Causes, effects and solutions of operational problems in wastewater systems due to nonwoven wet wipes

vorgelegt von

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Abstract

Operational problems due to sewer system incompatible nonwoven wipes in wastewater systems affect nearly all wastewater system operators in regions where nonwoven wipes are used as convenience products. They disrupt the operation of the critical infrastructure, cause equipment failures, and large additional expenditures. To date, however, there is no agreement as to which nonwoven wet wipes are the source of the problems (those sold as “flushable” or those designated for a disposal via the household waste).

The overall aim of this thesis was to investigate the effects of nonwoven wet wipes in sewer systems, focussing on the sewer system compatibility of different types of nonwoven wet wipes. The distinction between “non-flushable” wet wipes and those marketed as “flushable” was of particular interest. For this reason, a survey among wastewater system operators and among the users of nonwoven wet wipes was conducted, field experiments were performed in a pumping station, and the clogging effect of different nonwoven wipes was investigated in the laboratory.

Occurrence, location, type, and financial impacts of the operational problems due to sewer system incompatible nonwoven wipes could be identified. The requirements of the wastewater system operators regarding flushability criteria were also determined. It was shown that wipes are primarily used by young parents and that baby wipes are most frequently wrongly disposed of via the toilet. A general interest of the public for the issue of sewer system compatibility of flushable nonwoven wipes could be determined, as well as a willingness to pay more for truly sewer system safe wipes. The results of the field investigation showed that non-flushable wipes designated for disposal via the household waste were the main cause for the pump blockages. However, a significant amount of nonwoven wipes sold as flushable could also be identified in the clogging material. The results from the laboratory investigations confirmed the clogging behaviour of the non-flushable wipes, which was previously indicated by findings from the field and experiences from wastewater system operators. The results also suggest that flushable nonwoven wipes, which meet the flushability criteria of the industry associations of the nonwovens industry, are compatible with wastewater pumps. In contrast, non-compliant flushable nonwoven wipes were shown to have a clear adverse effect on the pump, even at low concentrations.

Overall, the results of this study give an important insight into wipe-related operational problems and can be used to identify suitable solutions.

Zusammenfassung

Betriebsprobleme durch Vliestücher in Abwassersystemen betreffen nahezu alle Abwassersystembetreiber in Regionen, in denen Vliestuchprodukte genutzt werden. Sie stören den Betrieb der kritischen Infrastruktur und verursachen hohe Mehraufwendungen. Bislang konnte jedoch nicht festgestellt werden, welche Vliestücher ursächlich für die Probleme sind (solche, die als „spülbar“ verkauft werden oder die, die für die Entsorgung über den Hausmüll bestimmt sind).

Ziel dieser Arbeit war es, die Auswirkungen von Vliestüchern in Abwassersystemen zu untersuchen. Von besonderem Interesse war dabei die Unterscheidung zwischen "nicht spülbaren" Vliestüchern und solchen, die als "spülbar" vermarktet werden. Zu diesem Zweck wurde jeweils eine Befragung der Abwassersystembetreiber und der Anwender von Vliestüchern durchgeführt. Außerdem wurden in einer Pumpstation Pumpenverstopfungen untersucht und im Labor die Verstopfungswirkung verschiedener Vliestücher analysiert.

Vorkommen, Ort, Art und finanzielle Auswirkungen der Betriebsprobleme durch nicht abwassersystemverträgliche Vliestücher konnten identifiziert werden. Auch die Anforderungen der Abwassersystembetreiber an Spülbarkeitskriterien konnten ermittelt werden. Es konnte gezeigt werden, dass Vliestücher vor allem von jungen Eltern verwendet werden und dass Babytücher am häufigsten falsch über die Toilette entsorgt werden. Ebenso konnte ein allgemeines Interesse der Öffentlichkeit an abwassersystemverträglichen Vliestüchern festgestellt werden sowie die Bereitschaft, mehr für solche Tücher zu zahlen. Die Ergebnisse der Felduntersuchung zeigten, dass nicht-spülbare Tücher, die für die Entsorgung über den Hausmüll vorgesehen sind, die Hauptursache für die Pumpenverstopfung waren. Jedoch wurde auch eine signifikante Menge von als spülbar verkauften Vliestüchern im Verstopfungsmaterial identifiziert. Die Ergebnisse der Laboruntersuchungen bestätigten das Verstopfungsverhalten der nicht-spülbaren Vliestücher, was zuvor durch Erkenntnisse aus der Praxis und Erfahrungen der Abwassersystembetreiber indiziert wurde. Die Ergebnisse deuten jedoch auch darauf hin, dass als spülbar verkaufte Vliestücher, die die Spülbarkeitskriterien der Industrieverbände der Vliestuchhersteller erfüllen, verträglich für Abwasserpumpen sind. Hingegen beeinträchtigen nicht konforme spülbare Vliestücher die Pumpe auch bei niedrigen Konzentrationen deutlich.

Insgesamt geben die Ergebnisse dieser Studie einen wichtigen Einblick in Betriebsprobleme durch nicht abwassersystemverträgliche Vliestücher und können zur Ermittlung geeigneter Lösungsstrategien herangezogen werden.

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Terminology

Terms and definitions

Flushability	The term flushability or flushable is not protected. To date, wipe products labelled as “flushable” mostly pass through domestic wastewater systems. However, not all such products are truly compatible with the municipal wastewater system or the environment. Therefore, “flushable” is not the same as “sewer system compatible”. This distinction is made throughout this study.
Moist toilet wipe	A nonwoven wipe pre-moistened with lotion, which is sold for toilet hygiene and is usually labelled as "flushable". Also known as toilet wipe or moist toilet tissue.
Non-dispersibles	Items that do not disperse (break up) in wastewater and are thus non-flushable and sewer system incompatible
Non-flushable	Not conforming to the requirements of sewer system compatibility. Thus “non-flushable” means the same as “sewer system incompatible”
Sewer system compatibility	The property of a material whose disposal through the toilet is tolerated for reasons of hygiene and disease control and has no negative impact on the functioning of the domestic or municipal sewage system and the environment. The product can be degraded in the wastewater treatment plant and contains no plastic material. In addition, the product also contains no components that are harmful to the aquatic environment (for example, lotions on nonwoven wipes). Thus not every product labelled as “flushable” is also sewer system compatible.
Sewer system incompatibility	Not conforming to the requirements of sewer system compatibility. Thus “sewer system incompatible” means the same as “non-flushable”.
Water UK	Water UK is a membership organisation which represents all major statutory water and wastewater service providers in England, Scotland, Wales, and Northern Ireland
Wet wipe	Pre-moistened nonwoven wipe, sold as a disposable product for personal hygiene or other cleaning purposes.

Abbreviations

ANSI	American National Standards Institute. ANSI is a private non-profit organization that oversees the development of voluntary consensus standards for products, services, processes, systems, and personnel in the United States.
CD	Cross direction
CEN	European Committee for Standardization. CEN is a public standards organization for the development, maintenance and distribution of coherent sets of standards and specifications.
DIN	Deutsches Institut für Normung e.V. (English: German Institute for Standardisation) is the German national organisation for standardisation and is the German ISO member body
DN	Diametre Nominal, the European equivalent of Nominal Pipe Size
DWA	Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (English: German Association for Water, Wastewater and Waste)
EDANA	European Disposables and Nonwovens Association
INDA	Association of the Nonwovens Fabric Industry
ISO	International Organization for Standardization. ISO is an international standard-setting body composed of representatives from various national standards organizations.
IWSFG	International Wastewater Services Flushability Group
FCP	Flushable consumer products
FOG	Fats, oils, greases
HDPE	High-density polyethylene
MD	Machine direction
MONS	Matière organique non synthéthique – non-synthetic organic matter
OECD	Organisation for Economic Co-operation and Development. OECD is an intergovernmental economic organisation with 36 member countries to stimulate economic progress and world trade.

PES	Polyester
PET	Polyethylene terephthalate
PP	Polypropylene
PU	Polyurethane
PVC	Polyvinyl chloride
RQ	Research question
TAPPI	Technical Association of the Pulp and Paper Industry. TAPPI is a registered not-for-profit, international Non-Governmental Organization of about 14,000 member engineers, scientists, managers, academics and others involved in the areas of pulp, and paper.
TC	Technical committee
TÜV	Technischer Überwachungsverein (English: Technical Inspection Association)
UKWIR	United Kingdom Water Industry Research Ltd, is responsible for facilitating the shaping of the UK water industry's research agenda, developing the research programme, procuring and managing the research, and disseminating the findings.
USD	United States dollar
VSD	Variable speed drive
WC	Water closet or flush toilet
WERF	The Water Environment Research Foundation is a research organization advancing the science of all water to meet the evolving needs of its subscribers and the water sector.
WG	Working group
w/o	without
WRc Group	The WRc Group (WRc plc, Water Research Center public limited company) is an independent public limited company providing research and consultancy in water, waste, and the environment in the United Kingdom
WWC	Wastewater class
WWTP	Wastewater treatment plant

Symbols

Latin symbols

H	Head	m
Hz	Frequency	s^{-1}
N	Newton	(kg m)/s^2
Q	Flow rate	m^3/h
Q_{opt}	Flow rate in best efficiency point	m^3/h
t	Time	s

Greek symbols

η	Efficiency	-
η_{clear}	Clear water group efficiency	-
$\eta_{clogged}$	Group efficiency while clogging	-
η_{gr}	Group efficiency	-
µm	Micrometre	10^{-6}m

Currency symbols

€	Euro
£	British pound
AU$	Australian dollar
US$	United States dollar

1 Introduction

1.1 Background

Increasing standards for convenience and hygiene in the general population have caused a rising demand for disposable wipe products. These nonwoven wipes are used for cleaning purposes as well as personal hygiene (disinfection, make-up removal, nappy changing, and toilet hygiene to name a few examples). They replace reusable wipes such as cleaning cloths, face cloths, or dusters. Disposable nonwoven wipes allow consumers to perform cleaning or hygiene tasks more quickly and efficiently. Moreover, they are portable and always ready to use.

However, with the rising consumption of nonwoven wipes, the operational problems in wastewater systems have also increased in recent years.

When considering nonwoven wet wipes and their possible connection with operational problems in the wastewater system, it is important to differentiate them according to their designated disposal route. “Non-flushable” wipes include, e.g., cosmetic wipes and baby wipes. Despite being used in a bathroom setting, they should not be disposed of via the toilet but in the household waste (as per package instructions). Accordingly, these products are not manufactured to be sewer system compatible. Rather, they are very stretchy and tear-resistant due to their high tensile strength and often have a high content of synthetic polymer fibres (plastic; up to 100 %). These material properties make the products incompatible with wastewater systems. If incorrectly disposed of through the toilet, they can lead to wastewater system failures. Moreover, the high synthetic content means that the wipes cannot be biodegraded in the wastewater treatment plant (WTTP) or during sludge treatment. Nonwoven wet wipes marketed as “flushable” include moist toilet wipes and some intimate hygiene wipes and toilet disinfecting wipes. According to their package instructions, these nonwoven wipes can be safely disposed of via the toilet. These products often have a distinctly lower tear resistance and wet strength than non-flushable wipes and are mostly free of synthetic polymer fibres. However, a general compatibility of this product category with the wastewater system is not yet ensured for all nonwoven wet wipes labelled as "flushable".

Today, both types of nonwoven wet wipes (flushable and non-flushable) are partly being disposed of via the toilet by consumers, which can lead to deposits in the sewers, clogging of wastewater pumps, blockage of screens, and an increase of screenings. Figure 1-1 shows a blockage removed from a Berlin pumping station and screenings from a Berlin WWTP – both consisting mainly of nonwoven wipes. These operational problems are not only a serious hazard for the critical infrastructure, but also imply high costs for wastewater utilities, due to increased energy consumption and maintenance costs. Moreover, sewer system incompatible wipes can also cause harm to the environment. The Marine Conservation Society report on the Great British Beach Clean 2017 [1] concluded that the number of nonwoven wipes found on the UK coastline had increased by 94 % in 2017, with a near seven-fold increase over the last decade. Also of great concern for environmental organisations and the water industry is the lack of consistent criteria and regulations on flushability assessment [2].

Figure 1-1: Blockage removed from a Berlin pumping station (left) and screenings from a Berlin WWTP (right)

The operational problems caused by sewer system incompatible nonwoven wet wipes affect wastewater utilities throughout the world, especially where the use of convenience products is popular [3–8]. To date, however, there is no agreement as to which nonwoven wet wipes (flushable or non-flushable) are the source of the problems. Most wastewater utilities advocate a general ban on all nonwoven wet wipes, arguing that no wipe is safe to pump. The manufacturers of nonwoven wipes, however, argue that the aforementioned problems in wastewater systems are caused exclusively by non-flushable wet wipes (such as baby wipes) disposed of incorrectly via the toilet instead of the household waste.

A systematic and comprehensive investigation into wipe-related operational problems in wastewater systems, to analyse the issue and derive solutions, has not been conducted to date.

1.2 Aims and approach

The overall aim of this thesis was to investigate the effects of nonwoven wet wipes in sewer systems, focussing on the sewer system compatibility of different types of nonwoven wet wipes. The distinction between “non-flushable” wet wipes and those marketed as “flushable” was of particular interest. Depending on which type of wipes (flushable/non-flushable) are found to be the major cause for the existing operational problems in sewer systems, the possible solutions vary greatly.

Over the last years the author of this thesis was a member and deputy chairwoman of the DWA working group ES-7.8 *Störstoffe in Entwässerungssystemen (*Non sewer items in wastewater systems). The DWA (Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V.) is the German Association for Water, Wastewater and Waste. Its working groups formulate technical standards and contribute to standardisation work in the areas water, wastewater, and waste. The aim of the working group ES-7.8 is to find solutions for the operational problems due to non-sewer items in German wastewater systems. Over the last years the main focus of the working group ES-7.8 lay on nonwoven wet wipes.

Engaging and working with the DWA group on the topic of nonwoven wet wipes in sewer systems was of great help for this thesis. For the first time (at least in Germany) all relevant stakeholders of the issue were united in a productive and solution-oriented working group. The stakeholders include wastewater utilities, wipe manufacturers, manufacturers of the raw material for nonwoven wipes, manufacturers of machines to produce nonwoven wipes, pump manufacturers, and research institutions. Engaging with the different stakeholders helped in developing the research design of this study.

The research presented in this thesis involves results from online surveys (among wastewater utilities and the general public), results from field experiments in a wastewater pumping station, and results from laboratory experiments.

To enable a differentiated and solution-oriented examination of the operational problems due to nonwoven wet wipes in sewer systems, reliable data on the problem characteristics in Germany is necessary, but not available to date. For the purpose of characterising the wipe-related operational problems, an online survey among German wastewater utilities was conducted.

Understanding which wipes are used by the general public and subsequently end up in the sewer system is of paramount importance to define solutions and address the problem publicly. Therefore, an online survey among the general public was conducted to characterise nonwoven wet wipe use and disposal.

Understanding which nonwoven wipes are being disposed of via the toilet leads to determining which wipes are actually found in pump blockages. Therefore pump blockages from an inner city pumping station were analysed regarding the content and type of nonwoven wet wipes in the clogging material.

Laboratory experiments with different types of nonwoven wet wipes were conducted on a pump test stand to determine whether the findings from the field could be supported and to investigate the clogging effect of different types of nonwoven wet wipes.

1.3 Research questions

The following research questions were defined for the thesis:

RQ1: How do nonwoven wet wipes in sewer systems impact German wastewater utilities?

RQ2: How are nonwoven wet wipes being used and disposed of among the general public in Germany?

RQ3: Which types of nonwoven wet wipes can be identified as causing problems in sewer systems?

RQ4: Do different types of nonwoven wet wipes have different pump clogging effects and can this be demonstrated in the laboratory?

1.4 Thesis structure

The thesis is divided into seven chapters. Chapter 1 presents and explains the subject area, the overall aims, and the structure of the work. After this introductory motivation the available and relevant literature on the topic is reviewed in Chapter 2. The materials and methods used for the thesis are presented in Chapter 3. Chapter 4 contains the results of the online surveys, the field experiments and the laboratory experiments. Chapter 5 gives a discussion of the results, summarizes the uncertainties and reviews the possible weaknesses. Also, the results are linked to the research questions. Based on the results, conclusions are drawn and recommendations are discussed in Chapter 6. Finally, Chapter 7 gives an outlook on the topic.

2 Technical background

This chapter gives an overview over nonwoven fabrics, with a particular focus on nonwoven wipes, and presents the current state of research on nonwoven wet wipes in wastewater systems.

2.1 Nonwoven fabrics

Wet wipes are made of nonwoven fabrics. Nonwoven fabrics are manufactured sheets or webs in which the fibres are bonded mechanically, thermally, or chemically. This excludes products that are woven or knitted. As the porous fabric is made directly from the fibre (or molten plastic), it is not necessary to convert the fibres to yarn.

To date, the only internationally acknowledged definition for nonwovens is EN ISO 9092. It defines nonwovens as follows: “A nonwoven is an engineered fibrous assembly, primarily planar, which has been given a designed level of structural integrity by physical and/or chemical means, excluding weaving, knitting or papermaking” [9].

Recently, the international industrial associations serving the nonwovens industries, INDA (Association of the Nonwovens Fabrics Industry) and EDANA (European Disposables and Nonwovens Association), have proposed the following text to the International Standardization Organization: “A nonwoven is a sheet of fibres, continuous filaments, or chopped yarns of any nature or origin, that have been formed into a web by any means, and bonded together by any means, with the exception of weaving or knitting. Felts obtained by wet milling are not nonwovens.” [10]

Nonwoven products are manufactured to fulfil certain purposes and functions and thus can have very different product features. They can be engineered as disposable products for single-use or as durable re-usable products (or products with a long lifetime). On their website EDANA lists the most important products and applications for nonwovens [11]:

- Absorbent Hygiene Products
- Agriculture and Horticulture
- Automotive
- Building
- Cable wrapping

- Civil engineering or geotextiles
- Clothing, footwear, baggage
- Filtration
- Industrial
- Industrial wipes
- Medical
- Packaging
- Personal care products
- Personal care wipes
- Protective clothing

2.1.1 Manufacturing of nonwovens

The process of manufacturing nonwoven fabrics consists of a series of steps: 1) choosing the raw material, 2) forming a fibrous web, 3) bonding the web to enhance stability, and 4) finishing of the fabric to modify or enhance existing properties of the fabric [12]. The choice of raw materials determines the softness, the absorbency and the biodegradability of the finished nonwoven as well as the price. The web laying and web bonding are decisive for the achieved strength of the material.

Raw materials

The choice of fibre depends on the desired properties of the finished fabric as well as cost-effectiveness and processability. Nearly any type of fibre can be used to manufacture nonwoven products. This includes natural fibres (cotton, jute, flax, wool) as well as man-made fibres. According to [13], man-made fibres dominate nonwovens production, accounting for over 90 % of the total output. Man-made fibres can be divided into three classes: fibres from natural polymers (e.g. viscose rayon or regenerated cellulose), fibres from synthetic polymers (e.g. polyester (PES), polypropylene (PP), etc.), and fibres from inorganic materials (e.g. glass, carbon, etc.).

Web formation

In the web formation step, previously prepared/formed fibres (staple fibres packed in bales) or filaments (extruded from molten polymer granules) are combined to layers of loosely arranged networks: webs, mats, sheets, or bats [14, 15]. According to the respective method of web-formation, the nonwovens can be divided into drylaid nonwovens, wetlaid nonwovens, and spunmelt nonwovens (encompassing spunbond/spunlaid, meltblown, and flashspun) [13]. Figure 2-1 shows photomicrographs of four different nonwoven webs.

Figure 2-1: Photomicrographs of different types of nonwoven fabrics by web formation type [16]

Drylaid nonwovens

Drylaid nonwovens are made from staple fibres which are processed to a web in a dry state. There are two methods to dry lay webs, namely carding and airlaying.

Carding: Carding is a mechanical process in which fibres are separated and individual fibres are delivered in the form of a web.

Airlaying: In airlaying, the fibres (which can be very short) are uniformly dispersed in an airstream and laid on a conveyor belt or drum, where they form a random web. Airlaid webs have a lower density than carded webs, as well as a greater softness and an absence of laminar structure [15]. A wide variety of fibres and fibre blends can be used in airlaying.

Wetlaid nonwovens

The principle of wetlaying is similar to papermaking. Short fibres are suspended in a liquid and the aqueous solution is deposited on a moving screen or conveyor belt and drained to form a web. The web is then further consolidated and dried. Both man-made and natural fibres can be used for wetlaying; however, short fibre lengths (0.3 – 10 mm) are important for the manufacturing process [13, 15].

According to [17], wetlaid nonwovens can be distinguished from wetlaid paper "provided they contain a minimum of 50 % of man-made fibres or other fibres of non vegetable origin with a length to diameter ratio equals or superior to 300, or a minimum of 30 % of man-made fibres with a length to diameter ratio equals or superior to 600, and a maximum apparent density of 0.40 g/cm³. Composite structures are considered nonwovens provided their mass is constituted of at least 50 % of nonwoven as per to the above definitions, or if the nonwoven component plays a prevalent role."

Spunmelt nonwovens

The principle of spunmelting is producing filaments by extrusion spinning process from molten polymers. They are deposited on a moving conveyor belt as a random oriented web. As intermediate steps are eliminated, this is a very cost efficient method of producing fabrics [13, 15]. The two main spunmelting processes are spunbonding (also called spunlaying) and meltblowing.

Spunbonding (also called spunlaying): Polymer granules are melted and extruded as continuous filaments through a system of spinnerets in a current of air. The filaments are deposited onto a conveyor belt to form a uniform web. Some filaments may bond due to high temperatures; however, this is not the principal form of bonding. Nonwovens manufactured with the spunlaying/spunbonding process have high tensile strength. Co-extrusion of a second component is possible, e.g. to provide additional properties or bonding capabilities [15].

Meltblowing: Dissolved or molten polymers with a low viscosity are extruded into a high-velocity air stream. In the airstream the melt is cooled, solidified, and broken into microfibres. The fibres are blown onto a conveyor belt, forming a fine, randomly laid, self-bonding web, which has low to moderate tensile strength [13, 15].

Bonding

After web formation, the webs are consolidated in the bonding step to increase web strength. There are three basic nonwoven bonding processes: mechanical bonding, chemical bonding, and thermal bonding. Hydrogen bonding is also important for consolidating cellulosic webs. The bonding method employed is at least as important for finished fabric properties as the raw material.

Mechanical bonding

In mechanical bonding the web consolidation is achieved by physically entangling the fibres. There are two major methods of mechanical bonding: needle-punching and hydroentanglement.

Needle-punching: Needle punching is used to bond drylaid and spunbonded/spunlaid webs. Barbed needles are passed through the web, pushing, pulling and entangling the fibres. Different web types can be combined through needle-punching, achieving enhanced fabric properties. Needle-punched fabrics have a high tensile strength. Main applications are geosynthetics, filter media, waddings and paddings, automotive fabrics, insulation, wipes, and roofing [13, 18].

Hydroentanglement (also called spunlacing, wetlacing or water jet needling): Hydroentanglement is mainly used to consolidate carded and wetlaid webs, but others can also be bonded. The fibres are physically entangled by high-velocity water jets. In addition to bonding the web, the water jets can also be used to generate patterns and three-dimensional effects. Hydroentanglement, too, provides the possibility of combining two or more webs to produce multi-layer fabrics. Main applications for hydroentangled fabrics are wipes, surgical fabrics, domestic fabrics, and high-temperature protective clothing [13, 18].

Thermal bonding

Thermal bonding (also cohesion bonding) is used to consolidate drylaid, spunmelt and wetlaid webs, as well as multilayer materials. This method requires a thermoplastic component to be present in the web. This can either be the fibre itself or an additionally introduced low-melt or bicomponent fibre (binder fibre). The web is heated until the binder fibre melts or becomes viscous and thus bonds the fibres together. Thermal bonding systems in use include calendering, through-air thermal bonding, drum and blanket systems, and sonic bonding. Thermal bonded nonwoven fabrics are used across all sectors, including single-use hygiene disposable products and long-use durable products, e.g. in building or construction materials [13, 18].

