [g/l]	BOD5 [g/l]	Oil/fat [g/l]	pH
Dairy	0.15–1	0.8–4.5	0.8–5	0.05–0.5	3.5–13
Meat processing	0.8–4	2–8	1–4	0.3–2.5	6–8
Fish processing	0.5–5	5–50	1–10	0.02–0.5	4.9–7.1
Olive oil production	<100	30–300	10–150	<300	4–6

Figure 2: Typical wastewater characteristics of selected food processing industries [22, 115, 108, 113, 110]

Wastewater streams and characteristics

Dairies

In the dairy processing industry, edible products are made from raw milk. Important process steps in milk processing are [107]:

- Removal of dirt particles and skimming of the milk, usually by centrifugation or filtration
- Homogenisation under high pressure
- Sterilising heat treatment by means of pasteurisation, high-temperature or ultra-high-temperature heating
- Cheese production by curdling the milk with rennet, separation of the solid phase and ripening
- Production of sour milk products by fermentation of lactose to lactic acid
- Preservation by removing water, for example by evaporation or membrane filtration

On average, dairies produce about 1 m³ of wastewater per tonne of milk processed. This wastewater comes, firstly, directly from the production process (e.g. drip losses, rinsing milk, condensates) and, secondly, from cleaning processes (e.g. cleaning solutions, disinfection). Depending on the degree of contamination, production effluents can be partly reused or disposed of without treatment. Cleaning wastewater, on the other hand, accumulates in very large quantities (often discontinuously) and is often very heavily contaminated [22].

The main contaminant in dairy wastewater is milk itself, with the associated organic composition (mainly protein, lactose and fat) (Figure 2). High nitrogen and phosphorus concentrations are characteristic here, partly in relation to COD. In addition, there are residues of by-products (e.g. whey), fermentation cultures, detergents and production additives (e.g. cheese salt) [108, 109].

Meat and fish processing

Meat processing includes the steps downstream of slaughtering involved in producing edible products from raw meat. Similarly, the processing of fresh or frozen fish up to the final product is covered here. The most important processing steps in both cases include:

- Cleaning and trimming, such as the removal of skin, scales, bones and other body parts
- Adding additives, such as spices, preservatives or enzymes
- Preserving, such as by fermenting, smoking or drying
- Preparation of special foods, for example by emulsification, moulding or cooking
- Filling and packaging, e.g. into preserves

Meat and fish processing generates large amounts of animal waste that must be collected and disposed of. In fact, around 30–70% of fish is produced as waste in the manufacture of canned fish. In many cases, this waste can be reused as animal or fish meal. Wastewater is derived mainly from the frequent cleaning of process areas and equipment, which is necessary to ensure hygiene standards. In subsequent processing steps, the contamination of the resulting wastewater also increases, for example during cooking processes or due the addition of additives.

Animal residues – especially proteins and fats – are by far the most significant contaminants of industrial wastewater. They lead to high concentrations of organics (COD and BOD), phosphorus values in the 30–100 mg/l range and nitrogen values mostly >100 mg/l (Figure 2). Blood in particular has a very high COD content and should therefore be collected and disposed of separately wherever possible. Many animal residues, such as feathers, scales or tissues, are present in suspended form and have to be separated as solids [22, 110, 111, 112].

Production of olive oil

Olive oil is traditionally produced by simple pressing and filtering. However, as in all industrial sectors, the use of technology is increasing. Today, the extraction of oil from the olive mash is mainly achieved by centrifugation in two or three phases. Three-phase decanters require the addition of up to 50 kg of fresh water to process 100 kg of olive mash. In most cases, the oil obtained is refined chemically or physically to remove harmful phospholipids, free fatty acids and turbidity. Phosphoric acid, caustic soda and other additives may be used.

Olive oil production usually generates about 1 m³ of wastewater per tonne of product, mainly at the refining stage, for example during wet deacidification. The wastewater contains a high organic load, consisting of polyphenols, sugars, tannins, lipids, etc. (Figure 2). Phenols can reach concentrations above 10 g/l and are known for their high environmental toxicity [113, 114].

Treatment processes

Process selection and stages

The challenge posed by wastewater treatment in food processing industries is the high load of organic substances, i.e. solids, oils and dissolved substances. Coarse and suspended solids are usually removed in a first treatment step to avoid instances of clogging in subsequent process stages. Gravity sedimentation, which is otherwise frequently used, is seldom utilised in the food industry because of the relatively small differences in density between the solid and liquid phases. Instead, the following technologies tend to be used [22, 110]:

- Stationary or moving rakes and sieves
- Centrifugation (sometimes also three-phase centrifugation for simultaneous oil separation)
- Flocculation and flotation

Oils and fats are removed either in parallel with the solids or in a subsequent process step. Dissolved organic matter and nutrients generally have very good levels of biodegradability afterwards. In the food industry, particularly high standards are imposed with regard to the reuse or further use of treated wastewater due to strict hygiene regulations. Under favourable conditions, process streams can be recycled directly; on the other hand, however, there are rarely any production-related fields of application for collected and treated wastewater.

Separation of oils and fats

Industrial wastewater from food processing often contains insoluble fats and oils of animal or vegetable origin. The simplest and most widespread approach to separating an oily wastewater phase involves static fat separation. At low flow velocities, the difference in density between the water and fat phases is exploited to skim off the floating fat layer at the water surface. Faster and more complete separation is achieved when phase separation is brought about by centrifugal forces instead of gravity or by attachment to gas bubbles. Static hydrocyclones with rotating flow or rotating centrifuges or gas flotation systems can be used for this purpose.

Dairy, meat and fish processing, however, most commonly involves emulsified fats that cannot be removed by conventional gravity separators or centrifugal separators. The most common approach in these cases involves emulsion splitting with the aid of acids, metal salts or calcium hydroxide. Flocculation of the fats facilitates their separation, for example in a subsequent gas flotation stage. Flotation processes have proven successful for the separation of fats and oils because dispersed gas bubbles tend to attach themselves to hydrophobic substances and thus facilitate phase separation. In the food industry, pressure-release flotation is the main technique used. Oil removal by ultrafiltration can also be a suitable solution for more complex separation tasks. In these cases, parallel to degreasing, stubborn suspended solids or dyestuffs can also be removed [22, 110].

Biological cleaning

Biological treatment is very well suited to wastewater purification in the food industry. It should be noted that the biological treatment has be protected from being overloaded with oils and fats. Especially in dairies and in olive oil production, contaminants usually have to be reduced at the biological stage by means of upstream fat separation.

Aerobic and anaerobic processes can be used for the biological treatment of wastewater from the food industry. Anaerobic processes are usually very robust and are particularly suitable for heavily polluted wastewater. Another advantage is the relatively low amount of excess sludge produced. It is usually carried out in wastewater ponds or in biogas reactors with or without bacterial recirculation. In most cases, an aerobic stage is installed downstream of the anaerobic plant to ensure compliance with the limit values; nowadays, this is usually in the form of activated sludge or trickling filter processes.

Depending on the composition of the wastewater, difficulties can sometimes arise in the operation of biological cleaning stages. Some typical ones are mentioned here [22, 113]:

- Formation of bulking sludge due to high feed concentrations of very easily degradable COD
- Poor settling properties of the activated sludge due to a too high sodium/calcium (Na/Ca) ratio in the wastewater, e.g. from milk processing. In this case, sludge separation by flotation may be superior to conventional sedimentation.
- Disruption of biodegradation due to the presence of inhibiting substances, such as phenols, from olive oil production
- Insufficient removal of organic contaminants with low degradability, e.g. long-chain fatty acids or certain phenolic compounds from olive oil production □

CASE STUDY: **Olive processing industry in Jordan, Syria and Lebanon**

Treatment of wastewater from olive processing plants

Background

Olive processing is a major element of the economy in the MENA countries. The UNDP (United Nations Development Programme) commissioned enviplan® to develop, design and build a prototype of a mobile plant to treat the associated effluents. In Syria, Lebanon and Jordan, around 2,500 small businesses are active in this sector, processing mainly fresh olives. Approximately 1 m³ of fresh water is needed to process 1 t of olives and it becomes extremely polluted. For these farms, it is economically unviable to set up their own wastewater treatment system. During the annual processing campaign, UNDP wishes to offer mobile systems that travel to the plants distributed across the countries and treat their wastewater in a decentralised manner. The system has been in operation in Syria since 2009.

Special challenge/problem

When processing olives, many decentralised plants generate highly problematic wastewater, which in many cases has already led to the contamination of drinking water. High COD loads, high polyphenol concentrations and the discontinuous operation make biological cleaning impossible. Economic and technical conditions make it difficult for producers to install their own wastewater treatment plant on site. Therefore, during the campaign, the wastewater needs to be treated with the aid of decentralised, mobile plants at collection points.

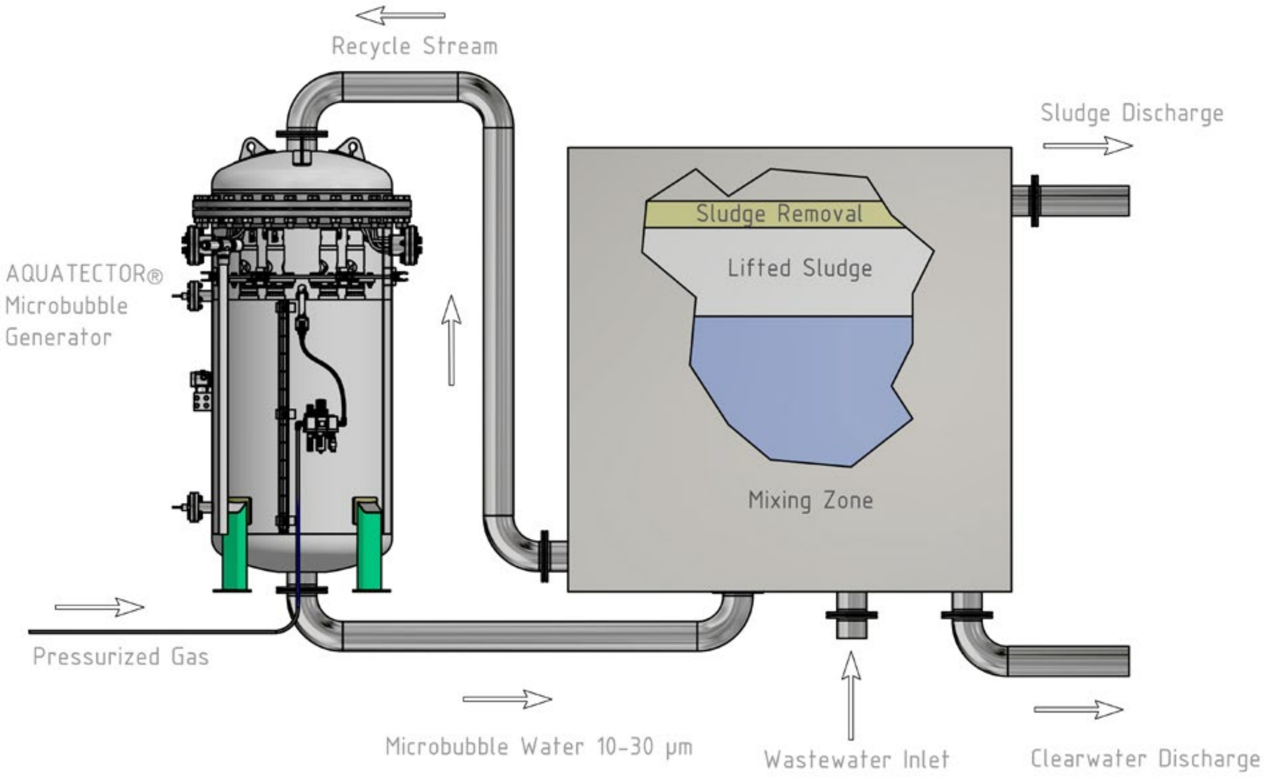
Solution

The AQUATECTOR® Microfloat® microflotation system is the only process worldwide that enables physico-chemical pre-treatment for subsequent further cleaning by means of backwashable reverse osmosis. This combination process can potentially purify wastewater to meet drinking water standards. The process, which was developed and patented by enviplan®, was presented as a technical demonstration project in 2009 in the form of a mobile, containerised system (Figure 1). The system has a capacity of 2–5 m³/h and can fairly easily be transported as a trailer version. Containerised solutions can also be implemented.

The combination of processes involves the following components:

- Oil separator
- Two-stage AQUATECTOR® Microfloat® microflotation as physico-chemical cleaning stage
- Open-channel reverse osmosis system

Figure 1: Mobile AQUATECTOR® Microfloat® unit for seasonal treatment of wastewater from olive processing in the context of pilot projects in Lebanon, Syria and Jordan



Results

The mobile system achieves the effluent qualities mentioned in Table 1. It is a robust technology that can treat a volume of 2–5 m³/h or more in seasonal operation at different collection points. Three central systems, with capacities of 35 m³/h, have been built in Spain, for example. In this context, the systems are used as wastewater pre-treatment stages utilising exclusively AQUATECTOR® Microfloat® technology, as the client wanted operations to continue on a year-round basis. The microflotation system is monitored via an HD camera system, which enables visual evaluation of the flotation blanket. The plant effluent quality is further controlled via turbidity measurement, conductivity measurement, temperature and pH control.

Contribution of the technology provided

The AQUATECTOR® system allows wastewater to be treated efficiently with regard to oils, solids and other organics. The focus is on the low space requirements and the significant robustness of the process. Within a combination of processes involving oil separation and reverse osmosis, the wastewater can be treated to meet drinking water standards in a very compact way. □

Parameter	Unit	System feed	System discharge (reduction)
Free oils	g/l	Max. 20	95–99 %
COD	mg/l	100,000	90–95 %
BOD	mg/l	50,000	90–95 %
Solids	mg/l	2,000–3,000	>99 %
Polyphenols	mg/l	500–5,000	>95–98 %

Table 1: Feed and discharge values of the constructed system (example values)

CASE STUDY: **Fish processing industry in Morocco**

Biological wastewater treatment for secure compliance with legal requirements

Background

A factory producing canned fish in southern Morocco, processing mainly sardines, mackerel and tuna, needed to install a wastewater treatment plant that would reliably comply with all legal requirements for discharge into the local sewer system. The Moroccan specifications basically relate to the temperature, pH, COD, BOD5, fat and solids content parameters.

Special challenge/problem

During fish processing, large quantities of scales, fish remains, fats, oils and other organic waste are produced. Some of this gets into the production wastewater. This wastewater load can lead to blockages in the municipal sewage system and unpleasant odours.

It was intended that a wastewater treatment plant be planned and constructed that would reliably reduce the very high organic wastewater load to the required limit values within a very limited installation space. The production process is characterised by strong daily fluctuations in wastewater volumes and loads. In addition, the system solution should not involve the formation of odours and the sludge treatment should achieve a dry substance (DS) of 30%.

Solution

EnviroChemie planned, installed and commissioned a multi-stage system solution in response to the challenge. Before approximately one day’s worth of production wastewater is buffered in a tank, it is pre-treated using a high-performance belt filter and a grease separator. This removes solids, especially fish scales, as well as 50% of the fat and oil content from the wastewater. Subsequently, a Flomar® dissolved air flotation system removes inorganic and organic wastewater components, thereby effectively and economically reducing the wastewater pollution load. The continuously operating flotation stage is preceded by physico-chemical conditioning. This removes up to 98% solids and grease and reduces COD by up to 60%. The flotation sludge is dewatered and deposited together with the excess sludge with a DS of 30%, and the resulting wastewater from the dewatering process is discharged into a receiving water body.

The wastewater is then fed into a Biomar® OBBR (Oxidative Moving Bed Biofilm Reactor)-type aerobic reactor where the COD and BOD load is further reduced. The Biomar® OBBR technology uses specially designed plastic bodies that provide an ideal growth area for microorganisms in a protected environment. These

Figure 1: Space-saving installation – Flomar® flotation for wastewater pre-treatment and screw press for sludge dewatering in a fish factory in Morocco

plastic bodies move freely in the water and are kept in suspended motion within the reactor by the aeration process. The unique structure of the growth bodies and the free movement in the water ensure that the biomass is protected and allow optimal contact of the biofilm with the wastewater components and oxygen. The biological system is aerated using compressors.

The wastewater is fed into a sedimentation system after a retention time of about one day. Some of the biosludge is reused in the biological stage, while the rest is stored in a sludge tank together with the flotate sludge. Finally, the sludge is dewatered using a screw press and sent to landfill.

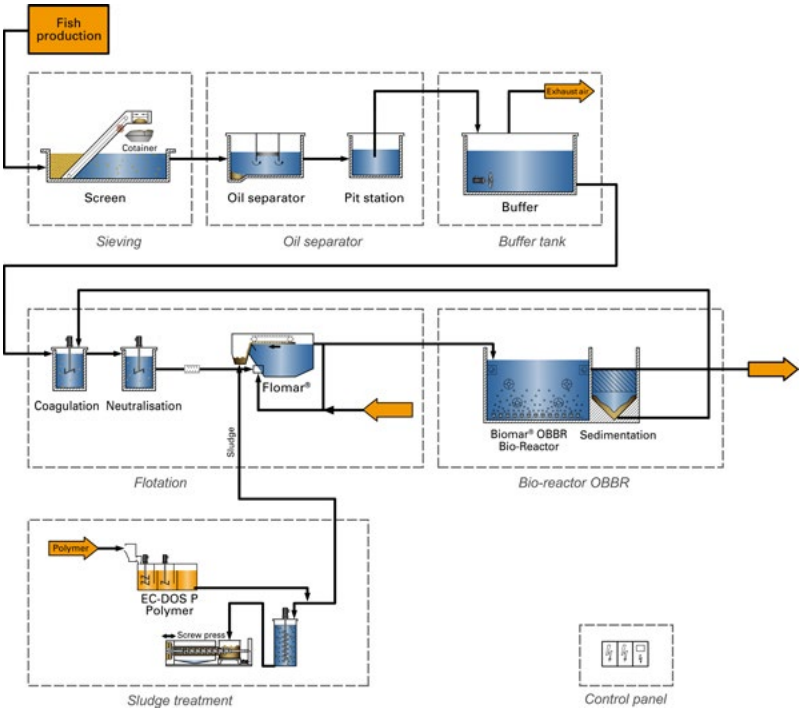


Figure 2: Process diagram of the wastewater treatment plant in a fish factory in Morocco

The buffer tank, the sludge tank and the flotation are covered. Any gases produced are extracted and fed into the biology treatment to break down the odour molecules. The system runs completely automatically, and all motors are equipped with frequency converters to optimise energy consumption.

