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Sustainable Wastewater Management in Industrial Laundries

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A rapid rise of global population has led to the intensive production of laundry wastewater. Industrial laundries release effluents in large volumes containing many contaminants, which causes the effluent to be loaded with suspended solids while displaying variable chemical and physical values. In consequence, the laundry wastewater has highly toxic properties and imposes negative impacts on the environment, such as water bodies pollution and eutrophication. On average, the laundry business uses around 15 L of freshwater to process 1 kg of linen. A conventional laundry with the capacity of 10 t linen/d produces a total amount of 150 m^3 of wastewater daily. Due to the rising amount of discharge effluent, the adequate wastewater treatment is necessary in order to minimize the environmental impact.
This review begins with an assessment of the amounts and chemical composition of laundry effluents, which varies depending on the location. Then it evaluates the available treatment technologies. Understanding of the basic treatment methods is fundamental for the development of an effective treatment system, that would typically consist of multi-processes (physicochemical, biological, or combination of both). Such systems would ideally treat, purify, and recover water and valuable substances from the detergent. The outcome of this review is a general overview and evaluation of available recovery technologies for laundry wastewater treatment and recommendations for their further development.

1. Introduction

The need for wastewater recycling becomes highly essential mainly due to the depletion of water reserves along with high water consumption associated with the rapid population growth, urbanization, and industrialization. Wastewater management and treatment is one of the biggest challenges for the circular economy as many industries depend on water and to prevent contamination of the environment (Smol et al., 2020). Different types of wastewater such as municipal, hospital, petroleum and laundry wastewaters are produced in industrial or urban areas. Many researches have been focusing on water recovery from these water sources, and on reuse of wastewater from industrial laundries. Industrial laundry wastewater accounts for about 10 % of the total amount of urban wastewater generated (Zoroufchi et al., 2021) and has shown to be one of the promising ways to reduce the water shortage as well as protect the environment (Bilad et al., 2020). However, the effective management of industrial laundry wastewater is not systematically addressed in the literature.
Industrial laundries use water as one of the main inputs and release substantial volumes of wastewater. This effluent is loaded with pollution and is usually insufficiently treated. Therefore, it is essential to treat the laundry wastewater (LWW) to preserve and maintain the quality of water bodies and ecosystem. LWW is typical for high values of total suspended solids, turbidity, electrical conductivity, and total phosphorus.
This review brings a summarized evaluation of LWW, including its composition and consumption. Besides, the available treatment and recovery technologies are evaluated.

2. Methodology

The goal of the methodology is to find relevant articles on the management and treatment of industrial laundries wastewater. The abstract and citation database Scopus is used for the search. In the first step, the used phrases are looked at within titles, abstracts and keywords. Also, the year range is limited to 2017 - 2022 and the

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language is limited to English. The summary of search results for the given keyword phrases can be found in Table 1.

Table 1: Overview or searched articles by the database Scopus from the time period of years 2017 – 2022.

Keyword phrases	Years					
	2017	2018	2019	2020	2021	2022
Laundry Wastewater	32	33	42	56	64	15
Laundry Wastewater AND Wastewater Treatment	24	24	31	47	50	9
Laundry Wastewater AND Wastewater Management	10	6	13	14	15	2
Industrial Laundry Wastewater	6	8	6	9	19	6
Industrial Laundry Wastewater AND Wastewater Treatment	5	6	5	8	17	4
Industrial Laundry Wastewater AND Wastewater Management	2	2	0	1	6	3

The search key generated 45 articles on industrial laundry wastewater treatment and 14 on wastewater management. After searching through the abstracts and excluding the studies dealing exclusively with industrial laundry wastewater, relevant articles have been selected with focus on:

- trends in water consumption and production
- composition of industrial laundries effluent
- wastewater treatment technologies and management.

The results of a detailed analysis of final 20 articles are presented in the following chapter.

3. Results and Discussion

The industrial laundry process differs from that in households mainly in the amount of linen processed, as well as in the consumption of water, energy and chemicals. The consumptions are related to the machines used, the speed of linen processing, the types of linen, and the prescribed procedures for laundry process depending on the contracts with customers. According to the origin of the linen, industrial laundries can be divided into categories such as hotel, restaurant, and hospital laundries, and according to the capacity into low (>3,000 kg/shift), medium (3,000 - 5,000 kg/shift) or high-capacity laundry (over 5,000 kg/shift). The washing process consists of the following steps: flushing, pre-washing, main washing, rinsing, finalizing, and water extraction (Máša et al., 2013). It can also include bleaching, bluing, and starching, alongside other specialized processes for wool, silk and other fabrics. The wastewater production and its chemical composition may vary depending on the washing technology and applied steps.