Chemical bonding

In chemical (or adhesive) bonding the fibres are bound together by a liquid based bonding agent. Water-based binders are most commonly used, but powdered adhesives, foam, and organic solvent solutions can also be applied. Different techniques are used for applying the binder, e.g. impregnating, coating, spraying or print bonding. The binder also affects the properties of the final product, e.g. its strength, softness, waterproofness and breathability. Binders can also be applied to already bonded webs (such as needle-punched and hydroentangled fabrics) to provide enhanced properties. Chemically bonded nonwoven fabrics are used in automotive fabrics, filters, packaging, and nonwoven healthcare products, such as surgical clothing and wipes [13, 18].

Finishing

To enhance or add certain desirable properties to the final product, nonwoven fabrics undergo a finishing process. By improving the appearance, aesthetics or functionality of a nonwoven, its value is increased. There is no standard finishing procedure. Methods employed are wet finishing (e.g. washing, chemical impregnation, dyeing, and coating) and dry finishing (e.g. calendering, embossing or microcreping). Figure 2-2 gives a systematic overview of the process steps in manufacturing nonwoven fabrics.

OVERVIEW OF MANUFACTURING PROCESSES OF NONWOVEN FABRICS

Raw materials		**Natural fibres** Wool, cotton, flax	**Man-made fibres** • Natural polymers (viscose rayon, …) • Synthetic polymers (PET, PP, …) • Inorganic materials (glass, carbon, ...)
Web formation	**Drylaid** • Carding • Airlaying	**Wetlaid**	**Spunmelt** • Spunbonding/Spunlaying • Meltblowing
Web bonding	**Mechanical** • Needle punching • Hydroentanglement	**Thermal** • Calendering • Through-air • Sonic	**Chemical** • Water-based binders • Foam • Powders • Organic solvents...
Finishing		**Wet finishing** • Washing • Impregnation • Dyeing • Coating...	**Dry finishing** • Calendering • Embossing • Micro-creping...
Products		**Spunmelt nonwovens** • Spunbond/spunlaid • Spunmelt • Spunlace...	**Staple fibre nonwovens** • Wetlaid • Airlaid • Carded • Wetlace • Airlace...

Figure 2-2: Systematic overview of manufacturing processes for nonwoven fabrics

2.1.2 Nonwoven wipes

Nonwoven wipes can be classified as disposable single-use products and those that are durable or semi-durable and intended for longer use. They are sold either as dry wipes or wet wipes (containing lotion). They can also be distinguished according to their intended use, as personal care wipes (personal hygiene, including baby wipes, household cleaning, etc.) and industrial wipes. Industrial wipes can be used for a wide variety of applications, e.g. in manufacturing, maintenance, food industry as well as janitorial and medical applications.

Wet wipes

Wet wipes are pre-moistened nonwoven wipes. Nowadays, they are used for many purposes in daily life, mainly for personal care applications. They provide users with time-saving, ready-to-use products and often replace conventional dry-and-wet combinations in cleaning and hygiene tasks (e.g. wash cloth and water). Moreover, they can be used on the go or at home and thus reflect the need for fast and convenient solutions and the increased need for hygiene.

The variety and applications of personal care wet wipes have steadily grown over the last years. While baby wipes have been on the market longest [6], nonwoven wipes for personal care now include cosmetic wipes, cleansing wipes, wipes for toddler and adult toilet hygiene (moist toilet wipes), feminine hygiene wipes, hand and body cleaning wipes, household cleaning wipes, and many more.

By modifying base materials and impregnating lotions, manufacturers can tailor wipes to different needs and meet varying requirements. The majority of wipes are made from blends of synthetic polymers (polyester, etc.) and natural polymers (viscose fibres and/or wood pulp) [2]. The advantage of the viscose/wood pulp fibres is their high absorbency and their biodegradability. Important properties of the synthetic polymer fibres are their strength, softness and solvent resistance. For household cleaning wipes, high tensile strength and a soft, surface-friendly material are of importance. The same attributes are required of baby wipes. Thus these wipes are manufactured using high percentages of synthetic polymers, leading to products which are not biodegradable but soft to the touch. For cosmetic wipes, on the other hand, absorbency is a major factor, while wipes marketed as “flushable” should to be biodegradable. Therefore these wipes have a higher percentage of natural polymers. Depending on their intended use, the wipes can be further adapted using impregnating lotions, such as biocides, alcohols, perfumes, surfactants, etc.

Wet wipes can further be categorized according to their designated disposal route into “flushable” and “non-flushable” wet wipes (see Figure 2-3). Different aspects of “flushability” are discussed in chapter 2.3. Excepting moist toilet wipes (and very few other products, such as some toilet disinfecting wipes and some intimate hygiene wipes) all other wet wipes should be disposed of via the household waste, as per package instructions. Aspects such as biodegradability or fast disintegration in water are not considered in manufacturing these products, as these properties would counteract other necessary requirements (such as high tensile strength).

For moist toilet wipes, however, biodegradability and fast disintegration are inherent requirements to ensure their sewer system compatibility and thus justify the label “flushable”. For this reason moist toilet wipes have a significantly lower wet strength and tear resistance and should consist of fully biodegradable fibres. Figure 2-3 gives an overview over nonwoven wet wipes for personal care, classified according to their flushability labelling.

Nonwoven wet wipes for personal care			
Labelling	Non-flushable		Flushable
Disposal according to packaging	Waste		Toilet
Wipe type	Dry wipes	Wet wipes	Wet wipes
Examples	Dusters	Baby/cosmetic wipes	Moist toilet wipes, very few disinfecting wipes
Requirements	High tensile strength, soft surface		Biodegradability, low wet strength
Sewer system safe	No		Not all

Figure 2-3: Nonwoven wet wipes categorized according to their designated disposal route

Flushable wipes

Wipes labelled as “flushable” (also called “dispersible wipes”) are pre-moistened nonwoven wipes which are mainly sold as moist toilet wipes. According to the manufacturers and the packet instructions, they can be disposed of via the toilet. However, experiences of the last years have shown that “flushable” does not necessarily mean “sewer system compatible”. Some nonwoven wipes marketed as flushable do not disintegrate sufficiently, while others contain a small amount of synthetic polymer fibres to enhance their strength [2]. This precludes them from being biodegradable and thus sewer system compatible. Nonetheless, the last years have seen a shift from “flushable by size” to truly sewer system safe, which can be achieved by the appropriate combination of raw materials and manufacturing technologies.

Prerequisites for producing sewer system compatible nonwoven wet wipes are a) using short, 100 % biodegradable fibres (no synthetic polymers) combined with b) using bonding processes that are reversible [8, 19]. Thermal bonding, as well as most chemical bonding procedures, lead to irreversible crosslinks between fibres. Thus the nonwoven wet wipe cannot disintegrate into separate fibres in the water. Incorporating water-soluble or redispersible polymeric binders as a chemical bond is an option for creating dispersible wipes. Their sewer system compatibility, however, is only given if the binders are biodegradable and environmentally acceptable. Moreover, technical challenges with water-soluble binders include preventing the binder from dissolving during storage [19]. Hydroentanglement, on the other hand, has proven to be an appropriate bonding method for dispersible wet wipes in the past [14, 19]. Figure 2-4 gives an overview of the technology combinations being employed successfully to manufacture truly flushable (sewer system compatible) nonwoven wet wipes.

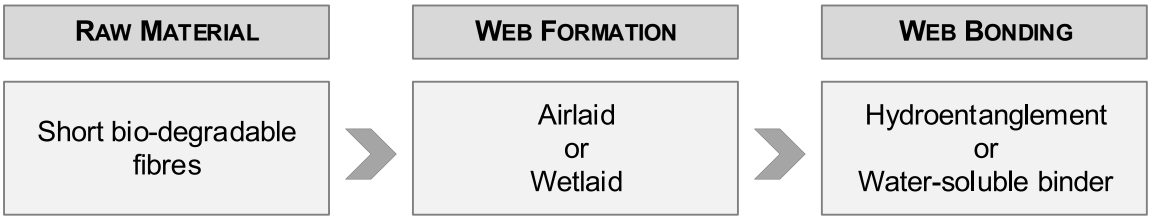


Figure 2-4: Overview of technology combinations to manufacture truly flushable (sewer system compatible) nonwoven wipes

2.1.3 Market overview of the nonwovens and wipes industry

The first nonwoven wet wipe, the “Wet-Nap”, was invented in the United States in 1958 by Arthur Julius and first sold to Kentucky Fried Chicken restaurants in 1962. Today Julius’ company Nice-Pak is the world’s leading producer of nonwoven wet wipes [20, 21]. The first wipes specifically marketed for babies followed soon after (e.g. Proctor & Gamble’s Pampers and Kimberly-Clark’s Huggies) and by 1990 private label baby wipes were available in many supermarkets [22]. In Europe the first moist toilet wipe was introduced by Hakle as *Hakle Feucht* (Hakle Moist) in 1977 in Germany [23]. In the United Kingdom (UK) moist toilet wipes (named moist toilet tissue) were originally sold by the company Andrex (which is called Cottonelle in the US and Germany) [24].

The global nonwoven wipes market reached US$3.1 billion and 1.1 million tonnes in 2016, with an annual growth of 6.8 % in USD between 2011 and 2016. Growth forecasts predict a market value of US$4.4 billion and 1.5 million tonnes in 2021 (predicted annual growth is 7.0 % in USD) [25]. North America and Western Europe are the leading markets for nonwoven wipes, with Western Europe slightly ahead of North America. While baby wipes were the most sold product up until

2003, they were then supplanted by household wipes in the consumer wipes section, when the diversity of the product range was broadened [14].

In Europe, the nonwoven fabrics (including nonwoven wipes) are a steadily growing market. Production of nonwovens (single-use as well as durable products) reached 2.4 million tonnes in 2016 (a growth of over 233 % since 2000), as shown in Figure 2-5. The estimated total turnover of nonwoven roll goods in 2016 was around €7.6 billion (~ US$8.4 billion) [26].The market share of personal care wipes (based on deliveries) amounted to 12.4 % (Figure 2-6) and thus was the second largest sector in Europe, behind hygiene products. Germany is by far the largest producer of nonwoven fabrics and products in Europe, followed by Turkey and Italy (Figure 2-7). Overall, EDANA estimates that nearly 27,000 people were employed in the nonwovens industry in 2016 (an increase of 6.0 % compared to 2015) [26].

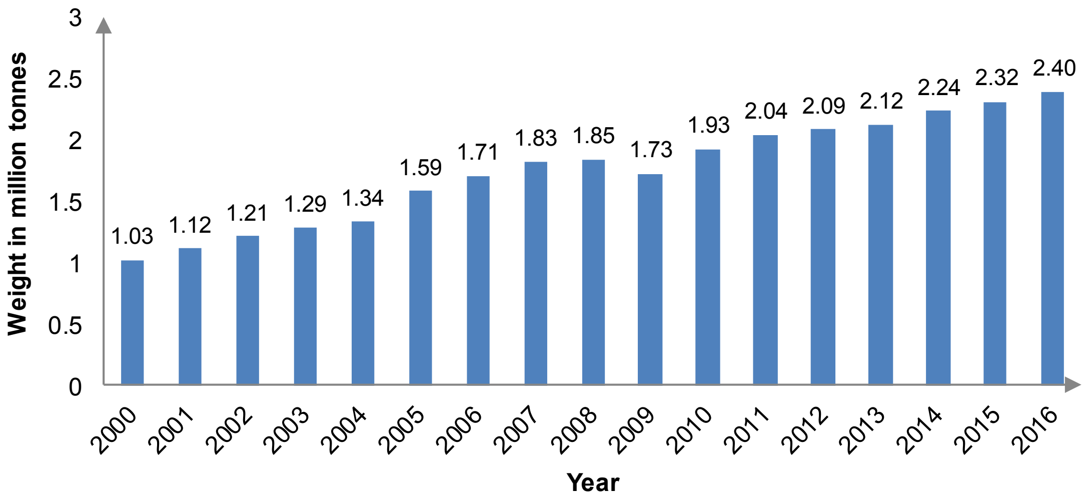


Figure 2-5: Nonwoven production in Greater Europe in million tonnes in 2016, data from [26]

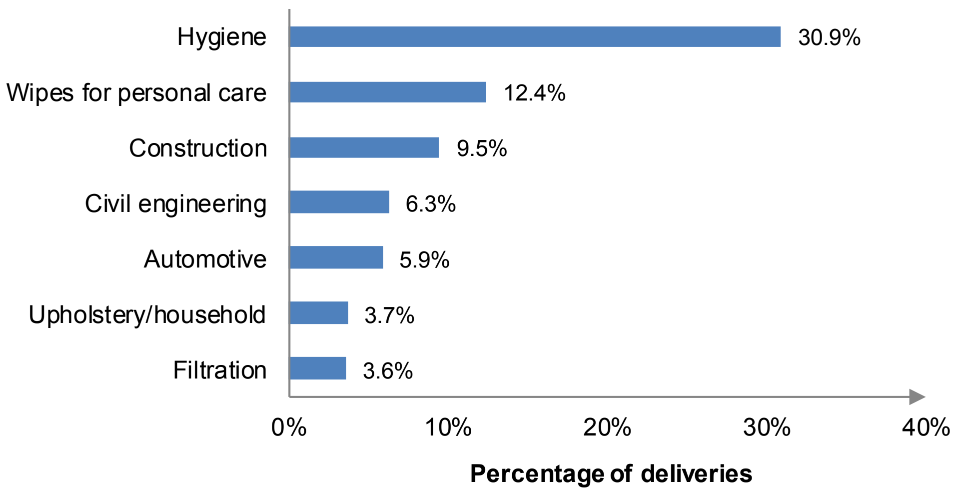


Figure 2-6: Main market segments of nonwovens roll goods (in terms of market volume) in Europe in 2016, data from [26]

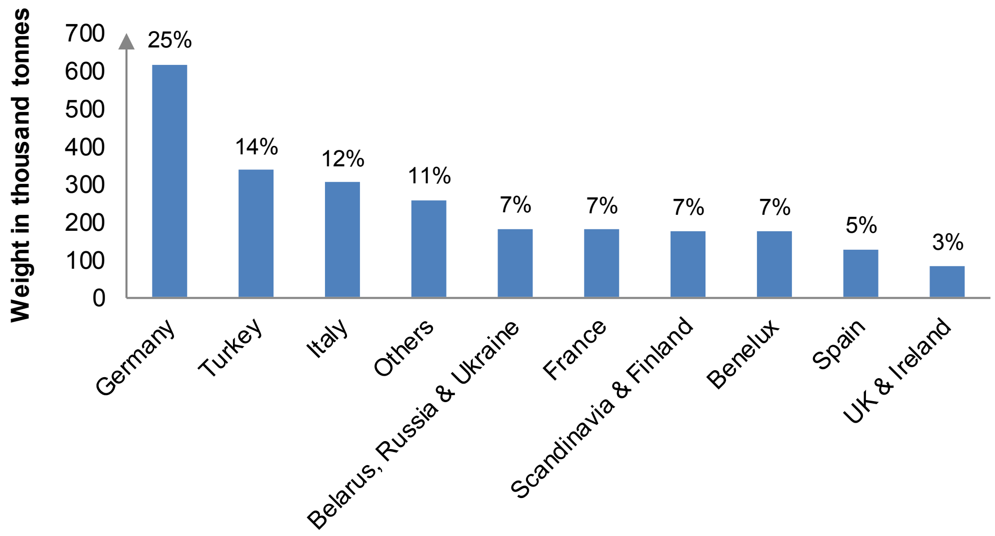


Figure 2-7: Nonwoven production in Greater Europe in thousand tonnes in 2016, data from [26]

2.2 Nonwoven wipes in the wastewater system

According to the ISO Technical report 24524 [27], wastewater transport and treatment systems are increasingly confronted with products that are marketed as "flushable", but that are not compatible with the current infrastructure, as they do not disintegrate adequately and are not biodegradable.

Despite this, little is known about the fate of nonwoven wet wipes in sewer systems and only limited information is available in the current scientific literature. Most studies focus on suspended solids that originate from sanitary sources and surface run-off [28–30]. A small number of research groups have focussed on transport properties of large solids in sewers [31–37]. Fewer still have researched characteristics of flushable consumer products (FCPs) in sewers, focussing mainly on their disintegration. Karadagli, McAvoy et al. [38] developed a theoretical approach for physical disintegration of FCPs, while Karadagli, Rittman et al. [39] investigated the effect of turbulence on the disintegration rate of FCPs. A newer investigation by Pantoja Munoz, Gonzalez Baez et al. [2] analysed the fibre composition of non-flushable and flushable nonwoven wet wipes. They found that some flushable nonwoven wet wipes contain synthetic polymer material (PET, HDPE, PU, etc.). Moreover, some of the flushable wipes in their study were marketed as "biodegradable", despite containing synthetic non-degradable polymers. Based on these material properties, at least some flushable nonwoven wet wipes can be considered as possible sources for microplastic fibres in the aquatic environment.

Clogging and blockages caused by nonwoven wipes in the wastewater system are a concern for wastewater utilities worldwide. So far, there are only very few published studies regarding clogging and blockage problems or physical wastewater composition, especially focussing on nonwoven wipes. This chapter gives an insight into the magnitude of the problem confronting wastewater utilities, based on the available literature. It also discusses the available studies on wastewater composition and occurrence of nonwoven wipes in the wastewater system.

2.2.1 Impacts on wastewater utilities due to nonwoven wipes

All over the world, utilities and their customers face property damages, financial costs, microbial and chemical threats and health risks due to operational problems caused by nonwoven wet wipes in sewer systems. This leads to high investments for repair and replacement of damaged wastewater equipment [40]. Articles reporting on damages caused by nonwoven wet wipes have been published in various languages by well-known print and online media such as the New York Times (US) [41–44], The Guardian (UK) [45–49], National Post (Canada) [50, 51] and Süddeutsche Zeitung (Germany) [52].

Sydney Water, the water and wastewater utility serving Greater Metropolitan Sydney, Australia, has been observing increasing operational problems due to sewer system incompatible nonwoven wipes over the last years. According to [3] and [4], 500 tonnes of nonwoven wipes are being removed from Sydney's sewers every year – an average of 1.3 tonnes per day, which amounts to yearly costs of AU$25 million (~ US$17 million). In response to the increasing amount of wipes being flushed, Sydney Water launched a public education campaign called "Keep wipes out of pipes" [3] in 2015, for which they have won numerous prizes (see Figure 2-8). In the campaign Sydney Water calls upon their customers not to flush any wipes, regardless of their label (flushable/non-flushable), as in their experience and according to their tests even the wipes labelled as flushable are not sewer system compatible at all (due to low disintegration and plastic fibres in the products).

Figure 2-8: Images from the public education campaign by Sydney Water to reduce the amount of nonwoven wipes being flushed into their system [3]

New York City found that with the increasing sale of nonwoven wipes (flushable and non-flushable), the presence of sewer system incompatible wipes in their systems has also increased – leading to numerous problems such as back-ups, pump cloggings and screen blockages [6]. NYC Water, part of the New York City Department of Environmental Protection, spends US$18.8 million every year to deal with damage caused by wipes and other non-sewer items (such as grease). The city estimates that of the 53,000 tonnes of screenings collected from its 14 WWTPs, 95 % was wipes. NYC Water, too, requests that no nonwoven wet wipes, whether labelled flushable or non-flushable, be flushed into their system, as they do not think that any nonwoven wipe is sewer system safe [5]. Again, cited reasons are the use of plastic fibres in flushable products and the products' slow disintegration, compared to paper-based toilet paper.

In London, UK, Thames water clears five wet wipe-related blockages an hour from its sewer network. This makes 85,000 blockages a year and costs around £12 million (~ US$14.88 million) [7]. In the recent past, so-called "fatbergs" have become headline news in London. These conglomerates of congealed fat and non-biodegradable solids (mainly nonwoven wet wipes) block sewers and can cause sewer overflows. In 2013, a fatberg was found in the sewers in Kingston-upon-Thames, London, and in 2015 a 10-tonne fatberg broke a sewer in Chelsea, London, costing Thames Water £400,000 (~ US$530,630) to fix [53]. The largest fatberg so far, named “Fatty McFatberg” by the British public, was found in 2017 in Whitechapel, London. It weighed over 130 tonnes and spanned 240 m (see Figure 2-9). Ninety-three percent of its structure was said to consist of wet wipes [53, 54].

Thames Water is trying to raise awareness of the issue of wet wipes in sewers with the campaign “Bin it – don’t block it” [55]. In the campaign they name fat, cooking oil, wet wipes, and sanitary products as the biggest cause for blockages in their system. They advocate only flushing the three Ps – pee, poo and (toilet) paper – and nothing else. Moreover, they ask of their customers to try using alternatives for wet wipes, e.g. pre-moistening toilet paper with cleansing foam before use.

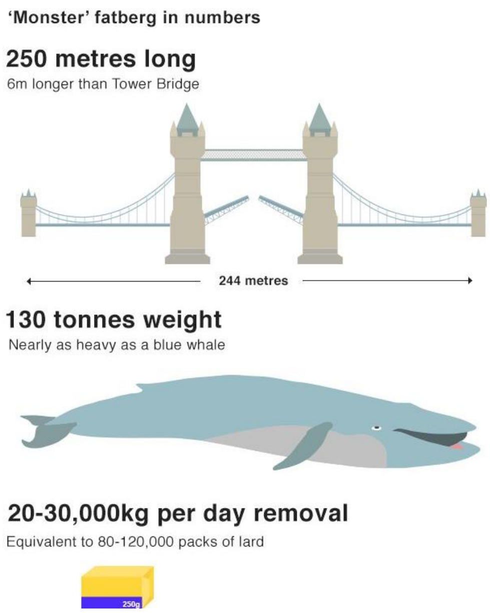


Figure 2-9: East London Whitechapel fatberg from 2017 in numbers [56]

Wessex Water Services Limited, a water supply and sewerage utility company serving an area of South West England covering 10,000 square kilometres, published a “wet wipes evidence report” [57] in which they documented the consequences of flushing sewer system incompatible wet wipes. In 2015, they cleared more than 13,000 blockages from the public sewer network. Analyses showed that 80 % of the sewer blockages resulted from customers disposing of inappropriate items down the toilet or sink (sewer misuse), as shown in Figure 2-10. Of these sewer misuse blockages, 70 % were due to nonwoven wet wipes being flushed into the sewer system. In their report Wessex Water states that many customers have contacted them to complain that they experienced blockages even when using only nonwoven wet wipes labelled as “flushable”.

Wessex Water follows a two-pronged approach to counteract the problem. They lobby manufacturers and retailers as well as educating the public on what can and cannot be flushed. Moreover, they approached the UK Advertising Standards Agency with their report, arguing that manufacturers of wet wipes were wrongly using the term "flushable" for their product and thus were misleading the public and encouraging customers to inadvertently break the law [57].