Parameter	Unit	System feed	System discharge
Wastewater volume	m³/day	800	800
Fats and oils	mg/l	3,000–6,000	< 50
COD	mg/l	13,000–25,000	< 2,500
BOD	mg/l	6,500–12,500	< 1,000

Table 1: Feed and discharge values of the completed facility

Results

The newly installed, energy-efficient plant solution for wastewater treatment reliably achieves all required purification goals (see Table 1). Odours are effectively eliminated. The sludge treatment achieves a DS of 30%. The entire plant technology has been automated and visualised for easy operation by the on-site operators.

An additional benefit results from the removal of approximately 95% of scales and fish remains from the wastewater. These are processed into fish meal, which can be sold. The separated fats and oils are also converted into fishmeal.

Contribution of the technology provided

The plant installed here treats wastewater in a complete and customised way, including mechanical and biological treatment stages. The very compact system tolerates volume and load fluctuations of the wastewater feed while minimising odour generation. The separated oils, fats, scales and fish residues are reused as fish meal. □

CASE STUDY: **Milk processing in India**

Process water treatment of dairy effluents

Background

Chitale Dairy, a leading company in the dairy processing industry in India, was faced with the task of equipping its expanded production site in Bhilwadi, Maharashtra, with a new process water treatment system.

Special challenge/problem

The challenge in treating dairy effluents generally lies in their high fat, COD and BOD contents, which need to be removed. In this case, suitable process steps needed to be identified for the treatment of highly contaminated wastewater volumes for an acceptable level of investment and operating costs.

Solution

As part of the expansion of its plant site, the company awarded a contract for the construction of a process water treatment plant with a throughput of 1,800 m³/day. In response, A.T.E. HUBER Envirotech (AHET) gave the company a comprehensive overview of the technologies available on the market and their advantages and disadvantages. Biological processes can be an efficient option for purifying dairy wastewater if plant operation is stable and appropriate metrological monitoring is in place. After a detailed discussion with the operators, it was decided to opt for AHET's AVR-AF® technology, which is suitable for the effective degradation of fats, proteins and edible oils.

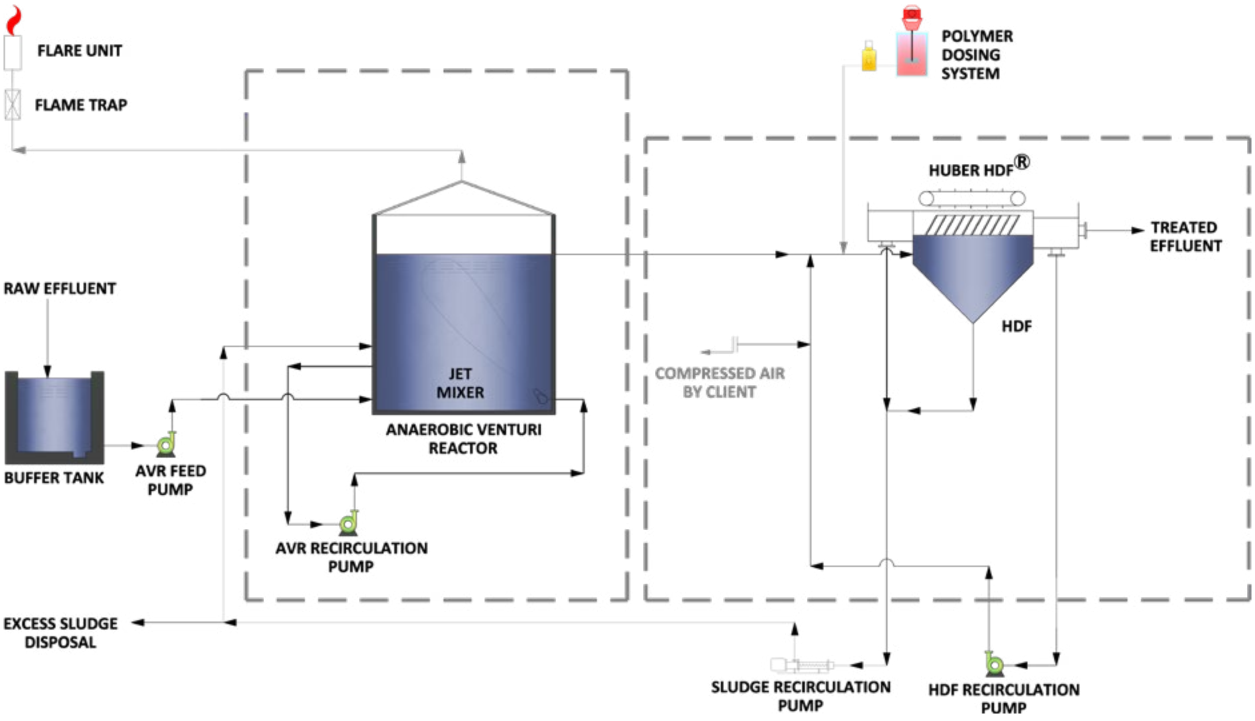


Figure 1: Flow diagram of the plant design based on A.T.E. HUBER Envirotech's AVR-AF® technology at Chitale dairy in Bhilwadi, Maharashtra, India

Figure 2: Chitale dairy plant in Bhilwadi, Maharashtra, India

The AVR-AF® technology involves an anaerobic Venturi reactor with subsequent dissolved air flotation (HUBER HDF®) and aerobic post-treatment (Fig. 1). It is a reactor based on the jet zone loop design. Energy-efficient jet mixers, which have no moving parts and ensure uniform mixing, are used in the reactor instead of mechanical mixers. The process is suitable for high concentrations of suspended substances of up to 15,000 mg/l.

Compared to other technologies, the AVR-AF® technology produces less sludge and requires less maintenance. Existing anaerobic stirred tank reactors can be upgraded to AVR-AF® standards. Dissolved air flotation helps maintain a high concentration of suspended solids. In turn, this helps to increase process efficiency and reduce the anaerobic tank volume. The biogas produced in the anaerobic stage is purified (removal of H2S) and converted into electricity in a combined heat and power plant. Energy generation was another decisive criterion for the operator, taking account of the operational cost efficiency factors involved.

Results

A plant for the treatment of 1,800 m³/day of dairy wastewater was designed, installed and commissioned by AHET. The average COD content was 2,100 mg/l in the feed stream and less than 50 mg/l in the discharge stream, which corresponds to a COD removal of about 96%. The quality of the effluent meets all Indian environmental protection standards, and almost 750 m³ of biogas is produced per day, meeting 50% of the plant's energy needs.

Contribution of the technology provided

The AVR-AF® technology used here enables energy-efficient treatment of wastewater thanks to the special nozzle mixing technology and, in combination with dissolved air flotation (HUBER HDF®), very high concentrations of solids. This makes the plant compact, while maintenance requirements and sludge production are low compared to other processes. In addition, biogas is recovered as an energy source. Aerobic secondary treatment allows for very low effluent concentrations. □

CASE STUDY: **Soya food processing**

Recycling of treated wastewater for cooling systems using reverse osmosis

Background

The production and processing of soya beans is a major industry in both India and many other tropical and subtropical regions. A company located in Thailand, which processes soya as a foodstuff, had previously used mains water for its cooling units. However, the cost of mains water had increased considerably in the area over the past few years. The customer was in search of a treatment solution that would enable treated wastewater from the existing treatment plant to be reused. Part of the flow of the treated wastewater is fed into the reverse osmosis system, which in turn then feeds the desalinated water into the cooling system.

Special challenge/problem

The quality of the treated wastewater was extremely poor. High levels of non-biodegradable proteins and oils were daily challenges that could lead to noticeable membrane fouling. In addition, the storage of wastewater in treatment lagoons was encouraging the propagation of algae. The use of membrane technology for wastewater treatment is a sensible option under these conditions when – as, in this example, due to economic criteria – the treated water is intended to be recycled or re-utilised.

Solution

The challenges related to water quality were resolved by means of the ceramic flat membranes from CERAFILTEC along with process-integrated membrane treatment function (CapClean). The immersed ultrafiltration membranes are fully regenerated in each automated treatment cycle, which involves the use of chlorine with a soaking time of 3 minutes. This innovative treatment procedure is only possible thanks to out-in ceramic flat membranes and a modular design including a chemical sprinkler system. The accrued retentate (8%) is fed back into the treatment plant. The on-site operator regularly monitors the flow rate, pressure, turbidity and pH-value in the system.

Results

Phase 1 of the system (300 m³/day) was brought into operation in December 2019. Following a 6 month performance assessment, the customer has started expanding the capacity of the system by a further 2,100 m³/day. Due to the system's extremely low power consumption as well as the savings made in the use of mains water, it was determined that the system would break even within less than 3 years.

Contribution of the technology provided

The membrane system installed has an integrated treatment function and facilitates extremely efficient membrane treatment due to its special modular design. This means it can be operated in a stable and energy-efficient way even under challenging conditions, for example when there is strong possibility of wastewater fouling. □

Dimension	Unit	Inflow	Outflow
Colour	Pt-Co	117	39
COD	mg/l	68	30
BOD5	mg/l	9	4
TSS	mg/l	18	< 1
TDS	mg/l	946	967
Turbidity	mg/l	11.2	0.18
Oil concentration	mg/l	7.2	0.2

Table 1: Relevant inflow and outflow concentrations in the Cerafiltec system

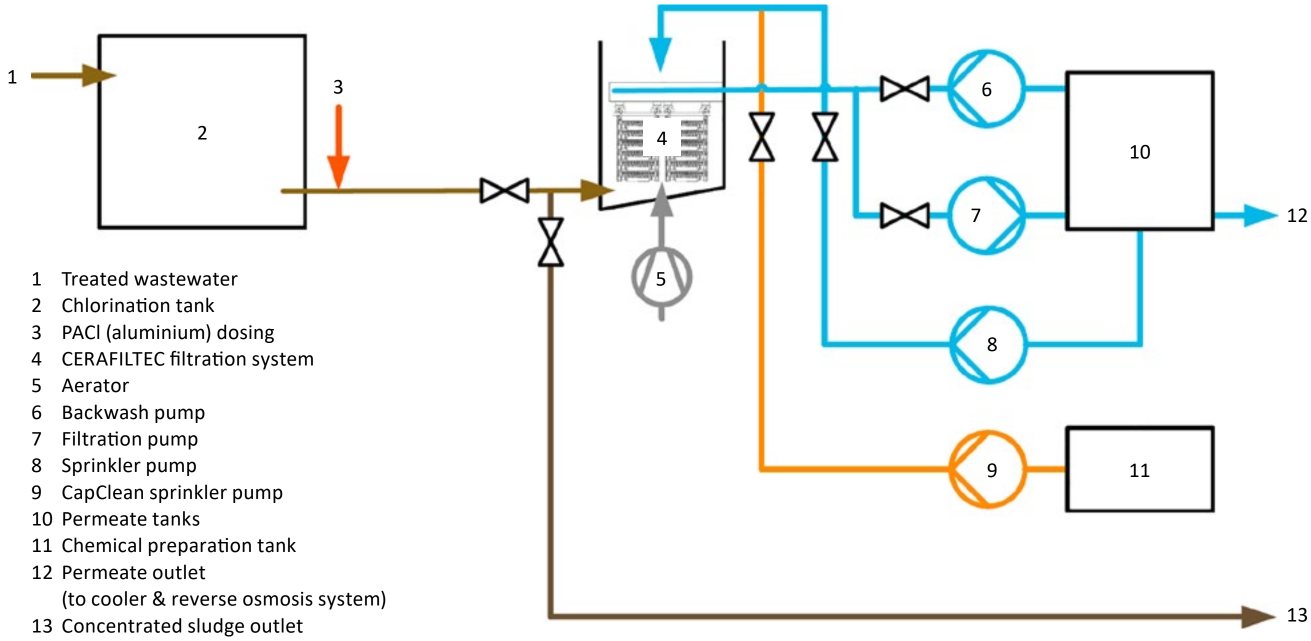


Figure 1: Process flow chart of the Cerafiltec filtration system for water recycling

Figure 2: Photograph of the integrated Cerafiltec system

6

METAL PRODUCTION AND PROCESSING

Country-specific information

India

The metal industry has historically been an important driver of the Indian economy due to the availability of ore resources. In the last decade, the country's steel industry has grown to make India the second-largest producer in the world, contributing significantly to the national GDP with an annual production of about 110 million tonnes (Table 1). Other metals, such as copper or aluminium, are also produced in significant quantities. In addition to the value added within metal production, steel forms an important basis for numerous downstream industries. By far the largest share (over 60%) of the steel produced is used in the construction industry, for example in infrastruc-

ture and building construction. Other relevant users of steel are the consumer goods and automotive industries [9].

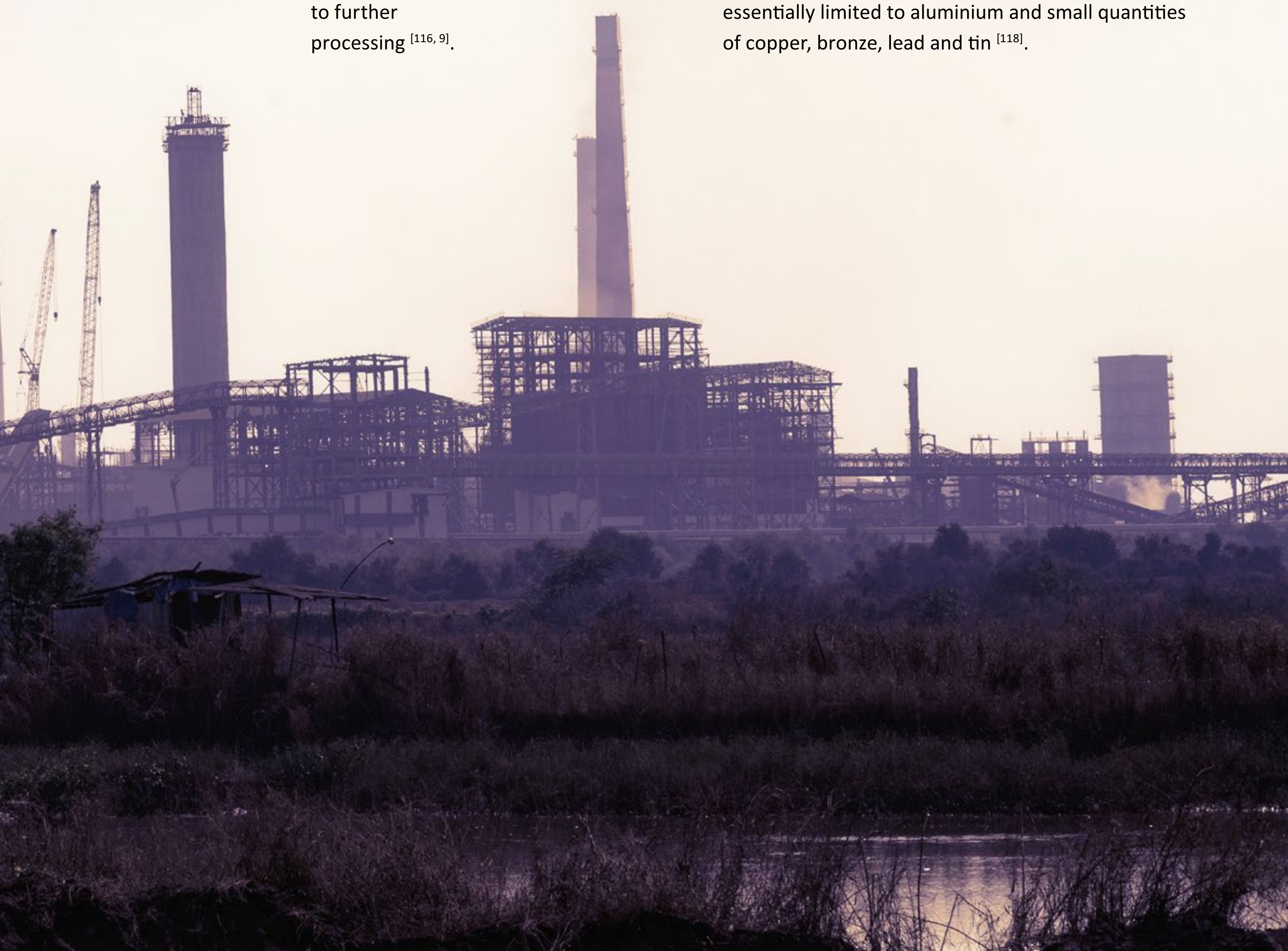
Due to their geographical proximity to India's natural iron ore and coal resources, steel production is centred in the states of Odisha, Jharkhand, Chhattisgarh and Karnataka. Steels of various grades are produced there in modern, well-equipped steel mills. 45% of steel production takes place directly in ventilated blast furnaces. However, an important intermediate product of the Indian steel industry is sponge iron, which is typically obtained by direct reduction using coal and then smelted mostly in electric arc furnaces.

The Indian metal industry is largely (about 80%) privately owned, with the most dominant company being the internationally active Tata Steel. About 50% of the steel is produced by integrated production companies that cover the entire production chain from steel smelting to further processing [116, 9].

Alongside the industry's extraordinarily high energy consumption, other environmental protection aspects are gaining increasing prominence. Stricter environmental protection requirements are currently being drawn up by the government. Compliance with corporate energy and water management plans is already expected as standard. The most important concrete measure in this context is often the reuse of water flows close to production and the recirculation of cooling water [117].

MENA

In the MENA region, too, the demand for metals and metal components is closely linked to general economic growth. However, most countries are net importers and produce only steel in relevant quantities locally (Table 1). In some countries, such as Egypt or Jordan, existing production capacities have been underutilised for years due to shortages of raw materials and natural gas. The production of non-ferrous metals continues to play a subordinate role and is essentially limited to aluminium and small quantities of copper, bronze, lead and tin [118].



Steel is typically produced in electric arc furnaces, except in Egypt, where blast furnaces are also in operation [119]. The steel products consist mainly of carbon steel and to some extent stainless steel, while special and alloy steels play a much smaller role. Surface refinement – if any – usually takes the form of hot-dip galvanising. The main buyer of steel in the MENA region is the construction industry, for example for the construction of buildings and infrastructure. In the medium term, the local automotive and energy industries are also expected to increase their demand for steel. In line with demand, the steel industry produces significantly more long products (approximately 70–80%) than flat products (approximately 20–30%). In Morocco, Egypt and Jordan, reinforcing bars (rebars) account for by far the largest share of sales in the steel market [120].

Industry and wastewater generation

Metal production and processing is an important upstream industry for the manufacture of various consumer and capital goods. It includes the production of iron, steel and other metals, their processing by primary and forming processes and surface finishing, and the manufacture of metal products.

