Tampere University of Applied Sciences

Wastewater of industrial laundry

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ABSTRACT

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Laundry wastewater contains a high amount of pollutants that lead to negative impacts on the environment. This thesis aimed to study the wastewater management at industrial laundries. Sources, properties together with impacts of laundry wastewater were represented, and consecutively, wastewater treatment technologies were described and discussed. The data was collected from literature.

Industrial laundries generally provide both water washing and dry cleaning services to customers. As water washing is the most commonly applied method, the majority of laundry wastewater is generated from this process. Separated water from dry-cleaning also enter the same wastewater streams of other processes. Typical characteristics of laundry wastewater includes an alkaline nature (pH 9,5-11) and relatively high pollutant parameters such as total suspended solids, biological oxygen demand or total organic carbon. These impurities are originated and characterised by washing chemicals and laundered textiles. The concentration and types of pollutants in laundry wastewater is uncertain and varied case by case. Severe effects of laundry wastewater on the treatment process, receiving water body and human health were indicated.

Most of laundry wastewater is pre-treated on-site before being released to the public sewage system or a wastewater treatment plant. Treatment technologies are selected and operated depending on regional regulation and characteristics of wastewater. Preliminary treatment techniques such as screening, flow equalisation, oil/water separation are employed to eliminate gross pollutants (sand, large particles). More advanced methods are utilised to remove suspended solids, heavy metals and other remaining pollutants, such as dissolved air flotation, ultrafiltration.

Stricter standards, together with the continuous increase in fee of water and discharging wastewater, forced industrial laundries to reuse or recycle processed water, by implementing advanced techniques. However, along with working efficiency, an affordable operation fee is also considered as one of the priorities in the investment of new treatment technologies.

Keywords: industrial laundry, laundry wastewater, wastewater treatment

CONTENTS

GLOSSARY

BOD_5	Biological Oxygen Demand (incubation time of 5 days)
CBWs	Continuous Batch Washers
COD	Chemical Oxygen Demand
DAF	Dissolved Air Flotation
FOG	Fats, Oils and Greases
SS	Suspended Solid
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UF	Ultrafiltration
VOCs	Volatile Organic Compounds
Wes	Washing Extractors
WW	Wastewater
WWTP	Wastewater Treatment Plant
WWTS	Wastewater Treatment System

1 INTRODUCTION

Industrial laundry is one of the industries which have the highest water consumption, and thus, it generates an enormous amount of wastewater. This causes a burden on the public sewage system. An industrial laundry in north-western Poland with the average washing capacity of 65 tons textiles per day, generated nearly 500 m^3 of wastewater daily in 2010 (Bering, Mazur & Tarnowski 2011, 36). Besides that, laundries wastewater contains a high amount of impurities originated from washing chemicals and dirt originated from washed textiles. In addition to a great amount of fats, oils, suspended solids, surfactants, heavy metals and organic solvents might also exist in laundries wastewater (Mozia et al. 2016). These substances potentially pollute the aquatic environment when laundry wastewater is being discharged without proper treatments. Therefore, industrial laundries must focus on their wastewater treatment in order to ensure the quality of treated wastewater and thus prevent the environmental impacts caused by the industry.

Generally, laundry wastewater is either sent to the public sewage system after pre-treatment or adequately treated on-site. The level and methods of in-situ wastewater treatment system vary between laundries as well as regions, because of the differences in regional regulations, washing capacity, wastewater characteristics and financial situation. Accessible wastewater treatment techniques applied in industrial laundries nowadays includes gravity settling, screening, equalisation, dissolved air flotation, and oil separation.

Performing a practical training at an industrial laundry in Viet Nam gave a valuable chance to get a close observation of the industrial laundry operation and its on-site wastewater treatment system. It is interesting to understand how the laundry wastewater is generated and processed. Hence, this thesis was conducted to investigate the generation and treatment of wastewater coming from industrial laundry.

The content of this study focuses on the sources, characteristics, treatment technologies and impacts of wastewater at industrial laundries, comprehensively.

Firstly, the general information of industrial laundry is presented, including different classifications, customers, operations and washing processes. Secondly, the laundry wastewater characteristics are analysed, according to its quantity and quality. Followingly, concerns of discharging laundry wastewater and technologies which have been implemented in the on-site wastewater treatment system are introduced. Finally, the impacts of laundry wastewater on the sewage system, treatment plant and environment are indicated. (Figure 1)

FIGURE 1. Content of the study

2 METHODOLOGY

This study is an analysis of published research data focusing on wastewater of industrial laundry. The stages of thesis conducting process are stated in Figure 2. The report is conducted by performing a comprehensive search of books, journal articles, scientific reports and regulations available from online academic resources (Stage 1). References are selected based on the relevant to industrial laundering activities, properties and impacts of laundry wastewater, and desirable treatment practices (Stage 2). Information collection is then used for conducting the literature review and assessing the matters of concerns (Stage 3).

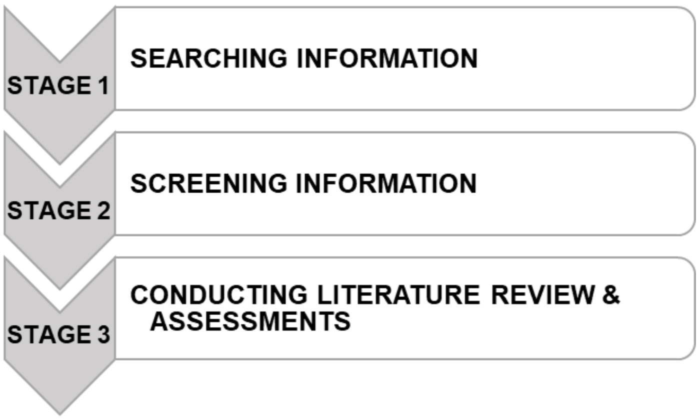

FIGURE 2. Stages of conducting a thesis

Analysis of research data can be seen as the most suitable method for providing either general or meticulous understanding of the industrial laundry wastewater. Assessment and comparison between regional regulations or treatment technologies can be performed thoroughly based on a vast collection of data.

3 INDUSTRIAL LAUNDRY

3.1 Definition, customers and classifications of industrial laundry

Industrial laundry, a service industry has been rapidly growing in the modern society. This industry plays an essential role in other businesses such as hotels, restaurants, hospitals, factories. Due to the demand of regular clean linen or working uniforms supply, many organisations engage the services of industrial laundries, so that they could both ensure the cleaning quality of service textiles as well as save the cost for operation of laundry systems. Laundering textiles at an extensive scale is more efficient in energy and water consumption than compared to the on-site washing.

According to Standard Industrial Classification (SIC 7218), industrial laundries are facilities that primarily operate to provide laundering or dry-cleaning services to other industrial and commercial customers. Textile items might belong to either laundering facilities or customers. It includes, but not limited to: working uniforms, protective apparel, mats and rugs, dust control items, wiping towels and other textiles items. Textile rental companies providing laundering services are also categorised as industrial laundry facilities. (EPA 1989 2000)

Customers of industrial laundries vary from restaurants, hotels, gasoline stations to manufacturing factories. Over 80% of the laundered textile is made up of working uniforms, shop towels, floor mats and mops. The remaining portion consists of items such as restaurant and hotel linens and other different commercial laundering products. (EPA 1989, 8). Based on washing capacity, industrial laundries are classified into low-capacity laundries, large commercial laundries, on-site laundries & laundromats (Table 1).

TABLE 1. Classification of industrial laundries (Swartz et al. 2017, modified)

<table>
<tr><th colspan="2"></th><th>Washing capacity</th><th>Features</th></tr>
<tr><td colspan="2">Low-capacity laundries</td><td>less than 1,5 tons/day</td><td>- Customers mainly are hotels, residences, cafeterias.
- the most common type in Europe</td></tr>
<tr><td colspan="2">Large commercial laundries</td><td>3 - 50 tons/day</td><td>- Using the Continuous Batch Washes (CBWs) system
- Large hospitals belong to this group, but they are specialised to deal with textiles having blood, faeces, pathogens and medicine etc.</td></tr>
<tr><td rowspan="2">On-site laundries</td><td>large scale</td><td>0.5 - 3 tons/day</td><td rowspan="2">- Using Washer-Extractors Wes) system
- These facilities usually own laundered textiles and located as a part of hotels, hospitals, factories or nursing homes.</td></tr>
<tr><td>small scale</td><td>less than 0,5 tons/day</td></tr>
<tr><td colspan="2">Laundromats</td><td>2 - 4 tons/week</td><td>- Using manually or coin-operated WEs
- Owned by public members</td></tr>
</table>

3.2 Operation of industrial laundry

Soiled textiles, after collected from the customer site, go through various stages such as sorting, pre-spotting, main washing, drying and finishing (Figure 3). The sorting step depends on colour, soiled level, ownership, and fabric content of textiles. Sorted textiles then go to the pre-spotting in which a part of dirty marks will be spotted and treated with typical solvents. Textile items, after sorted and pre-spotted, are transferred to the washing machine for the main washing stage. Washed textiles are then dried and conveyed to the last step – finishing, in which cleaned textiles are ironed and folded.