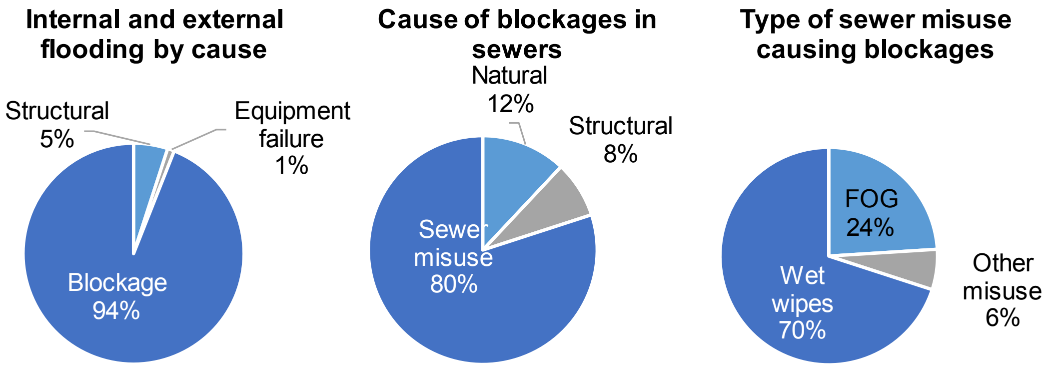


Figure 2-10: Causes of blockages and flooding in the catchment area of Wessex Water, UK, adapted from [57]

In Germany, concrete information regarding clogging and blockages (e.g. number of blockages, costs) is not publicly available from wastewater utilities. The larger utilities inform their customers on their websites that waste should not be flushed down the toilet and mention wet wipes among other non-sewer items, such as cooking oil and grease, or pharmaceuticals [58, 59]. Nonetheless, publications in journals and magazines for the wastewater sector show that the operational problems due to nonwoven wet wipes have been increasing for more than 15 years in the whole country [8, 60–63].

Conclusions:

- It is evident that nonwoven wet wipes cause operational problems in wastewater systems all over the world.
- The utilities' main issues with flushable nonwoven wipes are their low dispersibility compared to toilet paper and the fact that at least some of them contain plastic fibres.
- The utilities call on their customers to refrain from using and flushing any type of wet wipe, whether labelled flushable or not. However, it is unclear whether the operational problems the utilities encounter due to wet wipes are caused by flushable wet wipes or non-flushable wet wipes.

2.2.2 Studies on the amount of nonwoven wet wipes in urban wastewater

To date, there are very few published studies regarding the amounts and type of nonwoven wipes in the wastewater or in clogged wastewater pumps, and hardly any literature in reviewed scientific journals. Of the few investigations that can be found, many do not distinguish between flushable and non-flushable nonwoven wipes, as this distinction is difficult to make for wipes that have been in the wastewater system.

In 2015, the author of this thesis conducted a field campaign [64] to investigate the physical constituents in wastewater, focussing on nonwoven wipes. Twelve samples were collected in two inner city catchment areas over the course of a year. All physical constituents were removed from the current wastewater flow, thus enabling specific values to be determined per m^3 wastewater. The samples were dried and analysed by a textile laboratory. The fraction "nonwovens" was not further distinguished into flushable and non-flushable nonwoven wipes.

It was found that the amount and composition of the wastewater constituents varied greatly from one sample to another, without clear correlation to season or weather (see Figure 2-11). Nonwoven wipes were present in most samples and it could be shown that the concentration of nonwovens increased along the path of wastewater transport, accumulating in critical points, such as the pumping station wet well (suction chamber) and the pump itself (see Figure 2-12). This is an example of how even small amounts of sewer system incompatible nonwoven wipes in the wastewater system can cause problems during transport and treatment.

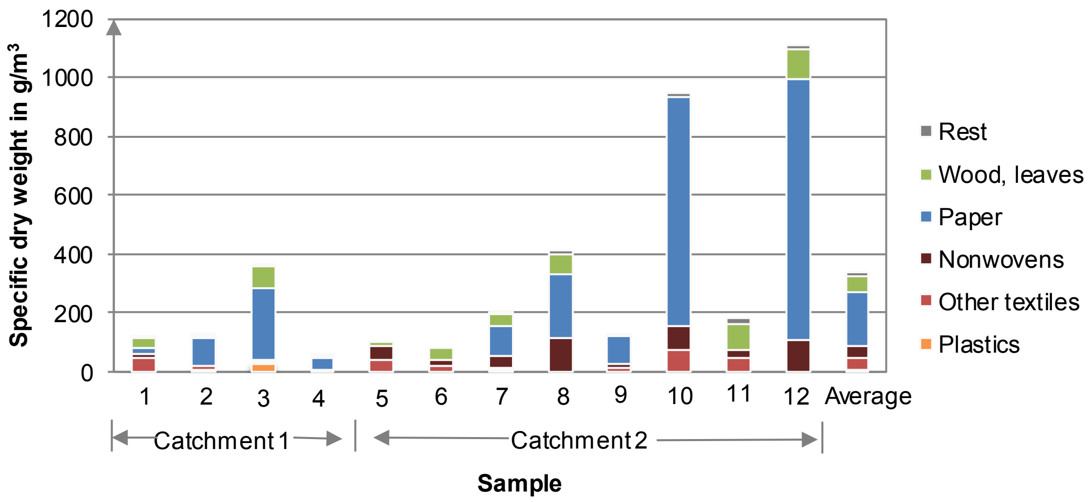


Figure 2-11: Solids per m^3 wastewater in samples of Berlin wastewater [64]

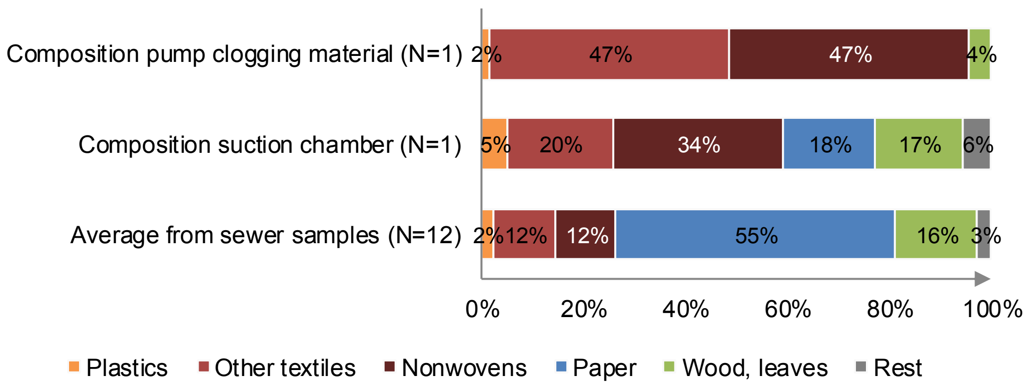


Figure 2-12: Percentage distribution of solids in samples from Berlin wastewater system, adapted from [64]

The New York City Law Department (USA) commissioned Fuss & O'Neill Engineers to conduct a forensic evaluation of so-called non-dispersibles in wastewater in 2016. Two grab samples were collected from screens of two separate channels of the Wards Island Wastewater Treatment facility. The purpose of the investigation was to provide a snapshot of materials present in the inflow to the WWTP and to determine the types of wipes recovered, including the brand [65]. The study remains unclear on whether dry or wet weights were used to determine the fractions (an important distinction, as different materials have very different water absorption capacities). Furthermore it remains unclear how such a high degree of identification was reached regarding the nonwoven wipes in the samples (identification was determined by visual inspection and comparison with reference samples).

The study found that only 1.6 % of materials in the samples were flushable (wipes sold as flushable), while 98.4 % were non-sewer items that should not be flushed but disposed of via the household waste. Of the non-sewer items, the largest fraction was made up of nonwoven wet wipes. These were mainly found to be baby wipes, which accounted for over a quarter (27.6 %) of the total sample, as can be seen in Figure 2-13.

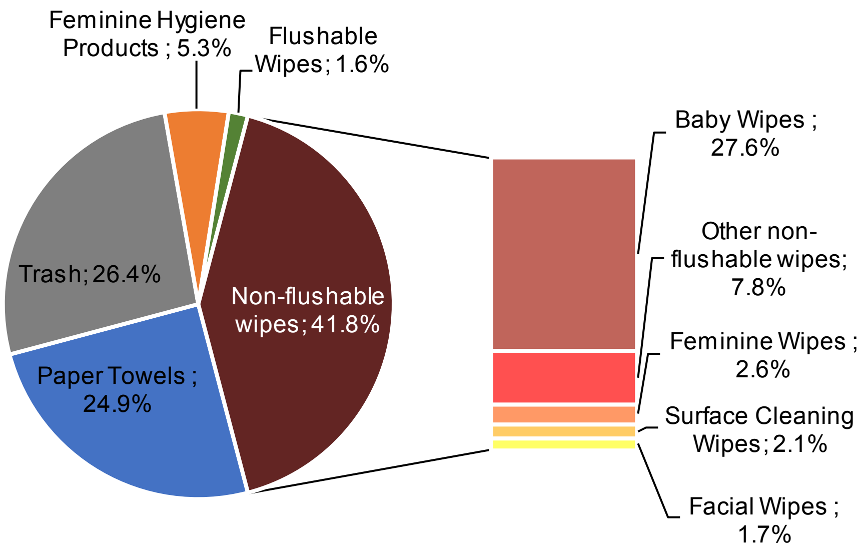


Figure 2-13: Percentage distribution of solids in study of NYC WWTP.
Average of two grab samples from two separate channels of Wards Island Wastewater Treatment Facility, own figure with data from [65]

In the UK, the WRc Group, an independent public limited company providing research and consultancy in water, waste and the environment, has conducted several studies for Water UK (a membership organisation representing all major statutory water and wastewater service providers in England, Scotland, Wales and Northern Ireland) on nonwoven wipes in sewers in the past. The most recent study was finished in autumn 2017 and comprised 54 samples from sewers, pumps and WWTPs [66]. The objective of the study was to obtain updated information regarding the composition of sewer blockages and pump clogs which could then be used to help reduce the incorrect disposal of non-flushable products. Sample constituents were sorted into different categories, according to their intended use (e.g. textiles, baby wipes, female hygiene products) and the wet weight for each fraction was determined (samples were hand-wrung). The process of identification of wet wipe samples is not described and a large proportion of wipes remains unidentified, as is shown in the following Figure 2-14.

Just as in the New York study, only a minor proportion of all samples was made up of wipes sold as “flushable”. By far the largest fraction of identified constituents across all samples were the baby wipes. A small amount of other non-flushable wipes was also identified along with materials/textiles and feminine hygiene products.

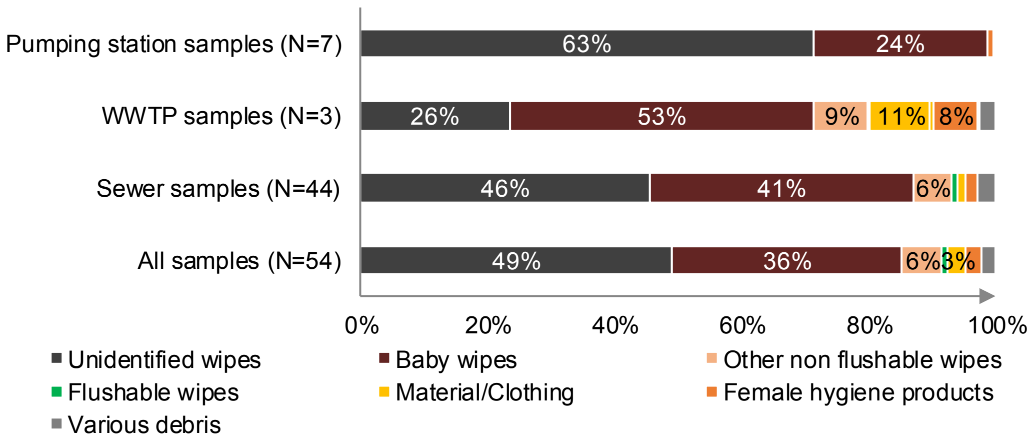


Figure 2-14: Percentage distribution of solids in study of UK sewer system. Own diagram with data from [66]

Conclusions:

- All of the studies presented here show that nonwoven wipes are a constant constituent in wastewater. They can become concentrated during wastewater transport and accumulate in pumps and sewers.
- However, it is important to distinguish the nonwoven wipes according to their designated disposal route. Less than 2 % of wipes analysed in the studies were found to be nonwoven wipes that were sold as flushable. The remaining wipes were all non-flushable wipes, mostly baby wipes.
- Further investigations are necessary, especially for the German wastewater system and with an improved method of identifying the different types of nonwoven wet wipes.

2.3 Flushability

2.3.1 Standardisation efforts

While consumers assume that “flushable” products must have been rigorously tested to carry that label and to ensure compatibility with wastewater transport and treatment infrastructure, there is in fact no standard definition of flushability. Internationally there have been several efforts to standardise flushability in the past, but to date none have been completed successfully. In the specifications below, the term “flushability” is used to mean sewer system compatibility.

International standardisation efforts - ISO

An ISO (international standard) initiative was commenced in 2014 by Canada. Initially ISO/TC224/WG10 (ISO Technical Committee 224/Working Group 10) had the goal of developing a technical specification for flushable products. The international committee consists of both utility representatives as well as representatives from the wipes manufacturing industry. The work was interrupted due to a dispute over responsibility within different ISO groups. Subsequently, the scope was reduced to a Technical Report and finalized by the working group at the end of March 2018: *ISO/TR 24524 - Service activities relating to drinking water supply, wastewater and stormwater systems — Hydraulic, mechanical and environmental conditions in wastewater transport systems* [67, 68]. The Technical Report was published in February 2019.

ISO/TR 24524:2019 details the hydraulic, mechanical and environmental conditions generally found in wastewater transport systems from toilets through to wastewater treatment plants, the general powers of wastewater services to manage discharges to sewers, and the responsibilities imposed on wastewater services by applicable local, regional or national legislation. The conditions listed in the document may be taken into account when designing and evaluating the performance of products designed to be flushed down the toilet [68].

European standardisation efforts - CEN

Working Group (WG) 22 (from CEN/TC165/WG22 - Drain and sewer systems outside buildings) develops standards for the collection and transport of wastewater outside buildings. Among other things, they deal with the control of inputs into wastewater systems [69].

WG 22 aims to develop a standard for the handling of introduced substances and the compatibility of a wide range of products with the wastewater system. This standard can act as a guideline for wastewater utilities. At a later stage, specific test methods may be integrated or appropriate test methods from other standards may be referred to. Currently, coordination is necessary with other working groups to determine competencies regarding the definition of criteria for flushability.

German standardisation efforts - DIN

There are no independent efforts by DIN (the German Institute for Standardisation) on the subject of flushability. In the DIN Standards Committee *Water Practice* (DIN-Normenausschuss Wasserwesen - NAW) the National Working Group (NA) 119-05-35 AA *Design and operation of drains and sewers* functions as a national mirror committee to CEN/TC165/WG 22 and ISO/TC224/WG 10 [69].

2.3.2 Flushability guidelines and specifications from industry and organisations

There are several approaches by institutions and industry associations to define test protocols to evaluate the sewer system compatibility (termed “flushability” in the respective specifications) of products labelled as flushable. The following specifications and guidelines have been published to date: *Protocols to Assess the Breakdown of Flushable Consumer Products* by the Water Environment Research Foundation (WERF) in 2003 [70], *Test Protocol to determine the Flushability of Disposable Products* by UK Water Industry Research (UKWIR) in 2012 [71], *Publicly Available Flushability Specifications* by the International Water Services Flushability Group (IWSFG) in 2016/2018 [72–74], *Guidelines for Assessing the Flushability of Disposable Nonwoven Products* by the Association of the Nonwovens Fabrics Industry (INDA) & European Disposables and Nonwovens Association (EDANA) in 2008/2018 [75] and *Fine to Flush Water Industry Specification* by the UK Water Industry in 2019 [76]. Their collective aim is to define and quantify the term "flushable". Some of the aforementioned flushability specifications serve manufacturers as voluntary and self-regulated guidance. However, uniform, consistent, and binding standards for flushable products that satisfy both wastewater utilities and manufacturers of nonwoven wipes have not been determined to date. Moreover, the term “flushable” is not protected and can be used indiscriminately to market and advertise products. So far only Belgium (2015) and Spain (2019) have passed legislation on performance and labelling of flushable products, based on the INDA/EDANA Flushability Guidelines, but partly adapted to conform to requirements of local utilities [77, 78].

In the following sections the relevant specifications and guidelines for flushability, including requirements for flushable products and test methods, are presented. They respectively claim to ensure the sewer system compatibility of products advertised and sold as “flushable”.

Requirements and test methods from INDA/EDANA

INDA and EDANA represent hundreds of companies worldwide along the nonwoven value chain. Both associations work internationally with authorities and organisations to define standards and product definitions.

INDA and EDANA have defined *Guidelines for Assessing the Flushability of Disposable Nonwoven Products* (first edition, GD1, published in 2008 and fourth edition, GD4, published in 2018) [75] to ensure the flushability of nonwoven products to be disposed of through the toilet. They have also published a Code of Practice (COP) with specifications regarding labelling of flushable and non-flushable nonwoven wipes to communicate the correct disposal to the customer [79]. As a central element the COP contains a “Do-Not-Flush” symbol (DNF symbol) to promote consumer awareness of wipes not meant to be flushed (see Figure 2-15). According to the COP, this symbol should be printed on the front of the package of all non-flushable nonwoven wipes (especially baby wipes, but recommended also for all other consumer wipes). The labelling guideline clarifies the position, size and visibility of the DNF symbol. INDA and EDANA stipulated the implementation of the COP by October 2018. However, while some non-flushable wipes display the “Do Not Flush” symbol on the front of the package, not all manufacturers and retailers comply with the COP. INDA/EDANA’s Flushability Guidelines, as well as the COP, are voluntary and self-regulated and thus adherence to the guidelines cannot even be enforced for INDA/EDANA members.

Figure 2-15: “Do Not Flush” symbol from the Code of Practice of INDA and EDANA [79]

The overall objective of the INDA/EDANA Flushability Guidelines is to ensure that any product that is marketed as “flushable” can be flushed into the sewer system without affecting the infrastructure and the operation of the sanitary facilities.

For a nonwoven wipe to be deemed sewer system compatible, and thus flushable, by INDA and EDANA it must

- clear toilets and properly maintained drainage pipe systems;
- pass through properly maintained wastewater conveyance systems and be compatible with wastewater treatment, reuse and disposal systems without causing system blockage, clogging or other operational problems; and
- be unrecognizable in effluent leaving on-site and municipal wastewater treatment systems and in digested sludge from wastewater treatment plants that are applied to soil [75].

The Flushability Guidelines comprise seven tests that evaluate the performance of the flushable wipe for different parts of the wastewater system (toilet, household drainlines, household pumps, and municipal wastewater pumps) as well as assessing the fate of the wipe in a wastewater environment (disintegration, settling, biodisintegration and biodegradability). An overview of the tests is given in Table 2-1. Only if all seven tests are passed, the nonwoven wipe is GD4 compliant and thus may be labelled as "flushable". If one or more of the tests are failed, the wipe is "non-flushable" and must be labelled with the "Do Not Flush" symbol. The tests can be carried out in accredited testing laboratories (e.g. the Center Technique du Papier (CTP), Grenoble, Switzerland, and SGS Labs, Appleton, USA).

Table 2-1: Overview of the seven tests in the INDA/EDANA Flushability Guidelines

	INDA/EDANA Flushability Test
Performance in wastewater infrastructure	FG501 Toilet and Drainline Clearance Test
	FG503 Household Pump Test
	FG507 Municipal Pump Test
Performance in wastewater environment	FG502 Slosh Box Disintegration Test
	FG504 Settling Test
	FG505 Aerobic Biodisintegration/Biodegradation Test
	FG506 Anaerobic Biodisintegration/Biodegradation Test

While the INDA/EDANA Flushability Guidelines are the only test protocols that are used by wipes manufacturers to date, they are often criticised by wastewater utilities. Main point of contention is that the guidelines were developed without sufficient input from wastewater utilities (especially from Europe) and thus serve industry interests, while failing to protect the wastewater infrastructure [40].

Wastewater utilities especially criticise

- that the use of plastic fibres in flushable nonwoven wipes is not expressly forbidden (the Flushability Guidelines state that manufacturers should comply with local legislation);
- that the procedure for the Slosh Box Disintegration Test and the associated acceptance criteria are too lenient and do not reflect actual conditions in the sewers; and
- that the pump tests (the Municipal Pump Test in particular) are not suitable to assess the clogging behaviour of nonwoven wipes in wastewater pumps.

Nonetheless, INDA/EDANA Flushability Guidelines were adopted without adjustment as Belgian legislation in 2015 (then third edition, GD3) [80]. Spain published a standard on flushability in January 2019 [78]. They include a settling test, a disintegration test, and an aerobic and anaerobic biodisintegration test very similar or identical to INDA/EDANA Flushability Guidelines. Additionally the Spanish standard requires that flushable products do not contain plastic fibres.

Requirements and test methods from IWSFG

The International Wastewater Services Flushability Group (IWSFG) is an international coalition of national and regional wastewater services' associations and organisations and individual wastewater services seeking to provide clear guidance on what should and should not be flushed down the toilet to protect customers, wastewater systems, their workers, and the environment. They put together a position statement on non-flushable and flushable labelled products in 2016 which is supported by over 250 water organisations worldwide [81].

It is the goal of the IWSFG to develop criteria for the flushability (i.e. sewer system compatibility) of products that can be disposed of via the toilet and to clearly identify non-flushable products. To this end, the IWSFG established its own *Publicly Available Flushability Specifications (PAS 1-3)*. To ensure worldwide acceptance among wastewater utilities, two draft versions of the Flushability Specifications were published in July 2017 and January 2018 for public comment. The final version of the Flushability Specifications was published in June 2018 [72–74]. However, as an international association of wastewater utilities, the IWSFG cannot impose any mandatory requirements for flushable or sewer system compatible products.

To be flushable according to the IWSFG, products should

- break into small pieces quickly;
- not be buoyant;
- not contain plastic or regenerated cellulose but only contain materials which will readily degrade in a range of natural environments [81].

The IWSFG Flushability Specifications specify five criteria that must be met for a product to be deemed suitable for flushing down the toilet and thus sewer system compatible. The criteria and associated test methods are listed in Table 2-2. The test methods in the IWSFG Specifications are strongly based on the INDA/EDANA test procedures, but are in some cases stricter in design and acceptance criteria. However, the IWSFG Specifications contain fewer tests than the INDA/EDANA

Flushability Guidelines, as the pump tests (household and municipal), aerobic biodisintegration/biodegradation test, and anaerobic biodegradation test are considered unnecessary to evaluate the flushability of a product. Unlike INDA/EDANA Flushability Guidelines, the IWSFG Specifications require that the flushable products do not contain plastic fibres, and, if they do, the percentage weight of these fibres should be below 1 % (in Criterion one: Safety in the Environment and Composition of Materials [72]).

Table 2-2: Criteria and test methods as specified in the IWSFG Flushability Specifications, adapted from [72]

IWSFG Criterion	Test method and reference documents
Safety in the Environment and Composition of Materials	TAPPI/ANSI Test Method T 401, Fiber Analysis of Paper and Paperboard; Responsibility of manufacturers to comply with all relevant and current legislation
Toilet and Drain Line Clearance	Test according to INDA/EDANA FG501, with stricter acceptance criteria for toilet clearance
Disintegration	IWSFG 2018: PAS 3 Disintegration Test Methods – Slosh Box. Method similar to INDA/EDANA FG502, but with stricter procedures and different acceptance criteria.
Settlement	Method and acceptance criteria same as INDA/EDANA FG504
Biodisintegration	Method and acceptance criteria same as INDA/EDANA FG506 (A)

Manufacturers and retailers of nonwoven wipes criticise that the IWSFG Flushability Specifications are too stringent, in particular the Disintegration Test, as no nonwoven wipe on the market can comply with the acceptance criteria. The experimental parameters, conditions, and pass/fail criteria of the Slosh Box Disintegration Tests of INDA/EDANA and IWSFG are compared in Appendix A. In 2018, Basel et al. presented a comparative trial of the INDA/EDANA and IWSFG Slosh Box Disintegration Test with different nonwoven wipes as well as with conventional toilet paper [82]. They came to the conclusion that the IWSFG Slosh Box Disintegration Test was too strict to clearly differentiate sewer system compatible flushable wipes from non-flushable wipes, whereas the INDA/EDANA Slosh Box Disintegration Test was able to make that distinction.