Metal production

Ferrous and non-ferrous metals are usually produced by smelting the corresponding ores. Traditionally, pig iron is extracted in blast furnaces at temperatures of up to 2,000°C and then oxidised to produce

Annual production volumes

Country	Steel	Aluminium	Copper	Zinc
India	109,272	2,750	450	688
Egypt	7,807	317	4	n.a.
Morocco	600	n.a.	n.a.	n.a.
Jordan	150	n.a.	n.a.	n.a.
Tunisia	50	n.a.	n.a.	n.a.

Table 1: Annual production volumes for selected materials in 2018 [1,000 t per year] [119, 118]

steel, generating waste streams of highly dust-laden converter gas and steelworks slag. The alternative steelmaking method of melting sponge iron or pig iron in an electric arc furnace has become established regionally. In the subsequent metallurgical treatment, oxygen, carbon, nitrogen or hydrogen are removed to adjust the steel alloy and steel purity and are discharged together with the waste gas [121, 122].

Non-ferrous metals are extracted from ores by means of hydrometallurgical or pyrometallurgical processes and further concentrated by means of electrolytic processes. Thanks to its outstanding thermal and electrical conductivity, copper is a major industrial non-ferrous metal today. In addition, aluminium is playing an increasingly important role due to its low specific weight. Aluminium is typically extracted from bauxite using the Bayer process. In this, the mineral is dissolved in caustic soda at elevated temperatures and then precipitated as aluminium hydroxide [123]. Due to the large quantities of highly polluted waste gas streams involved, the main wastewater streams from metal production originate from the scrubbing waters used for waste gas purification.

Primary and transforming processes

Today, steel and other metals are usually cast continuously in continuous casting processes and then processed into long or flat products in hot rolling mills. Casting in shaft furnaces can produce blast furnace gas, which has similarities to converter gas and must be cleaned accordingly, in either a dry or wet process. In hot rolling, water is used not only for indirect cooling but also for high-pressure descaling and direct cooling and thereby comes into direct contact with the metal product. After mechanical or chemical surface treatment, to remove scale for example, the properties of the metal product are further refined by means of cold rolling. Further processing by machining, forming or joining processes serves as a transition to the manufacture of metal products and usually requires no significant water consumption [124, 125].

Surface finishing

In many cases, metal components are subjected to surface finishing to enhance their functional or decorative properties, such as corrosion protection. First of all, this involves a surface pre-treatment using chemical and sometimes mechanically assisted cleaning, degreasing or pickling techniques. The key aspect of surface refinement is a metallic coating, which can typically be applied by electrolytic deposition, but also by means of reduction or dipping processes. The most widely used coating processes include electroplating (e.g. chrome plating) and hot-dipping (e.g. hot-dip galvanising). Finally, the metal surface can be further modified by oxidation (e.g. burnishing). Chemical and electrolytic surface finishing is usually carried out in immersion or spray baths, which are (semi-)continuously regenerated and, with a few exceptions, are operated without producing wastewater. Wastewater is mainly produced in the rinsing processes that follow each individual treatment step [126, 127].

Wastewater streams and characteristics

Gas scrubbing

Highly polluted waste gases are produced in coke production, blast furnaces and other pyrometallurgical processes, among other things. In addition to dry flue gas purification, wet gas scrubbing is still the best available technology in many cases where both gaseous and particulate pollutants have to be removed. Dry dedusting processes are mainly used in connection with electric arc furnaces. As a result, hardly any gas scrubbing water is produced there compared to the blast furnace route. The resulting scrubbing water is usually recycled in a semi-closed circuit. The most common contaminants in gas scrubbing water include (Table 2) [122, 128, 129]:

- Suspended dust particles
  Wastewater from gas scrubbing in blast furnaces contains approximately 1–10 kg of solids per tonne of metal produced. These consist mainly of iron and manganese oxides, as well as phosphorus and nitrogen compounds.

- Water-soluble gases
  Converter gas and comparable gases from non-metal production can contribute high loads of nitrogen oxides and sulphur dioxide to wastewater. Dissolved dicyan is also a common contaminant.

- Dissolved nitrogen compounds
  Gas scrubbing waters from coke production often contain organic nitrogen compounds as well as inorganic nitrogen (especially ammonium, but also thiocyanides).

- Dissolved salts
  As a result of contact with the secondary raw material, waste gases typically contain further dissolved inorganic contaminants, such as sulphur compounds, fluorides and chlorides. Heavy metals (e.g. arsenic) can also play a relevant role, especially in the converter gas scrubbing waters.

- Organic dissolved substances
  Gas scrubbing water is often contaminated with organic contaminants, such as phenol, naphthalene or polycyclic aromatic hydrocarbons. Blast furnace gases can also introduce auxiliary substances from the casting moulds into the wastewater (e.g. separating agents and binders such as amines).

- Cyanide
  Elevated concentrations of cyanides are observed in most gas scrubbing waters. In converter gas, cyanide contamination is closely related to the unloading, start-up and shut-down processes used.

Direct contact with the product

In some process steps in the industry, process water comes into direct contact with the metal or by-products. This is the case, for example, with granulation water used for processing blast furnace slags. This produces an alkaline reaction and contains sulphides. However, the largest wastewater stream contaminated by direct product contact arises from the product cooling waters used in continuous casting and hot rolling. They are mainly contaminated by solids. For example, approximately 15–40 kg of mill scale is discharged in the process water per tonne of rolled steel. In addition, there are often high concentrations of oils and emulsions originating from product and plant lubrication or hydraulic leakages (Table 2) [22, 130].

Surface finishing

The acidic or alkaline treatment baths and electrolyte baths used in surface finishing are usually (semi-)continuously regenerated and disposed of as hazardous waste after they have been left standing for a long time, if necessary after appropriate concen-

Process step	Typical contaminants	
Gas scrubbing (coke oven)	1–4 g/l	Phenol
	2–6 g/l	NH4+
Gas scrubbing (converter gas)	0.2–1 g/l	TSS
	0.1–5 mg/l	Phenol
	2–200 mg/l	NH4+
	0.1–50 mg/l	Cyanide
Direct cooling (hot rolling)	0.1–2 g/l	TSS
	10–200 mg/l	Oil
Degreasing	0.5–1 g/l	TSS
	0.1–0.2 g/l	Oil
	0.3–0.5 g/l	COD
Electrolytic surface coating	5–100 mg/l	TSS
	0.1–1 g/l	COD
	0.1–10 mg/l	Phosphate-P
	0.1–0.5 mg/l	VOX (volatile organic halogens)

Table 2: Concentration ranges of the most important contaminants in wastewater from different process steps in metal production and processing [130, 131, 133]

tration. The process waters produced in the intermediate product rinses are run, in accordance with the best available technology, in a semi-closed circuit. The discharged partial flow has to be treated as wastewater.

The rinsing waters from pre-treatment generally consist of acidic solutions (mainly hydrochloric, sulphuric or nitric acid) (Table 2). Even though this is no longer considered state of the art, they may also contain organic solvents and chlorinated hydrocarbons. Typical contaminants in these rinsing waters are cyanides, chlorides, sulphates and phosphates, in addition to dissolved metals. Wastewater from electrolytic processes often contains a range of auxiliary substances such as wetting agents, brighteners, surfactants, complexing agents and pH buffers in addition to the corresponding metal ions. In hot-dip galvanising and other immersion processes, water is used mainly for indirect cooling of the melting furnaces and may be contaminated with hardening salts, biocides and antiscalants [131, 132].

Cooling water

Cooling water is used in almost all industrial processes and serves to dissipate excess energy and to bring product or process water back to ambient temperature after processing. Cooling water is produced in large quantities, especially in metalworking at high temperatures – the more energy is used in a process, the more energy must also be dissipated. The possible uses of cooling water listed below as examples (according to [22]) also apply in part to other industrial sectors.

In once-through water cooling, water is used once for cooling, having been drawn, for example, from a well or surface water, and leaves the plant again after use. This results in a very high level of water consumption, but depending on the discharge conditions involved, there is little or no need to treat the water.

In the open cooling circuit, water is evaporated via a classic wet cooling tower and partially recycled. While results in lower water consumption than with once-through cooling, the partial evaporation also leads to an increase in the concentration of chemical constituents. These can lead to deposits and corrosion and must therefore be removed from the cooling water. Furthermore, the warm and humid environment of a cooling circuit is an ideal environment for the growth of bacteria, with legionella being a particular hazard here.

In a closed cooling circuit, cooling takes place via a heat exchanger with the result that the cooling water does not come into contact with the surrounding atmosphere. The only water losses here result from leaks or other losses in the system. An increased concentration of constituents therefore plays almost no role in this system, although corrosion products can accumulate. The main disadvantage of this process is the relatively high level of energy required.

Treatment processes

Process selection and stages

The effluents generated in metal production and processing can differ greatly in terms of their volume flows and composition. As a result, the selection of suitable cleaning processes is highly dependent on the location and plant. A widely used method involves the combined treatment of all of the collected wastewater in a central industrial wastewater treatment plant by means of chemi-

cal-physical processes (e.g. sedimentation, precipitation, filtration) and/or biological cleaning. This is generally done with the following objectives [22]:

- Separation of solids
- Separation of oils and fats, if necessary
- Removal of dissolved organic, metallic and other inorganic contaminants
- Neutralisation, if necessary

In many cases, decentralised pre-treatment of individual wastewater streams can significantly improve the overall efficiency of wastewater treatment. The treatment regimen can be specifically adapted to the relevant contaminants and purification objectives.

Decentralised cleaning of process wastewater is also a prerequisite for the (partial) reuse of water. Completely closed water circuits can typically be achieved within closed cooling systems, e.g. for cooling moulds via heat exchangers. In many cases, treated wastewater that does not have the required purity for reuse can be used for other applications with lower quality requirements [22, 130, 134].

Gas scrubbing

In most cases, gas scrubbing water is first neutralised before the suspended solids it contains are removed. The solids are separated by sedimentation in circular clarifiers, usually with the addition of flocculants to improve the settling properties of the very finely suspended particles. In individual cases, a combination of processes using hydrocyclones or sand filters may be necessary to achieve a largely solids-free effluent.

Further purification, for example by means of ion exchange or adsorption, can be useful if the wastewater either needs to have environmentally hazardous substances removed from it (e.g. polycyclic aromatic hydrocarbons) or if it contains valuable metal compounds that can be recovered in an economically viable way. Wastewater that contains cyanide can be treated by stripping, oxidation, biodegradation or complexation. The most commonly used method is the reaction to glyconitrile with the addition of formaldehyde, followed by oxidation of the glyconitrile (e.g. by hydrogen peroxide) [128, 129, 134].

Direct contact with the product

Wastewater from direct contact with the product often contains high concentrations of solids, which can lead to deposits and damage to machinery (e.g. to pumps). For this reason, at least one grit trap is usually installed as close as possible to the point of occurrence for the purpose of removing a large proportion of the solids. Wastewater treatment typically focuses on the separation of oils and further solids removal. In the first step, floating oils and greases are generally removed by gravity separation to prevent clogging of downstream equipment. The solids are usually removed in a two-stage process consisting of sedimentation and sand filtration. Often, residues of oils and greases are also retained in the sand filtration process. Occasionally, alternative approaches to simultaneous oil and particle separation, such as gap filtration or flotation, are also used. If the wastewater contains appreciable concentrations of cooling lubricant emulsions, additional thermal or chemical emulsion splitting may be required, possibly in combination with biological or oxidative post-treatment. If the wastewater is treated using the best available technological means, 95% reuse (e.g. for product cooling in the hot rolling mill) is considered feasible [22, 130, 135].

Surface finishing

Due to the often low pH values, the first treatment step for wastewater from surface pre-treatment and finishing usually involves neutralisation, for example using calcium hydroxide or caustic soda. In many cases, precipitation reactions occur even at this stage; i.e. dissolved metal ions are separated as hydroxides and can be separated as solids in the following step. The solids are usually separated by sedimentation (if necessary, with the addition of flocculation aids), occasionally also in combination with filtration processes.

Further treatment is necessary if the wastewater contains environmentally hazardous solutes. Cyanides are typically oxidised by means of UV radiation or hydrogen peroxide, as the use of hypochlorite can lead to the formation of adsorbable organically bound halogens. If chromium (VI), which is highly toxic, is still used for surface treatment, the corresponding residues in the wastewater have to be reduced to the less problematic chromium (III) using

sodium bisulphite or iron (III) sulphate. Once it has been treated in this way, the water can in some cases be reused or recycled for product rinsing. However, passivation and chromating processes in particular place such high demands on water purity that reuse is then out of the question [22, 131, 136].

Cooling water

As mentioned above, the treatment of cooling water in the widely used open cooling circuits is a crucial process [22]. On the one hand, high chloride concentrations in the cooling system – especially at low pH values – often cause metal corrosion, potentially leading to leaks in the system. Deposits on heat exchangers and other cooling elements, for example due to calcium carbonate, are another common phenomenon. Deposition leads to a reduction in heat transfer performance and also promotes biofilm growth. Bacterial growth – especially that of biofilms, which can contain pathogenic Legionella bacteria – is one of the main problems in cooling systems and can quickly lead to plant closures due to the high health risk. Typically, these problems are tackled by the use of chemicals, such as biocides, softeners and corrosion inhibitors. These have to be purchased externally and often used in large quantities, which is a disadvantage from an economic point of view. In addition, the substances used are often harmful to the environment, which is why the cooling water leaving the plant requires additional purification. For these reasons, alternative processes are increasingly being developed and utilised to reduce the consumption of chemicals. Some examples are listed here (based partly on [137]):

- UV disinfection to remove bacteria
- (Membrane) filtration for the separation of solids
- Desalination and physical conditioning of water
- On-site generation of biocides
- Electrodeposition for the targeted removal of ions □

CASE STUDY: **Zinc recovery/zinc leaching in India**

Application of pH probes and a modular multi-channel meter for pH control

Background

Hindustan Zinc Ltd is a major Indian mining and raw material producer with an annual turnover of about €250 million and about 6,800 employees. Its main products are zinc, lead, silver and cadmium. At the Chittorgarh/Rajasthan site, the zinc extraction process was to be further optimised and automated with robust measurement technology.

Special challenge/problem

Water is used as a solvent in the extraction of zinc from zinc calcite. To dissolve the zinc out of the zinc oxide, the process water has a neutral or slightly acidic pH value in the first stage of the process. This must be adjusted with the addition of sulphuric acid and maintained during the process. In a further process step, the process water is again enriched to a strongly acidic solution to recover the remaining zinc from zinc oxide and zinc iron. This process results in the production of a solid and a liquid; the liquid contains the zinc and is referred to as the product of leaching; the solid is referred to as the residue, which nonetheless contains precious metals (usually lead and silver) that are sold as by-products. At the end of the process, the process water has to be purified and neutralised. Due to its chemical composition, the process water placed a strain on the previous electrochemical pH sensors, which in turn reduced their service life and the reliability of the measured values. For this reason, a combination of suitably robust measurement technology, automated sampling and sensor cleaning as well as integrated pH control was sought.

Figure 1: JUMO tecLine HD pH and redox sensors

Figure 2:
JUMO AQUIS touch S modular multichannel meter with integrated controller and screen recorder

Solution

During zinc extraction, the client measures and controls the pH value of the process water. To optimise and automate this process, Jumo proposed installing a combination of two products, each in duplicate: the JUMO tecLine HD pH and redox combination electrode with HD electrodes and the JUMO AQUIS touch S modular multi-channel measuring instrument for liquid analysis with integrated controller and screen recorder.

Results

The JUMO tecLine HD pH and redox combination electrode was installed in a bypass line in which samples of the process water are measured.
The combined system consists of a pH sensor, transmitter, level sensor, cleaning system and valves for dosing acid and water, and was specially adapted for the customer. Using this combination, both the measurement and the entire process optimisation and automation can be performed within a single control unit. The use of process water and sulphuric acid could be significantly reduced overall, with target values for savings of between min. 8 and max. 15%. The customer is completely satisfied with the solution installed by JUMO.

Contribution of the technology provided

The measurement technology that has been installed offers maximum flexibility thanks to the stand-alone system programming facility, resulting in optimised operation of the process sequences. The high availability of spare parts locally also reduces service costs. □

7

TEXTILE AND LEATHER INDUSTRY

Country-specific information

India

The textile industry is a key sector of the country's economy and contributes about USD 61 billion to the GDP (2.3%). The major textile manufacturing centres are in Tamil Nadu, Gujarat, Maharashtra and Rajasthan. Support from the Indian government in the form of export promotion measures and the allowing of 100% foreign investments has led to a surge in investment in the industry in recent years [138].

The Indian textile industry includes companies of widely different sizes, from traditional small businesses to the capital-intensive factories operated by multinational firms (such as Arvind, Vardhman Textiles and Welspun India). Micro-enterprises and small businesses are predominant, being represented in the entire value chain from raw material processing to garment production. Synthetic fibres, such as polyester, viscose and nylon, as well as natural fibres, are used as raw materials. India is the world's largest cotton producer with an annual production of 33.7 million bales and the second-largest silk producer with 18% of global silk production. Yarn-spinning, weaving and knitting mills make up the strongest segment of the textile industry in India. Numerous small and medium-sized dyeing and printing companies are involved in textile finishing. The value chain is completed by – mostly industrial – sewing factories. The sub-sectors of textile finishing, dyeing and bleaching plants in particular have been classified by the Central Pollution Control Board as highly polluting and are therefore intensively monitored for water pollution. A ZLD approach is also mandatory for businesses that generate wastewater quantities of more than 25 m³/day [139, 140]. This poses major challenges for many companies, as often even the simplest wastewater treatment facilities (e.g. sedimentation basins or neutralisation) are not available, are incorrectly dimensioned or are poorly maintained and operated.

The Indian leather industry, which is the second-largest producer, represents about 13% of the global production of leather and leather goods. An important basis for this industry is the availability of the corresponding raw material. In India, in fact, has 20% of the word's cattle and 11% of other livestock and produces 280 million m² of leather annually in its tanneries. Many of the leather production facilities are based in the states of Tamil Nadu, West Bengal and Uttar Pradesh. In these regions, as well as in other promising ones, the government is currently promoting the development of 'Mega Leather Clusters'. These are specialised industrial parks designed to increase the efficiency of the sector and improve environmental protection through optimal infrastructure connections. One focus is also on the construction of combined industrial wastewater treatment plants, as tanneries are among India's heaviest water polluters and tannery wastewater has recently been classified as highly polluting [140, 141].