FIGURE 3. The general operation of industrial laundries (Visualisation based on information of ASEAN 2012)

Most industrial laundries provide services of basic laundry (wet cleaning) and dry cleaning. When the textile has an abundant load of both organic-solvent-soluble and water-soluble soil, it will go through the dual-phase process. The dual-phase washing process is a combination of dry cleaning and water washing.

3.2.1 Water washing

Water washing or normal washing is known as the most commonly used procedure in industrial laundries. A survey among industrial laundries conducted by EPA, in 1994, showed that approximately 97% of laundering activities related to water washing processes and more than 80% of interviewed facilities operated entirely in water washing (EPA 2000, 4-12). Water washing is an operation in which soiled textiles goes through washing phases happening in the water, with the adding of detergents and other chemicals (Figure 4). After washing stages, the washed textiles go to an extraction of 5 to 15 minutes to eliminate the retained water. Before being delivered to the customers, dried textiles are moved to final steps for drying, pressing, and folding and if needed, minor repairing and destaining.

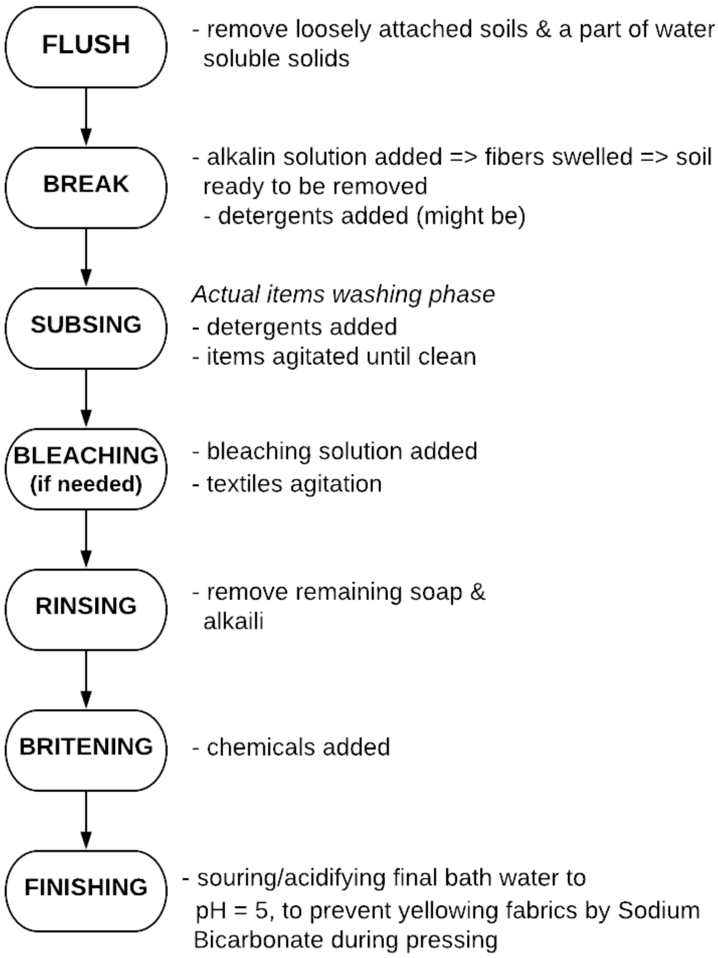

FIGURE 4. General stages of a water-based laundering operation (Visualisation based on information of Preliminary Data Summary for Industrial Laundries 1989)

While small-sized commercial laundries utilise formulated detergents, larger laundering facilities use washing formulas. Typical washing formulas are defined for different categories of linens, based on the soil level and fabric content of textiles. Washing formula decides the duration, number of cycles and added chemicals for each washing stage. Table 2 gives an example of a washing formula applied for heavy-soiled working uniforms.

TABLE 2. A specific washing formula for heavy soil textiles (Rigss & Sherrill 1990, modified)

OPERATION	Washer Water Level	Temper-ature (F)	Time (min)	Added chemicals	pH
Flush	High	100-110	2-5		
Flush	High	140-160	1-2		
Break, Suds	Low	180	10-12	Alkali, soap/detergent	11.5-12.5
Suds	Low	165-180	5-8	Detergent	
Flush	High	140-160	1-2		
Bleach	Low	140-160	8-10	Bleach	9.8-10.8
Rinse	High	120-140	1-2	Antichlor	
Rinse	High	105-115	1-2		
Rinse	High	105-115	1-2		
Finish	Low	105-115	4-6	Sour; mildistat; softener	5.5-7

Laundry detergents are complicated combinations; it is composed of numerous chemicals which are classified into main groups: surfactants, builders, bleaching agents, additives (Swartz et al. 2017). Surfactants and builders are two groups of chemicals that hold the highest percentages in detergents composition. Surfactants are known as surface-active chemicals; it is used to suspend dirt in the water medium. Surfactants are grouped as anionic, cationic, non-ionic and amphoteric surfactants (OECD 2011). Builders employed in detergents or washing formula to reduce water hardness, raise pH, and improve surfactants activities. Bleaching factors aim to sustain the whiteness of washed textiles and eliminate bacteria presented in items. Other substances such as brighteners, enzymes, fabric softeners, antichlor, and fragrances are added to ensure washing efficiency as well as improve the quality of cleaned textiles. The list of functionalities and examples of frequently used washing chemicals are given more detailed in Appendix 1.

3.2.2 Dry cleaning

Dry cleaning is a textile washing technique based on organic solvents. It is targeted for fragile textiles which cannot endure the harsh cycles and chemicals used in water-washing machines. Differing from normal washing technique, it consumes a nominal amount of water, resulting in the small wastewater generation. For 1 pound (0.45 kilograms) of textiles, dry cleaning processes use nearly 0 to 0.25 gallons, approximately to 0.95 litters of water; while in water washing, the water consumption ranges from 1.5 to 3.6 gallons (5.5 to 13.6 litters) (EPA 2000). In dry cleaning, soiled textiles after sorting and pre-spotting, go through 3 primary stages: solvent washing, redundant solvent extracting and tumble drying.

In general, the dry cleaning solvents used in industrial laundries are grouped as petroleum solvents and synthetic solvents. Petroleum solvents are flammable hydrocarbon mixtures, similar to kerosene, and have low-prices. On the other hand, halogenated hydrocarbons as synthetic solvents, are high-priced and incombustible. Perchloroethylene (also known as tetrachloroethylene) and trichlorotrifluoroethane are synthetic solvents used in dry cleaning industry nowadays. Tetrachloroethylene (or perc) is the most widely consumed dry cleaning solvent with the holding of roughly 50% in the industrial dry cleaning formations (EPA 1995,4.1-1).

A basic dry cleaning unit includes a washing chamber, solvent storage tanks and a system for used solvent recovery (Figure 5). In the dry washing machine, soiled linens are soaked and rotated in a chamber which is loaded of a proper amount of solvent and, if needed, a small amount of detergents and water. Washing cycles takes more than 25 minutes or from 8 to 12 minutes in dry cleaning machines using petroleum or halogenated solvents, respectively. The optimal condition is between 20 and 30 Celsius degrees, as higher temperature could cause the solvent damage (Garfield 1985, 216).