Requirements and test methods from UK Water Industry

The UK Water Industry published the Water Industry Specification (WIS) 4-02-06 *Fine to Flush – Specification for a testing methodology to determine whether a product is suitable for disposal through a drain or sewer system [76]* in January

2019. Water Industry Specifications are prepared by the UK Water Industry for the specification and purchase of products used in the industry. They generally cover products for which there is no suitable European or British standard. WIS 4-02-06 was prepared in a collaboration between the WRc Group and Water UK. This WIS specifies the test methods and requirements to determine whether a product is suitable for disposal through a toilet into a drain or sewer system. Like all the other flushability guidelines presented, the specifications of the UK Water Industry are based on a voluntary commitment by manufacturers or retailers of nonwoven products.

A product that is to be sold as "flushable" (i.e. sewer system compatible) according to UK Water Industry must be assessed against nine different criteria. Two are general requirements that demand a manufacturer’s declaration that these are fulfilled. The requirements and tests are summarized in Table 2-3.

Table 2-3: Criteria and test methods as specified in WIS 4-02-06, adapted from [76]

UK Water Industry Criterion	Test method
Intended Use	Manufacturer’s declaration
Safety in the environment	Manufacturer’s declaration
WC bowl clearance	Method similar to INDA/EDANA FG501, but using only test product. Slightly different pass criteria.
Drainline clearance	Method similar to INDA/EDANA FG501, but using only test product. Slightly different pass criteria.
Disintegration in the drainline	Three hours in water on an orbital shaker table
Snagging in the drainline	Snagging on snag points in pipe
Disintegration in the sewer system	Method as for first disintegration test, but with higher rotation and longer duration
Settlement	Test method and pass criteria similar to INDA/EDANA FG504
Determination of synthetic and non-synthetic organic compounds	MONS Test (dissolving organic matter with bleach)

As the WIS 4-02-06 Fine to Flush was only published in January 2019, not many organisations have commented on it yet. According to the WRc Group, only one nonwoven wet wipe has passed the Fine to Flush tests so far [83].

Requirements and test methods from DWA

Due to increasing operational problems as a result of rising amounts of nonwoven wipes in German sewer systems, the DWA (Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. - German Association for Water, Wastewater and Waste) established a national working group in 2017 to address the problem (AG ES-7.8 *Störstoffe in Entwässerungssystemen* – Non-sewer items in the wastewater system). Their report on nonwoven wipes in sewers in Germany is estimated to be published in September 2019 [8]. In the report they detail requirements that products have to fulfil to be deemed sewer system compatible, and thus flushable, according to German wastewater utilities. The working group consists of wastewater utilities, wipe manufacturers, manufacturers of fibres for nonwoven wipes, manufacturers of machines to produce nonwoven wipes, pump manufacturers and research institutions. An overview of the criteria to be fulfilled and the associated test methods are given in Table 2-4. The requirements are based on both INDA/EDANA Flushability Guidelines and IWSFG Flushability Specifications. DWA agrees with the settling test and disintegration test from INDA/EDANA (although stating that these have to be adapted if new knowledge regarding suitable disintegration arises). However, similar to IWSFG, DWA demands the fulfilment of additional criteria regarding safety in the environment and avoidance of plastic fibres in products. A test to evaluate the biological degradation of sewer system compatible nonwoven wipes is also considered necessary, however, a suitable test could not be suggested to date. The INDA/EDANA biodegradation tests (FG505 and 506, also used by IWSFG), which are based on OECD 301B and OECD 311 tests, are considered unsuitable to reflect biodegradation of wipes in wastewater. As an association of German wastewater utilities, the DWA cannot impose any mandatory requirements for flushable or sewer system compatible products.

Table 2-4: Criteria and test methods as specified by DWA working group ES-7.8, adapted and translated from [8]

DWA Criterion	Test method
Products should not contain plastic	Manufacturer’s declaration
Health and environmental safety of products	Manufacturer’s declaration (not hazardous to health or environment based on national legislation)
Products settle with an adequate velocity	Method and acceptance criteria same as INDA/EDANA FG504
Products disintegrate in an adequate time frame	Method and acceptance criteria of Slosh Box Disintegration Test of INDA/EDANA FG502. To be adapted if new findings indicate stricter test parameters.
Products can be biodegraded in an adequate time frame	The aerobic and anaerobic biodegradability of liquid and solid phase must be demonstrated by appropriate test methods. Whether this criterion is necessary or whether it is covered by the requirement "Products must not contain plastic" must be reviewed in the future.

Conclusions:

- While several approaches exist to regulate the sewer system compatibility of nonwoven wipes sold as “flushable”, none of these specifications is mandatory for manufacturers and retailers.
- The INDA/EDANA Flushability Guidelines are the only set of rules that are being followed, at least partly, by manufacturers. However, compliance is not monitored by INDA or EDANA.
- The presented specifications are similar in several key points, but differ in others. The most important aspects for the wastewater associations, in which they all concur, are a) fast disintegration, b) settling and c) material composition (no plastic).

3 Material and methods

To characterise the problems caused by sewer system incompatible nonwoven wet wipes as well as the use and disposal of wet wipes in the general population, two surveys were designed, executed, and evaluated. Field experiments were conducted to analyse, quantify and characterise the nonwoven wet wipes found in pump blockages. Finally, the clogging behaviour of several types of nonwoven wet wipes was investigated in the laboratory using a test stand for the functional performance of wastewater pumps. The methods and materials used for these investigations are described below.

3.1 Survey among wastewater utilities regarding operational problems due to nonwoven wet wipes

The aim of the web-based survey among German wastewater utilities was to collect data regarding the occurrence, location, type, and cost of operational problems due to sewer system incompatible nonwoven wipes in wastewater systems. The focus lay on characterising the magnitude (frequencies and costs) of the problems.

3.1.1 Structure of the survey

The survey among wastewater utilities was conducted online using a questionnaire comprising 44 questions. Additional data regarding size and infrastructure of the respondents' utility, sewer system and catchment was requested (name of the utility, population in catchment, location of catchment, number of pumping stations, length of sewer network, number and size of WWTPs). The survey covered four sections:

1) Characteristics of the problem;
2) Costs;
3) Solutions; and
4) Future approaches.

To avoid misunderstandings the general term “wet wipes” was used instead of introducing the term “nonwoven”, which is not generally known in the public. An overview of the questionnaire (English translation) is presented in Appendix B, Figure B-2.

Both open-ended and closed-ended questions were used in the survey. Closed questions were used as dichotomous questions (yes/no, agree/disagree), multiple choice questions (either with single or multiple response options) or scaled questions. Filter questions were used to navigate respondents individually through the questionnaire (additional optional questions could be asked, depending on the previous answer given). On the first page of the questionnaire the respondents were given a brief introduction to the topic and advised on data privacy (the landing page of the survey is shown in Figure B-1 in Appendix B.

3.1.2 Implementation of the survey

The wastewater utility survey was carried out with the survey software G3plus from Rogator AG, RogEditor version 3.2.0.2, survey version 995 (within a free university framework agreement). The collected data was stored on a company server in a server farm in Nuremberg. A desktop version as well as a smartphone version of the survey were formatted.

Several pre-tests of the survey were conducted to improve the validity and quality of the survey. Online and hardcopy versions of the questionnaire were pre-tested by practitioners of utilities as well as by academic experts. This resulted in optimisation of questions and formatting. The pre-tests also verified that the survey could be run on all well-established operating systems (Microsoft Windows, Mac OS) and web browsers (Mozilla Firefox, Windows Explorer, Apple Safari, and Google Chrome).

Survey data was collected from 23.01.2019 until 02.03.2019. The survey was distributed through the mailing list of the DWA regional groups Nord (North, comprising the federal states Lower Saxony, Schleswig-Holstein, Hamburg and Bremen), Nord-Ost (North-East, comprising the federal states Berlin, Brandenburg, Saxony-Anhalt and Mecklenburg-West Pomerania) and Nordrhein-Westfalen (North Rhine-Westphalia). The mailing lists contained several hundred utilities, however the exact number of utilities was not disclosed by DWA. The regional group Bayern (Bavaria) distributed the link to the questionnaire to their so-called “neighbourhood-groups” (regional groups on a lower regional level, each comprising several wastewater utilities). DWA regional group Sachsen/Thüringen (Saxony/Thuringia) and DWA regional group Hessen/Rheinland-Pfalz/Saarland (Hesse/Rhineland/Saarland) published the link to the survey on their respective websites. To ensure a better coverage of utilities across Germany, a further 330 utilities were contacted with a request to participate in the survey by email or by telephone and email. After two weeks an email reminder was sent via the mailing lists of DWA groups Nord, Nord-Ost, and Nordrhein-Westfalen as well as to the mailing list of utilities. Figure 3-1 shows in which areas utilities were contacted by their DWA regional groups and in which areas utilities were contacted directly.

Figure 3-1: Overview of German federal states by contact mode for distribution of the survey Light blue: Survey link distributed to utilities by DWA Regional Groups; Dark blue: Survey link distributed to regional neighbourhood groups by DWA Regional Group; Green: Survey link published on website of DWA Regional Group and utilities contacted directly [84]

3.1.3 Analysis of survey results

After completion of the collection phase, the data was evaluated and interpreted. In a first step the survey data was cleaned. This included removing empty questionnaires and those that were clearly inconsistent as well as removing nonsensical responses to open-ended questions. Also, if several persons from one utility had answered the survey, their answers were aggregated to one set of answers so that every utility was represented by one questionnaire (inconsistent answers within utilities were removed). Respondents that submitted incomplete surveys were included in the analysis, but they had to have answered the utility specific questions in the beginning of the questionnaire and at least the first of the questions of the actual survey topic. Thus, different questions had different sample sizes in the final data analysis. If a respondent missed some utility specific information, they were contacted after the completion of the survey by email or telephone and the missing data was added, as far as possible. After data cleaning the original sample of 538 respondents was reduced to 226 of which 202 respondents had completed the questionnaire and 24 had submitted incomplete questionnaires.

Descriptive statistics were used to analyse the survey data. Depending on the questions and the level of measurement, this included frequency and percentage response distributions, measures of central tendency and dispersion measures (interquartile range).

3.2 Survey among the general public regarding use and disposal of nonwoven wet wipes

The aim of the web-based survey among the general public was to collect data on the use and the disposal of nonwoven wet wipes, both in private households and professionally. The main focus lay on finding out which wipes were being flushed down the toilet.

3.2.1 Structure of the survey

The survey was conducted online using a questionnaire comprising 25 questions. At the beginning of the questionnaire sociodemographic data was requested (age, sex, children and children's ages, post code). The survey covered four sections:

1) Private use of nonwoven wet wipes;
2) Professional use of nonwoven wet wipes;
3) Disposal of nonwoven wet wipes; and
4) General questions regarding moist toilet wipes.

To avoid misunderstandings the general term “wet wipes” was used instead of introducing the term “nonwoven”, which is not generally known in the public. An overview of the questionnaire (English translation) is presented in Appendix C, Figure C-4. Both open-ended and closed-ended questions were used in the survey. Closed questions were used as dichotomous questions (yes/no, agree/disagree), multiple choice questions (either with single or multiple response options) or scaled questions. Filter questions were used to navigate respondents individually through the questionnaire (additional optional questions could be asked, depending on the previous answer given). On the first page (landing page) of the questionnaire the respondents were given a brief introduction to the topic and advised on data privacy (the landing page of the survey is shown in Figure C-3 in Appendix C).

3.2.2 Implementation of the survey

The survey was implemented in the same way as described for the utility survey in section 3.1.2. Survey data was collected from 14.05.2018 until 18.06.2018. The survey was distributed through the following channels:

- Mailing list of the Chair of Fluid System Dynamics at TU Berlin
- Private mailing lists of employees and students at the Chair of Fluid System Dynamics at TU Berlin
- Twitter account of TU Berlin (for the tweet see Figure C-1 in Appendix C)

- Private Facebook, WhatsApp, and twitter accounts of friends, family and colleagues
- Previously compiled mailing list comprising email addresses for 30 child care facilities and 30 old people's homes for every German federal state (more than 900 addresses in total)
- Printed flyers containing a short description of the survey and quick response codes (QR codes), which were distributed to students and interested members of the public, e.g. during the event "Long Night of the Sciences 2018" (which invites the public to tour laboratories and research facilities in Berlin; for the flyer see Figure C-2 in Appendix C).

3.2.3 Analysis of survey results

After completion of the collection phase, the data was evaluated and interpreted. In a first step the survey data was cleaned. This included removing empty questionnaires and those that were clearly inconsistent as well as removing nonsensical responses to open-ended questions. Respondents that submitted incomplete surveys were included in the analysis, if they had given their sociodemographic data and had answered at least one question. Thus, different questions had different sample sizes in the final data analysis. Moreover, some questions included the answer option "no comment", which also caused varying question-specific sample sizes. After data cleaning, the original sample of 1038 respondents was reduced to 948 of which 908 respondents had completed the questionnaire and 40 had submitted incomplete questionnaires.

Descriptive statistics were used to analyse the survey data. Depending on the questions and the level of measurement, this included frequency and percentage response distributions, measures of central tendency and dispersion measures (interquartile range).

3.3 Field experiments in the wastewater pumping station

The aim of the field experiments in the wastewater pumping station was to identify the types of nonwoven wipes to be found in pump blockages and, if possible, draw conclusions as to whether they had been sold as "flushable" or as "non-flushable".

3.3.1 Pumping station

Pump blockages were collected in a pumping station located in the east of Berlin, Germany. The pumping station is connected to a catchment area with a population of 143,200 and a size of 15.3 km^2, as shown in Figure 3-2. The catchment consists mainly of residential areas and is drained by a separate sewer system. The average daily volume of wastewater during dry weather conditions is 18,500 m^3.

The investigated dry-installed pump with an inlet diameter of 200 mm had a closed three-channel impeller with an outer diameter of 404 mm (see Figure 3-3). The pump is part of an experimental set-up of TU Berlin in the aforementioned pumping station. It pumps wastewater from the first to the second sump of the pumping station (overall, the pumping station is equipped with five further dry-installed pumps), thus being exposed to real wastewater. The speed of the test pump is controlled by a variable speed drive (VSD). For the evaluation of the operating condition of the pump several parameter were monitored, as shown in Table 3-1.

Incipient clogging was detected by monitoring the flow rate and the delivered head as well as the power consumption. A “blockage” was defined as a reduction in the flow rate of 10 %. When the blockage criterion was reached, the pump operation was halted and the blockage was removed by hand through a maintenance opening.

Table 3-1: Overview of the monitored parameters of the pump test stand

Parameter	Monitoring equipment
Delivered head	Two pressure sensors on the suction side and one pressure sensor on the pressure side of the pump, each with a resolution of 1 kHz
Flow rate	Magnetic inductive flow meter
Rotational speed	Incremental encoder
Power consumption	Measured via the variable speed drive (VSD)

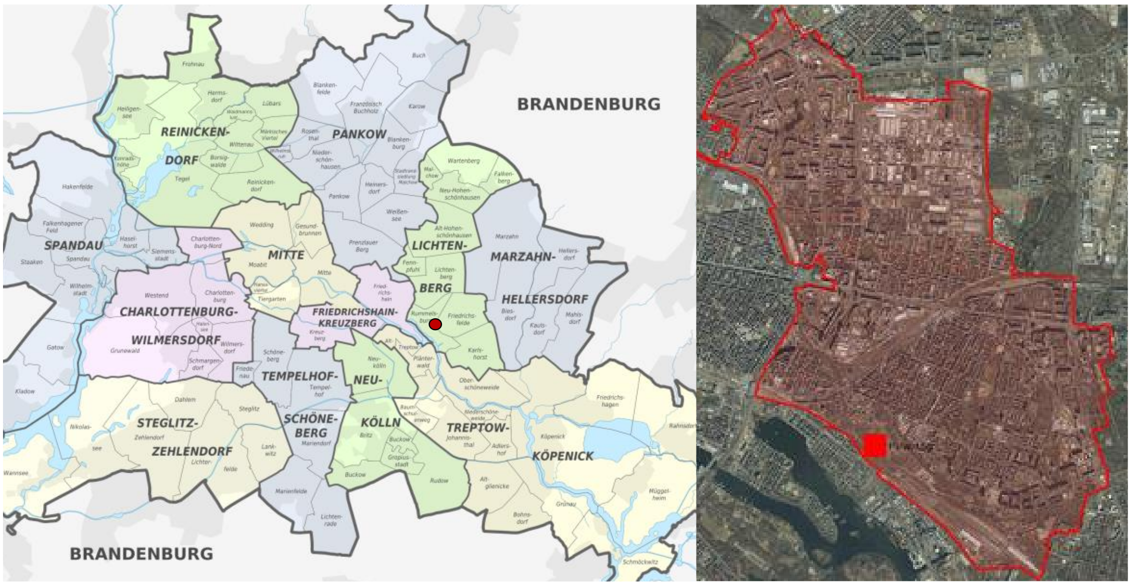


Figure 3-2: Left: Map of Berlin with pumping station used in study (red dot) [85]; Right: Catchment area of pumping station used in study (red square)

Figure 3-3: From left to right: Wastewater pump from which blockages were collected; view into the impeller of the pump; view into the clogged impeller

3.3.2 Analysis of pump blockages

After removal, the material was submerged in a basin with disinfectant and gently detangled. The material was then separated into fractions (wipes, feminine hygiene products, paper, rests, etc.) and left to dry slightly. Further analysis of the fractions was conducted by a textile laboratory (Sächsisches Textilforschungsinstitut e.V., STFI), specializing in the analysis of nonwoven fabrics. They determined the dry weight of each constituent of the blockage and analysed the types of nonwoven fabrics of the wet wipes using typical structure characteristics and laboratory tests, such as scanning electron microscopy (SEM).

Three pump blockages were collected at different times of day (morning, noon and early afternoon) to account for diurnal variations throughout the day. One blockage was collected in early summer (26.06.2018, noon) and two in early winter (both on 05.12.2018, one in the morning and one in the early afternoon). Figure 3-4 shows the rinsing and detangling of the wipes (left) and the blockage constituents sorted into fractions (right).

Figure 3-4: Left: Disinfecting, rinsing and sorting of blockage material; right: Constituents of pump blockage, sorted into fractions

3.4 Laboratory experiments

The aim of the laboratory experiments was to investigate whether different types of nonwoven wipes show different clogging behaviour in a wastewater pump. To do so, a pump test stand with measuring equipment was used and several different testing procedures were implemented.

3.4.1 Test pump

A pump with an inlet diameter of 100 mm and a closed two channel impeller with a diameter of 256 mm was used for the laboratory investigations. In a systematic investigation of the functionality of 19 wastewater pumps performed by Poehler et al. [86], this pump was shown to be the most susceptible to clogging. This can be seen in the diagram showing the reduction of the normalised group efficiency (ratio of clogged group efficiency to clear water group efficiency) in Figure 3-5. Six of the tested impellers are shown as graphs in Figure 3-5, while the highlighted grey area shows the range of all 19 tested impellers. The red graph (called two a) was clearly the most clogging sensitive pump and thus was used in this investigation. By using this clogging-sensitive pump instead of a more clogging-robust pump, it was ensured that the worst case clogging scenario in the field was covered.

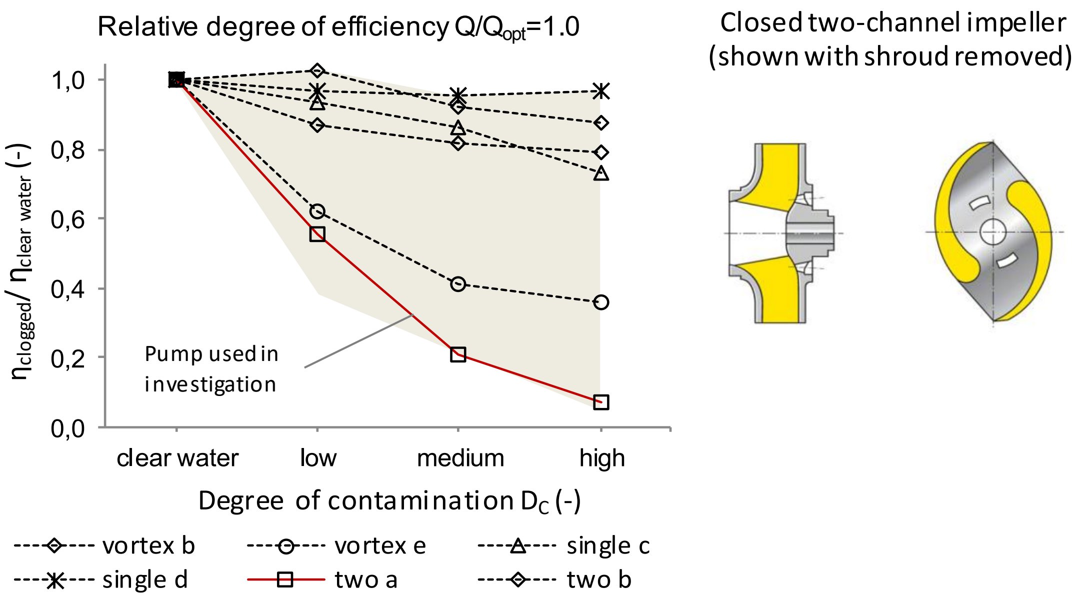


Figure 3-5: Left: Normalised group efficiency of several wastewater pumps for different wastewater contaminations [86]. Right: Schematic of closed two-channel impeller [87]

3.4.2 Test stand

The test stand consisted of two tanks, a fresh water tank and a wastewater tank. They each had a maximum capacity of 3.5 m^3 and were connected to the suction pipe (stainless steel, DN 200) of the pump. At the discharge of the pump (expansion to PVC, DN 150) the flow could be routed through a filter into the fresh water tank or directly into the wastewater tank (see Figure 3-6). The different loops were controlled by the use of fast closing and opening pinch valves charged with pressurised air. The pipes at the inlet and outlet of the pump were made of transparent PVC.

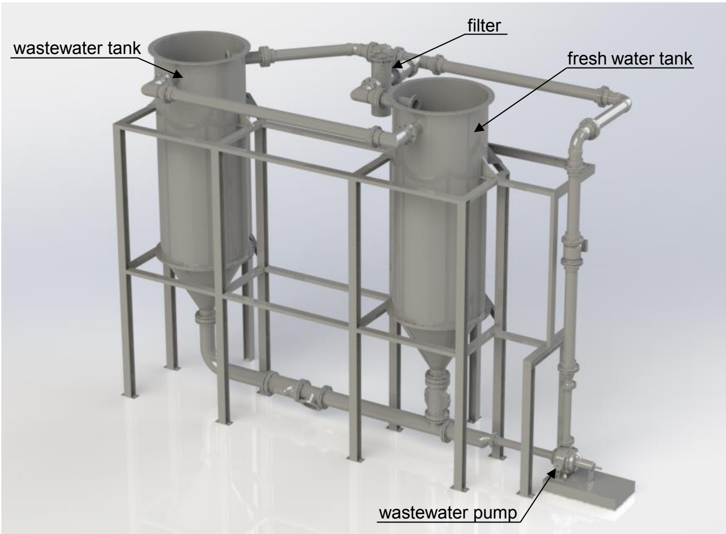


Figure 3-6: Test stand in laboratory [88]

3.4.3 Testing procedures

To assess the clogging effect of different nonwoven wipes on the pump, two testing procedures were performed.

Short time performance test

With the short time performance test the clogging effect of the wipes during a single pump cycle (with each wipe passing the pump once) can be described.

The amount of wipes for the wastewater class being tested (see section 3.4.5) was added into the nearly empty wastewater tank, which was subsequently filled with 2 m^3 clear water from the fresh water tank. This ensured even mixing and distribution of wipes in the wastewater tank. The artificial wastewater was then pumped into the freshwater tank via the filter (see Figure 3-7). The measurements started as soon as the pump began operation. After the test, the residues in the filter and in the impeller were removed. Their respective dry weight was determined after several days air-drying, followed by several cycles in a commercially available clothes dryer (in a protective cover to ensure no fibres were lost), in turn followed by several hours of acclimatisation at room temperature.

To ensure the reproducibility of the results, all short time performance tests were performed in duplicate. The repeatability of the results was high and thus the results were averaged. If two short time performance tests showed very different results, a third test was performed.