MENA

The textile industry in the MENA region is highly export-driven, with the US and Europe as the main markets. While many countries have traditionally focused on the production of raw materials and feedstocks, complete value chains are now increasingly being developed. In many cases, governments are endeavouring to assist the industry through targeted support measures. In addition to the conclusion of trade agreements, these also include financial support for the establishment of new production sites (e.g. Egypt) and for the further training of skilled workers (e.g. Morocco) [142, 143].

In Egypt, the textile industry plays an important role, representing about 3% of the country's GDP. Cotton is a key raw material here, whereas synthetic fibres are usually imported. The rest of the value chain includes spinning mills, weaving mills and textile finishing and is dominated by public sector companies. Sewing factories, in contrast, are 90% privately owned; examples here include Oriental Weavers – one of the largest carpet producers worldwide – and Yesim, which produces goods for brands such as Nike [142, 144]. The Moroccan textile industry has been experiencing an upswing recently, thanks to the ongoing development of value chains beyond the provision of raw materials (cotton, yarn). There are plans to further encourage these developments by means of targeted support, with the aim of further increasing the sector's contribution to the country's GDP (currently at 8%) and creating more jobs [143, 145]. In comparison, the textile industry in Tunisia and Jordan is less robust. Foreign companies provide most of the investment in this sector, but economic uncertainties undermine the international competitiveness of the two countries. There is a potential opportunity, especially in Tunisia, to focus on sub-sectors that add more value, such as technical textiles [146, 147].

While leather production and processing are traditional industries in many MENA countries, they usually play a subordinate role in today's economy. As in the textile sector, state interventions are underway in many places to increase the sector's competitiveness and attractiveness for foreign investors.

These also include support for new production sites with modern infrastructure with the aim of reducing water pollution, especially from tanneries, and meeting international standards [148, 149, 150].

Industries and wastewater generation

Textile industry

The textile industry produces flat woven fabrics from raw fibres and processes them into textiles. While the textile industry represents the most important preliminary stage of the clothing industry, technical and medical textiles are also produced. Water is used in large quantities in the textile industry as a solvent for chemical dyes and auxiliary substances, and for washing out excess chemicals. The main process steps in the textile industry are [151]:

- Spinning
  Production of yarn from natural raw fibres (e.g. animal wool, cotton) or synthetic fibres (e.g. polyester, polyamide, polypropylene)

- Fabric manufacturing
  Production of fabrics, mostly by weaving, stitch-forming processes or braiding of yarn

- Finishing
  Finishing processes can be carried out on fibres, yarns, fabrics or finished goods. These include pre-treatment (including desizing, bleaching and mercerising), dyeing, finishing (e.g. crease-resistant finishing, flame-retardant finishing), printing and coating.

Leather industry

The leather industry involves the transformation and modification of animal hides into versatile, durable leather. The main manufacturing steps in leather production are [152]:

- Beamhouse: Preparation of the hides by soaking, liming (depilating) and fleshing
- Tannery with all the associated intermediate steps
- Wet finishing and dyeing: Neutralising and greasing, as well as dyeing and drying the leathers
- Preliminary and final finishing: Studding, sanding, embossing and fulling of leathers
- Production of leather goods: Further processing of the material, for instance into shoes and other leather goods

The leather industry is a very water- and wastewater-intensive sector, as water is used as the main solvent and mode of transport. For example, the processing of 1 t of animal hides generates about 600 kg of solid waste and 15–50 m³ of wastewater. About 500 kg of chemicals are used for processing, 85% of which are rinsed out again with the wastewater. By far the largest proportion of wastewater is produced in the beamhouse during steeping, liming and tanning. The preliminary and final finishing and further processing into leather goods, on the other hand, has significantly less environmental impact [153, 154].

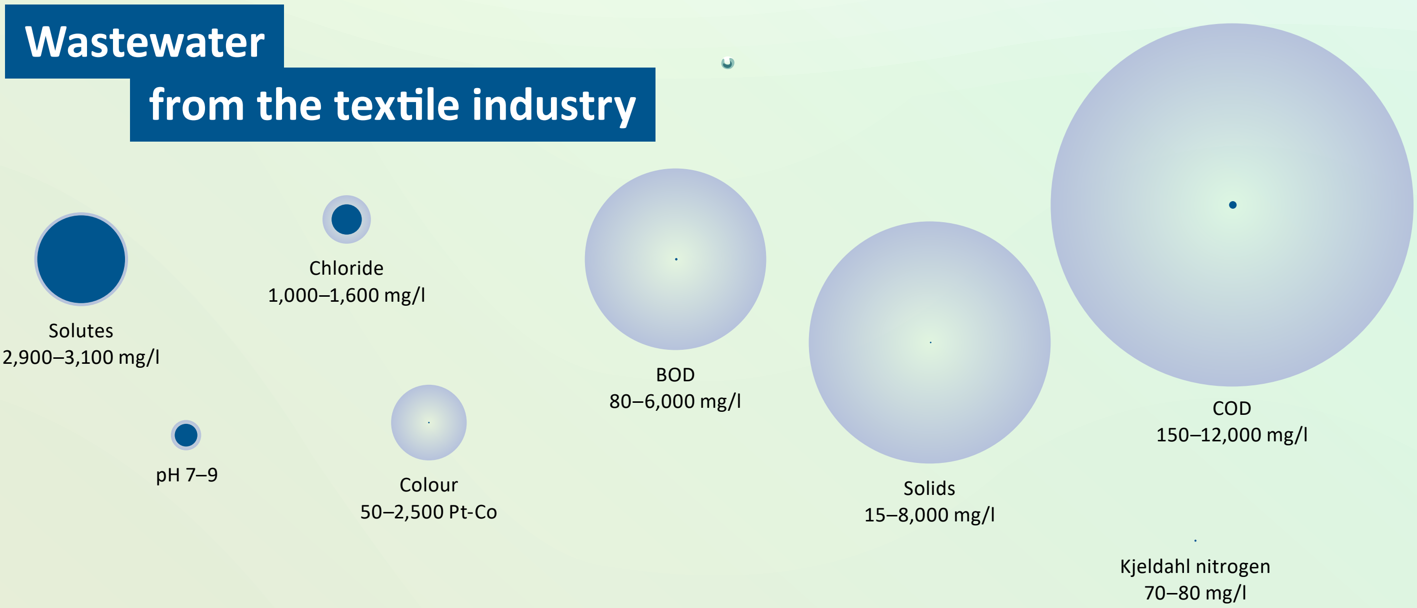


Figure 1: Typical concentrations of contaminants in wastewater from the textile industry [155]

Wastewater streams and characteristics

Spinning and fabric manufacturing

Wastewater from the textile industry can contain all the chemical substances that occur throughout the production chain. In the prewashing processes performed by spinning mills, contaminants from raw fibres, such as pesticide residues from natural fibres, are often introduced into the wastewater. The yarns are sized (i.e. impregnated) prior to fabric production and then desized again. As a result, the wastewater from desizing contains both the sizing agents (e.g. starch, starch ether, alcohols or polyvinyl alcohol) and auxiliary substances used for desizing (e.g. acid or oxidising agents) [22].

Textile finishing

The main wastewater streams in finishing plants are the effluents from pre-treatment and dyeing and from finishing, which may contain the following contaminants depending on the type of finishing and type of fibre involved (Figure 1):

- Dyes
- Finishing chemicals (e.g. softeners, perfluorinated and polyfluorinated alkyl compounds (PFAS), flame retardants)
- Chemical auxiliaries for pre-treatment, dyeing and finishing (e.g. surfactants, complexing agents, reducing and oxidising agents)
- Acids, bases and neutral salts

Process stage	Process steps	Wastewater
Soaking and fleshing	Soaking of (possibly preserved) hides with the use of auxiliary materials, followed by mechanical fleshing	- BOD, COD and solids of animal origin - Salts - Organic nitrogen - Auxiliary materials
Liming and depilation	Swelling and disintegration of the hides under alkaline conditions to detach the hairs	- Lime and alkalis - Sulphides - Organic nitrogen (ammonium) - BOD, COD and solids of animal origin
Decalcification and pickling	Removal of residues from liming, followed by preparation of the hide for absorption of the tanning agent by adding enzymes and, if necessary, acid	- Ammonium - Sulphides - Calcium salts - BOD, COD and solids of animal origin
Tanning and retanning	Conversion of collagen fibres into leather fibres and preservation of the hides by incorporating tanning agents, if necessary with retanning after neutralisation	- Tanning agents, e.g. chromium (III) - Acids - Complexing agents - Auxiliary materials
Dyeing	Dyeing of the leather and fixing of the dye, followed by additional pigmentation or coating, if necessary	- Dyes - Organic solvents - Organically-bound halogens (AOX)

Table 1: Process steps and typical wastewater contaminants of the process steps in the leather industry with the greatest environmental impact [157]

In addition to the other process steps that involve a high COD load such as desizing, the bleaching process results in the discharge into the wastewater of both oxidising agent residues and any reaction products and auxiliary substances used. If sodium hypochlorite (NaClO) is used, organic halogen compounds, e.g. trichloromethane, are often formed. When bleaching with hydrogen peroxide, problems are most likely to arise in relation to the auxiliary substances, such as the complexing agents used for stabilisation.

The composition of dyeing effluents strongly depends on the fibres and shades involved. Because of the metal complexing dyes used in each case, typical contaminants include copper when dyeing dark shades, for example, and chromium (III) when dyeing polyamide and wool. Urea, which is used to print cellulose with reactive dyes, can constitute an important source of nitrogen in wastewater.

Organofluorine, low-molecular-weight compounds and flame retardants are often used in the finishing process [153, 22].

Beamhouse

75% of the BOD and COD in leather production comes from the beamhouse (Table 1, Table 2). The steeping and liming process results mainly in the production of effluents with organic residues, such as blood and tissue residues or soluble proteins. Detached hair and other solids constitute a very significant source of wastewater pollution. Lime, ammonium and dissolved hydrogen sulphides are often used as auxiliary substances for depilation, and these are also carried into the wastewater, where they produce pH values of 12 and higher. In addition, the wastewater may contain auxiliary substances such as preservatives (mostly sodium chloride), surfactants, enzymes or biocides [22, 156].

Process stage	pH-value [-]	COD [mg/l]	Organic nitrogen [mg/l]	Ammonium nitrogen [mg/l]	Sulphide [mg/l]	Chromium [mg/l]
Soaking and fleshing	7–13	2,500–100,000	200–5,000	20–300	1,200–4,000	
Liming and depilation	12–13	17,000–100,000	2,000–5,000	100–300	1,200–4,000	
Decalcification and pickling	7–9	1,000–17,000	300–900	30–7,000	<300	
Tanning and retanning	3–4	3,000–12,000	ca. 200	<300		300–4,000
Dyeing	3.5–5	8,000–70,000	ca. 200	100–900		10–500

Table 2: Typical concentrations of contaminants in wastewater from the leather industry [154]

Leather tanning

Finally, mineral, synthetic or vegetable tanning agents are used to complete the leather production process and stabilise the material. 80–90% of tanneries worldwide use chromium (III) salts for tanning because they are readily available and produce high-quality leather. In such cases, the wastewater from the tannery, as well as from a number of downstream process steps, is often heavily contaminated with chromium. The toxic and environmentally hazardous glutaraldehydes are an alternative tanning agent, especially in the production of leather used in furniture and cars. In addition to the tanning agents, tannery wastewater often contains leather fibres, inorganic salts and fats [157, 22].

Treatment processes

Process selection and stages

Effluents from the textile and leather industry have very different characteristics depending on the industrial sector, process stage and specific product involved. The most important objectives of wastewater treatment are:

- Separation of suspended solids
- Reduction of organic load (BOD and COD) as well as nitrogen and phosphorus
- Removal of highly concentrated auxiliary chemicals
- Decolourisation
- Neutralisation

In leather processing, wastewater from the beamhouse, for example, often requires separate pre-treatment in order to separate out solids. For this purpose, sedimentation, filtration or flotation technologies are employed depending on the application involved. This ensures the efficiency and trouble-free operation of the downstream wastewater treatment system. The central stage of wastewater treatment in both the textile and leather industries is usually biological cleaning, in which BOD and COD loads, as well as many organic and inorganic contaminants, are thoroughly degraded. In the leather industry, mainly aerobic processes are used for biological nitrogen elimination, such as upstream or downstream intermittent denitrification. Persistent (auxiliary) substances are removed in the full stream or in individual partial streams by means of further physico-chemical processes such as precipitation, adsorption, oxidation or reduction [158, 159].

Example of decolourisation

Dyeing processes play an important role in both textile and leather production. While certain dispersed or high-molecular dyestuffs are adsorbed to the activated sludge in the biological cleaning stage, aerobic biodegradation does not take place or takes place only very slowly. This makes targeted decolourisation of the wastewater necessary. The following approaches are available for decolourisation [22, 160]:

Reduction

Reductive cleavage of azo dyes with iron (II) salt in an alkaline environment (adjusted by milk of lime), usually before biological treatment.

Adsorption

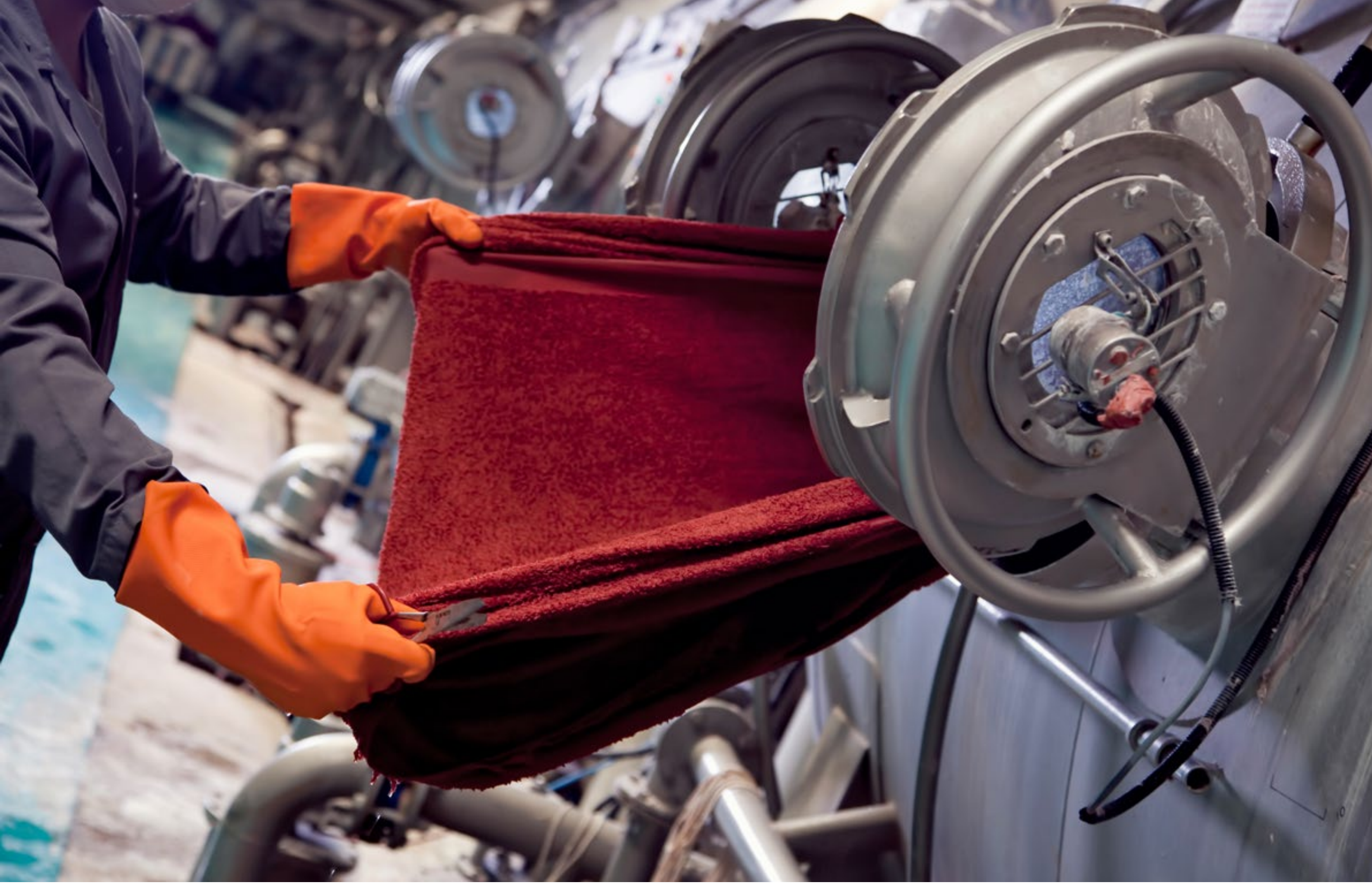
Decolourisation at levels of 80% and above can be achieved by adsorption to granulated activated carbon in fixed-bed filters. The use of powdered activated carbon enhances process flexibility.

Precipitation

Anionic dyes or hydrolysates can be removed by the use of organic, cationic polymers. At a slightly alkaline pH value – depending on the dye involved – approximately 90% decolourisation can be achieved.

Membrane filtration

Many high-molecular-weight dyes can be effectively retained by means of ultrafiltration or nanofiltration. In view of the high costs, however, this approach is only worth considering if other synergies, such as solids retention or water recycling, are exploited.



Chromium (III) removal

When chromium (III) salts are used as tanning agents in leather production, chromium concentrations of up to 4 g/l can occur in the process wastewater. On the process side, chromium discharge can be reduced by using alternative tanning agents or by improving process efficiency. On the wastewater side, chromium is removed to a considerable extent in biological cleaning. Here, chromium is bound in the sludge by adsorption and finally disposed of together with the sewage sludge (if necessary as hazardous waste).

In some cases, additional targeted pre-treatment may be necessary to reduce the chromium loads in the wastewater. This is usually done in wastewater sub-streams that are as concentrated as possible, by precipitation with magnesium oxide, hydrated lime and/or aluminium chloride. Under favourable circumstances, the precipitation sludge can then be dissolved again with sulphuric acid and, after adding the necessary auxiliary substances, reused for chrome tanning [22, 161].

Hydrogen sulphide

Hydrogen sulphide is a colourless, corrosive, highly flammable and highly toxic gas, which merits particular attention in the treatment of sulphide-containing wastewater. Animal protein compounds, particularly those found in wastewater from the beamhouse, decompose rapidly to dissolved H2S or, in an acidic environment, to gaseous hydrogen sulphide.