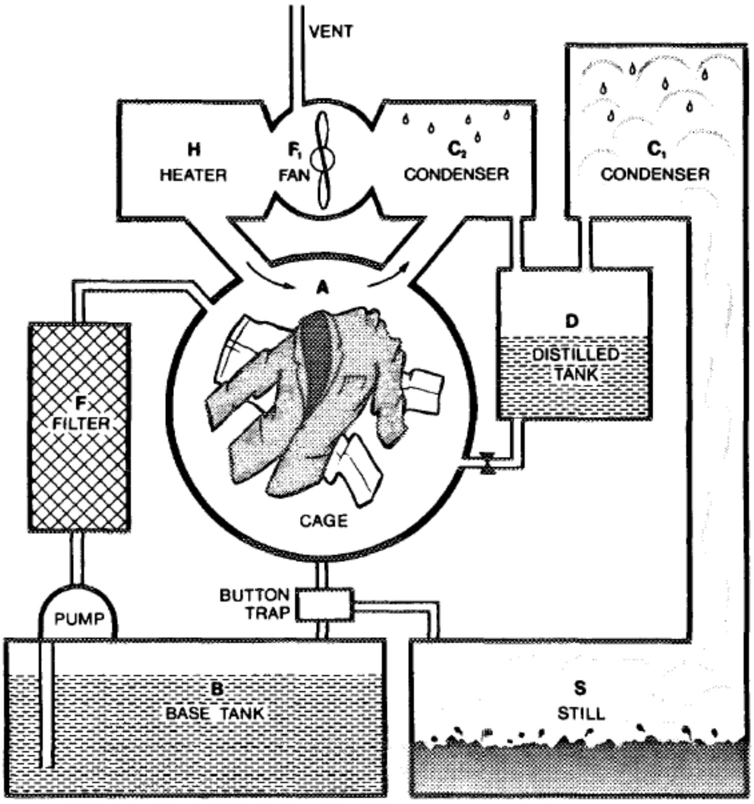

FIGURE 5. A dry-cleaning unit of industrial laundries (Garfield 1985)

The high cost of synthetic solvents results to the need of recovering the used-solvent, which usually happen along with the cleaning phase. Used solvent goes under various filtration stages to eliminate soil particles, and lint originated from cleaned textiles, before going back to the washing chamber. Solvent recycling involves processes of condensation, filtering, distillation, absorbance and stabilisation (EPA 2005, 25).

4 INDUSTRIAL LAUNDRY WASTEWATER

As one of the highest water-consuming industries, industrial laundry generates a massive amount of wastewater (WW) every day, which causes a burden on public sewage systems. Besides that, industrial laundry effluent contains a high amount of organic matter and heavy metals, which are originated in soiled textiles and washing detergents. Therefore, WW is considered as the primary pollution source of laundering industry. If the effluent from laundering facilities is not adequately treated, a considerable amount of impurities will enter to the public sewage system and eventually contaminate the natural water resources.

Wastewater analysis plays an essential part in the wastewater management of industrial laundries. Quantity and quality are the two main parameters to analyse characteristics as well as the pollution level of industrial laundry wastewater. Primary factors determining characteristics of laundry wastewater are laundry process, washed textiles and washing formulas.

4.1 Quantity of industrial laundry wastewater

In industrial laundries, water-washing and dual-phase washing regarded as two processes that generate the highest amount of wastewater (EPA 2000, 4-12). Supplied water goes through washing stages and ends up in the wastewater system. Another wastewater source is from the dry-cleaning process, water is added during the dry-cleaning phase and eventually separated during solvent recovery process. Some laundry facilities discharge the separated water from dry cleaning into the same wastewater stream with other processes.

Wastewater flow is influenced by the size of the facilities, laundering processes, washing formulas, textiles amount and recycling level. In case laundering facilities do not have wastewater recycling system, it can be estimated that the wastewater production amount is corresponding to water consumption.

4.2 Quality of industrial laundry wastewater

According to Finnish Industrial Wastewater Guide 2018, effluent from laundries has an alkaline nature (pH 9.5-11) and a high temperature. Typically, the values of pollution parameters like total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), and fats, oils and grease (FOG) in laundry wastewater are 1000 ppm, 5000 ppm, 1300ppm and 1100ppm, respectively (Janpoor et al. 2011). Washing chemicals and soil in textiles contribute to the significantly high concentration of solids of laundry wastewater. As can be seen from Table 3, the concentration of organic matters in laundry wastewater is higher several times compared to domestic sewage.

TABLE 3. Conventional & nonconventional pollutant concentrations of sewage generated from domestic and industrial laundries (EPA 1989, p28,30)

Pollutant	**DOMESTIC** Concentration Range (mg/L)	**INDUSTRIAL LAUNDRY** Average concentration (*) (mg/L)
BOD_5	100-300	**1300**
COD	250-1000	**5000**
TOC	100-300	**1400**
TSS	100-350	**1000**
Oil & Grease	50-150	**1000**

(*) *The average concentrations were obtained based on measurements from 73 industrial laundries in 1975.*

While wastewater flow influences on the efficiency of the treatment system, the contaminated potential arises from the impurities in the effluent. Types and concentration of those impurities are determined by washing chemicals and soil in textiles. Therefore, the pollutants in laundry wastewater are abundant and different between industrial laundries.

Generally, effluent pollution level of laundries is analysed for its pH, TSS, BOD_5, COD, phosphorus, surfactants (anionic and non-ionic substances). Depending on the testing purposes and authority requirements, other analytical tests could be conducted for the priority and nonconvention pollutants: pesticides and herbicides, heavy metals, other contaminants (cyanide, pathogens, nutrients). Treatment method is thus decided, based on the wastewater quality. (EPA 1989)

The first factor that defines the quality of laundry wastewater is detergents, one of the most consumable components in industrial laundries. Washing chemical is the primary factor that characterises the quality wastewater, not only because of its indispensable role but also its great consumption amount. As the fundamental function of washing chemicals is to eliminate soil presented on textiles, most of the added chemicals do not remain on textiles. As a result, washing chemicals will enter the wastewater stream. In laundry wastewater, these substances exist either as its original forms or transformed ones due to the chemical reactions.

The need-to-be cleaned textile as the second primary source is responsible for the quality of wastewater. Soil removed from textiles enter wastewater stream and contribute a significant amount of solid. Customers types of business determine laundered textiles amount and soil level; hence, it is considered as a determinant of laundry wastewater quality. For example, while effluent generated from processes of laundering working uniforms belong to a gasoline station contains a considerable amount of oil and grease, effluent from washing healthcare textiles contains bacteria, pathogens, viruses, blood.

Table 4 indicates the differences in pollutant load in wastewater between washing working uniforms and washing shop towels. As being used to wipe up solvents, dirt, and spilt liquids in repairing or machinery stations, shop towels or wipers or rags contain a considerable amount of volatile organic compounds. It can be seen that the concentration of VOCs in wastewater from washing towels is significantly higher than in wastewater from washing uniforms (106 times). Measured value of BOD_5 in the wastewater of laundering shop towels is five-time higher than one generated from washing uniform process.

TABLE 4. Pollutant load in wastewater generated from washing uniforms and washing shop towels (EPA 1989, modified)

Pollutant	**Average Raw WW Shop Towels (A)** (Pounds/ 1000 pounds towels)	**Average Raw WW Uniforms (B)** (Pounds/ 1000 pounds uniforms)	**The ratio of A: B**
Total volatile organic compounds[2]	1.49	0.014	**106**
Total semi-volatile organic compounds[2]	1.11	0.032	35
Total pesticides and herbicides[2]			
Total priority pollutant metals[2]	0.718	0.154	4.7
Total common metals[3]	16.6	3.55	4.7
Total other metals[4]	0.420	0.115	3.7
BOD_5	46.3	8.29	**5.6**
COD	188	47.3	4.0
TSS	78.6	9.14	8.6
Oil and Grease	113	3.58	32
Flow (gal/lb production)	2.1	1.7	1.2

1 Estimation is based on average concentrations and productions, during a two-day sampling episode and long-term average flow rates
2 Lists of specific pollutants
3 Ca, Fe, Mg, Na
4 Al, Ba, B, Co, Mn, Mb, Sn, Ti, V, Y

5 WASTEWATER TREATMENT TECHNOLOGIES IN INDUSTRIAL LAUNDRY

5.1 Regulation of discharging laundry wastewater

Laundry wastewater has two main pathways of discharging. The first option is integrating with municipal wastewater to receive the full treatment before releasing to the water body. In order to discharge into the public sewage system, industrial wastewater must comply with the standards of the public sewage system, and thus employ their own pre-treatment system. The second option is to adopt an entire wastewater treatment. The treated wastewater then could either send to receiving water sources or reuse as processing water, irrigation water as long as the regulations of regional authorities are carried out.