Since the laundry industry consists of large-scale plants with significant wastewater production, it appears to be an important and current issue that need to be addressed. Covid pandemic has increased the requirements for laundry sanitation, which is associated with higher energy consumption for water heating or higher consumption of laundry chemicals. Globally, rising energy prices are increasing the cost of laundry services, and overall, the laundry process needs to become more efficient and sustainable. The results from *Table 1* show that the number of studies dealing with LWW is gradually increasing. However, the number of scientific articles dealing with industrial laundries effluent has only been increasing since 2021.

3.1 Laundry wastewater production and future perspective

The professional laundry care industry is an important sector linked to healthcare and tourism, as not all of these establishments have space for their own laundry facilities. The amount of produced industrial LWW mostly depends on the amount and composition of linen and the laundry equipment. The larger the laundry and the newer the technology, the lower the water consumption and wastewater production/kg of linen. For example, large CBWs (continuous batch washing machines) are able to manage water very efficiently, leading to water savings; however, they are only used in medium (3,000−5,000 kg/shift) and high-capacity laundries (over 5,000 kg/shift).

The generation of wastewater in the industrial laundry processes varies from 6 to 25 L/kg of dry linen. However, according to Lutterbeck et al. (2020), hospital laundries require 35 - 40 L/kg of dried linen. Water consumption and industrial LWW production appear to be significant and are expected to increase. The market value of the dry cleaning and laundry industry is approximately $ $70 \cdot 10^9$ (Businesswire, 2019). It is expected to grow at CAGR (compound annual growth rate) of 4 % over the next five years (Globe Newswire, 2020).

3.2 Chemical composition of laundry wastewater

Laundry wastewater (LWW) commonly contains a mixture of substances from laundry detergent and dirt residues. The effluents from industrial laundries possess a complex chemical composition and originate from

the use of soap, soda, and detergent in removing grease, dirt, and starch from soiled linen. The EU, the USA and Japan have introduced regulations on the composition of laundry detergents. Generally, the effluents are alkaline (Ho et al., 2021), highly coloured and have a large organic load (de Santana da Silva et al., 2018).
Chemicals generally found in the LWW are reactive dyes, chlorine, sodium hydroxide, potassium permanganate, enzymes, optical brighteners, humectants, dispersants, surfactants, hydrogen peroxide, softening agents, phosphates, potassium, fats, oils, and greases (de Santana da Silva et al., 2018). Overall, the composition of LWW depends on the washing process and on the origin of the washed linen, especially the concentration range of surfactants in real LWW is very variable (Collivignarelli et al., 2019). For example, in the case of hospitals, the wastewater would have a high concentration of surfactants and organic load (Khan et al., 2022). Releasing the hospital LWW without any treatment poses potential threats to the environment. The water might contain a wide range of pollutants (e.g. pharmaceuticals, chemicals, radioelements, antibiotics and pathogens).
In general, it was found that the most observed characteristics of LWW are COD, BOD_5, pH, turbidity, electrical conductivity, and concentration of anionic surfactants. Both COD and BOD_5 values are required by environmental authorities, as BOD_5/COD ratio is used to evaluate the biodegradability of the wastewater. It was also found that not all the studies quantified the amounts of nitrogen and phosphorus, even though the values of these parameters are legally established for wastewater discharges.

Table 2: Range of values of the characteristic parameters of raw wastewater from industrial laundries.

Country	pH [-]	COD [mg/L]	BOD_5 [mg/L]	N_{total} [mg/L]	P_{total} [mg/L]	MBAS [mg/L]	TSS [mg/L]	EC [µS/cm]	Turbidity [NTU]	References
PL	8.2	631−768	370−390	10−11	4.0−4.7	8.9−21.1	/	/	/	Mozia et al., 2020
PL	7.9−9.0	727−944	335−542	6.7−12.7	1.9−5.4	5.7−11.8	56−230	2,009−5,747	/	Bering et al., 2018
IT	7.0−9.0	400−1,000	/	/		1−15	90−200	1,300−3,000	40−150	Ciabattia et al., 2009
USA	12.5	1,138	/	/	22	/	359	724	858	Kim et al., 2014
CA	7.5−8.5	686−1,088	190−210	/	/	44−59	/	1,800−2,300	/	Zoroufchi et al., 2021
BR	10.0−10.9	245−587	58−87	/	/	11.7−19.6	/	278−647	52−64	Nascimento et al., 2019
NA	7.7−9.1	31−884	9−270	5.6−68.6	32−135	/	/	320−1,680	/	Daouda et al., 2021
SA	7.0−10.2	88−648	/	/	0−45.8	/	/	360−2,200	/	Daouda et al., 2021
CN	7.4−10.0	456−574	/	/	/	/	/	320−1,753	97−179	Hu et al., 2021

COD: Chemical Oxygen Demand; BOD_5: Biological Oxygen Demand; MBAS: anionic surfactant; TSS: Total Suspended Solids; EC: Electrical Conductivity.