The formation of hydrogen sulphide can be prevented by minimising sulphide inputs into the wastewater and preventing the mixing of acidic water flows (e.g. from tanning) and sulphide-containing water flows (e.g. from liming) within the in-house sewage system. The best available technology still consists of removing sulphur compounds from wastewater sub-streams prior to biological cleaning, for instance by precipitation with iron salts or catalytic oxidation with manganese salts. In the biological stage, dissolved hydrogen sulphide is finally completely oxidised to sulphate or converted to elemental sulphur. In any case, it is important that all possible emission sources are reliably encapsulated and that exhaust gases are reliably extracted and treated [157, 162]. □

CASE STUDY: Textile industry in India

The world’s largest industrial solar dryer

Background

NTIEM (Narol Textile Infrastructure & Enviro Management), which represents approximately 120 member companies in the Ahmedabad area with a combined annual fabric production of about 2,800 million metres, decided to expand the common effluent treatment plant (CETP) from its previous permitted discharge limit of 40 m³/day to a maximum nominal capacity of 450 m³/day. The plant’s total dewatered sludge volume was 160 t/day in 2017. In addition to reducing waste mass and disposal costs, the project involved the production of a CO_2-neutral substitute fuel for industrial use.

Initially, a low-temperature net belt dryer was planned for the drying of the primary sludge along with a storage building for the secondary sludge (surplus sludge). To achieve these aims, the sludge was to be temporarily stored in a building with a floor area of 12,000 m², while the leachate was to be returned to the plant for treatment and the sludge then disposed of at a landfill site.

Special challenge/problem

The reinforced concrete construction work for the storage building had already been completed when the decision was made to install the Zizmann solar drying system. The drainage route was located to the side of the building, and the sludge was fed by wheel loaders and human operatives. The desired dry matter content of 25% was not consistently achievable with the dewatering units. Mechanical impacts resulting from shovel operations, loading of transport vehicles by wheel loaders, and dumping at the drying unit was leading to a deterioration in the sludge quality. There was also an increased risk of odour pollution caused by volatile chemical and biological compounds. The degradation of the drying performance due to the high levels of humidity during the monsoon was also a major problem that had to be taken into account.

A cost-effective and tried-and-tested technology was needed for a project of this size. The combination of solar drying technology from Zizmann with production and installation by a local partner met all the client’s requirements. Due to previous experience during the drying process that resulted in dust generation with a dry matter content of up to 90% dry residue (DR), a sewage sludge-drying technology that would also meet health protection requirements was required.

Solution

Thanks to its mechanical flexibility, the system could easily be adapted to fit the existing conditions (Figure 1). By using strip foundations as walking surfaces for the Zizmann drying plant, it was possible to avoid having to dismantle the existing concrete structure. The original height of the sludge storage building was reduced by more than five meters, significantly reducing the planned costs for the building construction and covering some of the costs for the drying system as well.

Zizmann dryers are designed as endless-chain conveyors, which in this project would be driven by a 4kW Siemens gear motor, in a similar way to the chain scraper secondary clarifier. As drying only takes place on the surface in contact with fresh air, it is essential that the turning mechanism should constantly generate a new series of evaporation surfaces. The proven system guarantees turning intervals of up to 60 times per hour for dust-free sludge movement. The constant air exchange with adapted flow velocities ensures ATEX-free drying within the discharge area at a rate of 1 m/s, as well as rapid surface drying in the wet sludge input area at a rate of 5 m/s combined with evaporative cooling

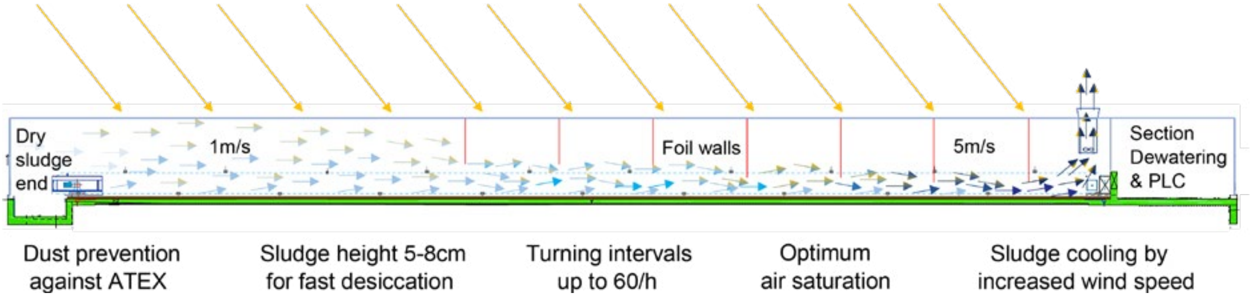


Figure 1: Schematic representation of the solar sludge drying process

at the sludge surface. This reduces the risk of new odours forming in the wet sludge area (wind-chill effect).

With the aim of generating a high-quality CO$_2$-neutral substitute fuel with a calorific value of Ø 12MJ/kg by drying to 90% DR, more cost-effective recycling options in the cement industry were considered instead of ongoing disposal at landfill sites.

During the monsoon season, the sludge is temporarily stored and sent for drying after a certain delay. Even at the structural work stage, the potential for later optimisation was taken into account, thereby ensuring that an additional heating system can now be retrofitted if required. This would eliminate the need for seasonal sludge handling.

Results

Despite fluctuations in the DR content during dewatering, the sludge input quantity is 35,000 t/year instead of the envisaged 30,000 t/year, a level +15% higher than expected. In some cases, dry matter content levels of up to 93.5% were achieved in summer. Water evaporation amounts to 27,200 t/year on average, so that now only 7,800 t/year of dry sewage sludge are reused as substitute fuel in the cement industry.

Despite being originally designed to treat only secondary sludge, the drying plant is now fed with a mixture of primary and secondary sludge due to its operational benefits and stable performance.

Eleven independent drying lines were installed. At the end of the storage building, an automatic discharge system including a belt and ascending conveyor ensures that the sludge is transported to a silo for storage until it is transported away. When the plant was commissioned, the client took measures to relocate the dewatering machinery to the input side of the hall in order to reduce the work steps needed and thus the mechanical impacts on sludge quality, enabling 24/7 operation and hence increasing the drying capacity.

With the automatic infeed and discharge system, visual inspections and maintenance take 0.5 hours per line per day. The drives for the turning and ventilation mechanisms are located at each end of the drying building, making maintenance of the technology very straightforward, without operatives needing having to cross the entire building.

By reducing the mass to be disposed of to only about 22% of the originally dewatered sewage sludge volume, vehicle movements were minimised along with the associated emissions and fuel requirements. Cooperation with a local cement plant is also helping to significantly reduce disposal costs, so that estimated cost savings of around 25–30% are being achieved thanks to the recycling of dry sludge.

Contribution of the technology provided

Thanks to the system’s flexibility, the solar sewage sludge drying system installed places relatively low demands on the spatial conditions of the drying halls. The automatic turning technology allows for largely dust-free and odour-free operation with minimal operating and maintenance effort. Up to 15–20% better drying performance is achieved, with no need for treatment of evaporated water or air in this case. □

8 PAPER AND PULP INDUSTRY

Country-specific information

India

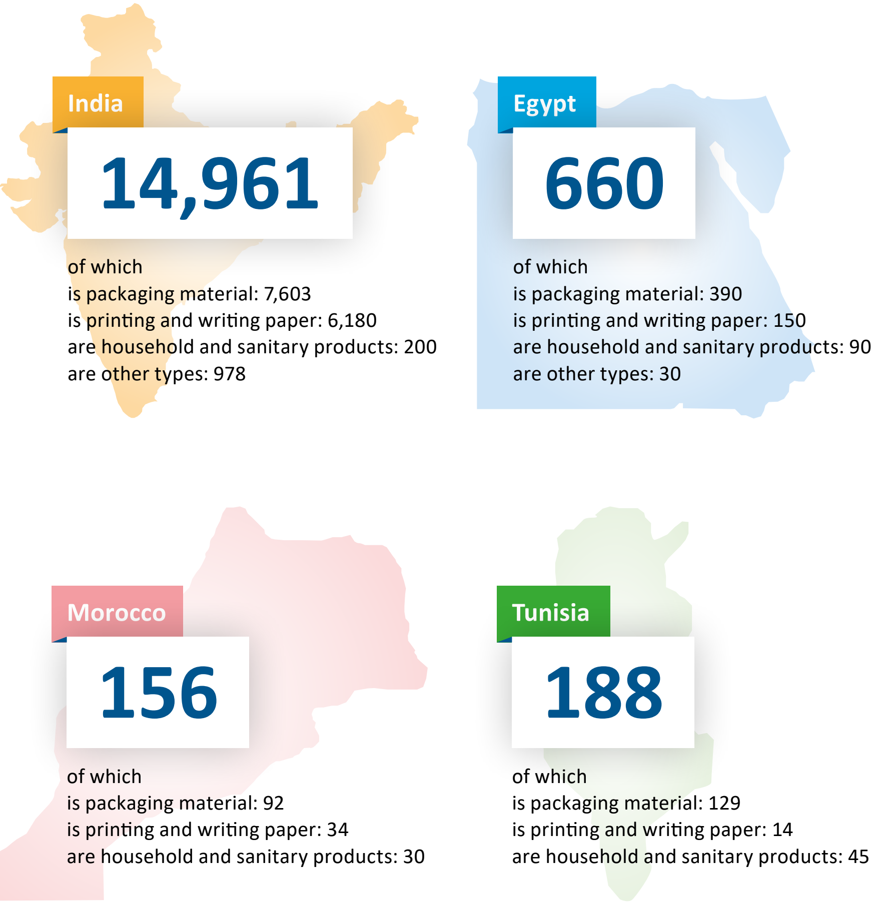
India's paper industry plays a rather minor role globally, with an annual production of about 15 million tonnes and an annual turnover of USD 9.62 billion. The approximately 800 production sites in the country mainly produce packaging material (51% of production), printing and writing paper (31%) and newsprint (18%) (Figure 1). Per capita paper consumption in the country is low by international standards – but with rising income levels, higher literacy rates and growing newspaper circulation, a strong increase is expected in the coming years [163, 164, 165].

The main cost factor in paper production (constituting approximately 50% of production costs) is the raw material required. Of India's 3.3 million-km² land area, only about 0.7 million km² is forested and, in view of tightening restrictions on land clearing, wood is a very limited resource in India. The lack of availability of cheap, suitable raw materials along with competition from imported products therefore presents a major challenge for the national paper industry. Consequently, the focus is increasingly shifting towards alternative raw materials, with 30–40% of paper still made from wood fibre, 50–60% from recycled recovered paper and 15–25% from agricultural residues [163, 166, 167].

The Indian paper industry is dominated by small and medium-sized units, some of which are in considerable need of modernisation to meet today's standards of productivity, energy efficiency and environmental protection. India's Central Pollution Control Board has classified paper manufacturing as a particularly polluting industrial sector and has enacted a series of measures since 2015 to improve industrial water protection. For example, paper mills are required to develop an environmental management plan and demonstrate proper wastewater treatment. ZLD regulations for wastewater-free disposal apply specifically to black liquor [164, 165]. Uncertainties still exist, however, with regard to the technical implementation and the handling of the concentrates that are generated.

Annual paper production

Figure 1: Annual production (in 1,000 tonnes(t)) of paper and paper products and their breakdown into product categories, shown for five sample countries in comparison (in 2017) [171]



India

14,961

of which
is packaging material: 7,603
is printing and writing paper: 6,180
are household and sanitary products: 200
are other types: 978

Egypt

660

of which
is packaging material: 390
is printing and writing paper: 150
are household and sanitary products: 90
are other types: 30

Jordan

54

of which
is packaging material: 3
is printing and writing paper: 3
are household and sanitary products: 47

Morocco

156

of which
is packaging material: 92
is printing and writing paper: 34
are household and sanitary products: 30

Tunisia

188

of which
is packaging material: 129
is printing and writing paper: 14
are household and sanitary products: 45

MENA

Paper manufacturing is a niche market in the MENA region and almost all of the countries there are net importers of fibres and paper products [168, 169, 170]. The main reason for this is the limited availability of raw materials: Depending on the country and region, forest cover is typically in the range of less than 5%, so wood fibres have to be imported for paper production. As a result, some countries have focused on processing alternative fibres, such as bagasse and rice straw as a much-used fibre resource in Egypt. The main raw material for paper production in the MENA region is still recycled recovered paper.

A high proportion of the paper products manufactured is used for packaging purposes, for example as cardboard or packaging paper (Figure 1) [171]. The rest of the output is used firstly for writing and printing paper and secondly for household and sanitary products, in varying proportions depending on the country concerned. An exception here is Jordan, where the manufacture of household and sanitary products has accounted for by far the largest share of paper production in recent years.

The regional paper industry is generally characterised by outdated production sites and low production volumes. In Egypt in particular, the industry is heavily dominated by state-owned enterprises that fail to exploit existing production capacities. To stimulate the industry, an improvement in recovered paper recycling would be necessary in the medium term to increase the availability of raw materials locally. Potential opportunities could also result from focusing on activities that offer greater added value and investment in modern production technologies [170, 172].

Industry and wastewater generation

Pulp is made from cellulose-containing materials – usually wood or other vegetable raw materials, such as bagasse, straw or cotton stalks. The processing of recovered paper as a raw material is also gaining increasing momentum in the paper industry. Pulp production includes the mechanical comminution and chemical pulping of the cellulose by-products, for instance lignin and hemicellulose. In 95% of global pulp production, pulping is carried out using the sulphate process by boiling with alkaline sodium sulphide solution at elevated pressure. The pulp is then washed and, if necessary, bleached. If recovered paper fibres are used, chemical pulping is not necessary. The recovered paper is disintegrated in drums after removal of non-paper components before the recovered paper fibres are sorted and fractionated. In the production of graphic papers, ink has to be removed by flotation ('de-inking') or washing (wash 'de-inking'). In paper mills, the pulp is further processed – possibly with the addition of fillers, glue or pigments – into paper, board and cardboard. Paper webs are produced by dewatering the paper pulp in paper machine screens, presses and thermal dryers [173, 174].

Water serves as the most important solvent and transport medium in pulp and paper production, and is also used for cooling, cleaning and steam generation. The state of the art today involves the recycling of process water to the greatest degree possible – with or without an internal recirculating water purification system – before disposal. The effective water consumption of the entire paper production process is in the range of 0–100 m³ per t of paper and is significantly influenced by raw material quality, product requirements and technical conditions (e.g. corrosion, concentration and precipitation). The wastewater from paper production is polluted with COD loads of >1,000–20,000 mg/l and high amounts of filterable substances due to frequent recirculation (Table 1). Wastewater from upstream pulp production is particularly problematic, as it brings with it approximately 50% of the residual substances from pulping. They therefore differ

Process	Wastewater intensity [m³/t]	COD [kg/t]	Filterable substances (FS) [kg/t]	Phosphorus [g/t]	Nitrogen [g/t]	AOX [kg/t]
Pulp production (sulphate comp.)	20–90	5–30	0.2–5	10–40	50–500	50–200
Pulp production (sulphite processing)	20–80	20–70	0.5–6	10–200	100–2,000	0–400
Pulp production (mechanical)	10–20	1–15	0.1–1	2–10	40–200	0–5
Paper preparation for recycling	1–30	0.5–4	0.1–2	1–20	10–200	0.3–1
Paper production	3–20	0.2–2	0.02–1	0–10	0–100	n.a.
Production of speciality papers	10–50	0.5–7	0.1–2	0–60	0–500	n.a.

Table 1: Typical concentrations of contaminants in wastewater from the pulp and paper industry [179], with further information in [22]

fundamentally in quantity and composition from the wastewater derived from paper production. The cooking liquor from chemical pulping is the most polluted process water and is normally evaporated and incinerated. In addition, polluted wastewater is produced during bleaching and decolourising of the fibres [175, 176, 177].

Wastewater streams and characteristics

Pulp production

Cooking liquor and condensate

The process water produced during chemical pulping is known as cooking liquor (in the widely used sulphate process) or cooking acid (in the less common sulphite process). Nowadays, it is usually thickened and burned in recovery plants. The evaporation condensates contain soluble plant components and insoluble fine particles as well as the chemical additives used. The most problematic contaminants are the lignin compounds, which have low biodegradability, and other organic compounds such as saccharides, fatty acids and resin acids [22, 174].

Bleachery wastewater

Pulp is traditionally bleached by the application of elemental chlorine or chlorine compounds. The resulting oxidation products, e.g. chlorinated acids and phenols, are highly toxic and persistent. For this reason, the use of elemental chlorine is now avoided as much as possible. The main problem associated with bleachery wastewater – namely its toxicity and the low biodegradability of its constituents – is significantly reduced when elementally chlorine-free and totally chlorine-free processes are used. Based on the state of the art, chlorine dioxide, hydrosulphite, ozone and hydrogen peroxide are the preferred bleaching agents today. In the reducing process with hydrosulphite, no substances are transferred into the solution, making it wastewater-free. In oxidation bleaching with hydrogen peroxide, on the other hand, soluble oxidation products can be formed and end up in the wastewater [173, 174].

Paper production

Wastewater from paper production is usually low in concentration and non-toxic. The low level of pollution is due to the fact that the raw materials deployed are insoluble in water and only a few water-soluble additives are used. The main contaminants consist of residues from pulp, wood pulp or recovered paper that are not retained in the paper machine screen, e.g. filterable substances and COD (some of which is difficult to break down). The organic matter in wastewater consists of 30–60% carbohydrates, as well as lignin compounds and degradation products. The BOD5:COD ratio in untreated paper mill effluent is typically between 0.3 and 0.6, with 0.5 as a typical value. The presence of surface-active production additives (e.g. defoamers, pulp deaerators), which can influence or interfere with wastewater treatment, can be problematic [22].

Treatment processes

Process selection and stages

Wastewater treatment in the pulp and paper industry is primarily concerned with removing solids and organic loads. Typical treatment consists of mechanical pre-treatment – mainly for solids separation – and a biological stage. Physico-chemical processes are used if the wastewater contains substances that have low biodegradability, or if improvements in COD reduction or more extensive solids retention need to be achieved.

Pre-treatment

If wastewater flows occur at irregular intervals, adequately dimensioned equalisation tanks are installed upstream of the wastewater treatment facility. Mechanical pre-treatment is primarily used to separate solids, especially cellulose fibres, from process water streams and wastewater streams. The following processes are usually used, often with the addition of flocculants:

- Sedimentation
- Flotation, usually dissolved air flotation
- Filtration, usually disc filters

Since the suspended substances consist of comparatively small and light particles, an upper limit of 1–1.5 $m^3/m^3/h$ is usually set for the surface feed in the sedimentation process. This results in long retention times and, in conjunction with the high temperatures, the risk of anaerobic decomposition in the sedimentation tank [22, 179]. In the case of individual substance flows, e.g. vapour condensates from the sulphite process, additional partial flow treatment is necessary before they are discharged into the wastewater treatment system.