Industrial laundries discharge wastewater into the public sewage system or the wastewater treatment plant (WWTP) and pay for the treatment fee. The quality of discharged wastewater must satisfy the standard of the sewage system or WWTP. There is a significant tariff of releasing wastewater that does not meet the standard of the public sewage system. In some regions, it is mandatory for industrial laundries to pre-treat their wastewater before sending it to the centralised treatment plants.

Table 5 presents the limits for pollution parameters of industrial wastewater in Viet Nam. Class A includes limits which are set for discharging WW to the receiving water bodies which are used as water supply sources. On the contrary, limits of class B standard is applied for discharging WW to receiving water bodies that are not used as water supply sources. As an example, a laundry located in an industrial park in Ho Chi Minh City, Viet Nam, needs to pre-treat WW before releasing WW to the sewage system of the industrial park. The quality of pre-treated WW from this industrial laundry must meet the limits of class B standards.

TABLE 5. Standard for pollution parameters of industrial wastewater in Viet Nam (QCVN 24: 2009/BTNMT, modified)

Parameter	Quality required for discharge to receiving water body		Unit
	Class A	Class B	
pH	6-9	5,5-9	-
BOD_5 (20°C)	30	50	mg/L
TSS	50	100	mg/L
COD	50	100	mg/L
Sulfur	0,2	0,5	mg/L
Ammonia (as N)	5	10	mg/L
FOG	10	20	mg/L
Phenol	0,1	0,5	mg/L
Total Nitrogen	15	30	mg/L
Total Phosphorus	4	6	mg/L
Faecal Coliforms	3000	5000	MPN/100mL

Together with the fundamental fee counted by the effluent amount, there might be additional fees applied for the over-limitation of specific parameters. Each region has their own policy to decide the industrial effluent tariffs, concerning to the water consumption, effluent generated amount, and pollutant load limitation. Table 6 introduces the limitation of laundry wastewater parameters in cities in South Africa. For instance, the City of Cape Town set limitation for pollutant parameters such as pH, COD, Orthophosphate, TSS, electrical conductivity (EC), sulphate and FOG, as shown in Table 6. Industrial wastewater has the higher concentrations than the regulation will be applied for an extra. eThekwini as another example, limits of parameters are set separately for wastewater sources with the daily capacity above and under 25 ML. There are extra charges if the concentration of COD and SS in wastewater are higher than 360mg/L and 9ml/L. (Swartz et al. 2017)

TABLE 6. Wastewater standards for conventional pollutants of some municipalities in South Africa (Swartz et al. 2017, modified)

Local authority		pH	**COD**	Orthophos-phate	TSS	EC	Sulphate	FOG
			(mg/L)	(mg/L as P)	(mg/L)	(mS/m)	(mg/L as SO4)	(mg/L)
City of Tshwane		6-10	5000	10	2000	300	1800	500
City of Cape Town		**5.5-12**	**5000**	**25**	**1000**	**500**	**1500**	**400**
eThekwini	**V < 25 ML/d**	6.5-10	**Charge**		1000	400	250	250
	V > 25 ML/d	6-10	**Charge**		2000	-	250	250
Ekurhuleni		6-10	5000	50	1000	500	1800	500
Msundusi		6.5-9.5	-	20	400	400	250	2250
City of Johannesburg						500	250	
Mossel Bay		6-11	4000	-	1000	500	500	400
George		6-10	3000	-	1000	250	500	400

5.2 On-site wastewater treatment system

Generally, in-situ wastewater treatment system of industrial laundries insists on two levels, each delivers specific tasks, as shown in Figure 6. Stage 1 includes preliminary treatment technologies, aims to remove free oil and gross pollutant (large particle, sand, lint), and control the flow and temperature of WW streams. Stage 2 consists of primary and secondary treatment technologies, aims to control or remove the organic and inorganic pollutants in WW.

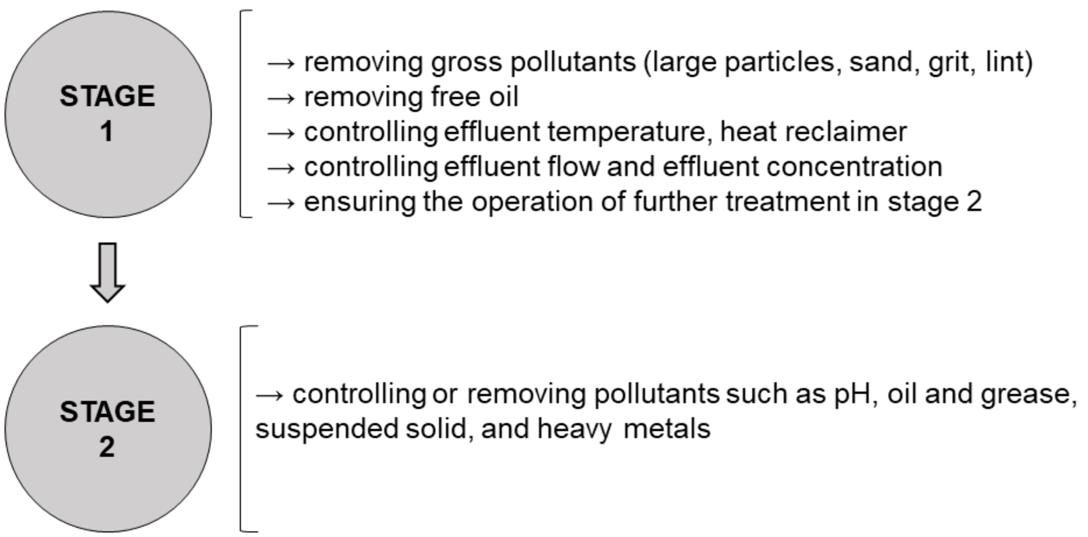

FIGURE 6. Main stages of in-situ wastewater treatment system at the industrial laundry

Both stages are aimed to assure the consecutive conveying of WW between laundry facility and treatment plant, and further treatment operation. Types and numbers of treatment unit are determined according to the below criteria:

- Regulations applied to laundry wastewater to be conveyed to the regional sewage system and wastewater treatment plants
- Quality and quantity of laundry wastewater
- Financial consideration of laundry company

Based on a survey of 190 industrial laundries conducted in 1993 by EPA, a list of implemented wastewater treatment technologies such as gravity settling, stream splitting, screening, equalisation, chemical emulsion breaking, chemical precipitation, dissolved air flotation was conducted (Appendix 2). Among that, technologies that were utilised by more than 10% of total in-scope industrial laundries are listed and briefly explained in Table 7 and Table 8. Table 7 includes preliminary wastewater treatment technologies that are operated in industrial laundry such as screening, sedimentation (gravity settling), stream splitting, flow equalisation, oil separation. All of these technologies are physical techniques and used to remove free oil together with the cross pollutants, as mentioned in stage 1 (Figure 6). Heat reclaimers are installed at the on-site treatment system to take advantage of high temperature in laundry wastewater; the recovered heat is then utilised to heat incoming water.

TABLE 7. Preliminary technologies used in laundry wastewater treatment

TECHNOLOGIES	DESCRIPTION
Screening	-Removing solids (sand, grit, lint, noncolloidal solids) Widely utilised in laundries to avoid blockages in sewage pipes/drains -Types: + Bar screen: grid pattern welded by steel bars, opening size of 6x19mm, removing large objects. + Lint screen: cylindrical or rectangular shaped by wire mesh or metal plate, opening size of 3x9mm, installed after bar screen, removing lint, sand, grit.
Gravity settling	-Removing solids (sand, grit) and free oil, combining with screenings -In catch basins/ settling pits, heavier solids settle to the bottom of the basin, lighter solids float to the surface Treatment performance based on WW properties, the structure of the tank, hydraulic detention time
Stream splitting	-Minimising the WW treatment system -A trend and sump system are operated to segregate laundry wastewater into heavy and light contaminant streams. Heavy WW stream is treated, while light WW stream can be recycled, reused, or straight released to the treatment plant.
Flow equalisation	-Controlling effluent flow and concentration of pollutant and ensuring the further treatment efficiency -Wastewater is retained in holding tanks/equalisation tanks until being releasing at steady flow and inflexible pollutant concentration.
Oil/Water Separation	-Oil rise to the surface due to its lower density, separated from water and mechanically skimmed from WW
Temperature reclaimers	-Heat reclaim systems are implemented, coming water is heated by noncontact heat transfer from laundry WW

Table 8 includes technologies which are more sophisticated than those in table 7. Technologies mostly are chemical, physical or chemical-physical methods such as pH adjustment, chemical precipitation (CP), dissolved air flotation (DAF), membrane filtration, activated carbon filtration (carbon adsorption). They are operated to remove suspended solids, heavy metals and other pollutants, as mentioned in stage 2 (Figure 6). Sludge dewatering as a supplementary technique comes along with DAF, CP technologies.