The composition of LWW varies throughout the world and continents, also depending on the origin of washed linen. The results from Table 2 show that the effluent from laundries washing the hotel linen showed a higher electrical conductivity (Bering et al., 2018), washing different types of uniforms leaves the water more alkaline and coloured (Kim et al., 2014). It can be seen that European regulations on phosphorus have resulted in lower phosphorus concentration than that found, for example, in Africa. It has been reported that the effluent from a laundry washing very dirty items contains mineral oils, heavy metals and dangerous substances and the COD values are in the range of 1,200 − 20,000 mg O_2/L. The LWW from hospitals containing blood and urine have COD 600 − 2,500 mg/L, and industrial laundries washing the linen from hotels have COD 400 - 1,200 mg/L (Šostar-Turk et al., 2005). Unfortunately, many studies do not specify the type of washed linen, especially the studies reporting higher surfactant concentrations. The discharge of anionic surfactants into the wastewater is responsible for a high organic pollution load, high total suspended solids, conductivity, apparent colour, turbidity, alkalinity, and phosphate content (Kitte et al., 2019). The industrial LWW is rich in various chemicals; it is unfortunate, that the studies do not focus on the recovery of secondary raw materials, as such a solution would be very beneficial.
The industrial laundry effluent is highly influenced by the ingredients of the detergent used. A typical composition of a laundry detergent is as follows: anionic and non-ionic surfactants, softener (e.g. phosphates, zeolites), bleaching agents, enzymes, redeposition and discolouration inhibitors, foam regulators, optical brighteners, floating agents and fragrances (Koohsaryan et al., 2020). The main ingredient, surfactants, are organic compounds whose purpose is to lower the surface tension. Typical surfactants used in laundry detergents are

linear alkylbenzene sulfonates, dodecyl sulphates and sulfonates, olefin sulfonates, alkyl amides, polyoxyethylene ether sulfates (Rame et al., 2021). Surfactants are harmful to the environment because they cause foaming in the receiving water bodies and accumulate in the environment due to non-biodegradable nature (Kitte et al., 2019).

In the EU, the surfactants shall comply with biodegradation criteria described in the regulation (EC) No. 648/2004 of the European Parliament and the Council of 31 March 2004 on detergents. This regulation sets the limit for the content of phosphates and other phosphorus compounds in consumer laundry detergents at 0.5 g per recommended dosage for the washing cycle and the biodegradability of surfactants must be at least 60 % within 28 d. Dosing of detergents is automated, which helps to reduce the application of excessive amounts (Bering et al., 2018). Also, according to Máša et al. (2013), the composition of laundry detergent in the European market significantly varies in individual countries.

In Europe, the United States of America and Japan, the use of sodium triphosphate (STPP) as a builder for water softening in detergents has either been stopped or has fallen considerably and is continuing to be reduced. However, in other countries, such as Russian Federation, China, Africa, and Latin America, the use of detergents is generally increasing without a significant tendency to try to minimize the use of STPP. Higher concentrations of released phosphates combined with nitrogen are responsible for deteriorating waterbodies due to eutrophication. In addition, the use of antimicrobial agents on textiles, such as silver nanoparticles, is rising. The Ag leaching into the water during the laundry process and its subsequent discharge into the environment pose ecotoxicological risks, and its recovery also leads to environmental sustainability (Nawaz et al., 2018). In addition, Ag^+ ions could be the competing cation for water softeners and thus impair the effectiveness of the detergent.

3.3 Wastewater treatment technologies

In general, the laundry wastewater treatment system can be categorized into three main processes: physicochemical, biological, and a combination of both. The physicochemical category involves membrane filtration, stripping, evaporation, absorption, adsorption, and electrocoagulation; after these treatments, obtained water can be reused (Ho et al., 2021). Biological methods involve aerobic (e.g. MBBR) and anaerobic processes and biofilters or wetlands. The conventional treatment systems consist of multi-processes for the removal of pollutants to meet the water discharge or reuse specifications (Bilad et al., 2020).

Among the methods for LWW treatment, physicochemical and physicochemical-biological ones are reported as effective in surfactants removal. However, especially in effluents with high surfactants concentration, the operational costs can be quite high due to the need to regenerate adsorbent materials, oxidants costs and the high production of sludge that need to be disposed (Collivignarelli et al., 2019). Membrane microfiltration and ultrafiltration are efficient in reducing COD, turbidity and phosphates (Bilad et al., 2020). Adsorption for LWW is considered as an efficient and economical method even though many factors affect the performance efficiency (e.g. pH value, dosage, ionic strength, coexisting ions, temperature). The most influencing factors are dosage (higher dosage increases the efficiency) and pH (lower pH enhances the absorption). In addition, adsorption coupled with coagulation is an efficient and environmentally friendly method. For example, Kitte et al. (2019) showed a promising performance using jackfruit seed powder as a coagulant with removal efficiency for anionic surfactant (MBAS), turbidity, COD and BOD 91.7 %, 85.1 %, 82.9 % and 77.6 %. Obtained results showed that the coagulation process is very pH sensitive and that this biodegradable coagulant could be an environmental replacement for typical chemical coagulants (e.g. alum and ferric chloride).