Biological cleaning

Both pulp and paper mill effluents often contain an imbalanced mix of nutrients, as the degradable compounds involved are mainly carbohydrates, while nitrogen (N) and phosphorus (P) concentrations are low. For this reason, it is often necessary to dose nutrients in such a way that a BOD5:N:P ratio of around 100:5:1 is achieved. In addition to the lack of nutrients, one of the main problems with biological treatment can be the insufficient microbiological degradation of individual wastewater constituents. Lignin, for example, forms about 50% of the cellulose by-products in wood and is only metabolised very slowly by microorganisms.

Aerobic and anaerobic processes are generally used for treatment. The most commonly used aerobic process is the single-stage or multi-stage activated sludge process, which is sometimes also implemented in a membrane bioreactor format for improved retention of solids. However, biofilm systems, such as submerged biofilters or trickling filter systems, are also used. Anaerobic reactors are increasingly utilised for wastewater treatment from paper production using recovered paper due to the high specific COD loads involved. Anaerobic cleaning is mostly carried out in UASB (upflow anaerobic sludge blanket) or EGSB (expanded granular sludge blanket) reactors with high COD volumetric loads [173, 180]. The biogas produced can be used to generate electricity.

Production-integrated measures

In both pulp and paper production, in-house measures can be effective in significantly reducing the wastewater volume and emission load. They can be seen as a prerequisite for subsequent measures aimed at largely eliminating residual wastewater pollution. Measures integrated into the production process can significantly reduce water consumption in paper production, for example from 100 m^3 to <10 m^3 per t of paper. Especially in recovered paper processing mills with very high COD loads in the process water, the water cycles can thereby be closed off to a substantial degree even to the extent of achieving wastewater-free (ZLD) operations. Although the concentration of pollutants increases significantly with increasing water reuse, the overall pollution load can thereby be minimised [22]. In pulp and paper production nowadays, there are a large number of production-integrated optimisations that are considered state of the art [22] and that should always be tried before treating the entire wastewater stream. □

9

LANDFILL SITES

Country-specific information

India

High population growth and rapid urbanisation have posed major challenges to India's management waste over recent decades. 377 million of the country's 1.334 billion inhabitants live in urban areas and generate 62 million tonnes of municipal waste annually [181]. The amount of waste is increasing by about 5% per year. A particularly large amount of municipal waste is generated in the densely populated regions of India, such as Maharashtra, Uttar Pradesh, Tamil Nadu and West Bengal. According to estimates, approximately 40% of the waste comprises biologically recyclable materials while 20% consists of recyclable material [182]. Organic waste comes mainly from private households, although here, too, the consumption of packaged goods is increasing and with it the proportion of plastic, paper, glass and metal waste. An important role is also played by the approximately 5 million tonnes of electrical goods that are disposed of as waste annually in India, as well as construction waste, which, depending on the estimate, accounts for up to 30% of the total waste generated [181, 182, 183].

In India, local authorities are responsible for organising waste management. They are governed by the waste disposal and handling regulations issued by the Ministry of Environment and last revised in 2016. However, many municipalities face financial difficulties when it comes to maintaining a functioning waste management system. Of the costs incurred, 90% goes on the collection and transport of waste, leaving hardly any budget for proper processing or landfilling. In practice, 70% of all municipal waste is currently collected and most of this amount (over 70%) is disposed of at landfill sites or dumps. Of the waste collected, 28% undergoes treatment, while incineration or composting of waste is uncommon (Figure 1) [182, 184]. Increasingly, private international waste management groups such as Veolia and SUEZ are looking to participate in the operation of landfills and recycling facilities in India [185, 186].

Waste is mainly dumped in simple waste dumps, i.e. without sealing, landfill exhaust gas systems or wastewater treatment. There are large waste dumps in Chennai, Coimbatore and Surat, for example, and the amount of land required for this is increasing very rapidly across the country (by about 1,240 ha annually). Since 2016, both recyclable packaging materials and biologically recyclable household waste have had to be collected and treated separately to limit the amount of waste going to landfill. The importation of plastic waste is decreasing due to bans since 2017 so as not to exceed the national recycling capacities [187]. For environmental reasons and because many existing dumps are already reaching their capacity limits, the development of regulated landfill sites is currently gaining in importance. Since 2013, more than 400 new regulated landfill sites have been constructed in India [182].

MENA

Waste generation in most MENA countries is around 200–300 kg per inhabitant per year, with sometimes significant differences between the densely populated metropolitan regions (a large quantity of waste) and more rural regions (less waste). The composition of municipal waste also shows a fairly uniform picture: Organic kitchen and agricultural waste make up the largest share (approximately 50–70%), followed by plastic and paper. In comparison, Tunisia and Morocco generate slightly more biodegradable waste and less packaging material than Egypt and Jordan. Other industrial waste streams can be added on a country-specific basis. In Egypt, 6.5 million tonnes of industrial waste are disposed of annually, and in Tunisia 5.3 million tonnes. Most of this waste consists of phosphogypsum. In Jordan and other countries in the region, the disposal of used tyres (2.5 million t annually in Jordan) also plays an important role [188, 189, 190, 191].

Waste management is given different political and financial priorities in different countries of the region. Morocco can be considered a pioneer in this field, as the implementation of a series of environmental protection and waste management programmes has increased the share of waste collected from 44% to over 85% since 2008 [189]. In contrast, only 10–80% of waste is collected in Tunisia and only 30–65% in Egypt, with strong differences between rural regions (a low rate) and urban areas (a higher rate of collected waste) [188, 190]. Most of the collected waste is deposited in landfill, either in simple dumping sites or in regulated landfill sites with appropriate environmental protection measures (Figure 1). Composting or recycling are uncommon due to the failure to separate waste.

In Tunisia, waste disposal is carried out by private companies, which deposit waste in contractual coordination with the responsible environmental authorities. Here, 70% of the collected waste is disposed of in regulated landfill sites with an annual capacity of approximately 2 million tonnes [192]. In Jordan, waste is disposed of by regional operating companies at about 25 landfill sites across the country, most of which are simple rubbish dumps. 50% of the waste is sent to the regulated Algbawi landfill site in Greater Amman, which is by far the largest and most modern in the country [193]. By 2025, political measures are intended to drastically reduce the amount of waste – and particularly the proportion of biologically recyclable materials –sent to landfill [194]. In Morocco, more than 50% of the collected waste was still being disposed of in simple dumping sites in 2014. However, it can be assumed that this rate has decreased since then due to the construction of over 60 new regulated landfill sites, most of which are operated under BOT* contracts. The country's largest landfill site, at Oum Azza, is operated by Teodem, a local subsidiary of the French company Pizzorno Environnement. In francophone Morocco and Tunisia, the major companies Veolia and SUEZ also operate, partly through subsidiaries. Egypt has only a few regulated landfills in operation and more than 80% of the collected waste is disposed of in simple dumps [188, 189, 190, 191].

Industry and wastewater generation

With the degree of industrialisation, waste generation is also increasing rapidly worldwide. According to estimates, in fact, a total of 7–10 billion tonnes of waste were generated in 2015 [195]. In addition to household waste, this also includes waste streams from industry, agriculture and hospitals. Depending on the region involved, household waste consists mainly of biologically recyclable materials (kitchen and garden waste), packaging materials (paper, glass, plastic), electronic waste and bulky waste. Industrial waste consists of production waste, construction waste and slaughterhouse waste, for example. Both household and industrial waste can sometimes contain pollutants, e.g. materials containing asbestos, tar or bitumen, biotoxic chemicals or pathogenic contaminants.

*Build-operate-transfer, i.e. transfer of ownership of the plant to the customer before the end of the concession period

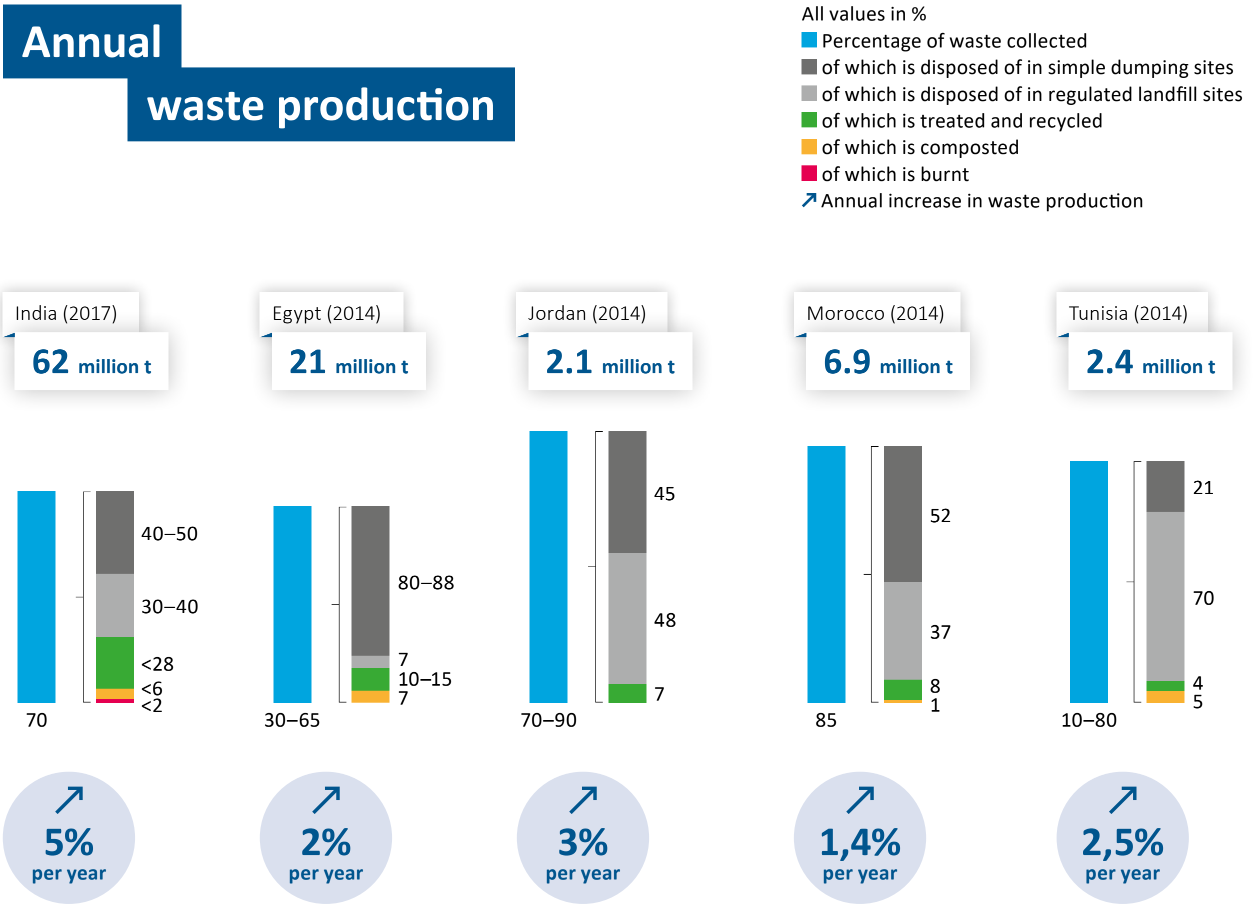


Figure 1: Annual waste generation and typical disposal routes of collected waste, shown for five sample countries in comparison [181, 184, 188, 189, 190, 191]

In many industrialised countries, the recovery of recyclable materials (e.g. paper, glass, plastics, metals) and the composting of biologically recyclable waste are now widespread. Globally, however, landfill remains by far the most important waste disposal pathway. Improper waste disposal can lead to environmental pollution through uncontrolled biological and chemical-physical decomposition processes – with the formation of landfill gases (especially CO_2 and methane) and the formation of landfill leachate being particularly problematic. Environmental impacts can be minimised by creating regulated landfill sites in which contact between waste and environmental media is reduced as much as possible. For example, care is taken to select a site with geologically impermeable subsoils and to additionally prevent leachate from escaping by means of technical barriers. Membranes or sealants are used to seal the landfill, and any leachate generated is collected, diverted and treated at the bottom of the landfill [196].

Wastewater streams and characteristics

Landfill leachate

Wastewater that requires treatment is generated at regulated landfills in the form of landfill leachate. Most of this is rainwater that enters the landfill, percolates through it and accumulates contaminants when it comes into contact with waste. However, water is also produced in the landfill as a reaction product when carbonaceous materials decompose to form methane, CO_2 and organic by-products. The leachate itself can then also undergo a chemical reaction with materials that would otherwise not decompose, such as ashes and materials containing cement or gypsum.

Landfill leachate typically contains a range of organic and inorganic dissolved contaminants in addition to solids (Table 1). The organic substances present are mainly alcohols, acids, aldehydes, sugars and humic substances. There are also inorganic compounds (e.g. sulphates, chlorides, ammonium, iron, aluminium, zinc compounds) and heavy metals (e.g. lead, nickel, copper, mercury). In addition, biocidal substances are released from many types of waste, such as aromatic and halogenated hydrocarbons, phenols, phthalates, aromatic sulphonates and phosphonates [197, 198].

The specific composition of the leachate depends not just on the type of waste sent to landfill, but also on the age of the landfill site. The decomposition processes within the landfill pass, over time, through several phases from the start of dumping to stabilisation. These are summarised as follows [196, 199]:

- Oxidation: Short phase immediately after deposition in which the organic matter is decomposed with the available oxygen, accompanied by CO_2 formation and a slight increase in landfill temperature.
- Acid fermentation: Once the oxygen reserves have been used up, anaerobic fermentation begins with acid formation and a further increase in landfill temperature.
- Methane fermentation: Methane formation from organic acids, leading to a renewed increase in pH, up to stabilisation of the landfill.

Parameter	Concentration	Unit
pH	4.5–9	-
Conductivity	2,500–35,000	µS/cm
Solids	2,000–60,000	mg/l
BOD5	20–57,000	mg/l
COD	140–152,000	mg/l
Total nitrogen	14–2,500	mg/l
Ammoniacal nitrogen	50–2,200	mg/l
Phosphorus	0.1–23	mg/l
Chloride	150–4,500	mg/l

Table 1: Typical concentrations of landfill leachate [200]

Leachate of acid fermentation

Acid fermentation takes several months and is characterised by anaerobic fermentation processes. This process results in the formation of predominantly volatile fatty acids, which can represent up to 95% of the dissolved organic matter. In comparison, the leachate contains only small amounts of high-molecular-weight compounds. In this phase, the wastewater has very high organic loads overall, i.e. high BOD5 and COD values, typically in ratio of BOD5:COD>0.5. Due to the acid formation, the pH value of the leachate drops to between 5.5 and 6.1. Under these chemical conditions, it is also increasingly likely that metal ions are dissolved and can contaminate the wastewater as well [198, 201].

Leachate from methane fermentation

After one year at the latest, anaerobic methane fermentation begins, and this can last for more than 20 years. This phase is characterised by increased activity of methanogenic bacteria, which form methane and CO_2 from organic acids. Acid degradation increases the pH of the leachate to 8.0–8.5, and the concentration of dissolved metals in the water decreases accordingly. The leachate is less contaminated with readily degradable organic constituents, e.g. alcohols, volatile acids or amines. At the same time, there is an increase in the proportion of high-molecular-weight and poorly degradable fractions, e.g. humic or fulvic acids. This is also expressed in typical BOD5:COD ratios of <0.1, which make biological wastewater treatment difficult [199, 201].

Treatment processes

Process selection and stages

The concept of systematic wastewater treatment in waste management is a new one compared to other industries and is still in its infancy in many regions of the world. One challenge lies in the heterogeneous, variable and often unknown composition of leachates produced, depending on the type of waste sent to landfill and the decomposition processes taking place. Since landfill sites have to be managed for at least 30–50 years, the reliable and robust operation of wastewater treatment also hast to be ensured over comparatively long periods of time. Before the wastewater is discharged into the public sewerage system or into nearby surface waters, the following separation tasks should at least be partly completed:

- Retention of solids
- Neutralisation, if necessary
- Removal of dissolved salts, nutrients and metals
- Separation of biocidal substances, partly in the low concentration range

Landfill leachate from acid digestion is normally readily biodegradable due to its high BOD5:COD ratio. It can therefore be largely purified in conventional activated sludge or fixed-bed processes. During methane fermentation, however, the biodegradability of the leachate decreases significantly. In addition, the wastewater may already contain persistent or toxic substances that are directly discharged from the waste sent to landfill. In both cases, biological treatment is not sufficient, and physico-chemical processes must be used (in addition). The most common approaches used in this context are [197, 201]:

- Precipitation
- Coagulation and flocculation
- Adsorption
- Oxidation process
- Membrane filtration

Advanced combination processes

To deal with the sometimes complex composition of the water and to put in place a reliable multi-barrier system, known physico-chemical treatment processes are often combined for the purpose treating leachate. Adsorption processes to activated carbon, for example, are robust in operation and, based on experience, can be combined effectively with biological cleaning processes. For example, powdered activated carbon can be dosed directly into the biological treatment system, the effluent from biological treatment can be purified using granulated carbon, or granulated carbon can itself be used as a carrier material for biological cleaning [202, 203].

Membrane processes are also well suited as a post-treatment step after biological cleaning. Traditionally, ultrafiltration membranes are used in membrane bioreactors (MBR) for solids retention. However, the effluent from biological treatment or MBR can also be further purified, for example by reverse osmosis, if persistent substances need to be removed [204, 205]. However, it should be noted that the concentrate stream is treated and not returned directly to the landfill body. The combination of coagulation and nanofiltration processes is also worth considering in order to achieve a high effluent quality and at the same time reduce problems with fouling in the membrane stage [206, 207].

In addition to conventional ozonation of wastewater, more advanced oxidation processes and combinations of these are also gaining acceptance in some applications. The biodegradability of wastewater constituents, which is often improved by oxidation, can be exploited by placing oxidation processes upstream of a biological cleaning stage. However, a reverse approach is often observed, namely the post-treatment of biologically treated wastewater, e.g. by means of ozonation or Fenton processes for the degradation of persistent substances [208, 209]. Good synergies in terms of cleaning performance can be achieved, especially at low pH values, by combining coagulation and (often Fenton) oxidation processes [210, 211]. □

CASE STUDY: **Landfill in Morocco**

Biological leachate treatment – the Oum Azza waste utilisation centre

Background

In Oum Azza, Morocco, TEODEM, a subsidiary of Groupe Pizzorno Environnement, operates the largest waste recycling centre in North Africa. The plant receives about 850,000 tonnes of waste per year from 13 municipalities in the Rabat-Salé-Skhirat region.