Other advanced technologies might be operated as on-site treatment, in order to perform other purposes such as:

- Ozone, UV, Chlorination and peroxides processes (Disinfection)
- Ion exchange technology (Water softening)

TABLE 8. Technologies used in wastewater treatment at industrial laundries

TECHNOLOGIES	DESCRIPTION
pH Adjustment	-Ensuring the effectiveness of further WW treatment process and acquiring the pH limit of treatment plant -Caustics or acids are added to adjust the pH of WW
Dissolved Air Flotation	-Removing SS, emulsified oil and dissolved pollutants -Chemicals added to form precipitates, by changing the repellant surface charges of molecules in WW. Forming and removing agglomerated particles with the support of coagulation, flocculation and injected air flotation. Added chemicals are aluminium sulfate, calcium chloride.
Chemical Precipitation	-Removing SS, emulsified oil and dissolved pollutants -Precipitation agents, lime as an example, added to convert ions into insoluble forms. Agglomerated particles are formed with the support of coagulants and flocculent agents. Precipitates are mechanically removed.
Sludge Dewatering	-Minimising the cost of sludge treatment, easier handling and transferring -Methods: self-evaporation, heat drying, filtration, squeezing, vacuum withdrawal, centrifugal separation and compaction
Membrane Filtration + ultrafiltration + microfiltration + Reverse Osmosis	-Removing SS -Semipermeable polymeric membranes are used to split the suspended particles of the pressurised WW stream into particles with low molecular weight pass through membrane; water, water-soluble solvents, dissolved solids permeate through the membrane; and the rest as a combination of high concentration of larger atomic, SS, colloid that does not permeate through the membrane
Carbon Adsorption	-Removing SS, VOCs -WW goes through a highly porous structure of activated carbon and dissolved volatile organic compounds adsorb onto the surface of activated carbon

6 IMPACTS OF INDUSTRIAL LAUNDRY WASTEWATER

Wastewater, solid waste and gas emission are primary pollution sources at industrial laundries. However, this study mainly focuses on the environmental impacts coming from wastewater generated at laundry facilities. Figure 7 reveals the routes of wastewater generation at industrial laundries. Processed water from water washing and dry cleaning is conveyed either directly or indirectly to the centralised WW treatment system. Laundry wastewater does not meet the standard of centralised WW treatment system have to go through in-situ treat system before entering the system.

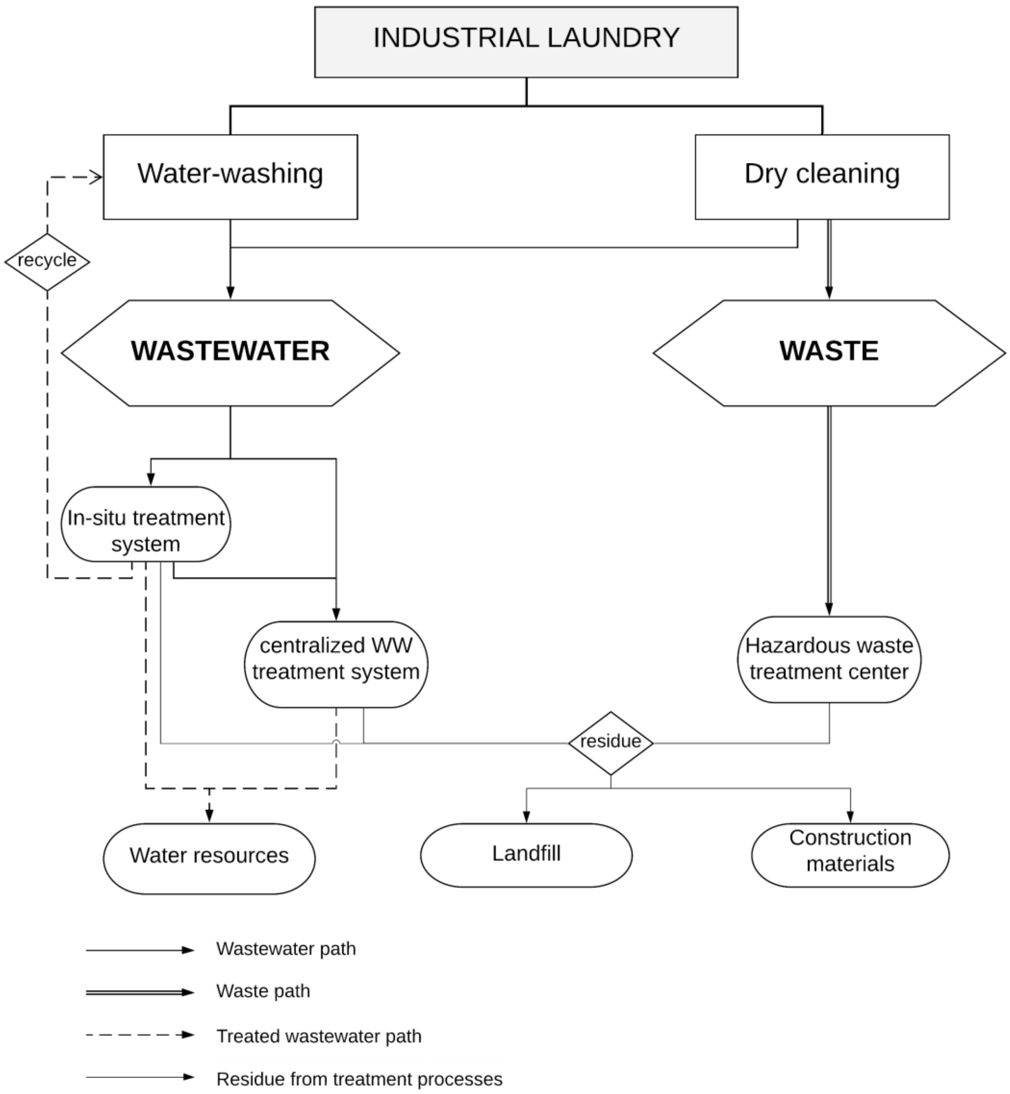

FIGURE 7. Route of wastewater and waste generated from industrial laundering process (Visualisation based on data taken from EPA 1995)

Wastewater is the most potential polluting source of industrial laundry, not only because of its enormous generated amount but also the environmental concerns of impurities in it. Impurities represented in laundry effluent are originated from both detergents and cleaned textiles. As categories and soiled level of textiles vary due to customer type of business, it is troublesome to analyse potential risks based on those criteria. Therefore, impacts of laundry wastewater will be analysed, mainly based on washing chemicals and some specific pollutants detected from earlier studies. Pollutants in laundry wastewater are grouped into conventional, priority and nonconventional pollutants as showed in Figure 8.

Conventional pollutants

- BOD_5, TSS, pH and FOG

Priority pollutants

- priority organics (Phenol, Toluene, Trichloroethene…)
- priority metals and elements (Lead, Mercury, Copper, Zinc…)

Nonconventional pollutants

- nonconventional organics (pesticides and herbicides, etc.)
- nonconventional metals and elements (Boron, Manganese, etc.)
- frequently measured pollutants (Fluoride, Ammonia, Nitrogen, Nitrate-Nitrite, Phosphorus, COD, TOC and Sulphide)

FIGURE 8. Categories of pollutants in laundry wastewater (Data taken in EPA 1989)

Not all chemicals used in laundry processes cause impacts on the environment or human health. Most of laundry compounds are biodegradable; however, part of them which have a slow biodegradation rate can generate subordinate substances during treatment processes and affect the ecological system when entering to receiving water sources. Figure 9 introduces four main routes of laundry chemicals in the wastewater streams. Among that, the 3rd route, which is entering the receiving water appear to pollute the environment the most.