Examples of LWW treatment methods and their removal efficiency are shown in *Table 3*. Results showed that the removal efficiency of physicochemical and physicochemical-biological methods could be sufficient for wastewater reuse as an alternative source for rinsing the linen, but not as a source of potable water. Evaporation is surprisingly absent among the methods mentioned; yet, given the availability of waste heat, it could be an effective method. Generally, a single-stage wastewater treatment of laundry effluent is unable to produce high-quality water, which is in line with the permissible limits in most wastewater reuse standards (Ho et al., 2021). Šostar-Turk et al. (2005) suggested using ultrafiltration or reverse osmosis over conventional methods (e.g. precipitation, coagulation, flocculation) as the generated permeate from such system meets the Slovenian regulation limits for reuse. However, membrane fouling is another issue typical for membrane systems. It was reported that frequent chemical washing of the membranes is required for a full-scale implementation to LWW treatments processes (Zoroufchi et al., 2021).

For example, in the study by Collivignarelli et al. (2019), a full-scale treatment system in Italy allowed for the treatment of 245 $m^3 d^{-1}$ of LWW. It was composed of three different stages of treatment in series: a biological, physical and chemical-physical phase. Monitoring the treatment plant for over three months, the system removed the non-ionic surfactant concentration almost totally (95.3 ± 0.8%), and the anionic surfactant removal was 76.7 %. The biological treatment operation costs are lower; however, the reaction time is longer, foaming occurs, and at high surfactant concentrations, the biomass dies and forms a sludge that has to be disposed of.

Table 3: LWW treatment through physicochemical, biological and physicochemical-biological methods.

Treatment type	Method	Removal efficiency [%]					
		COD	BOD	MBAS	N_{total}	P_{total}	Reference
Physicochemical	Combined coagulation, sand adsorption, membrane filtration	98.93	99.23	90.95	98.91	98.54	Šostar-Turk et al., (2005)
Physicochemical	Combined coagulation, flocculation, sedimentation, membrane filtration	68.9	/	71.7	27.1	/	Nascimento et al., 2019
Physicochemical	Combined coagulation, flocculation, ozonation	87.0	/	87.0	/	/	Ciabattia et al., 2009
Physicochemical	Coagulation	82.9	77.6	91.7	/	/	Kitte et al., 2019
Physicochemical-Biological	MBBR	89.0−94.0	95.0−98.0	94.5−99.5	32.0−84.0	55.0−71.0	Bering et al., 2018
Physicochemical-Biological	Combined MBBR, microfiltration, nanofiltration, ozonation	90.0−93.0	95.0−97.0	89.0−99.0	44.0−79.0	40.0−61.0	Mozia et al., 2020
Physicochemical-Biological	Submerged aerobic fixed film reactor coupled with tube settler	75.0	67.0	/	/	67.0	Khan et al., 2022

4. Conclusions and further prospects

Wastewater from industrial laundries (LWW) possesses the potential for recovery and reuse, which is important to save water supply and to significantly improve the environment. As found in the literature, physicochemical methods are often used in LWW treatment. However, their application can often present high operational costs and the generation of hazardous wastes. On the other hand, biological LWW treatment processes were considered feasible and cost-effective for the treatment of surfactants. Nonetheless, these methods suffer from insufficient quality of treated wastewater for reuse in the laundry process when used as standalone systems. Therefore, the most sufficient treatment method seems to be the combination of both – physicochemical and biological treatment processes, for example combined MBBR, microfiltration, nanofiltration and ozonation.

The composition and quantity of LWW vary from country to country, and even in the European Union, where different restrictions on the detergents are applied, the composition of laundry detergents varies. Therefore, the selection of treatment type and the method for potential wastewater reuse is a complex issue. Based on these results, it is clear that there is a need to construct a robust device that can handle a variety of operating conditions. The limitations in the use of phosphate-based detergents in combination with up-to-date wastewater treatment have demonstrated great improvements in the waterbodies. However, most of the methods have only been tested on a laboratory scale; therefore, the wastewater from laundries and its treatment possibilities deserves further research.

An effective LWW treatment process should consider the sufficient quality of treated effluent meeting the local regulations and the further research needs to focus on a techno-economical evaluation of such process. To conclude, it will always be necessary to look for a tailor-made solution.

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