Special challenge/problem

With the introduction of a modern waste management model, major steps have been taken in this region to protect people and the environment. Waste is collected and systematically used for materials recycling and energy recovery. Special importance is attached to the treatment of landfill leachate, which is produced during waste storage primarily by rainwater seepage and the inherent moisture of the waste. If leachate reaches water bodies untreated, it poses a threat to the environment.

In Oum Azza, approximately 280 to 300 m³ of leachate is produced daily and has to be thoroughly purified. The leachate treatment plant in Oum Azza consists of a screen, an aerated pond, an anoxic settling pond and a downstream reverse osmosis system.

Solution

Biological leachate treatment can be an efficient and robust technological removal method if reliable plant operation is ensured by continuous monitoring of influent and effluent quality. Surface aerators (three aerators of 75.0 kW each) were originally

Figure 1: Conversion to OxyStar aerators at the Oum Azza leachate treatment plant, Morocco

used to aerate the pond at Oum Azza, but they did not prove successful due to their inadequate aeration and mixing performance and high maintenance and energy consumption requirements. Using this aeration system, a reduction of approximately 40% of the daily BOD5 load of approximately 3,000 kg BOD5 was achieved. Due to the heavy aerosol formation of the surface aerators, there was also a strong odour nuisance. These operating problems prompted the operator to replace the existing aeration system with FUCHS OxyStar aerators. Four floating OxyStar aerators with a rated output of 22.0 kW each were installed (Figure 1).

Results

The four aerators, with a total power of only 88.0 kW, are sufficient for introducing all the oxygen required without the formation of aerosols and for mixing the pond contents effectively. The aerators were installed on robust floats to adapt to the fluctuating water levels (Figure 2). Within just a short period after commissioning, an approximately 70% reduction of the BOD5 load was confirmed by the plant operator. Electricity consumption was significantly reduced (Table 1).

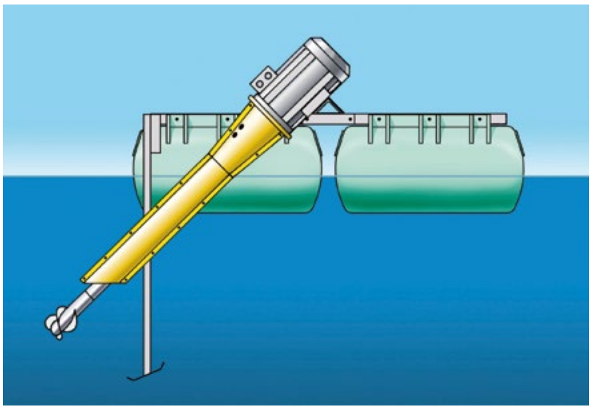


Figure 2: Schematic representation of the OxyStar aerator

Contribution of the technology provided

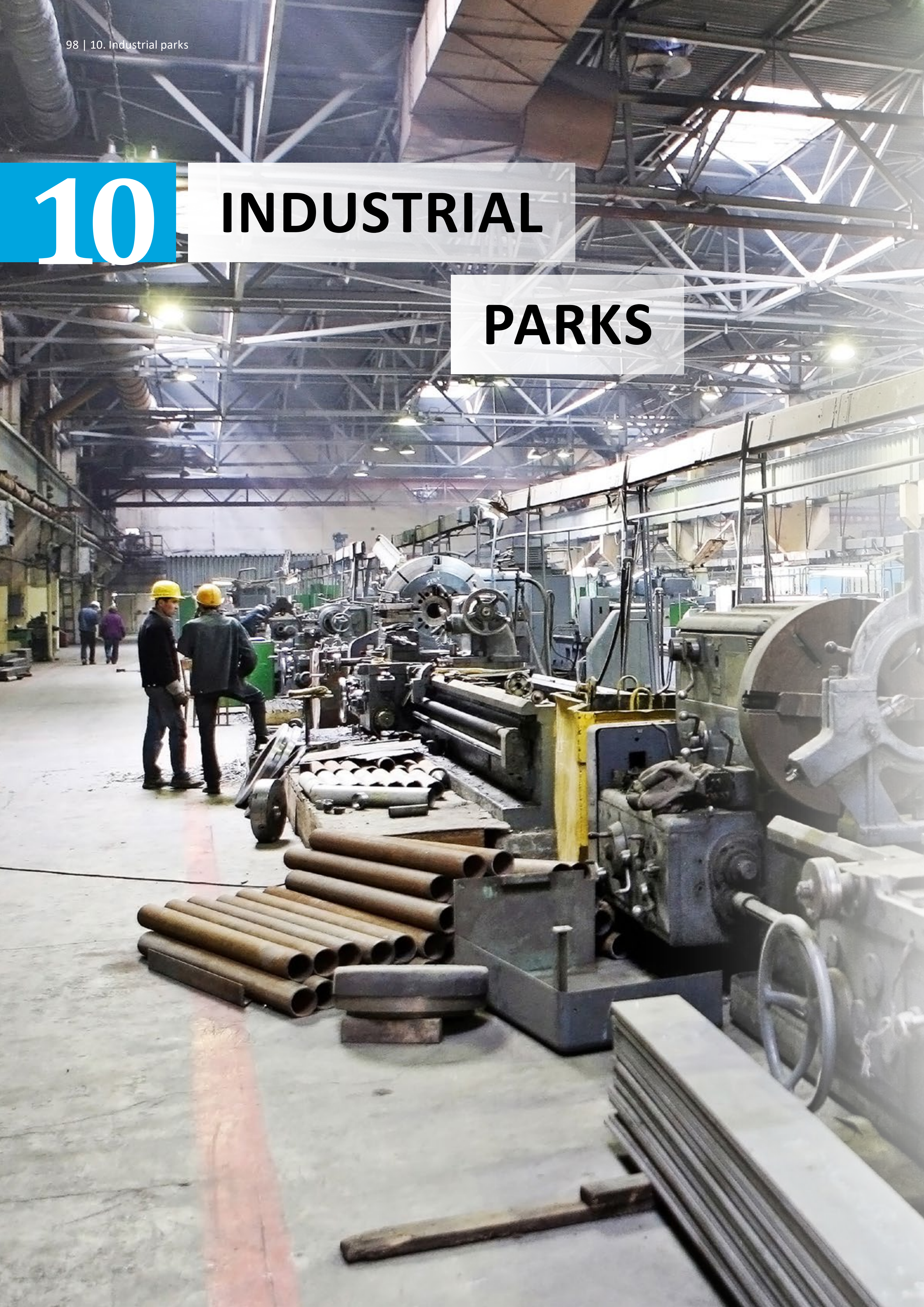
Compared to the previous solution, the supplied aeration device enables a very energy-efficient mixing of the treatment pond, thereby improving the cleaning performance (Table 1). Moreover, due to the functional principle underlying the self-priming aerators, no aerosol formation occurs. The retrofit was carried out without interrupting operations, and it was not necessary to empty the basin. □

Structure of the plant	**- Screen** **- Aerated pond** **- Settling pond** **- Reverse osmosis**
Wastewater inflow	280–300 m³/day
Pollution load BOD5	3,000 kg/day
Volume of aerated pond	approx. 7,000 m³
Resulting volumetric load	430 g BOD5/m³/day
Installed aeration equipment	4 OxyStar aerators on floats
Nominal power	22.0 kW each
Total installed capacity	88.0 kW
Power density	approx. 12.5 W/m³
BOD5 degradation rate	approx. 70%
Electricity savings compared to the previous model	approx. 60%

Table 1: Summary of leachate treatment in Oum Azza, Morocco

10

INDUSTRIAL PARKS



Country-specific information

India

Since the 2000s, there has been an increase in the construction and expansion of industrial parks in India in order to meet the country's growing production capacities. This is mainly due to the high proportion of small and medium-sized enterprises within the chemical, textile, automotive, IT and electronics industries. The total number of industrial parks and their distribution are not centrally recorded at a national level, but current estimates indicate that the states of Maharashtra, Karnataka, Rajasthan and Gujarat have the highest number of parks (Figure 1) [212]

It is estimated that around 10–15% of Indian industrial estates have a common effluent treatment plant (CETP) [213]. These plants are most common in centres of the tanning, textile, chemical and electroplating industries. Typical plant capacities range from less than 1,000 m³/day to 30,000 m³/day [3]. The increasing development and expansion of industrial parks over the coming years will also increase the number of industrial effluent treatment plants.

This is a market that has traditionally been limited to Indian companies but is now opening up to international technology providers. The Indian government provides up to 50% of the investment funds for such plants, with up to 25% additionally provided by the local state government. The government's funding plan was originally for five years and was completed in 2018. However, new plans are in place to maintain the funding. Approval from the relevant regulatory authorities in the region is required for the establishment and operation of shared wastewater treatment facilities. A good overview on the use of CETPs, the legal background and the technologies used can be found in the Indo-German Environment Partnership report [214].

Furthermore, the introduction of special 'Green Tribunal Courts' is likely to strengthen the enforcement of environment-related regulations [215]. Due to changes in Indian legislation and liability regulations, the requirements for technical environmental protection at industrial effluent treatment plants have become more stringent. Site maintenance contracts have also increased from one year after commissioning to 15 years, leading to increased interest in durable technologies in particular.

MENA

Targeted support is currently being given to the development and expansion of industrial parks in all countries in the MENA region with the aim of increasing national economic competitiveness, creating jobs and improving productivity and environmental protection. This is being implemented by means of targeted policy programmes – such as the Industrial Acceleration Plan in Morocco – which provide national planning and financial support for the establishment of industrial parks. In Egypt, for example, 13 new industrial parks are under construction, while in Morocco calls for tender were issued for the planning and implementation of three more industrial parks in early 2020. Most projects nowadays are awarded as public-private partnership contracts [216].

In Egypt and Morocco, more and more 'eco-industrial parks' are being planned, with the aim of achieving both economic and environmental added value through the targeted use of synergies. In these parks, the provision of energy and water as well as the disposal of waste and wastewater is centrally organised and, as a result, optimised. Existing industrial parks are also being retrofitted with the appropriate infrastructure to meet stricter environmental protection requirements [217, 218]. In Tunisia, the need for retrofitting with wastewater treatment facilities seems particularly urgent since, in 2014 for example, only about 25% of industrial parks there were connected to a sewage system [219].

Infrastructure and wastewater management

Industrial parks are defined as demarcated industrial sites in which several independent manufacturing companies operate. While the concept has been used in the chemical industry for many decades, nowadays companies from different industrial sectors are also often brought together in industrial parks. The advantage of industrial parks is that the companies located there can be linked to each other through common value chains and have access to shared site infrastructure. This is usually provided by an operating company, which is often also the owner of the industrial park. The operating company's services usually include the following aspects:

- Mobility and infrastructure
- Road and rail access and/or commercial port, as well as mobility on the site
- Energy and media
- Primary energy (e.g. natural gas), but also other media such as technical gases, water of various quality levels, steam or refrigerants
- Waste disposal
- Proper disposal of commercial waste and toxic industrial waste, as well as wastewater disposal and treatment
- Management of central facilities
- Information and telecommunications technology, as well as plant fire brigade and plant security, depending on the size of the industrial park
- Logistics
- Management of hazardous goods transportation and storage of raw materials, consumables and supplies, finished products, etc.

Central wastewater treatment of all wastewater collected from the industrial estate in a shared cleaning plant can increase the efficiency of the cleaning process and significantly reduce capital and operating costs for the individual companies. At the same time, where conditions are favourable, there may be opportunities for local reuse or recycling of water or recovery and use of resources (such as nutrients and recyclables). For the responsible regulatory authorities, the centralised discharge of industrial wastewater increases transparency and simplifies the implementation of quality controls.

Special challenges

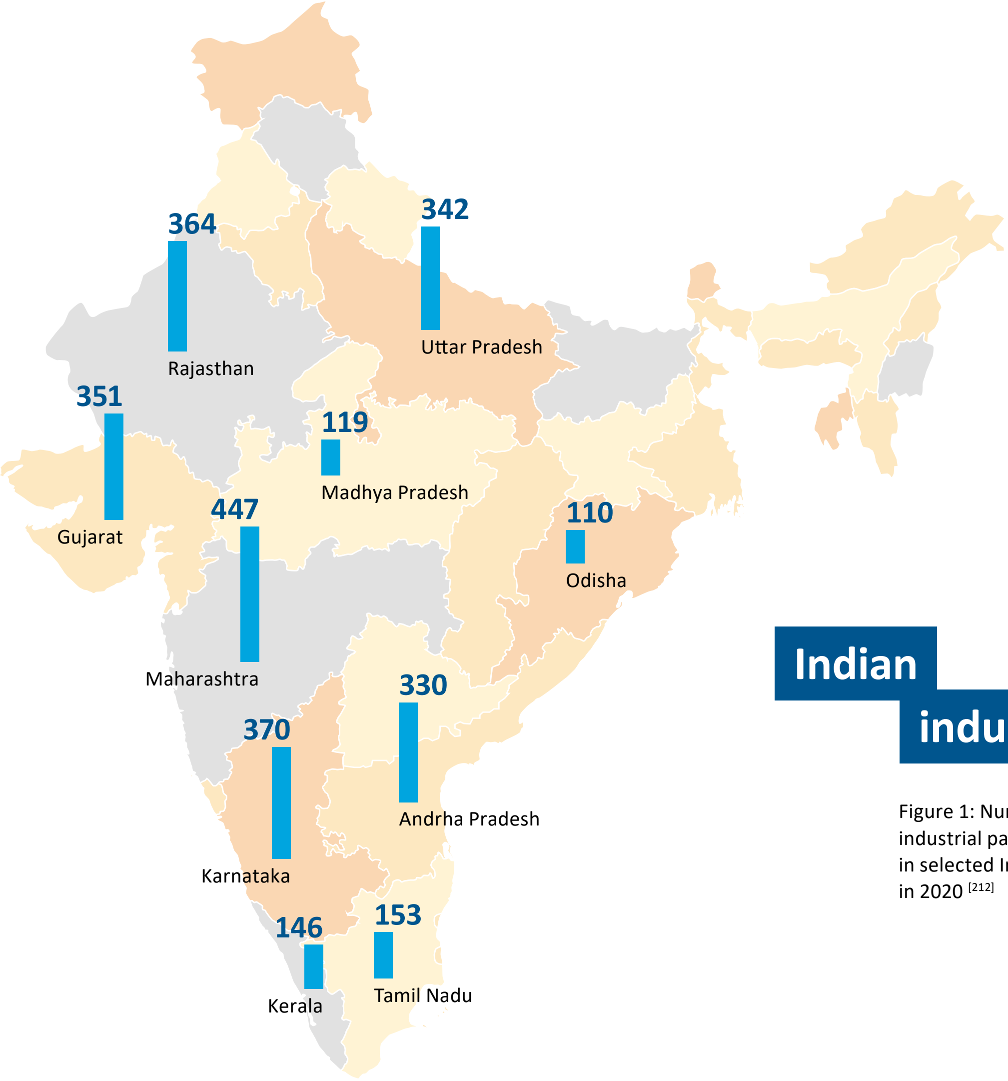
Heterogeneous wastewater streams

The wastewater streams generated by individual companies can differ significantly, and the complexity of the wastewater composition increases with the heterogeneity of the industries and uses located there. While some industries mainly generate organically polluted wastewater, in other cases the focus is on inorganic pollution. Biodegradability or compatibility of the pollutant load discharged is of particular importance, so as not to jeopardise the operation of a central biological cleaning stage. Wastewater with potentially toxic effects on the biology has to be retained and pre-treated on a decentralised basis.

To ensure long-term stable operation of the wastewater treatment plant, the discharged wastewater streams must meet certain conditions, most of which are contractually agreed. The wastewater of each individual discharger should therefore be monitored accordingly in real time before it is blended with the central wastewater network. In addition to the flow rate, the metrics to be recorded usually include quality parameters such as the pH value, COD, DOC (dissolved organic carbon) and conductivity as well as other specific parameters (e.g. heavy metals, organochlorine compounds, phenols, other toxic substances). If deviations from the permissible wastewater quality are detected unexpectedly, the discharge of wastewater can be stopped in good time and the problematic wastewater temporarily stored in equalisation tanks so that it can be treated separately. In this way, for example, the central biological cleaning stage can be protected from toxic shocks.

Common or separate treatment

In principle, separate treatment of wastewater streams is the preferred option, as individual



Indian industrial parks

Figure 1: Number of industrial parks recorded in selected Indian states in 2020 [212]

contaminants can be treated specifically, and mixing and dilution can be avoided. In practice, however, different wastewater streams are sometimes blended in order to feed wastewater with low biodegradability to the biological stage without further pre-treatment by mixing it with loads offering good biodegradability. Wastewater streams with opposing properties can also mutually offset each other when blended, for instance if they have different pH values or temperature levels.

On the other hand, it makes sense to discharge and if necessary treat weakly contaminated wastewater streams separately. This applies, for instance, to very slightly polluted water such as precipitation water or cooling water, which can normally be discharged or used without complex treatment. Wastewater from the industrial park's sanitation facilities should always be collected and treated separately from industrial wastewater. Feeding municipal wastewater into treatment plants on industrial parks can also be appropriate if geographical proximity allows this. If individual water streams are excessively polluted, it is considered state of the art to pre-treat them separately before mixing. The capacity of the treatment process, which is necessary in any case, can thereby be significantly reduced compared to a centralised system; at the same time, the process becomes more efficient. This applies to the following cases in particular [221]:

- The wastewater contains contaminants that have a negative influence on the subsequent treatment, e.g. substances that have a toxic or inhibiting effect at the biological stage.
- The wastewater contains substances that are difficult to remove in subsequent treatment, e.g. non-biodegradable constituents or heavy metals.
- The wastewater is of such high quality that it can be reused for cooling purposes, for example for watering green areas or as fire-fighting water.
- The wastewater contains constituents that need to be recovered specifically for reuse or recycling, e.g. nutrients, valuable substances or a high load of readily degradable substances to produce biogas.
- Suitable discharge parameters have to be defined and monitored for discharge into a central industrial wastewater treatment plant. The combined treatment of wastewater streams that are each difficult to treat – such as wastewater from the chemical industry with wastewater from the paper industry – does not make sense without suitable pre-treatment.