1	being absorbed into sludge of WWTP and disposed as solid waste
2	completely biodegrading in WWTP (become to CO_2 and H_2O eventually)
3	entering to receiving water together with treated wastewater from WWTP
4	evaporating during treatment at WWTP

FIGURE 9. Fate of washing detergents (Visualization based on data taken from Swartz et al. 2017)

6.1 Impacts on the sewage system and treatment process

According to Finnish Industrial Wastewater Guide 2018, the high value of Biological Oxygen Demand in wastewater might result in an explosion of methane. Wastewater coming to sewage system with a high acidity or overweighed concentrations of sulphate, sulphide, chloride, magnesium and ammonium can cause corrosions in concrete sewers. Therefore, the allowed pH value of coming wastewater is between 6 and 11 (Finnish Water Utilities Association 2018). Hydrocarbon compounds such as solvents, fats and oils present endanger of blockage, explosion, corrosion in the sewage system or even breakdown in treatment plants.

Laundry wastewater might contain substances disturbing nitrification process in wastewater treatment. Nitrification is an aerobic microbial process applied in wastewater treatment, to eliminate nitrate and nitrite compounds by using bacteria. However, those bacteria are highly sensitive to synthetic organic chemicals and heavy metals such as mercury, chromium, iron, copper, cadmium, nickel (Finnish Water Utilities Association 2018).

While the average concentration of oils and grease in laundry wastewater is 1000 mg/L (Table 3), the approved limit for fats concentration of industrial wastewater to enter to the sewage system is 100-200mg/L (Finnish Water Utilities Association 2018). Pre-treat is requested for that reason; as the dense appearance of fats, oils disturb the oxygen supply in the biological treatment process.

6.2 Impacts on recipient water body

Phosphate compounds are widely used in laundry detergents because of its versatility and functionalities such as water softening, pH control, anti-redepositing, souring and stabilising. Like other substances, after the washing process, phosphorus in detergents also enters the wastewater flow of laundry facilities and ends up in wastewater treatment plants. Although phosphorus fundamentally is a crucial macronutrient for all living organisms, a high concentration of it results in eutrophication in recipient water sources. Eutrophication is a phenomenon of overgrowing of living organisms on the surface water, thus eventually causes the oxygen depletion. As a result, eutrophication endangers aquatic living creatures and lead to the degradation of water quality. Sodium citrate, Ethylene diamine tetraacetic acid (EDTA), Nitrilotriacetic acid (NTA) or Zeolite A are possible substitutes of phosphate in detergent production. However, these substances have their weakness, such as high price (Sodium citrate), carcinogens (EDTA, NTA).

Washed textiles are originated from various industries; this results in varieties of heavy metals and elements exist in the wastewater stream. Most of heavy metals are dangerous to living creatures, even in a small concentration. Cyanide, employed in the colourant or mining industry, is a highly toxic substance to aquatic organisms, it enters to the public sewage system through laundry wastewater stream and might end up in receiving water. Metals such as silver, arsenic, cadmium are very harmful to freshwater fish, aquatic organisms and mammals. (Finnish Water Utilities Association 2018)

6.3 Impacts on human health

Nearly 50 per cent of tested wastewater sample taken from industrial laundries contains phenol (Appendix 1). Phenols and its derivatives such as nonylphenol, nonylphenol ethoxylates, octylphenols and octylphenol ethoxylates are employed in detergents, washing substances. These compounds are highly toxic to living things due to their persistence in the environment.

A study of indirectly discharged wastewater streams from 14 laundries in the US shows that there were 47 priority pollutants (among 86 pollutants). Among those pollutants, the concentration of some substances such as benzidine, arsenic, cyanide, lead, bis(2-Ethylhexyl)phthalate, methylene chloride and carbon tetrachloride were higher than safety criteria for human health, aquatic life; zinc and Lead amount were exceeded restriction level of WWTP (EPA 1989).

Wastewater from the dry-cleaning process is merged with wastewater stream from other processes. A part of cleaning solvent then enters the wastewater streams of laundry facilities. Organic solvents consumed in the dry-cleaning process, such as perchloroethylene (“perc”), acetal, n-propyl bromide, are considered as dangerous substances to aquatic environment. Severely human health impacts of PERC include skin irritation, impacts on organs and cancer risk. According to Finnish Industrial Wastewater Guide 2018, effluent generated from the dry-cleaning process, distillation waste or contact water cannot be discharged to the sewage system.

7 DISCUSSION

Pollution prevention in WW management at industrial laundries can be divided into two directions, based on two assessment parameters of laundry WW - quantity and quality. For the WW quantity, implementing water-saving washing machines can cut down a considerable amount of wastewater generation. Concerning the WW quality, the pollution potential comes from washing chemicals/detergents and soiled levels of washed textiles. Firstly, about washing chemicals, pollution prevention activities could be implemented, such as: employing environmentally friendly substances to prevent persistent and toxic substances entering the wastewater stream, using the injection system to achieve the optimal dose of washing chemicals for every washing operation. Secondly, about the soil content of textiles, industrial laundries could apply following pollution prevention activities, such as: refusing of certain items to prevent substances with a high concentration or toxicity entering the wastewater stream; or removing toxic substances in textiles before sending them to the water washing process. Steam stripping, centrifuging or pressing solvent laden textiles are conventional techniques which are used to eliminate VOCs in textiles.

Nevertheless, these activities also result in the increasing of laundering fee toward the customers and might reduce the launder quality. Replace traditional washing chemicals by eco-friendly ones certainly rise the total material cost, and thus, the service charge will be lifted. Additionally, the quality of cleaned textiles cannot be ensured due to the low concentration or absence of crucial substances.

The expansion of the laundry industry comes along with the escalation in the amount of generated wastewater. A massive amount of wastewater, stricter standards and higher wastewater-discharging fee require laundering facilities to pay more attention to the on-site treatment system. Wastewater is the unavoidable by-product of industrial laundries; it might cause several impacts to the environment, especially to natural water sources. In order to minimise the contamination causing by laundry wastewater, there should be improvements implemented to control the quality of wastewater. An on-site wastewater treatment system might include one or more units of conventional technologies or both conventional and advanced technologies. Type of treatment technologies are decided based on laundry wastewater's characteristics and pollutant removal efficiency of each technique.

TABLE 9. The average percentage of phosphorus and surfactants removal by Chemical Precipitation and DAF methods (Data* taken from EPA 2000)

Pollutant	Average Percent Removal	
	Chemical Precipitation	Dissolved Air Flotation
Total Hydrolysable Phosphorus	**88**	52
Total Orthophosphate	39	57
Total Phosphorus	**78**	58
Surfactants (Anionic)	48	**89**
Surfactants (Nonionic)	22	**55**

**Data based on six sampling events between 1993-1998*

Table 9 represents the removal percentages of surfactants and phosphorus by chemical precipitation and dissolved air flotation (DAF) methods. As can be seen from Table 9, chemical precipitation performs a higher percentage of phosphorus removal while DAF method achieves a better result in total surfactants removal. An industrial laundry can employ only the chemical precipitation technology if its wastewater contains much higher phosphorus concentration than the current limit of the treatment plant, and the surfactant concentration is not too high. On the contrary, dissolved air flotation can be operated when the laundry wastewater contains high surfactant concentration.

Advanced techniques acquire higher quality of treated wastewater; however, it requires greater installation and operation costs in comparison to primary treatments. Installation of sophisticated wastewater treatment methods requires industrial laundries to conduct attentive estimations, based on the financial, geographical and working capacity circumstances. An analysis in 1989 indicates that the installation of a UF treatment system caused an economic burden to all in-scope industrial laundries; although it produces a high quality of treated wastewater which is indicated by the high removal percentages of most pollutants (Appendix 4). However, the annual cost of operating a UF treatment system was higher than the before-tax profits of those laundries (USEPA 1989). Therefore, the wastewater treatment system considered as appropriate to a laundry facility must balance the working effectiveness and operation cost. As most of industrial laundries eventually release their wastewater to treatment plants, it seems unnecessary for treated wastewater to have a higher quality than requirements.