Longtime performance test

To determine the clogging effect of the wipes after prolonged stress (e.g. in a system with several pumping stations behind each other, where blocking and clogging can occur due to slow accumulation of fibrous materials), the longtime performance test was conducted. The procedure was identic to the short time performance test, except that the artificial wastewater was pumped in loop from the wastewater tank back into the wastewater tank for 60 minutes, as shown in Figure 3-7. After the test, the dry weight of the residues in the impeller was determined as described above.

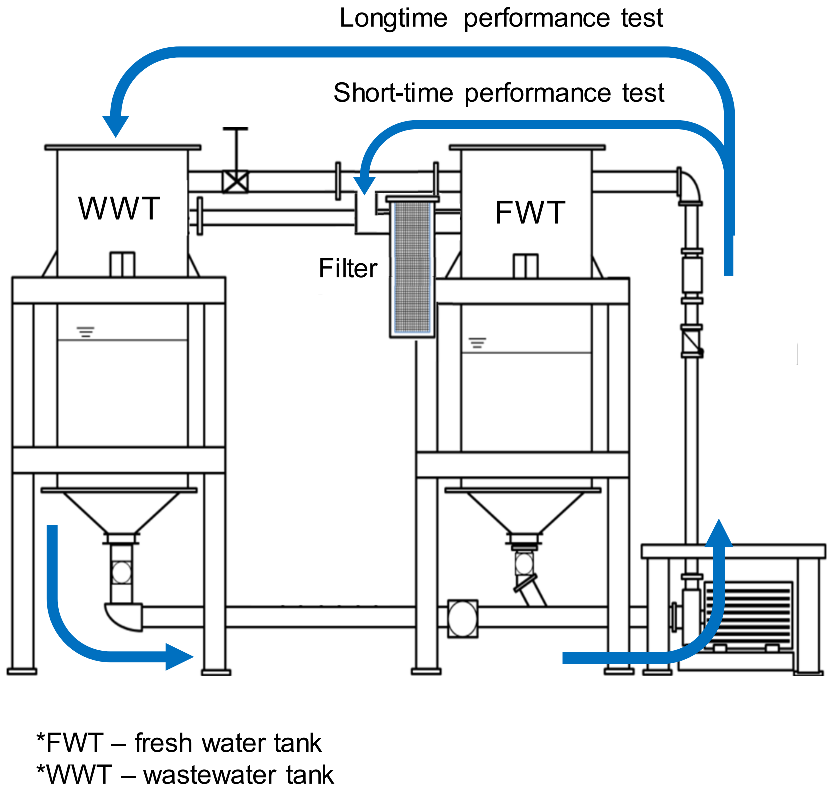


Figure 3-7: Overview of the two testing procedures, adapted from [89]

During all measurements the static head, the flow rate, and the electric power consumption were measured continuously. The speed of the pump was controlled by a VSD ($n = 1475\ min^{-1}$). To cover different operating conditions of wastewater pumps in the field, all experiments were conducted for the following operating points:

- Part load: Q/Qopt = 0.8 (Q = 136 m^3/h, H = 17.35 m, η_{gr} = 65.11 %)
- BEP: Q/Qopt = 1.0 (Q = 170 m^3/h, H = 15.11 m, η_{gr} = 66.04 %)
- Overload: Q/Qopt = 1.2 (Q = 204 m^3/h, H = 11.66 m, η_{gr} = 59.75 %)

Table 3-2 gives an overview of the tests conducted for each nonwoven wipe. In total, each wipe was tested at least 27 times (9 longtime performance tests and 18 short-time performance tests). However, in most cases several additional tests were conducted.

Table 3-2: Overview of tests conducted for each nonwoven wet wipe

		Wastewater class		
		WWC1	WWC2	WWC3
Operating point	0.8	ST, ST, LT	ST, ST, LT	ST, ST, LT
	1.0	ST, ST, LT	ST, ST, LT	ST, ST, LT
	1.2	ST, ST, LT	ST, ST, LT	ST, ST, LT

ST = Short-time performance test, LT = Longtime performance test

3.4.4 Investigated nonwoven wet wipes

Five different nonwoven wet wipes were investigated systematically, to determine whether they had different clogging effects on the wastewater pump. Based on studies from other countries (see chapter 2.2.2) and the results of the surveys and field investigations presented in the previous sections, moist toilet wipes and baby wipes were judged to be most relevant. Therefore, three moist toilet wipes, two of which were compliant with INDA/EDANA Flushability Guidelines (according to information from the respective manufacturers), and two baby wipes were investigated. For a more detailed description of the five nonwoven wipes (fibres, bonding etc.) see Appendix E.

Table 3-3: Overview of the nonwoven wet wipes investigated in the study

	Marketing claim	Compliant with INDA/EDANA Flushability Guidelines	Disposal recommended on packaging
Toilet wipe A	Flushable	Yes	Flush down toilet
Toilet wipe B	Flushable	Yes	Flush down toilet
Toilet wipe C	Flushable	No	Flush down toilet
Baby wipe A	Non-flushable	No	Household waste
Baby wipe B	Non-flushable	No	Household waste

3.4.5 Wastewater classes

To cover different degrees of wastewater contamination with nonwoven wipes, three wastewater classes were defined (shown in Table 3-4), and a respective degree of contamination was assigned to each. The amount of wipes for each defined wastewater class was added to clear water to generate the artificial wastewater, which was then presented to the pump. The amount of wipes used per wastewater class was based on a previous study by the author of this thesis [64]. This prior study showed that the average amount of nonwoven wet wipes found in the wastewater of the catchment area under investigation was 40 g/m^3 and reached 122 g/m^3 in the sump of a large pumping station, where the non-sewer items became more concentrated. The concentration of fibres chosen for this investigation reflect these values (see Table 3-5). Wastewater class three (WWC3, high contamination) is markedly higher than the values presented in the previous study [64]. This should demonstrate the clogging effect of nonwoven wet wipes with increasing concentration in the system (as may be expected in future). While the exact number of wipes was placed in the fresh water tank for each test, sometimes not all wipes were pumped and some remained in the tank or in the suction pipe. Thus the actual amount of pumped wipes was established for each test by determining the dry weight of the nonwoven wipes in the filter and the residues in the pump, respectively (see description of the test stand above).

Table 3-4: Wastewater classes used in the investigation

Wastewater class WWC	Wipes per m^3	Degree of contamination
Clear water	0	0
Low contamination WWC1	35	0.25
Medium contamination WWC2	70	0.5
High contamination WWC3	140	1

Table 3-5: Fibre loads resulting for each wastewater class

	Dry weight per wipe in g	Fibre content WWC1 in g/m^3	Fibre content WWC2 in g/m^3	Fibre content WWC3 in g/m^3
Toilet wipe A	1.26	44.1	88.2	176.4
Toilet wipe B	1.5	52.2	105	210
Toilet wipe C	1.57	54.95	109.9	219.8
Baby wipe A	1.38	48.3	96.6	193.2
Baby wipe B	1.66	58.1	116.2	232.4

3.4.6 Preparation of nonwoven wipes for testing

To ensure that the nonwoven wet wipes did not become buoyant in the fresh water tank before the beginning of the tests and to ensure an even distribution of the wipes in the tank, they were soaked in clear water for a certain amount of time, depending on the type of wipe (see Table 3-6). Pre-tests with the baby wipes showed that their high lotion content made sufficient mixing in the fresh water tank impossible, despite prior soaking. Therefore preparation for the baby wipes included a gentle washing cycle in a commercially available washing machine at 20°, without detergent and without a spin cycle. Afterwards the baby wipes were also soaked in clear water.

Table 3-6: Pre-treatment of investigated nonwoven wet wipes

	Pre-treatment in washing machine	Duration of soaking in hours
Toilet wipe A	No	~1
Toilet wipe B	No	~1
Toilet wipe C	No	~1
Baby wipe A	Yes	>24
Baby wipe B	Yes	>24

3.4.7 Analysis of laboratory results

To compare the clogging effect of the five investigated nonwoven wet wipes, the flow rate, static head, group efficiency (pump + motor), normalised group efficiency (ratio of group efficiency while clogging to clear water group efficiency at the respective operating point), and the residues in the pump and in the filter were measured or calculated respectively for each test.

4 Results

The focus of this study was the analysis of operational problems due to nonwoven wipes in wastewater systems. The following aspects were investigated:

1. Identification and characterisation of wipe-related operational problems in German wastewater systems.
2. Characterisation of use and disposal of nonwoven wipes in the general German population.
3. Identification of types of nonwoven wipes in pump blockages in the field.
4. Investigation of the pump clogging behaviour of different types of nonwoven wipes in the laboratory.

The following presentation of results is divided into four parts, according to the structure detailed above.

4.1 Results from the survey among wastewater utilities regarding operational problems due to nonwoven wet wipes

The survey among wastewater utilities regarding operational problems due to nonwoven wet wipes covered four sections: 1) Characteristics of the problem; 2) Costs; 3) Solutions; and 4) Future approaches. The focus of the following presentation is on the description of the sample and the main findings derived from the survey. Due to the amount of data generated, not all findings can be presented. An overview of the questionnaire is given in Appendix B. The term "wet wipes" was used in the survey (which is better known than the term "nonwoven wipes"). Also, the survey did not differentiate between wet wipes sold as "flushable" and wet wipes sold as "non-flushable", as in most cases this cannot be determined by utilities, once the wipes have entered their system.

4.1.1 Sample description

The sample comprised 226 respondents (utilities), of which 202 respondents had completed the questionnaire and 24 had submitted incomplete questionnaires. The response rate could not be calculated, as the number of potential respondents contacted was unknown. The representativeness of the sample is unclear, as the population size (wastewater utilities in Germany) is unknown and moreover not all utilities are represented in the DWA. Thus, the following results cannot be seen as representative, but only as an approximation for German utilities.

The respondents covered a range of regions and utility sizes, as shown in Figure 4-1 and Figure 4-2. The most respondents came from the federal states Lower Saxony (51 respondents, 23 %) and Bavaria (41 respondents, 18 %; see Figure 4-1 left hand side). No respondent came from Saarland and only two each from Rhineland-Palatinate and Hesse. As the city states Berlin, Hamburg, and Bremen each have only one utility, these states also only had one respondent, respectively. The distribution of respondents by DWA regional groups shows that the DWA regional group North was represented most strongly (69 respondents, 31 %), while the groups Saxony/Thuringia, North-East, and Bavaria represented between 15 % and 18 % of respondents. The fewest respondents came from the DWA regional group Hesse/Rhineland-Palatinate (4 respondents, 2 %).

Most respondents were small-sized utilities, with comparatively few pumps in their system, a total sewer length below 400 km and a population under 50,000, which can be seen in the diagrams in Figure 4-2. However, large utilities, with up to 1200 pumping stations, over 10,000 km sewer network or a catchment area population up to 4,000,000, also participated. The main work areas of the respondents in their respective utilities were pumping stations (85 % of respondents), WWTPs (81 % of respondents), and sewer systems (76 % of respondents), as shown in Figure 4-2 bottom right.

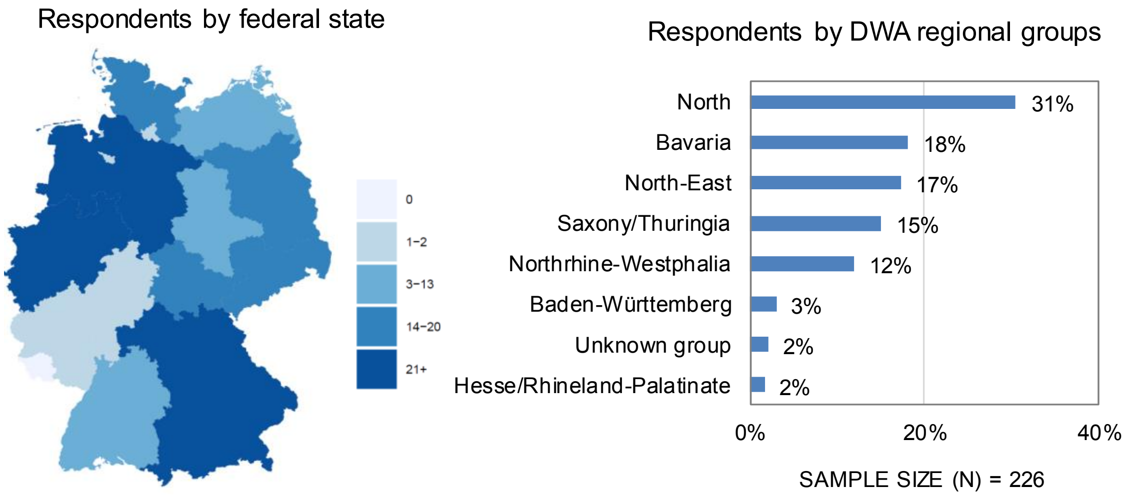


Figure 4-1: Left: Respondents by federal state. Right: Respondents by DWA regional group

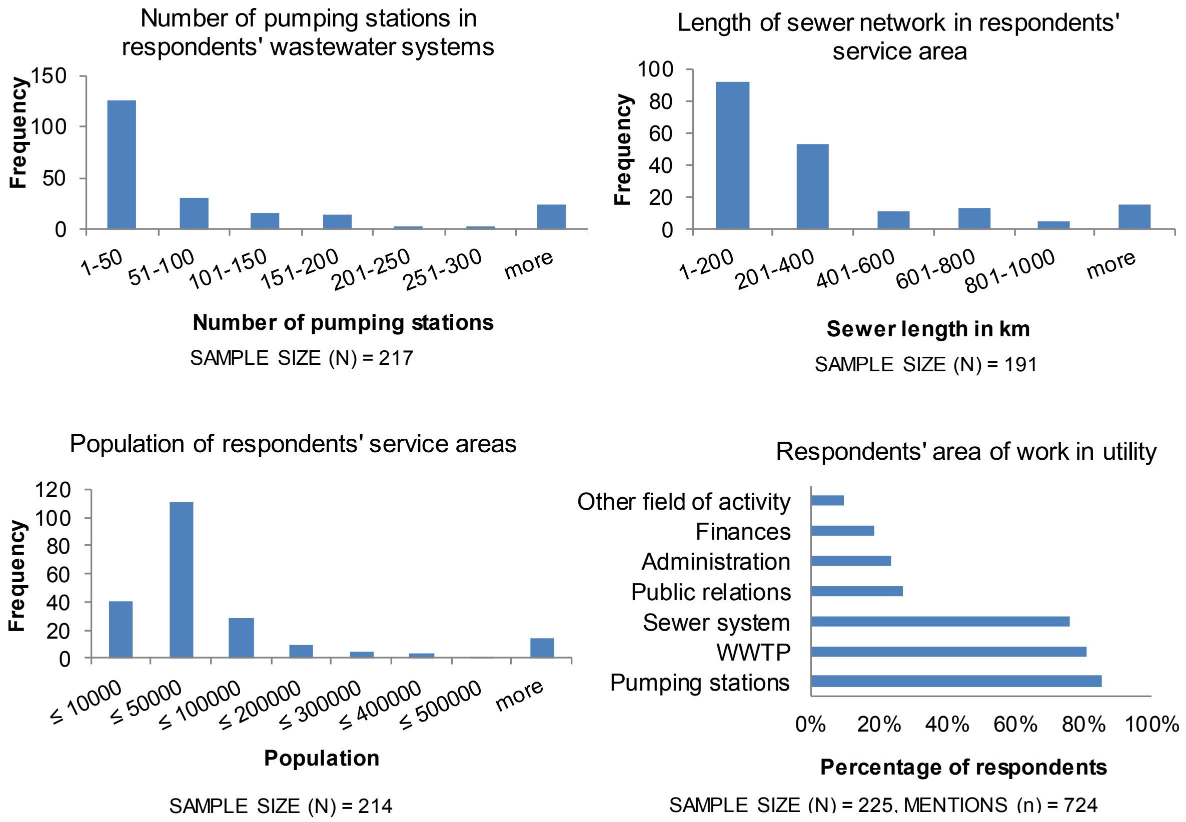


Figure 4-2: Characterisation of respondents' utilities and areas of work

4.1.2 Wipe-related operational problems in wastewater systems

Of the participating utilities, 93 % (210 out of 226) said they were experiencing operational problems due to nonwoven wet wipes. These problems have been with the majority of utilities (77 %, 159 out of 206) for 1 – 10 years and 90 % of utilities (181 out of 202) declared that the wipe-related problems have worsened since their first occurrence.

The collected data shows that the wastewater pump is the system element affected most severely by nonwoven wet wipes. Nearly all respondents with wipe-related trouble observe problems with their pumps (98 %, 204 out of 209). Half of the surveyed utilities also note problems in their sewer system (50 %, 104 out of 209) and roughly a third (35 %, 74 out of 209) in wet wells of pumping stations. Wipe-related issues at the inlet screens of WWTP trouble nearly half of the respondents (47 %, 99 out of 209). The other areas of the WWTP (grit chamber/grease trap, primary sedimentation, aeration tank, secondary sedimentation, sludge treatment) are significantly less affected (11 % - 4 %). A detailed presentation of the occurrence of wipe-related problems in 12 wastewater system sections is shown in Figure 4-3.

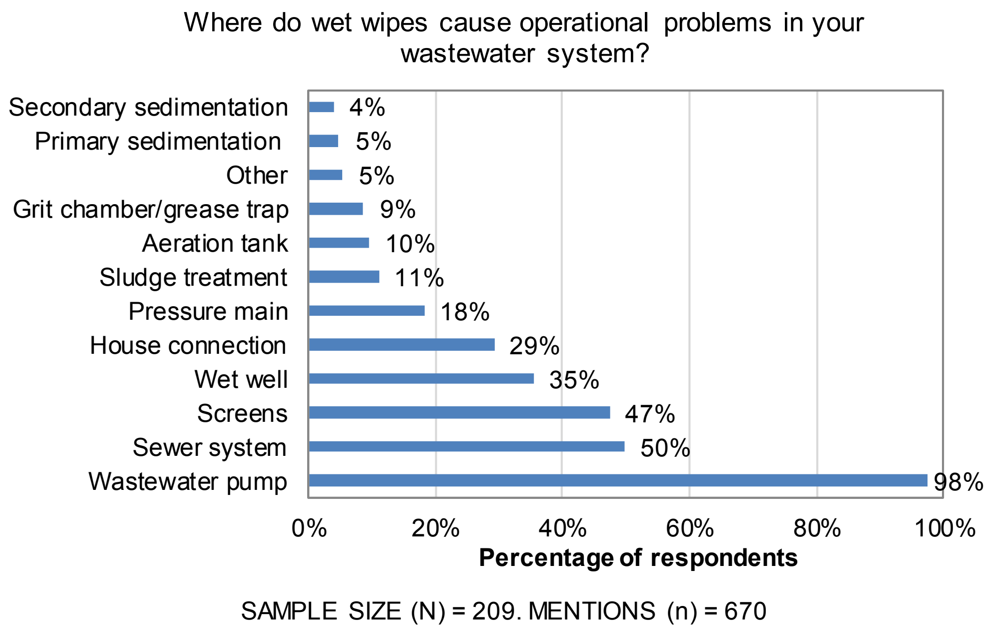


Figure 4-3: Location of operational problems due to wet wipes

The effect of the nonwoven wet wipes varies depending on the location of the problems in the system, as can be seen in Figure 4-4. In most locations the nonwoven wipes cause clogging. In the wastewater pump this is by far the major problem. In the sewers, pressure mains, and in the wet well they also form deposits. In the wet well, they additionally contribute to the formation of the scum layer. On the WWTP the nonwoven wet wipes cause blockages in the primary sedimentation, secondary sedimentation, and sludge treatment. However, the number of respondents in these system areas was so low that they cannot be regarded as representative and are not included in Figure 4-4. The effect of the wipes on WWTP screens was stated as an increase in the screenings as well as blinding of the screens. Other disturbances caused by nonwoven wet wipes in the WWTP are ragging in the basins and deposition of wipes on the oxygen injectors in the aeration tank.

Although mainly nonwoven wet wipes are associated with causing pump blockages, other non-sewer items are also found in the clogging material, according to the responding utilities. Most frequently these are (cleaning) rags and cloths (86 %, 161 out of 187) and feminine hygiene products (81 %, 151 out of 187). To a lesser extent textiles, nappies, and other non-sewer items are found (< 20 %).

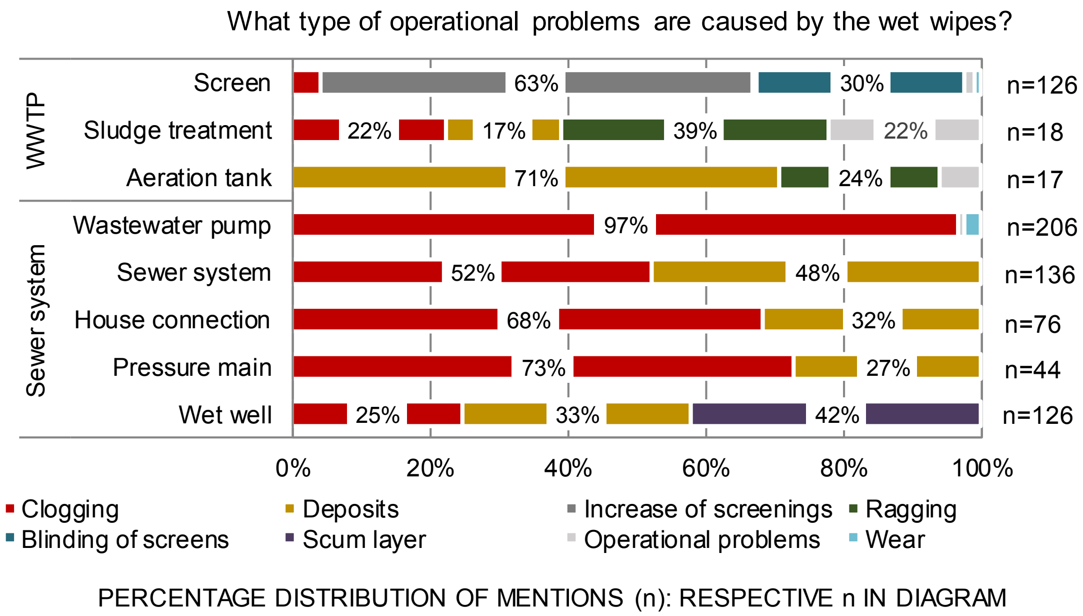
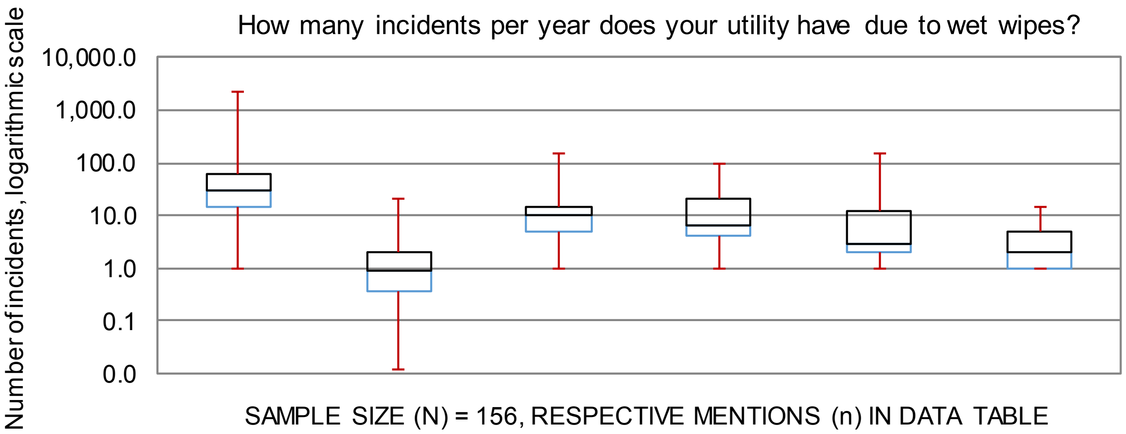


Figure 4-4: Type of wipe-related operational problems by location

The annual number of identified wipe-related operational problems varies greatly among utilities. Most frequently utilities are affected by pump blockages. The middle 50 % of respondents (interquartile range, IQR) note 15 – 61 clogged pumps per year, while the maximum lies at 2300 annual pump blockages. Normalised with the number of pumps in the respondents' catchments, this amounts to an annual maximum of 20 blockages per pump per utility (median value is 1 annual blockage per pump per utility). Other system elements, such as the house connections, the sewer system, or the screens in WWTPs, are affected less frequently (median ≤ 10). Figure 4-5 shows a boxplot diagram with data table to visualize the distribution of values regarding the annual frequency of different wipe-related operational problems.