Treatment processes

Process selection and stages

In most cases, the central wastewater treatment plant of an industrial park provides for generous equalisation tanks to buffer concentration and volume fluctuations in the plant feed. Before the industrial effluents are discharged into the treatment plant, relevant parameters should be monitored regularly. These include [22]:

- General parameters, e.g. temperature, pH and solids
- Inorganic substances, e.g. nitrogen, phosphorus and sulphate
- Metals, e.g. lead, cadmium, chromium, nickel, copper and mercury
- Organic substance parameters, e.g. low-volatile lipophilic substances or hydrocarbon index
- AOX, as a measure of organic halogen compounds
- Effective toxicity, e.g. to fish eggs

The common industrial effluent treatment plant provides for a treatment process consisting of at least one biological stage, but mostly of several stages [22]:

- Mechanical wastewater pre-treatment
- Separation of immiscible solids and oils by phase separation, e.g. in the form of coarse filtration, sedimentation or flotation
- Chemical cleaning

Intended use	Solids	Solutes	Turbidity	pH	BOD5	Chlorine
Irrigation	5–35 mg/l	500–1,000 mg/l		6–9	5–45 mg/l	0.5–5 mg/l
Street cleaning		1,500 mg/l	30 NTU	6–9	15	0.2 mg/l
Cooling water	30 mg/l				30 mg/l	1 mg/l
Toilet flushing		1,500 mg/l	30 NTU	6–9	10	0.2 mg/l
Boiler feed water	10-500 mg/l	1,000 mg/l				

Table 1: Guideline values of required water qualities for specific reuse purposes [222, 223]

- Removal of dissolved substances, such as salts or metals, by precipitation and flocculation processes, possibly accompanied by neutralisation of the wastewater
- Biological cleaning
- Degradation of nutrients and organic contaminants by anaerobic and/or aerobic biological processes
- Further treatment
- Removal of dissolved contaminants that are difficult to remove by advanced processes, e.g. oxidation, adsorption, ion exchange or membrane filtration

The specific set of advanced treatment processes selected will depend heavily on the discharging plants and the resulting wastewater quality. The desired effluent quality is also relevant – depending on the conditions of discharge into surface waters or the intended further use of the treated wastewater.

Reuse and further use

The efficient reuse or further use of treated wastewater relies on the targeted collection and separate treatment of different water streams as well as knowledge about their composition. This may require an appropriately planned wastewater and water network on the industrial park site – something that is much easier to implement in new developments than in conversions or extensions of existing parks. The targeted treatment of separate streams needs to be considered in relation to both the intended use of the treated water and the origin of the wastewater.

Treated wastewater is often used for infrastructural applications such as irrigation, street cleaning or toilet flushing. More production-related options include use as cooling water, boiler feed water or process water. The intended water use and the associated quality requirements have a direct impact on the treatment scheme required (Table 1). Wastewater that contains discharges from healthcare facilities and industrial wastewater with high pollutant loads (e.g. from electroplating or textile processing) are not suitable for reuse without specific treatment.

Site-specific quality specifications should be based on a precautionary, risk-based approach in which potential hazards in the planned water reuse scheme are analysed and efficient measures – from the source to the exposure stage – are identified. It is important to carry out a risk assessment that considers both the wastewater-borne pollutants and all relevant exposure pathways in order to identify which groups of people and which protected assets (soil, groundwater, plants) could potentially come into contact with the treated water.

A systematic approach can be based on the procedures set down in the Water Safety Plans or Sanitation Safety Plans of the World Health Organisation (WHO). Using this methodology, potential hazards in the system can be analysed, the associated risk assessed, measures for controlling them identified and appropriate monitoring criteria defined. This will ensure that the success of the risk minimisation measures can also be regularly verified. For efficient and reliable risk reduction, multiple barriers are needed at different starting points in the overall system, including the catchment area, water treatment process, water storage and distribution facilities, and application practices. A regional case-by-case assessment of both emission and immission aspects therefore has to be carried out at many points. Only when guarantees are in place that no harm to humans, animals or the environment is to be expected can reuse of treated wastewater be considered.

If no national/regional regulations for water reuse exist, the international standards of the International Organization for Standardization (ISO) can serve as guidance. Under ISO/TC 282, standards for water reuse for agricultural irrigation, urban applications and industrial wastewater have been developed. Detailed recommendations for treatment processes and how to combine them can be found in the thematic volume ‘Non-potable Water Reuse’ updated by the DWA in 2019 [8]. □

CASE STUDY: **Textile industry in India**

Increasing the capacity of treatment based on the use of sequential biological reactors (SBR) at a central wastewater treatment plant

Background

Currently, the common effluent treatment plant (CETP) in Surat, India, treats 100,000 m³/day of wastewater. As the member industries expand their production capacities, both the demand for water and the volume of wastewater are increasing. The effluent treatment plant is therefore being expanded in two phases to meet a water demand of 200,000 m³/day. To conserve natural water resources, the member companies agreed to reuse 100,000 m³/day from the effluent treatment plant. The expansion of the SBR plant from 50,000 m³/day to 80,000 m³/day is being presented, planned and implemented by the company Jäger Umwelt Technik GmbH.

Special challenge/problem

The existing SBR plant is based on the C-Tech process (cyclic activated sludge, developed by SFC Umwelttechnik), which has a biological selector in each of the six basins. The process was designed for BOD5 reduction, nitrification, denitrification and biological phosphorus elimination. For the modernisation of the plant, plans were made for the existing basins to be modified, with the construction of new ones avoided.

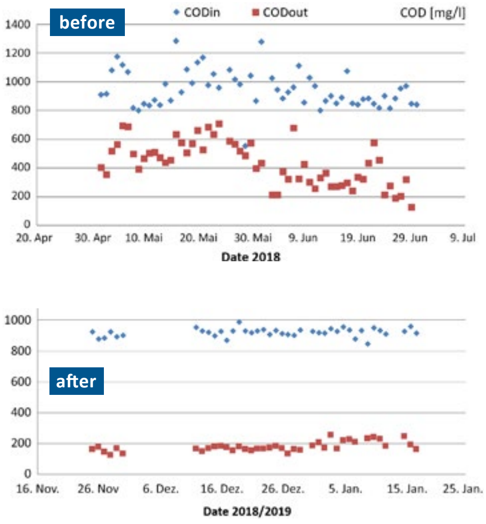


Figure 2: Feed and discharge data of the basin before and after commissioning of the SBR plant with the Biocurlz carrier material

Solution

One concept for expanding the plant without changing its footprint involves filling the existing basins with substrate material in order to increase the biomass density by means of the expanded specific surface area. With suitable feed conditions and reliable monitoring of stable plant operation, this type of biofilm process offers a space-saving and robust option for biological wastewater treatment. The additional sludge mass required, referred to as sessile biomass, is provided by biofilm growth on a textile medium. This additional biomass ensures the performance stability of the plant. The number of specialised bacteria also increases due to the high sludge age of the sessile biomass. This enables substances to be eliminated that typically have low degradability in industrial wastewater. The oxygen concentration and pH value in the system are monitored as standard, while the sludge volume is measured daily.

The textile substrate medium Cleartec Biocurlz, which consists of polyvinylidene chloride (PVDC), was selected for this purpose and permanently installed in stainless steel cages. It has proven to be wastewater-resistant and maintenance-free in many plants worldwide.

Figure 1: One of six SBR basins with Biocurlz cages and fine bubble tube aerators

Results

Since the wastewater constituents contains neither organic nitrogen nor phosphorus, the biological selector of the C-Tech basin is superfluous. The selector zone, which took up about one-fifth of each basin, was instead used as part of the conventional SBR process and increased the overall volume of the plant.

Finally, 360 stainless steel cages with a total length of over two million m of Biocurlz were distributed over six basins. 8,640 fine-bubble JetFlex® tube aerators were installed to ensure efficient aeration (Fig. 1).

The sludge volume index (SVI) of this process of <120 ml/g denotes excellent settleability of the sludge, which benefits the downstream ultrafiltration plant. Overall, the downstream treatment consists of flotation, disc filtration, ultrafiltration and reverse osmosis.

Fig. 2a) shows measurement data between May and July 2018, shortly before the expansion measures were initiated. On average, the COD concentration in the SBR feed is 950 mg/l, compared to a concentration in the effluent of 430 mg/l. This equates to a decomposition rate of around 55%. Fig. 2b) shows measurement data between November 2018 and January 2019, after the expansion activities were completed. In addition to the SBR plant, the pre-treatment of the wastewater also improved, with the result that the COD fluctuations in the inflow of the SBR plant were significantly reduced. The average COD concentration in the feed of the SBR plant is 920 mg/l, while the combined Cleartec-SBR treatment achieves a reduction of COD to 180 mg/l on average (Table 1). This corresponds to a degradation rate of over 80%.

Contribution of the technology provided

The modernised plant achieves a very good and stable degradation of the wastewater organics with minimal space requirements. The number of specialised bacteria was increased through the installation of carrier material. These remove substances that otherwise have low biodegradability, resulting to a significant reduction in effluent concentrations. Downstream treatment stages also benefit from the improved settleability of the biological sludge. □

Parameter	Feed	Discharge
pH	6.5–8.5	7.5–7.8
COD [mg/l]	950–1,400	140–230
BOD5 [mg/l]	300–500	-
Solids [mg/l]	300	40–60

Table 1: Overview of feed and discharge values for wastewater treatment

CASE STUDY: **Wastewater treatment in industrial areas in Morocco**

Turnkey construction of the ‘Nouaceur Industrial Zone’ wastewater treatment plant in Casablanca

Background

The government of the Kingdom of Morocco has decided to upgrade the wastewater treatment facilities at the country’s industrial zones to comply with the new discharge regulations. This decision takes into account the national and regional trend to build stand-alone industrial wastewater treatment plants for the purpose of reusing the treated wastewater and/or discharging it into a receiving water body in an environmentally sound way. The policy pursued by the government is aimed at equipping existing industrial areas with specific wastewater treatment plants adapted to the particular industrial park involved. These plants will contribute to environmentally sound wastewater treatment while at the same time relieving the burden on the municipal drainage infrastructure.

Parameter	Unit	System feed	System discharge
Medium inflow	m³/day	2,000	-
Max. Inflow pre-treatment	m³/h	400	-
Max. Inflow biological treatment	m³/h	200	-
BOD5	mg/l	400	≤ 25
COD	mg/l	1,200	≤ 120
DS	mg/l	600	≤ 20
N total	mg/l	200	≤ 15
N-Kjeldahl	mg/l	150	≤ 8
P total	mg/l	30	≤ 2

Table 1: Design parameters and the effluent values to be achieved for the treated wastewater of the ‘Nouaceur Industrial Zone’ wastewater treatment plant, Morocco

The location of the ‘Nouaceur Industrial Zone’ wastewater treatment plant project is in the Casablanca region, within the 285-ha SAPINO industrial park. More than 400 companies from a very wide range of sectors are located here. Industries represented include the manufacture of glass fibre-reinforced plastic pipes, packaging production, the food industry, the manufacture of aluminium cans, battery production, large-scale laundries, metal processing, detergent production and service providers and trading companies.

The project sponsor is the Moroccan Ministry of Industry, Trade and Green and Digital Economy (MICEVN). It has entrusted the project to LYDEC, the company responsible for drinking water supply, sewerage, electricity distribution and public lighting in the Casablanca region. The contractor is a consortium led by PWT Wasser- und Abwassertechnik GmbH.

Particular challenge

Industries are required to pre-treat wastewater locally; this pre-treatment can involve both mechanical and chemical processes. The client LYDEC first carried out a series of measurements. The parameters investigated were those shown in Table 1 along with electrical conductivity. The design parameters for the treatment plant were determined in consideration of a possible expansion and/or change in the population of the area. Furthermore, consideration was given to ensuring that peak inflows can be handled. The concept developed and implemented by the PWT includes a buffer basin necessary for equalising peak inflows and for the intermediate storage of contaminated wastewater. It also provides for the possibility of future expansion.

Solution

The Nouaceur treatment plant is an activated sludge plant involving aerobic and simultaneous sludge stabilisation in recirculation basins. The wastewater treatment consists of mechanical pre-treatment (coarse screen upstream of the lift station, fine screen and aerated grit and grease trap), a buffer tank to accommodate peak flows or contaminated wastewater, biological treatment by means of simultaneous denitrification and secondary sedimentation, chemical phosphorus elimination, and disinfection with sodium hypochlorite prior to discharge into the Oued Merikane. The expansion of the plant is currently under consideration. This would include a further cleaning stage involving sand filtration and UV disinfection so that water can be reused for irrigating green areas.

Sludge treatment includes mechanical dewatering of the sludge using centrifuges along with conditioning and sanitisation by the addition of lime, prior to disposal at the municipal landfill site. Due to the location of the treatment plant in a densely populated area, the facilities concerned are equipped with modern odour treatment and noise reduction equipment. Table 1 lists the design parameters and the effluent values to be achieved for the treated wastewater.

Technical measures to deal with unpredictable fluctuations

In this context, the following points should be noted:

- The chosen treatment process, involving a buffer tank for peak inflows or for contaminated wastewater, provides a certain degree of flexibility in cases where the quantity/quality of the wastewater is difficult to predict.
- The solution provides for the installation of corrosion-resistant materials, as higher salinity levels may occur in the wastewater due to the proximity of the project site to the sea.
- Hydrocarbon measurement and pH and conductivity measurements are installed in the feed area of the treatment plant so that any unusual wastewater can be identified and directed to the buffer tank. Depending on the results of the analysis of the stored water, it can then be sent for treatment or disposed of in accordance with environmental regulations.

Results

Construction of the wastewater treatment plant at the Nouaceur Industrial Zone is currently underway. Fig. 1 shows the aeration tanks constructed.

Contribution of the technology provided

The plant installed on the site incorporates complete mechanical, biological and chemical wastewater treatment. Special attention was paid to the specific requirements of an industrial wastewater treatment plant receiving water from a very wide range of sources, e.g. high plant flexibility and safety, as well as appropriate metrological monitoring of plant operation. □

Figure 1: Aeration basins under construction at the industrial wastewater treatment plant in Nouaceur, Morocco

11

FUTURE TRENDS

IN INTERNATIONAL INDUSTRIAL WASTEWATER TREATMENT


Gas flare
Sludge silo
Heating 1
Heating 2
Heating
0.00
0.00
0.00
Digestion containe

The increasing scarcity of resources and the growing relevance of environmental protection pose special challenges for industrial wastewater treatment in the 21st century. Despite regional differences in political, geographical and socio-economic conditions, some overarching developments can be identified in the treatment of industrial wastewater. Best available technology (BAT) codes of practice, which document the state of the art for environmentally friendly and resource-saving plant operation across all relevant industrial sectors, can also serve as a basis for formulating recommendations for the future [224].

Industrial wastewater treatment

Depending on the general conditions and the contaminants involved, industrial wastewater streams can either be discharged into surface waters without pre-treatment, fed into the municipal wastewater network or (pre-)treated at industrial wastewater treatment plants. Under certain conditions, synergies (for example, regarding the availability of nutrients) can be exploited through the joint treatment of industrial and municipal wastewater. In most cases, however, separate wastewater treatment is preferable, especially if (industry-related) minimum requirements for wastewater quality have to be met. In industrial plants, wastewater flows of variable quality often occur over time and may contain persistent or environmentally hazardous substances. The associated challenges can only be overcome by means of site-specific, specially designed industrial wastewater treatment systems [22].

There is an increasing trend towards the construction of common effluent treatment plants (CETPs), which enable efficient and robust wastewater treatment with minimal cost and effort for the individual discharging industrial plants. Because such plants often have to deal with a complex and variable mix of different wastewater streams, close cooperation with the industrial dischargers is essential in addition to the ability to operate plants flexibly. In most cases, it is appropriate and necessary to pre-treat individual wastewater streams prior to discharge into the central industrial treatment plant, taking into account the composition of each stream, and to have this treatment monitored by the plant operator [221].

Water efficiency at the plant level

Especially in regions where water is scarce – but increasingly also beyond such areas – improving water efficiency is a priority for many production sites. This is often driven by both a socio-ecological motivation and a wish to reduce the costs associated with fresh water, energy and wastewater disposal. The definition of the ‘state of the art’ also reflects the economical use of water in industry.

The most important basis for improving water efficiency is the reuse and recycling of process (waste) water. Depending on the available and required water quality, water flows can be recycled on a process-internal basis, with or without internal pre-treatment, reused close to the production site, or reused for other applications (e.g. irrigation of green areas or as fire-fighting water). Water recovery usually involves relatively costly treatment processes and is a sensible option under the following conditions in particular [22]:

- if it can reduce the demand for fresh water or energy
- if separated materials can be recycled or reused in an ecologically, economically and technically worthwhile manner
- if the reduction in the volume of wastewater reduces pollutants in the downstream treatment stage or does so directly in the aquatic environment

Completely wastewater-free operation (‘zero liquid discharge’) can be achieved by combining wastewater-free production processes (e.g. dry coating) with optimised water recovery within the plant. Wastewater-free processes typically follow the principle of maximum concentration (e.g. reverse osmosis, evaporation or crystallisation). These are sophisticated technologies that are usually associated with increased energy consumption and correspondingly high treatment costs [225]. These costs are, however, reduced accordingly if the wastewater has already been extensively treated beforehand.

Nonetheless, a high degree of water efficiency cannot be achieved solely by means of downstream wastewater treatment and recovery measures. Instead, process-integrated approaches that take into account different resource flows (e.g. fresh

water, wastewater, raw materials and energy) and cross-media aspects are now becoming increasingly important. The current state of the art involves, for example, optimised cleaning processes (on-site cleaning, i.e. ‘cleaning in place’ or CIP systems) to minimise product losses, the amount of freshwater needed and the use of chemicals, along with appropriate separation of wastewater streams and contamination levels. At the organisational level, the optimised planning of product and cleaning sequences, quantitative process balancing and control, and regular staff training can help to reduce wastewater pollution [226, 227].

Water management in the future

In addition to a quality and energy management system, most companies today also have an environmental management system in place to support the systematic implementation of environmental protection measures. In addition to setting up and operating the necessary wastewater treatment plants, corporate environmental management also covers the associated quality control aspects, such as compliance with discharge limits, and risk assessment, for example in the event of accidental emissions. A fundamental prerequisite for efficient (waste) water management consists of recording volumetric flow rates and parameters for all relevant water flows at the site (e.g. pH value, temperature, COD). Nowadays, this is usually done using online sensors, which inherently enable a certain degree of process automation [224, 228].

Advances in sensor technology, IT interfaces and data processing will enable further interconnections and process efficiency improvements in the future. In the medium term, digitisation will help to optimise industrial wastewater systems partly in the following ways:

- Availability of high-resolution process data thanks to online sensor technology
- Intelligent network control and automation of control centres
- Expansion of analytical capabilities by means of big data and/or smart data
- Coupling with environmental data such as climate, water availability, heat loads
- Predictive strategies for plant operation and condition monitoring
- Automation of early warning and decision-making processes

The widespread implementation of digital approaches will depend on the degree to which stringent IT security and data protection requirements can be fulfilled and which particular standardised data transmission interfaces will prevail [229, 230]. □

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