The rising tendency in fee of water and wastewater discharging require laundry facilities to reuse or recycle the processed water. According to the used purposes and washing stages, laundry wastewater could be divided into noncontact or contact cooling water, nonlaundry wastewater, laundry wastewater before and after treatment. It allows industrial laundries to reuse processed water; for example, noncontact cooling water can be reused in rinsing stages of water washing process or as process makeup water. In order to reuse wastewater, more advanced techniques should be applied to deliver higher capacity of solid removal. Laundry effluent treated by sedimentation combined with filtration can be used for the first rinse of the washing operation (Bhagat et al. 2018). For instance, a laundry in Germany implemented a wastewater treatment system combining of membrane bioreactors (MBRs), microfiltration and reverse osmosis membranes. The treated wastewater is applied in washing and rinsing stages (Mozia 2016).

8 CONCLUSION

In order to pursue a sustainable development, industrial laundries must pay attention to their wastewater management. Quality of wastewater needs to be checked frequently to prevent possible negative impacts to the sewers, treatment system and receiving sources. Investment into sufficient wastewater treatment and recycling systems can bring long-term interests to industrial laundries. However, technology selection must be meticulous, based on wastewater characteristics, regional regulations, and geographical, financial condition of each laundry. Figure 10 indicates three determinants of a wastewater treatment system (WWTS). Firstly, the WWTS should be applicable to the laundry facilities in size and operation capacity. Secondly, the installation and maintenance cost of the WWTS should be affordable to the financial situation of industrial laundry. The last and most important factor is the working effectiveness. Besides that, every laundry should set targets and detailed plans in several periods to promote the sustainable development.

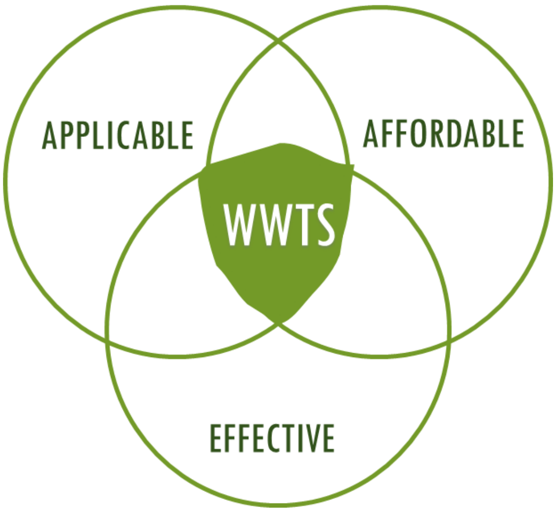

FIGURE 10. Determinants of a wastewater treatment system at industrial laundries

For further study, there are several sectors relating to laundry wastewater that need to be analysed. Along with wastewater treatment, sludge or concentrate are inevitable outputs, for example, in the process of dissolved air flotation, chemical precipitation or membrane filtration. Environmental impacts and treatment technologies concerning the residue of laundry wastewater treatment are not discussed in this study. Therefore, further research of laundry wastewater can be extended to the impacts and treatment methods of the residues in the treatment process. Another instance topic is to investigate the wastewater recycling systems and its applicability to be implemented at industrial laundries.

The outdated statistics and shortage in published data by industrial laundries are two limitations during the process of data collection. Firstly, most of the information about the characteristics and treatment technologies of laundry wastewater is given by surveys which were conducted for a long time ago. While washing process and technologies have been developing day by day, the gathered references do not provide information about new practices. Secondly, the majority of industrial laundries do not publish detailed data relating to their currently wastewater generation and treatment technologies. To evaluate the impacts of laundry wastewater and working efficiency of treatment technologies in a more factually way, more information is needed.

REFERENCES

EPA (Environmental Protection Agency). 2000. Technical development document for the final action regarding pre-treatment standards for the industrial laundries point source category. Washington, DC: US Environmental Protection Agency, Office of Water, Office of Science and Technology, Engineering and Analysis Division.

EPA (Environmental Protection Agency). 1995. Pollution prevention at industrial laundries: Assessment observations and waste reduction options. United States.

EPA (Environmental Protection Agency). 1989. Preliminary Data Summary Reports for Industry Laundries. United States.

Swartz, C.D., Swanepoel, G., Welz, P.J., Muanda, C. & Bonga, A. 2017. NATSURV 8: Water and Wastewater Management in the Laundry Industry. South Africa: Water Research Commission.

OECD (Organisation for Economic Co-operation and Development). 2011. Emission scenario document on the chemicals used in water-based washing operations at industrial and institutional laundries. Paris.

EPA (Environmental Protection Agency).2005. Best Practice Guidelines for Dry Cleaning. Ireland.

Garfield, E. 1985. Dry Cleaning. Part 1: The process and its history: from starch to finish. In: Essays of Information Scientist, Volume 8, Chapter 22, pp. 213-222.

Riggs, C.L. & Sherrill, J.C. 1990. Textile Laundering Technology. Florida: Textile Rental Services Association of America.

Mozia, S., Janus,M., Brożek,P., Bering, S., Tarnowski, K., Mazur, J. & Morawski, A. 2016. A system coupling hybrid biological method with UV/O3 oxidation and membrane separation for treatment and reuse of industrial laundry wastewater. Environmental Science and Pollution Research no. 23.

Finnish Water Utilities Association. 2018. Finnish Industrial Wastewater Guide – conveying non-domestic wastewater to sewers (Teollisuusjätevesiopas – asumajätevesistä poikkeavien jätevesien johtaminen viemäriin). Finnish Water Utilities Association publication series no. 69.

Bering, S., Mazur, J. & Tarnowski, K. 2011. Quantity and quality of industrial wastewater from laundry on example of "Fliegel Textilservice" company in Nowe Czarnowo. Civil and Environmental Engineering Reports 6, 33-44.

Bhagat, S., Tiyasha, T. & Bekele, D. 2018. Economical Approaches for the Treatment and Re-utilization of Laundry Wastewater - A review. Journal of Industrial Pollution Control, vol. 34, 2164-2178.

Janpoor, F., Torabian, A., & Khatibikamal, V. 2011. Treatment of laundry wastewater by electro-coagulation. Journal of Chemical Technology & Biotechnology. ·. Available from: https://www.researchgate.net/publication/228333036

Smulders, E. 2002. Laundry Detergents. Weinheim, Germany: Wiley-VCH Verlag GmbH.

EPA (Environmental Protection Agency). 1995. AP-42: Compilation of Air Emissions Factors. 5th edition. Chapter 4-1: Dry cleaning. New York, US.

QCVN 24: 2009/BTNMT. National Technical Regulation on Industrial Wastewater. The Ministry of Natural Resources and Environment. Hanoi. Viet Nam.

Association of Southeast Asian Nations (ASEAN) 2012. Maintain and Operate an Industrial Laundry- Trainee Manual.

APPENDICES

Appendix 1. List of washing chemicals and their functionalities

Chemicals/products used for laundering	Description of function in laundering	Common example
Surfactant	Rapidly wets the textile Removes dirt then suspends it in water Suspends oil	Alkyl benzene sulfonates
Builders	Softens water (removes calcium and magnesium ions) Enhance action of surfactants Provides alkalinity (assists in dissolving oily dirt)	Sodium tri-polyphosphate; Sodium carbonate; Zeolites
Alkalis	Provides alkalinity (assists in dissolving oily dirt)	Sodium silicate; Potassium silicate
Anti-redeposition agents	Prevents re-deposition of suspended dirt	Carboxy-methyl cellulose
Enzymes	Removal of stains Can smooth cotton fabrics	Proteases; Amylases; lipases
Bleach	Whitening and brightening of textiles	Sodium hypochlorite; Sodium percarbonate
Disinfectants	Kill or inhibit microbial growth on textiles	QACs – quaternary ammonium compounds
Fabric softeners	Soften and smooth textiles Reduce wrinkling and static electricity	Cationic surfactants
Fragrances	Neutralise inherent odour of detergents	Petroleum-based artificial fragrances
Optical brighteners	Gives whiter and brighter appearance to textiles	Amino-triazines
Preservatives	Prevent liquid detergent spoilage during storage	Glutaraldehyde
Solubilisers	Prevent gel and layer formation of liquid detergents	Xylene sulfonate
Foam regulators	Inhibit sud/foam formation	Siloxane- and paraffin-based products
Corrosion inhibitors	Inhibit corrosion of metallic parts	Sodium silicate

Swartz et al. 2017

Appendix 2. List of wastewater treatment technologies

Number of In-Scope Facilities Responding to Detailed Questionnaire Using Wastewater Treatment Technologies in the 1993 Operating Year

Technology	Number of Facilities Using Technology	Percentage of Total Number of Industrial Laundries Responding to the Detailed Questionnaire[1]
Gravity Settling	97	51%
Stream Splitting	20	11%
Screening	146	77%
Equalization	98	52%
Chemical Emulsion Breaking	9	5%
Chemical Precipitation	21	11%
Dissolved Air Flotation	35	18%
Sludge Dewatering	52	27%
pH Adjustment	42	22%
Ultrafiltration	2	1%
Centrifugation	6	3%
VOC Removal Technologies	12	6%
Oil/Water Separation	24	13%
Media Filtration	10	5%

[1]Percentages are based on the 190 in-scope industrial laundries that responded to the detailed questionnaire.