It is difficult for the utilities to establish a connection between external influences and wet wipe-related problems. Most commonly, the occurrence of these disruptions is associated with long periods of dry weather and subsequent rainfall (42 % of respondents, 83 out of 199). The correlation with heavy rainfall events is also considered important (34 % of respondents, 67 out of 199). However, just as often no correlation with external influences can be determined (32 % of respondents, 63 out of 199).



	Clogged pumps (n=156)	Cloggings per pump (n=156)	Clogged house connections (n=66)	Clogs in sewer system (n=62)	Blinding of screens (n=41)	Clogs in pressure mains (n=35)
Min	1		1	1	1	1
Max	2300	20	150	100	150	15
Median	30	1	10	6.5	3	2
IQR	15 – 61	0.4 - 2	5-15	4-20	2-12	1-5

IQR = Interquartile range

Figure 4-5: Annual frequencies of wipe-related operational problems

Conclusions:

- Nearly all surveyed utilities observe wipe-related operational problems, which have worsened since their first occurrence.
- Most frequently, the nonwoven wipes impact wastewater pumps, where they lead to clogging and blockages. To a lesser extent, other parts of the wastewater system are also affected.
- Apart from nonwoven wipes, other non-sewer items are also found in pump blockages, such as cloths and feminine hygiene products.

4.1.3 Financial impact of wipe-related operational problems in wastewater systems

Almost all wastewater utilities experiencing operational problems due to nonwoven wipes incur additional costs (98 % of respondents, 173 out of 177). Figure 4-6 shows that these are most frequently additional personnel costs (95 % of respondents, 164 out of 173) and repair and maintenance costs (83 % of respondents, 143 out of 173). Energy costs (55 % of respondents, 95 out of 173) as well as costs for replacement parts (50 % of respondents, 84 out of 173), new acquisitions (46 % of respondents, 79 out of 173), and public relations (31 % of respondents, 53 out of 173) are caused to a lesser degree.

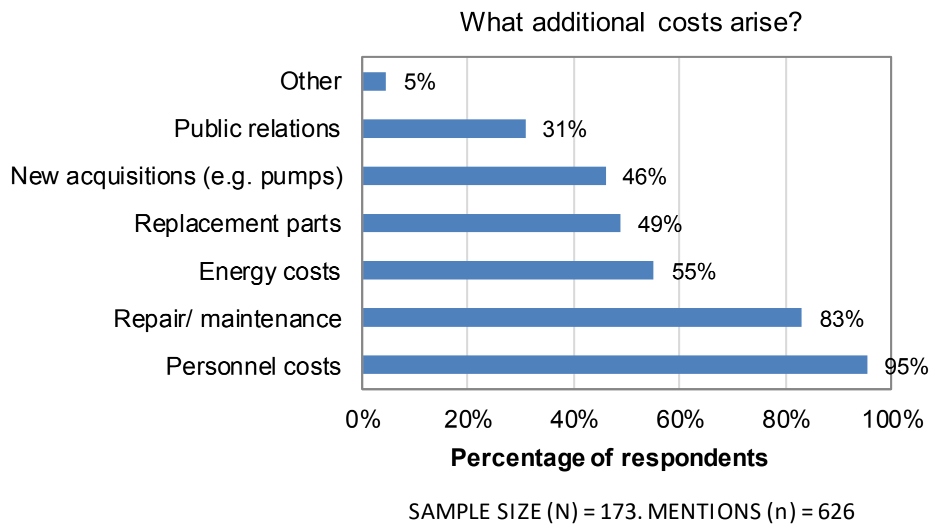
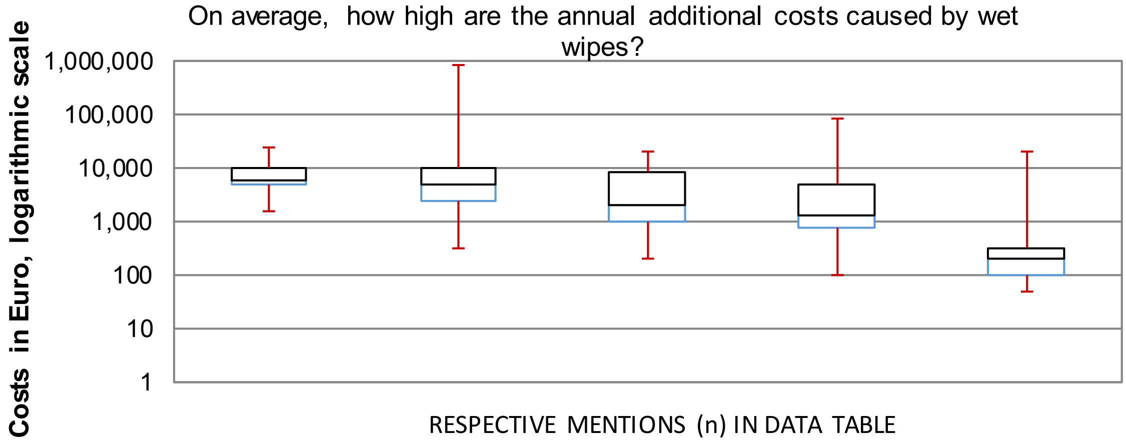


Figure 4-6: Additional costs incurred by wastewater utilities due to wipe-related problems

The scale of the additional costs of the utilities varies greatly and representative amounts could not be determined in the survey. Only few respondents could concretely quantify and allocate the financial effects of wipe-related problems. Nevertheless, it is clear from the data collected that the utilities partly incur very high costs. The boxplot in Figure 4-7 shows the range of additional expenditures. The minimum and maximum values and the median of the respective type of costs are given in the data table of Figure 4-7, as well as the range in which the costs of the middle 50 % of the utilities lie (interquartile range). It is evident that the personnel costs in connection with wipe-related operational problems cause the largest additional expenditures for the utilities. This is mainly due to the time-consuming elimination of pump blockages, which requires a high level of human resources. The personnel costs per pump blockage vary greatly among the utilities, ranging from 50 € to 20,000 €. For most utilities, however, the personnel costs per pump blockage lie below 300 €.



	New aquisitions in € (n=23)	Additional personnel costs in € (n=156)	Replacement parts in € (n=32)	Energy costs in € (n=62)	Personnel costs per pump blockage in € (n=41)
Min	1500	300	200	100	50
Max	25000	860000	20000	85000	20000
Median	6000	5000	2000	1250	200
IQR	5000 - 10000	2450 - 10000	1000 – 8500	725 - 5000	100 - 300

IQR = Interquartile range

Figure 4-7: Overview of the annual additional costs caused in wastewater systems due to wipe-related operational problems

Conclusions:

- Wipe-related operational problems cause additional costs for nearly all affected wastewater utilities.
- Despite not being able to concretely quantify and allocate costs in a representative way, it is clear that the financial impact arising out of these operational problems can be very high for the utilities.
- The personnel costs increase most strongly, mainly due to the time-consuming elimination of pump blockages.

4.1.4 Approaches to solving wipe-related operational problems

To avoid and reduce problems caused by nonwoven wipes in the wastewater system, the surveyed utilities use different methods. Since the survey data showed that wastewater pumps are the system element most strongly and most frequently affected by nonwoven wipes (see previous sections), this chapter focusses on solution strategies employed for pumping systems. Additionally, solution strategies involving the utilities' customers are presented.

Solution strategies employed for pumping systems

Most frequently and with the greatest success among the mentioned measures wastewater utilities switched to different pumps to avoid wipe-related problems, as shown in Figure 4-8. Other frequently used measures are the conversion to chopper pumps and the reverse rotation of the pump. Most often, these measures were successful, albeit at a slightly lower rate than the switch to other pumps. Further measures include using grinder pumps, varying the rotational speed of the pumps or installing screens before pumping stations.

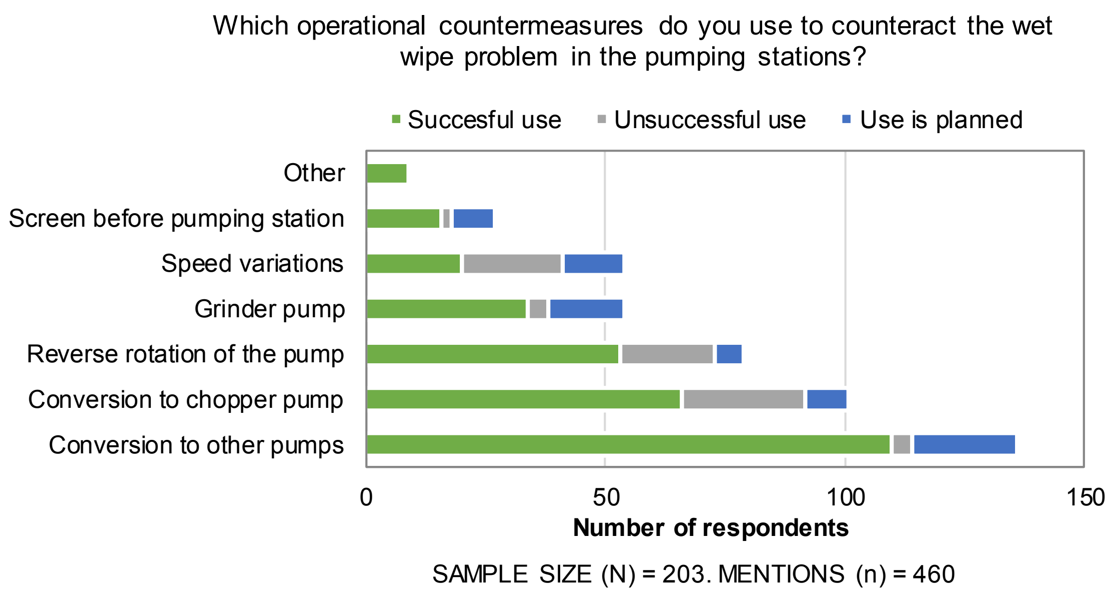


Figure 4-8: Operational counter-measures employed to avoid wipe-related problems

Figure 4-9 shows the distribution of impeller types before and after changing impeller technologies. Most often, the respondents exchanged single channel impellers (before: 56 %; after: 12 %) in favour of vortex impellers (before: 26 %; after: 51 %). Also, when having to exchange the previous pump, new impeller technologies were tested. Thus, the variety of impeller types after the change is greater than before, including, for example, adaptive two-channel impellers, screw centrifugal impellers, and chopper pumps.

In line with the most favoured impeller after an impeller exchange, most of the responding utilities find that vortex impellers are suited to pumping wipe-contaminated wastewater (92 %, 98 out of 107 respondents). Single-channel impellers are perceived as suitable by approximately half of the responding utilities (49 %, 40 out of 81 respondents), while two-channel and multi-vane impellers are thought of as unsuitable to pump wastewater with nonwoven wipes by the majority of respondents (85 %, 44 out of 52 respondents and 89 %, 46 out of 52 respondents). These perceptions are based mainly on the utilities' own experiences (93 %, 135 out of 146 respondents). To a lesser degree the experience of other utilities (21 %, 31 out of 146 respondents) and the manufacturers' declarations (14 %, 21 out of 146 respondents) are taken into consideration.

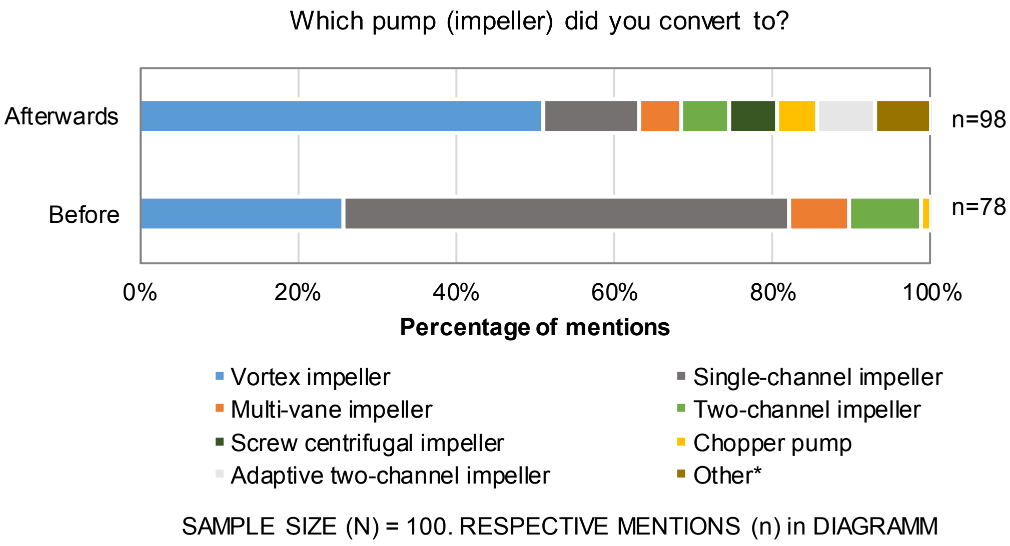


Figure 4-9: Distribution of impeller types before and after the impeller exchange

Solution strategies involving customers

About two-thirds of the surveyed utilities (67 %, 116 out of 173 respondents) have tried to determine the dischargers of the nonwoven wipes in their system, but less than half of them were able to successfully identify the polluters (46 %, 53 out of 116 respondents). Most often, residents (including families with small children) (67 %, 33 out of 49 respondents) and nursing homes (45 %, 22 out of 49 respondents) were identified as dischargers. Sewer controls and direct contact with customers (28 % respectively, 27 out of 98 respondents) were used most often for the identification of dischargers.

A total of 70 % of the responding utilities (126 out of 179) indicated that they had already informed their customers of the potential problems nonwoven wipes can cause in wastewater systems, while a further 8 % (15 out of 179) said that this step was being planned. The contact was most often made via newsletters to households, direct personal education, and information on the utility's website, as shown in Figure 4-10. The success of the employed measures often cannot be tracked directly. The respondents estimate that the newsletters and the direct personal education are the most successful measures.

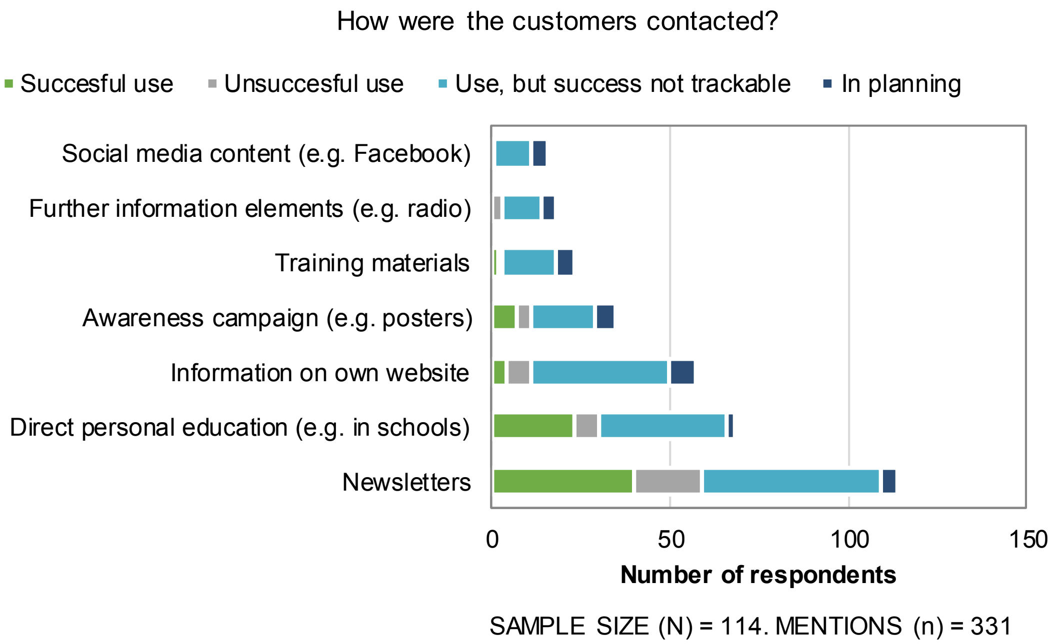


Figure 4-10: Modes of contacting customers regarding wipe-related operational problems

Conclusions:

- To avoid and reduce wipe-related operational problems in pumping systems, operators use different methods.
- Most often and with the greatest success the pump (or impeller technology) was exchanged for a different one, mostly for a vortex impeller, though other novel technologies were also used.
- Identifying the specific dischargers of the nonwoven wipes was only attempted by two-thirds of the surveyed utilities and of these, less than half were successful.
- However, the greater part of the utilities have contacted their customers in the past, to explain the potential of wipe-related operational problems. In most cases, newsletters, direct personal education, and information on utility websites was used, but a clear success could not be tracked.

4.1.5 Future approaches to wipe-related operational problems in wastewater systems

The surveyed utilities have concrete requirements for nonwoven wet wipes that are to be sold as flushable. An overview is given in Figure 4-11. Most importantly, flushable nonwoven wipes should not clog wastewater pumps (96 % of respondents agree that this criterion is “important”, 198 out of 206), they should disintegrate in wastewater after a short time (92 %, 189 out of 206 respondents) and the substances applied to nonwoven wet wipes should not be harmful for the environment (83 %, 171 out of 206 respondents).

Wastewater system operators overwhelmingly demand that these requirements should be mandatory for nonwoven wet wipes sold as “flushable”, to ensure their sewer system compatibility (93 % of respondents, 193 out of 207), see Figure 4-12. The operators want to be involved in developing these requirements (89 % of respondents, 170 out of 192) and they demand that the compliance with these requirements should be verified by an independent institution before the products are launched (95 % of respondents, 182 out of 192). In addition, a uniform and binding labelling obligation as to whether the respective nonwoven wet wipes are suitable for disposal via the toilet is also considered very important (96 % of respondents, 196 out of 205).

Conclusions:

- Most important for the surveyed utilities in regard to the sewer system compatibility of nonwoven wipes sold as “flushable” is that they do not clog pumps and disintegrate rapidly.
- The utilities demand that products sold as “flushable” should comply with flushability criteria, which they want to have a say in developing.
- They also demand a binding labelling practice regarding the disposal of flushable and non-flushable wipes.

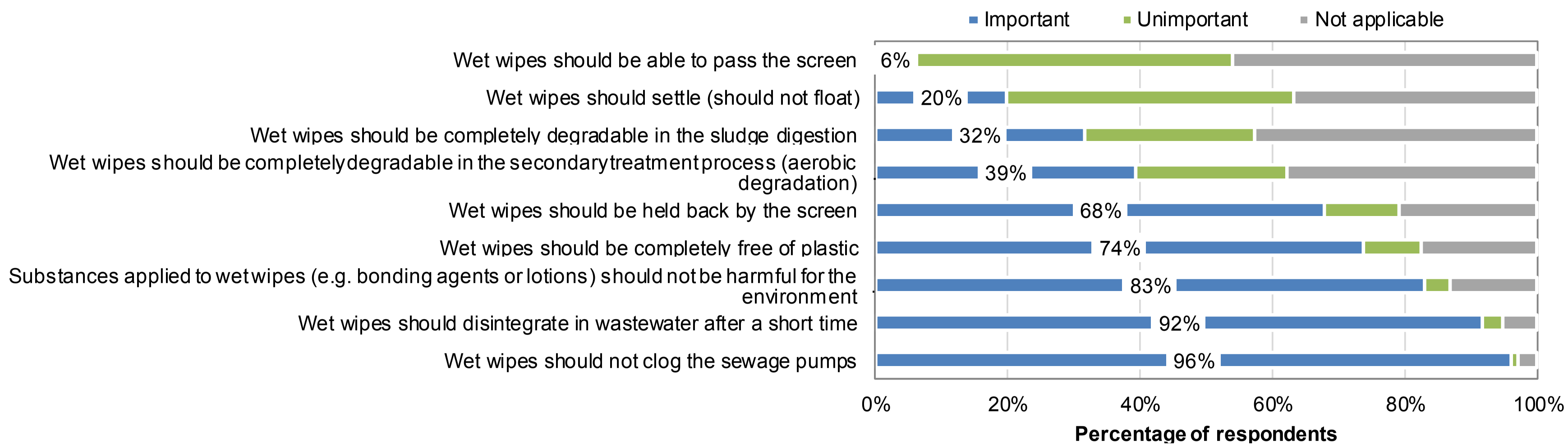


Figure 4-11: Flushability requirements of surveyed utilities

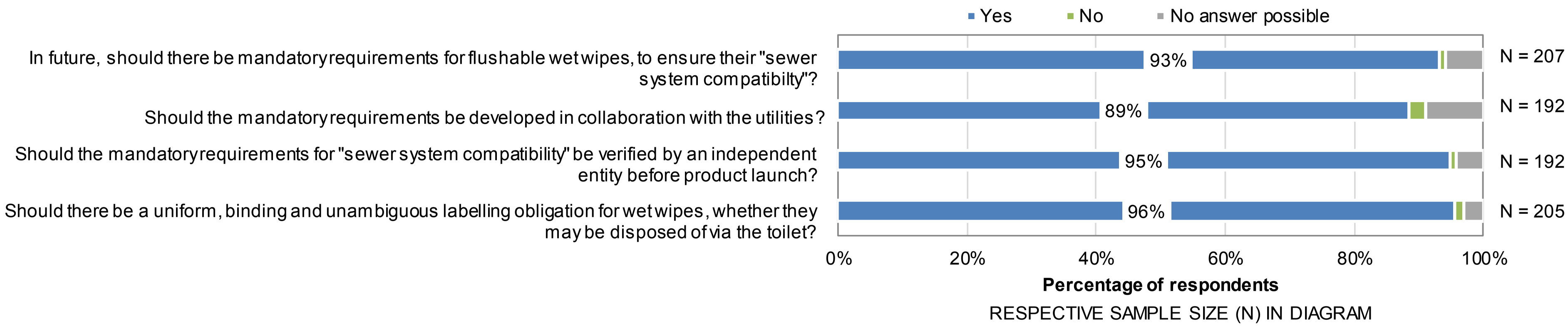


Figure 4-12: Demands of surveyed utilities regarding implementation of flushability guidelines

4.1.6 Interim summary and conclusions from the utility survey

The survey among wastewater utilities from all over Germany confirms that nonwoven wipes lead to operational problems in most wastewater systems. They affect wastewater pumps most strongly, where they cause clogging and blocking. This leads to a high financial impact on the affected utilities, mainly due to additional personnel costs for removing pump blockages. The surveyed utilities demand binding criteria for products that are sold as "flushable" and want to participate in the development of these criteria. Of greatest importance for them is that wipes sold as flushable do not clog pumps and disintegrate rapidly. Environmentally safe lotions and plastic free composition are also imperative.

In the past, a reliable data basis regarding the extent and character of the wipe-related operational problems in Germany was not available. This was demonstrated by the response of the Federal Government to a so-called small request (*Kleine Anfrage*) "Regarding the disposal of wet wipes via the toilet" [90] in December 2016. The issue was not seen as relevant and the government concluded that the economic impact of disposing of wet wipes via the toilet was incalculable, as they lacked information on the "nationwide costs or the average cost increases that can be caused in the wastewater treatment process when wet wipes are disposed of via the toilet" [91].

The results of this survey demonstrate both the relevance and the economic impact of the problem and can thus contribute to a nationwide discussion of the issue. They can also support the demand of the wastewater utilities to create a flushability legislation in the near future.

However, it has to be kept in mind that the results of this survey cannot be seen as representative. Despite covering most regions in Germany as well as representing small and large utilities, the sample size is probably too small to ensure completely reliable results. As the respondents had the option of selecting “no response” for some questions (to avoid wrong information being given, where expertise was missing), the sample size for specific questions is even more reduced. It may also be that utilities with wipe-related operational problems are overrepresented in the survey, as utilities with no such problems may have been more likely to ignore the questionnaire. However, this possibility cannot be verified.

If in future a similar survey were to be repeated, for example to track the reduction of wipe-related operational problems, then a better collaboration with DWA is necessary. A clear support and distribution of the survey in all DWA regional groups would ensure a better coverage of German utilities.

4.2 Results from the survey among the general public regarding use and disposal of nonwoven wet wipes

The survey among the general public regarding use and disposal of nonwoven wet wipes covered four sections: 1) Private use of nonwoven wet wipes, 2) Professional use of nonwoven wet wipes, 3) Disposal of nonwoven wet wipes, and 4) General questions regarding moist toilet wipes. To avoid misunderstandings, the general term “wet wipes” was used instead of introducing the term “nonwoven”, which is not generally known in the public. The focus of the following presentation is on the description of the sample and the main findings derived from the survey. Due to the amount of data generated, not all findings can be presented. As the sample size of people using nonwoven wipes in their professional lives is comparatively small (13 %, 125 out of 948) and therefore cannot be seen as representative, these results will not be included in this presentation. An overview of the questionnaire is presented in Appendix C.

4.2.1 Sample description

The sample comprised 948 respondents, of which 908 respondents had completed the questionnaire and 40 had submitted incomplete questionnaires. The response rate could not be calculated, as the number of potential respondents contacted was unknown. The respondents originated from a wide range of regions in Germany, covering nearly all of the country, as can be seen in Figure 4-13. The most respondents came from the Berlin/Brandenburg area in the north-east, but many also came from central and western Germany. Nearly three-quarters of the respondents (72 %, 688 out of 948) stated that they lived in a city. Only 12 % and 16 % respectively came from small towns and rural areas.

Of the 948 respondents, 41 % (386) were male, 58 % (555) were female and 1 % (7) did not choose a sex. The respondents’ ages ranged from 15 years to 90 years, with a median value of 34 years. The age group of 25 – 34 year olds is most strongly represented, both for males and females. In the older age groups the overrepresentation of female respondents is stronger than in the younger age groups. Compared to the German population, the sample is slightly younger (average age of the German population is 43.7 years [92]) and more female (German population: 49.4 % males and 50.6 % females [93]).

Of the respondents, 54 % (507) had children. Children between 0 – 5 years made up the largest age group (25 % of all respondents had children aged between 0 – 5 years). Children of this age are of special interest for the survey, as nonwoven wipes would likely be used for their care (in nappy changing or cleaning). Figure

4-14 gives a characterisation of the respondents by sex, age and children. A more detailed overview is given in Appendix D, in Table D-1 and Figure D-1.

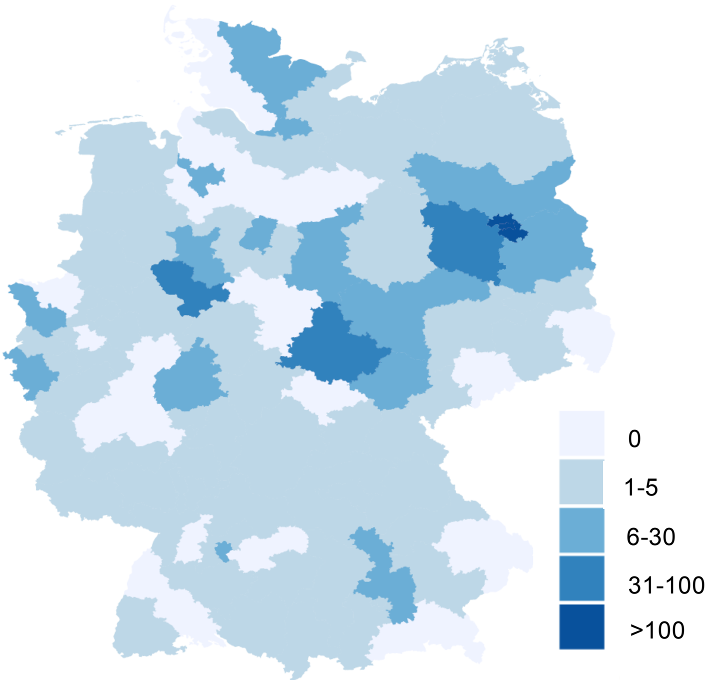


Figure 4-13: Distribution of respondents in Germany

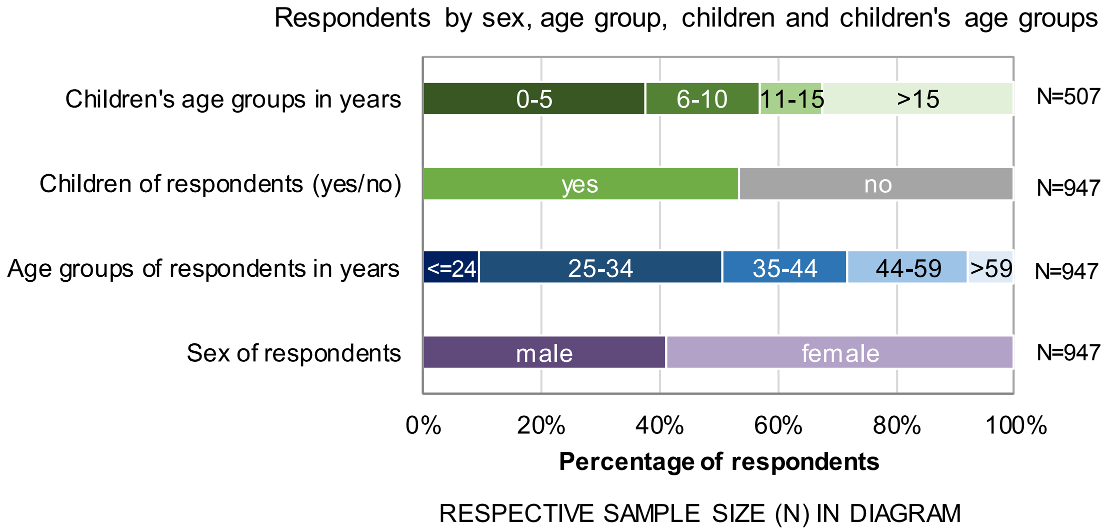


Figure 4-14: Characterisation of respondents by sex, age and children

4.2.2 Private use of nonwoven wipes

Of all respondents, 61 % (582 out of 948) use nonwoven wipes in their private lives. Significantly more women than men use nonwoven wipes (67 % compared to 33 %). The wipe users are mostly 25 – 34 year-olds (40 %), followed by 35 – 44 year-olds (27 %). People with children use nonwoven wipes more often than people without children (64 % compared to 36 %), most likely the parents with children aged between 0 – 5 years (46 %). These characteristics of nonwoven wipes users are summarized in Figure 4-15. It has to be kept in mind that partly these results may be slightly skewed due to the unequal distribution of the respective categories in the sample. However, when comparing Figure 4-14 and Figure 4-15, it is clear that these results are not only due to the sample composition.

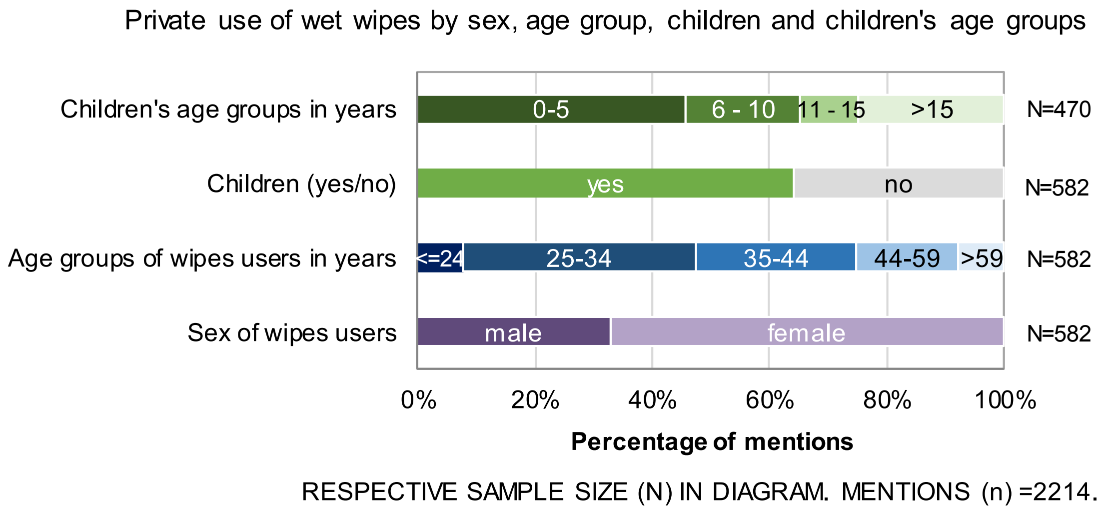


Figure 4-15: Characterisation of nonwoven wipes users

The wipes that are used most often in private households, by roughly half of the users, are moist toilet wipes (53 %, 305 out of 577) and baby wipes (48 %, 279 out of 577), as shown in Figure 4-16. These are the types of wipes that are most interesting with regard to the disposal via the toilet, as the toilet wipes are labelled as flushable and baby wipes are often found in the wastewater (see chapter 2.2.2). Approximately one-third of the wipe users also utilises hygienic wipes (33 %), cleaning wipes (32 %) and cosmetic wipes (29 %). Figure D-2 in Appendix D gives a more detailed characterisation of users of baby wipes and moist toilet wipes. As can be expected, baby wipes are mainly used by people with children (89 % of baby wipes users have children, 246 out of 276). However, 11 % of baby wipes users (30 out of 276) do not have children. Most of the children of the baby wipes users are aged between 0 – 5 years (61 % of children, 197 out of 325).

Half of the wipes users utilise them for personal hygiene (51 %, 295 out of 578) and for cleaning purposes (50 %, 290 out of 578). Somewhat fewer respondents use them for infant and toddler care (40 %, 233 out of 578) and other personal hygiene applications (39 %, 223 out of 578). These and other uses are show in in Figure D-3 in Appendix D.

The frequency of use for the different wipe products varies. Cleaning wipes, hygienic wipes and refreshing wipes are used least frequently – less than once a week by the majority of users, shown in Figure D-4 in Appendix D. Skin cleansing (cosmetic wipes) are mainly used once a day, in line with their intended application. The majority of moist toilet wipes users use them either once a day (30 %) or more often (25 %). Baby wipes are used most frequently. The majority of baby wipes users utilises them several times a day (57 %).

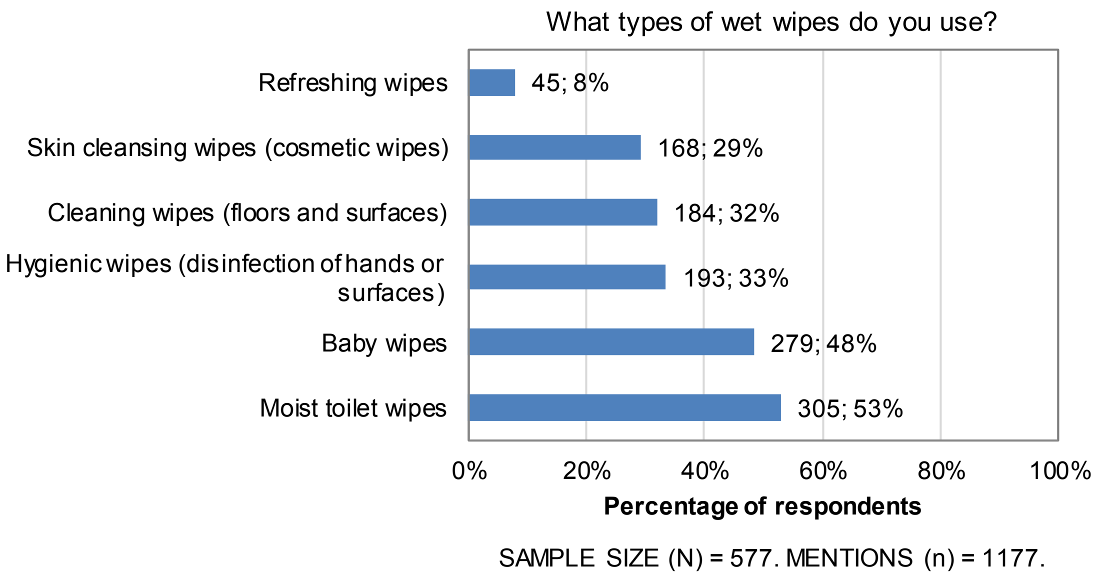


Figure 4-16: Distribution of nonwoven wipe types being used by respondents

Conclusions:

- Nearly two-thirds of the respondents use nonwoven wipes.
- The majority of wipe users are young women aged between 25 and 44 with young children (aged 0 – 5).
- Moist toilet wipes and baby wipes are the most popular wipe products.
- Main applications for the wipes are personal hygiene, cleaning and infant and toddler care.

4.2.3 Disposal of nonwoven wipes

In regard to the wipe-related operational problems in wastewater systems, the disposal practice of these products is of great interest. As can be expected, most users of moist toilet wipes dispose of these via the toilet (82 % do this always or often, 249 out of 304), as can be seen in Figure 4-17. In fact, it is remarkable that 18 % of moist toilet wipes users only rarely or never flush them down the toilet. Among the other nonwoven wipes which are labelled as “disposal via household waste”, baby wipes are the product which is most often flushed down the toilet – despite contrary advice on the package. In total, 13 % of baby wipes users (35 out of 271) always or often throw these into the toilet. The other wipe categories are flushed more seldomly.

The respondents flushing baby wipes are mainly female (70 %, 44 out of 64), aged between 25 and 44 years (89 %, 57 out of 64) and have children (86 %, 55 out of 64). Most of these children are very young, aged 0 – 5 years (52 %, 38 out of 64). An overview of these distributions is given in Figure 4-18.

The prior use of the baby wipes before their disposal via the toilet is also of great interest. Over half of flushing occurs after toilet hygiene for small children using the toilet (53 %, 40 out of 75), see Figure 4-19. The second most frequent prior application for the flushed baby wipes is toilet hygiene of the respondents themselves (43 %, 32 out of 75). Only one-fifth of respondents flushing baby wipes states that they dispose of them in the toilet after nappy changing. These results indicate that when small children have outgrown nappies, their parents still partly use baby wipes for their children’s hygiene, probably because they have become accustomed to the product. The same is likely true for the use of baby wipes for the respondents’ own personal toilet hygiene: Once the products are present in the household (due to small children) they are also used for the parents’ toilet hygiene.

However, it has to be kept in mind that the sample size of people disposing of baby wipes via the toilet is fairly small, which may mean that the results are not representative.

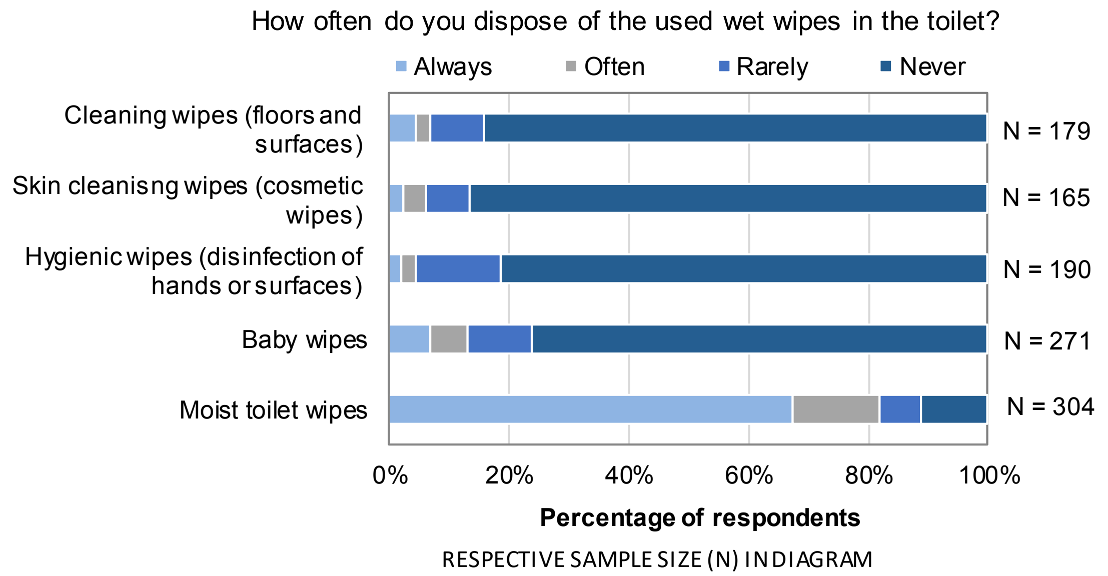


Figure 4-17: Toilet disposal of nonwoven wipes

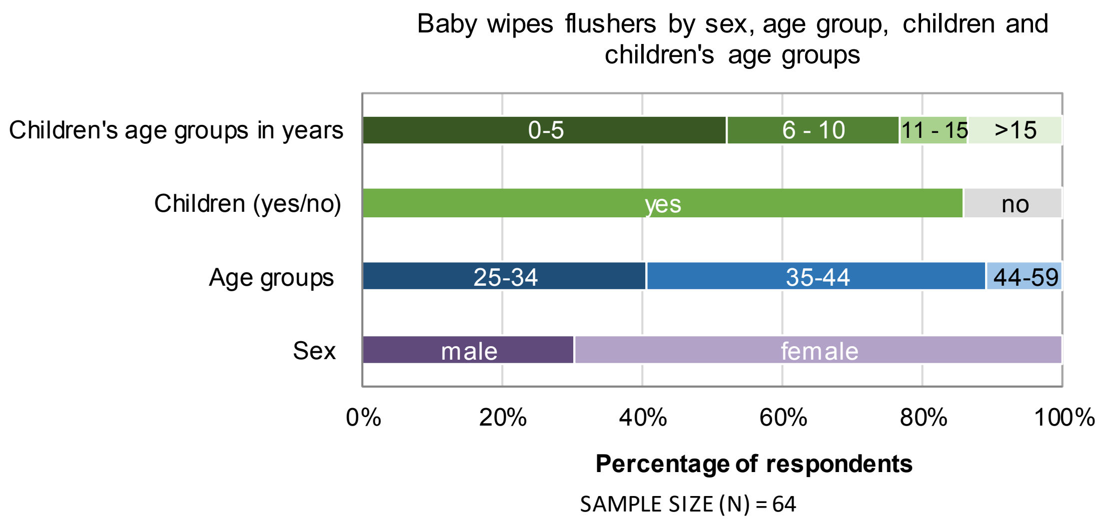


Figure 4-18: Characterisation of respondents flushing baby wipes

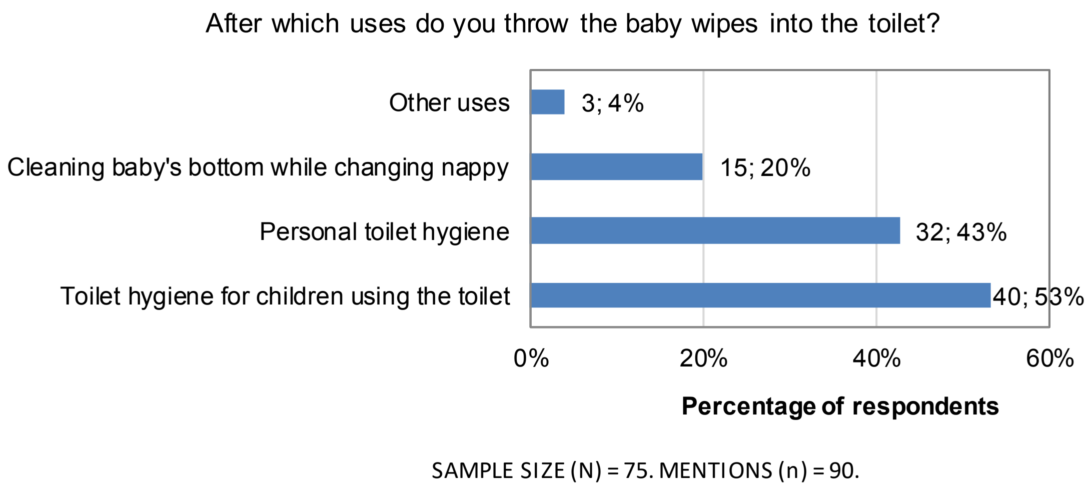


Figure 4-19: Prior uses of flushed baby wipes

Conclusions:

- Of the wipe products that are designed to be disposed of via the household waste, baby wipes are most frequently flushed down the toilet.
- The prior application of flushed baby wipes is most often toilet hygiene for small children, followed by adult toilet hygiene.
- The characterisation of users flushing baby wipes is similar to the sample composition of all wipe users; however, the majority of young women with children aged 0 – 5 is even more pronounced.

4.2.4 General awareness regarding moist toilet wipes and flushability

Nearly half of the respondents (49 %, 459 out of 937) are not aware of the fact that there is a difference between wipes sold as “flushable” and those sold as “non-flushable” (Figure 4-20, left). However, a total of 45 % of the respondents (417 out of 934) know that some of the wipes labelled as “flushable” can cause problems in the wastewater system (Figure 4-20, right). When confronted with concrete examples, most respondents judge the disposal of the respective wipes correctly, as can be seen in Figure D-5 in Appendix D. The majority of respondents classify moist toilet wipes as flushable (84 %, 775 out of 924), and all other wipe products as non-flushable. However, not all respondents are that clear on the disposal routes.14 % of respondents (132 out of 924) believe that baby wipes are flushable and 10 % (93 out of 924) believe that cosmetic wipes are flushable. In line with these results, most of the respondents have either no opinion as to whether disposal labelling on wipe packages is sufficient (because they haven’t thought about the topic yet; 50 %, 462 out of 923) or they find the labelling insufficiently clear (41 %, 380 out of 923).

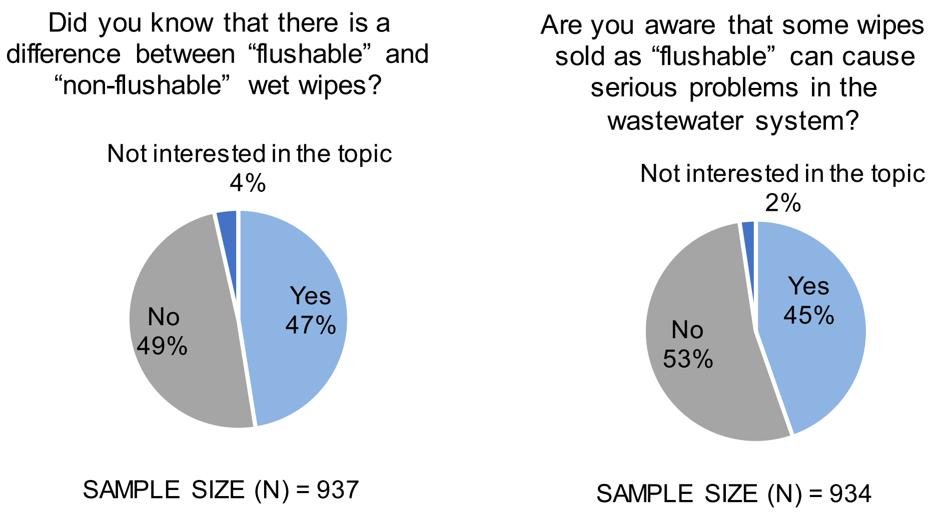


Figure 4-20: General awareness of flushability among respondents

Despite this, the survey shows that wipe consumers are interested in sewer system compatible flushable wipes. More than two-thirds of the respondents (68 %, 619 out of 909) would be willing to pay more for moist toilet wipes, if the product were proven to be harmless for wastewater systems. Of these respondents, 38 % would pay up to 50 cents more and 23 % would even pay more than 50 cents more (at an average package price of 1 €), as can be seen in Figure 4-21.