EPA. 2000

Appendix 3. List of pollutants represented in laundry wastewater from seven industrial laundries between 1993 and 1996

Pollutant of Concern	Number of Times Analyzed	Number of Times Detected	Percent Detected (%)	Concentration in Untreated Wastewater (mg/L)		
				Minimum	Maximum	Mean
Conventionals						
Biochemical Oxygen Demand 5-Day (BOD_5)	46	46	100.00	218.00	9810.00	2343.50
Oil and Grease (measured as HEM)	48	48	100.00	71.50	11790.00	1943.92
Total Suspended Solids (TSS)	46	45	97.83	4.00	7000.00	1773.93
Priority Organics						
1,1,1-Trichloroethane	48	22	45.83	0.01	156.64	4.01
1,2-Diphenylhydrazine	47	5	10.64	0.02	41.32	1.14
4-Chloro-3-methylphenol	47	8	17.02	0.01	2.06	0.14
Bis(2-ethylhexyl) Phthalate	47	43	91.49	0.04	42.01	6.80
Butyl Benzyl Phthalate	47	20	42.55	0.01	74.42	2.69
Chlorobenzene	48	8	16.67	0.01	1.41	0.08
Chloroform	48	25	52.08	0.01	1.19	0.07
Di-*n*-butyl Phthalate	47	20	42.55	0.01	9.98	0.73
Di-*n*-octyl Phthalate	47	25	53.19	0.01	2.61	0.30
Ethylbenzene	48	38	79.17	0.01	18.74	1.24
Isophorone	47	5	10.64	0.01	1.00	0.12
Methylene Chloride	48	25	52.08	0.01	16.26	0.63
Naphthalene	47	42	89.36	0.01	18.75	2.59
Phenol	47	23	48.94	0.01	0.96	0.15
Tetrachloroethene	48	35	72.92	0.01	46.22	1.97
Toluene	48	44	91.67	0.01	90.97	6.72
trans-1,2-Dichloroethene	48	1	2.08	0.01	0.10	0.03
Trichloroethene	48	7	14.58	0.01	20.00	0.48

Pollutant of Concern	Number of Times Analyzed	Number of Times Detected	Percent Detected (%)	Concentration in Untreated Wastewater (mg/L)		
				Minimum	Maximum	Mean
Nonconventional Organics						
2-Butanone	48	32	66.67	0.05	272.29	9.07
2-Methylnaphthalene	47	32	68.09	0.01	2.24	0.41
2-Propanone	48	46	95.83	0.05	603.15	20.95
4-Methyl-2-pentanone	48	26	54.17	0.05	65.27	2.65
∝-Terpineol	47	17	36.17	0.01	5.20	0.33
Benzoic Acid	47	34	72.34	0.05	12.23	1.77
Benzyl Alcohol	47	21	44.68	0.01	12.52	0.81
Hexanoic Acid	47	14	29.79	0.01	1.81	0.12
m-Xylene	48	40	83.33	0.01	25.29	2.29
n-Decane	47	41	87.23	0.01	712.40	51.60
n-Docosane	47	31	65.96	0.01	3.04	0.35
n-Dodecane	47	40	85.11	0.01	105.57	14.37
n-Eicosane	47	43	91.49	0.01	84.57	4.06
n-Hexacosane	47	27	57.45	0.01	3.73	0.36
n-Hexadecane	47	43	91.49	0.01	91.57	6.70
n-Octacosane	47	21	44.68	0.01	1.44	0.19
n-Octadecane	47	42	89.36	0.01	19.36	1.92
n-Tetracosane	47	25	53.19	0.01	8.34	0.46
n-Tetradecane	47	37	78.72	0.01	41.58	4.39
n-Triacontane	47	29	61.70	0.01	1.00	0.19
o-&*p*-Xylene	48	40	83.33	0.01	17.80	1.59
p-Cresol	47	1	2.13	0.01	0.20	0.06
p-Cymene	47	16	34.04	0.01	19.81	1.43
Pentamethylbenzene	47	11	23.40	0.01	2.33	0.22

Pollutant of Concern	Number of Times Analyzed	Number of Times Detected	Percent Detected (%)	Concentration in Untreated Wastewater (mg/L)		
				Minimum	Maximum	Mean
Priority Metals and Elements						
Antimony	47	34	72.34	0.01	8.24	0.26
Arsenic	47	15	31.91	0.010	0.18	0.02
Beryllium	47	18	38.30	0.010	0.02	0.003
Cadmium	47	44	93.62	0.010	0.70	0.10
Chromium	47	45	95.74	0.010	7.31	0.46
Copper	47	47	100.00	0.04	14.90	3.17
Lead	47	45	95.74	0.03	23.80	1.71
Mercury	47	28	59.57	0.010	0.01	0.001
Nickel	47	45	95.74	0.01	2.87	0.27
Selenium	47	12	25.53	0.010	0.26	0.03
Silver	47	24	51.06	0.010	0.17	0.02
Thallium	47	6	12.77	0.010	0.13	0.01
Zinc	47	46	97.87	0.010	29.40	5.02
Nonconventional Metals and Elements						
Aluminum	47	47	100.00	0.03	20.99	7.96
Barium	47	47	100.00	0.03	6.26	1.51
Boron	47	36	76.60	0.03	37.20	2.31
Cobalt	47	37	78.72	0.000	3.10	0.24
Iron	47	47	100.00	0.06	96.60	27.70
Manganese	47	47	100.00	0.02	1.77	0.56
Molybdenum	47	43	91.49	0.010	5.17	0.53
Tin	47	32	68.09	0.02	0.58	0.11
Titanium	47	45	95.74	0.01	1.32	0.23
Vanadium	47	31	65.96	0.010	0.19	0.04
Yttrium	47	15	31.91	0.010	0.04	0.01

Pollutant of Concern	Number of Times Analyzed	Number of Times Detected	Percent Detected (%)	Concentration in Untreated Wastewater (mg/L)		
				Minimum	Maximum	Mean
Bulk Nonconventionals						
Chemical Oxygen Demand (COD)	47	47	100.00	80.00	212000.00	12730.57
Total Organic Carbon (TOC)	47	47	100.00	106.00	37800.00	2208.32
Total Petroleum Hydrocarbon (measured as SGT-HEM)	43	43	100.00	7.00	4543.00	880.86

[1]Results are based on sampling data collected between 1993 and 1996 from seven industrial laundries facilities.

EPA. 2000

Appendix 4. Removal efficiency of dissolved air flotation and ultrafiltration

Technologies / Pollutants	Dissolved Air Flotation[1]	Ultrafiltration[2]
BOD5	63	65
TSS	34	100
COD	50	81
Oil & Grease	71	100
TOC	33	33-60*
Ammonia	0	100
Nitrogen, total	22	0
Nitrate-Nitrite, as N	38	0-69*
Total Phosphorus	34	0
Priority metals		
Copper	59	99
Lead	70	98
Zinc	58	99
Cadmium	24	99
Chromium	34	79
VOCs		
Tetrachloroethene	100	99
Ethylbenzene	93	100

(1) Data taken at two industrial laundries in ITD/RCRA Sampling Program.

(2) Samples were taken only from wastewater coming from washing shop towels and rags, which has a high concentration of pollutants—the UF system in combination with lint screen, equalisation basin with oil skimmer.

(*) Removal percentage was different in 2 measuring days. "Removal percentage of Day 1 – Removal Percentage of Day 2."

EPA. 2000, modified