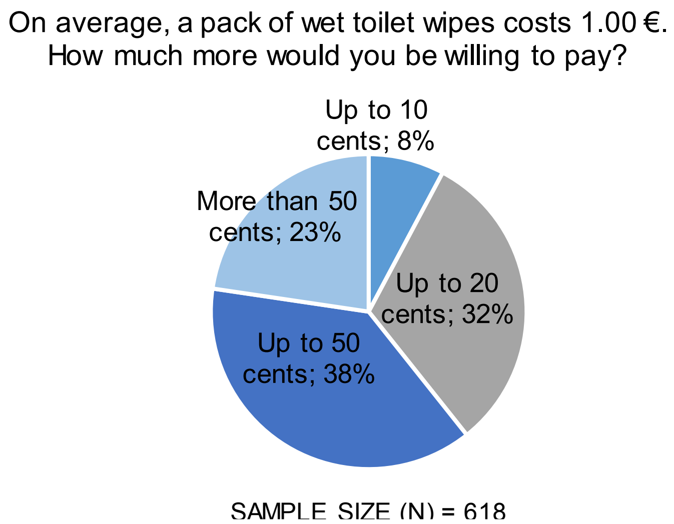


Figure 4-21: Distribution of additional costs respondents would be willing to pay for sewer system compatible nonwoven wipes

The importance of truly sewer system compatible flushable wipes for consumers can also be seen in Figure 4-22. The respondents clearly advocate requirements for flushability, such as environmentally friendly coating lotions (97 % of respondents find this important or moderately important), biodegradability of flushable wipes (94 % of respondents find this important or moderately important) and a general compatibility with the sewer system (92 % of respondents find this important or moderately important). A seal of approval is supported by slightly fewer respondents, but still the great majority (80 % of respondents find a seal of approval important or moderately important).

Conclusions:

- Despite only approximately half of the respondents being aware of issues regarding flushability of nonwoven wipes, most of them nonetheless correctly identify flushable and non-flushable wipes.
- Baby wipes are most often wrongly identified as flushable, followed by cosmetic wipes.
- Sewer system compatibility of flushable wipes is important for wipes users. They advocate flushability requirements as well as a seal approving flushability.
- The majority of users is willing to pay substantially more for moist toilet wipes proven to be sewer system compatible.

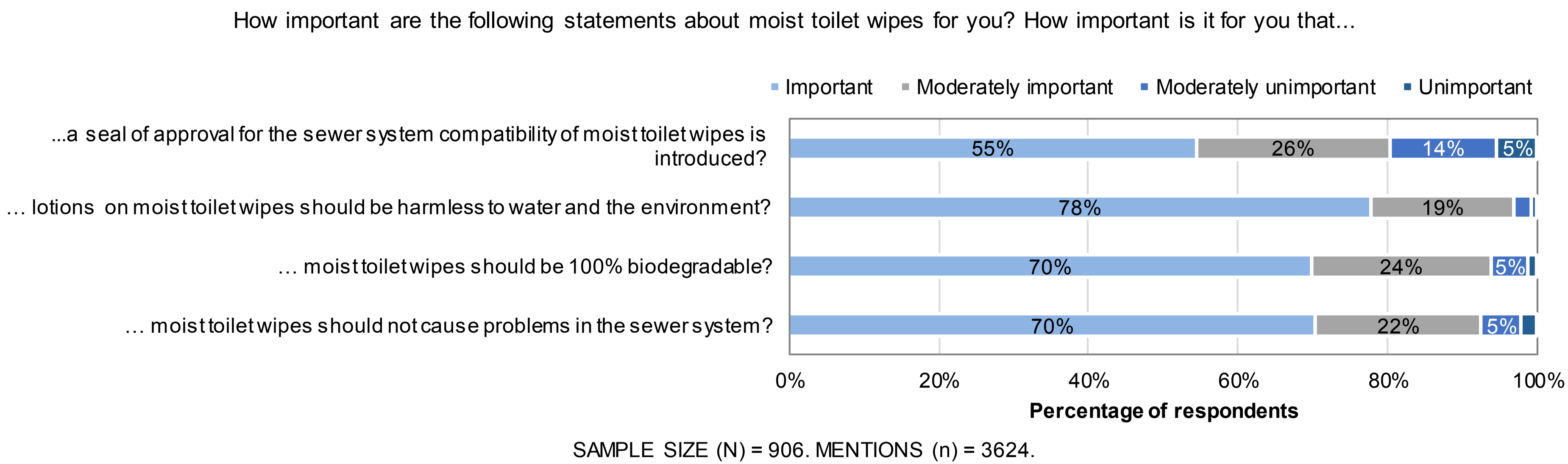


Figure 4-22: Relevance of sewer system compatibility of flushable wipes for respondents

4.2.5 Interim summary and conclusions from the user survey

The survey among the general population regarding the use and disposal of nonwoven wipes illustrates the importance of nonwoven wipes as convenience products in daily life. Most people use nonwoven wipes, especially with young children in their household. The correct disposal route for the different wipe products is adhered to by the majority of consumers. However, a significant part of wipe consumers flushes wipes designated for the household waste – especially baby wipes. Taking into account that baby wipes are used by nearly half of the nonwoven wipes consumers several times a day, this can lead to a significant impact on wastewater systems. These results are in line with studies in other countries, where mainly baby wipes were found in pump blockages (see Chapter 2.2.2). It is clear that the users of baby wipes are an important target group when addressing flushability of nonwoven wipes to reduce operational problems in sewer systems. Especially as the survey responses suggest that baby wipes are partly used for toilet trained children that have outgrown their nappies. Cementing the use of baby wipes as “flushable” toilet wipes at this young age should be avoided at all costs, as this habit will otherwise be continued. Educating the parents regarding the proper use of baby wipes will also help avoid the use of baby wipes in adult toilet hygiene.

It is promising that most respondents are in favour of sewer system compatible flushable wipes. This may indicate that once the public is sufficiently educated on the fact that flushability should mean “sewer system compatible” and not “flushable by size”, public pressure will lead to more (or maybe even exclusively) sewer system compatible flushable wipes on the market. This development can be supported by a positive flushability seal, which can help consumers make the “right” choice. Most respondents approve a flushability seal and even would be willing to pay more for moist toilet wipes proven to be sewer system compatible. However, this willingness likely is not completely transferrable to the actual purchase behaviour of the population. Past experience shows that on an abstract level people are often willing to spend more money on higher quality products (for example with regard to meat and animal welfare [94]), but this is not implemented in the actual purchase. Hopefully the stated willingness to support sewer system safety is nevertheless an incentive for manufacturers and retailers of wipes labelled as “flushable” that do not yet adhere to industry flushability guidelines.

As the sample drawn for this survey is not representative for the German population buying nonwoven wipes (it was assumed everyone above the age of 14), this may also be true for the results. However, the baby wipes users, an important target group for the survey, were likely represented quite well.

The skew in age in the sample (older people were underrepresented) may be due to the distribution mode of the survey. Older people have a lower affinity to computers, smart phones and the internet and therefore the survey link reached them more seldomly than younger people. Also, as the survey link was originally distributed via university mailing lists and contacts, this would naturally also include more young than older people. The slight overrepresentation of females cannot be explained. It may be that women and girls were more conscientious in filling out and passing on the survey.

As the flushability and sewer system compatibility of nonwoven wipes is increasingly being promoted by utilities and by the industry associations INDA and EDANA, a repetition of the survey in an adequate time frame would be of great interest. This could determine whether the disposal habits, especially regarding baby wipes, have changed. To ensure a more representative sample, older people should be targeted more directly and a more even geographic distribution of respondents should be ensured. Also, a larger sample of people using nonwoven wipes in their professional lives would be of interest, as many utilities suspect child care facilities, old people's homes, and hospitals to be major dischargers of non-flushable wipes.

4.3 Results from field experiments in a wastewater pumping station

Three pump blockages from an inner city pumping station in Berlin were collected and analysed. Figure 4-23 characterises the duration of pump operation until the predetermined blockage criterion was reached, the pumped volume until blockage, the total dry weight of each blockage, and the resulting specific dry weight of clogging material per m^3 wastewater for each blockage respectively. The time until the blockage criterion was reached (reduction in flow rate of 10 %) was overall very short. The maximum clog free operation time was achieved for blockage 1 (~17 minutes), whereas the pump was clogged after only ~11 minutes in the case of blockage 2. The resulting average clog free operation time was 13.73 minutes. The average pumped volume of wastewater until the blockage criterion was reached amounted to approximately 38 m^3. It is evident that not much material is needed to clog the pump and reach the blockage criterion, as can be seen in the diagrams showing the total dry weight of each blockage, bottom left hand side of Figure 4-23, and the specific dry weight (amount of clogging material per m^3 wastewater), bottom right hand side. Pump blockage 1 was the largest, with 186.24 g, while pump blockage 3 was the smallest, with 118.83 g (average weight of the pump blockages was 156.42 g). In relation to the respective pumped volume, this results in very low average amounts of clogging material per m³ wastewater, ranging from 3.31 g/m³ to 5.42 g/m³. While these values are pump specific (as the impeller technology can influence clogging), they nonetheless indicate that even very small amounts of sewer system incompatible products in wastewater can lead to adverse effects on pumping systems within a short time frame.

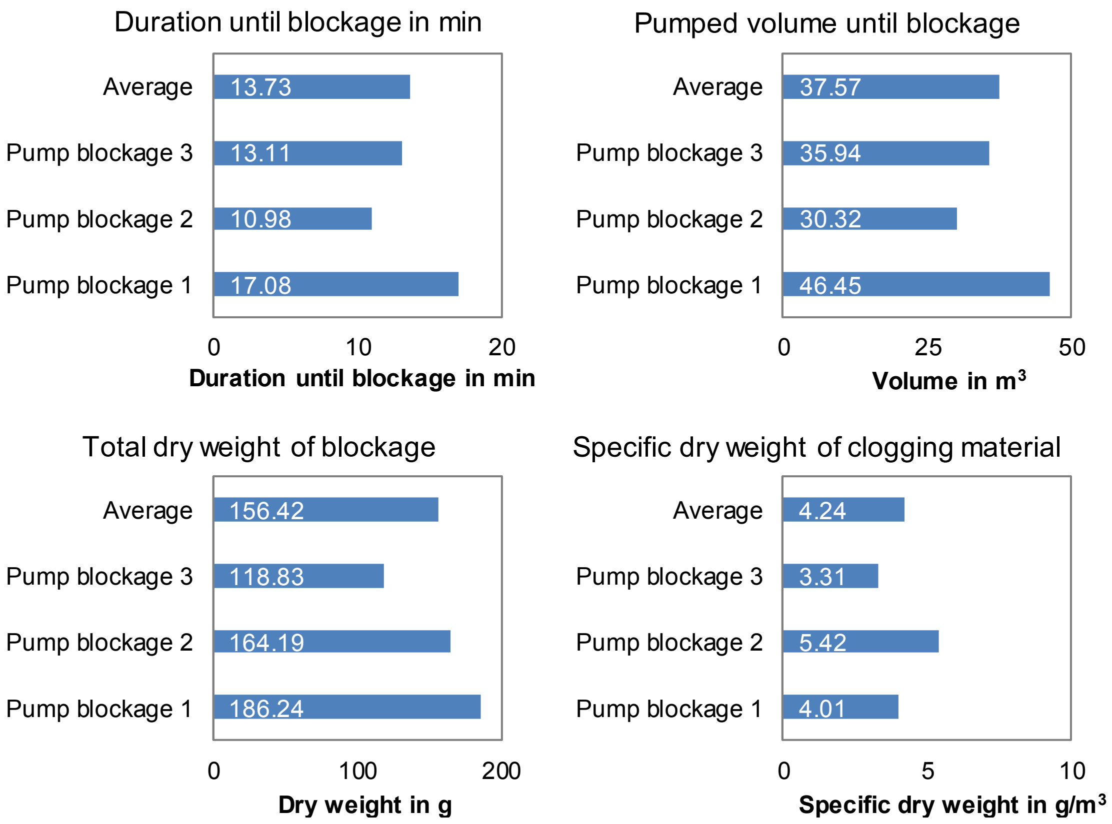


Figure 4-23: Characterisation of collected pump blockages

The following constituents were identified in the pump blockages (for details regarding nonwoven textile characteristics see chapter 2.1; the colours refer to Figure 4-24):

Spunbonded nonwovens (red box): Due to their high tensile strength and plastic content, spunbonded nonwoven wipes are mainly sold as non-flushable products, e.g. as baby wipes, cosmetic wipes or different kinds of household cleaning wipes. Designated disposal route for these products is the household waste.

Staple fibre nonwovens (green box): The staple fibre nonwovens in the examined samples were airlaid and wetlaid nonwovens (made of natural polymer fibres), which were mainly bonded thermally (calendering) or by hydroentanglement. These characteristics are most common for moist toilet wipes. Thus, the wipes in this category were likely sold as flushable moist toilet wipes.

Wetlaid nonwovens (paper) (blue box): Paper products that are made using the paper-laying process (wetlaying), such as kitchen roll, napkins or paper towels. Designated disposal route for these products is the household waste.

Feminine hygiene products (brown box): Tampons, sanitary pads, panty liners etc. The designated disposal route for these products is the household waste.

Rests (black box): Leaves, plastic wrappers, hair, and sand. The designated disposal route for these products is the household waste. Leaves and other debris may enter the combined sewer system through manholes.

Knotted rest (grey box): Knotted part of the blockage that could not be separated or detangled. Visual inspection showed that these rests were mainly made up of spunbonded nonwovens, often twisted with hair, and some smaller amounts of paper and organic rests.

While the type of nonwoven fabric used for each wipe was identified, it was not possible to determine with absolute certainty whether the wipes found in the blockages were originally sold as flushable or as non-flushable products. Based on nonwoven characteristics, it is nonetheless possible to draw conclusions as to the likelihood of their flushability labelling. Moreover, if wipes were individualized by the manufacturers by imprinting or embossing, a clear identification of the wipe product and thus of its flushability labelling was possible. Figure 4-24 gives an overview of the materials found in pump blockage #1 (the colours correspond with the description above).

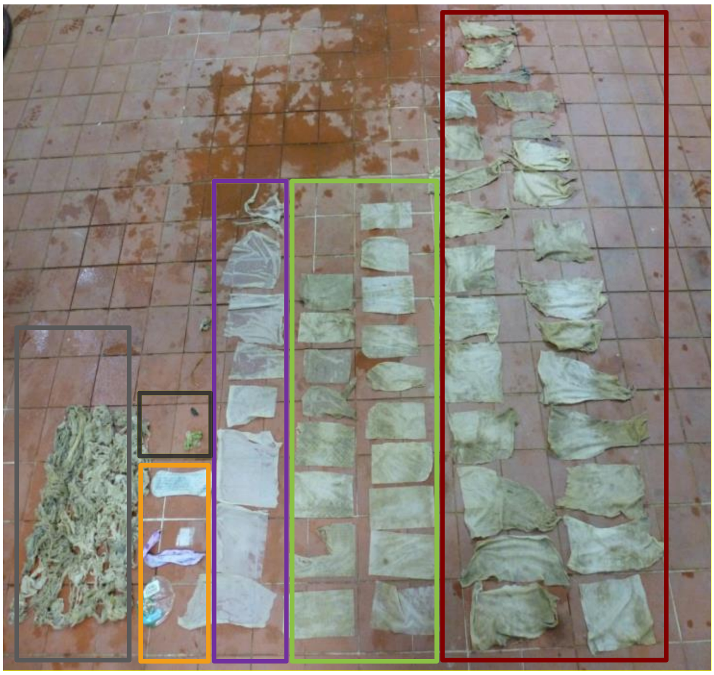


Figure 4-24: Overview of constituents of blockage #1

Figure 4-25 shows the percentage distribution of the analysed fractions (dry weight) in each of the three investigated pump blockages, as well as the average over all three. Paper rests were also identified in the pump blockages. However, as the paper was torn and crumpled and partly disintegrated when touched (and thus was probably mainly toilet paper), it was not considered in the analysis. These paper rests were likely caught up in the existing blockage, but did not contribute to its formation.

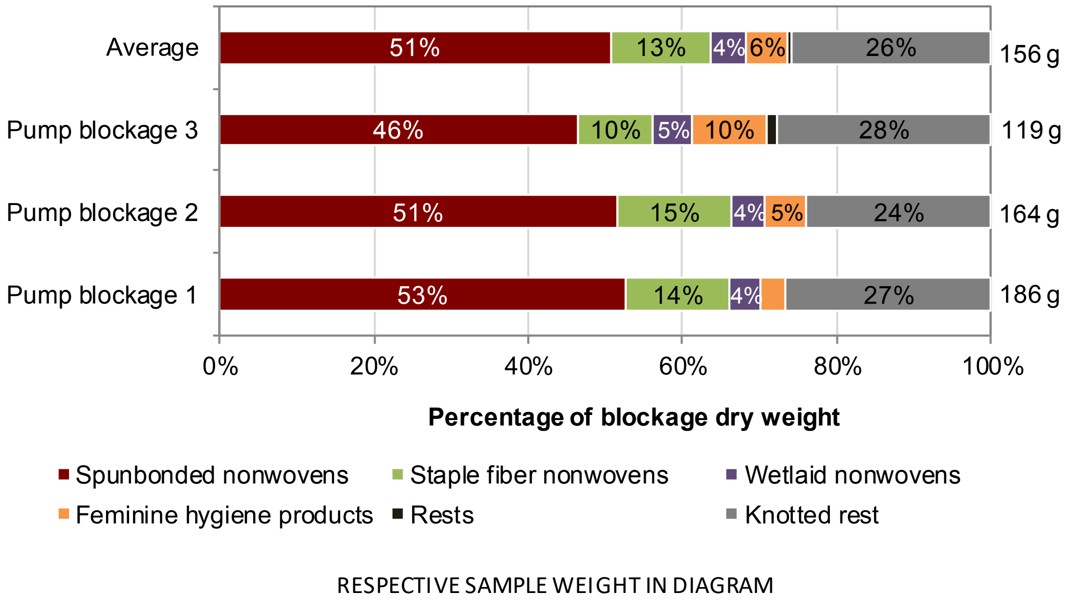


Figure 4-25: Percentage distribution of dry weight of fractions found in pump blockages in a study in Berlin

The largest fraction in each blockage were the spunbonded nonwovens – the non-flushable wipes (red), designated for the household waste. This fraction ranged from 46 % in pump blockage 3 to 53 % in pump blockage 1. On average, roughly half of the pump blockage (51 %) consisted of clearly identifiable spunbonded nonwovens. Taking into account that the fraction “Knotted rests” also consisted mainly of spunbonded nonwovens that were too entangled to separate, it is obvious that the blockages were made up mainly of non-flushable wipes that should never have been disposed of via the toilet.

The next largest fraction was the respective “Knotted rest”. As described above, it consisted mainly of spunbonded nonwoven wipes, which were entangled to a degree that made separation impossible. On average, the knotted rest made up approximately a quarter of the blockage material (26 %).

The staple fibre nonwovens (green) ranged from 10 % in blockage 3 to 15 % in blockage 2, resulting in an average of 13 % staple fibre nonwovens over all blockages. As explained above, these wipes were most likely sold as flushable moist toilet wipes. Some of the samples could be clearly identified as moist toilet wipes by their embossing, with the help of clean reference samples. One such example is shown in Figure 4-26. The nonwoven wipe found in the clogging material (left-hand side) is clearly identical with the reference sample from the pack of moist toilet wipes sold as flushable (right-hand side). As they are marketed as “flushable”, these nonwoven wipes should not be present in pump blockages.

Feminine hygiene products (brown) and wetlaid nonwovens (e.g. kitchen roll; blue) were found to smaller degrees. Feminine hygiene products were present with a maximum of 10 % in blockage 3 (and an average of 6 %) and wetlaid nonwovens with a maximum of 5 %, also in blockage 3 (and an average of 4 %).

Further materials, summarised in the category “Rests” (including leaves or plastic wrappers) were only found in blockage 3 (1 %).

Figure 4-26: Left side: Staple fibre nonwoven found in pump blockage. Right side: Reference sample of moist toilet wipe sold as flushable

Conclusions:

- Low amounts of clogging material in wastewater are sufficient to have a significant negative impact on pump performance.
- Main constituent of the pump blockages were spunbonded wipes, sold as non-flushable. On average, they made up half of the dry weight of the blockages and further spunbonded wipes were present in the knotted rest of each blockage.
- However, products that were likely sold as flushable moist toilet wipes, the staple fibre nonwovens, were also identified in every blockage, though to a much smaller degree (averaging 13 %).

4.3.1 Interim summary and conclusions from the field experiments

The analysis of pump blockages showed that even comparatively low concentrations of sewer system incompatible products can have a significant negative impact on pump operation. In the investigation, the maximum average concentration of clogging items in the pumped volume was 5.42 g/m^3, which corresponds to roughly 3 – 4 baby wipes per m^3 (at an average weight of 1.58 g/wipe). However, the development of blockages is a complex process. It is likely that after the first nonwoven wipes are caught in the pump, the likelihood increases that further material accumulates.

The major constituent of the clogs were demonstrated to be spunbonded nonwoven wipes designated for the household waste, such as baby wipes, cleaning wipes, and cosmetic wipes. This indicates that the main part of the operational issues and equipment failures in pumping stations due to nonwoven wipes is caused by wipe users incorrectly disposing of their used non-flushable wipes via the toilet instead of the household waste. These results are in line with blockage studies conducted in other countries (see chapter 2.2.2), where even larger proportions of non-flushable wipes were found in pump blockages.

Despite making up a comparatively small fraction in the analysed blockages (on average 13 %), the identified staple fibre nonwovens are nonetheless of great relevance. These wipes were most likely sold as flushable moist toilet wipes. Their presence in the pump blockages and their often well preserved condition indicate that the label “flushable” is not always reliable. Rather, despite being “flushable by size”, at least some of the moist toilet wipes labelled flushable are not pumping system or sewer system safe. Truly sewer system compatible flushable nonwoven wipes should disintegrate either before or in the pump.

Despite the small sample number, the analysis shows consistent results. The claim that no nonwoven wipe sold with the label “flushable” causes pump blockages could be clearly disproved. However, it could also be shown that the main cause of wipe-related operational problems in pumping systems are not the products, but wrong disposal behaviour of users. Unfortunately, further analyses of pump blockages were not possible within the scope of this study, due to time and cost constraints. Nonetheless, additional investigations are necessary to enhance the knowledge and understanding of materials in the blockages. This should include different regions and different catchment areas (rural/city) and possibly also target pumping stations in close proximity to hospitals and other care facilities.

4.4 Results from the laboratory experiments

The clogging effect of different types of nonwoven wipes was investigated in the laboratory using a pump test stand. Based on studies from other countries (see chapter 2.2.2) and the results of the surveys and field investigations presented in the previous sections, moist toilet wipes and baby wipes were judged to be most relevant. Therefore, three moist toilet wipes, two of which were compliant with INDA/EDANA Flushability Guidelines (FG), and two baby wipes were investigated systematically regarding their clogging effect on wastewater pumps.

The focus of the following presentation is on the description of the main findings derived from the investigations. Due to the amount of data generated, not all findings can be presented. For better understanding of the following diagrams, a continuous colour scheme for each nonwoven wipe will be used throughout the presentation of the results, see Table 4-1.

Table 4-1: Overview of colour scheme used continuously throughout the presentation of the results

	Flushable label	EDANA/INDA FG compliant	Colour	Colouring		
				WWC1	WWC2	WWC3
Toilet wipe A	Yes	Yes	Green			
Toilet wipe B	Yes	Yes	Blue			
Toilet wipe C	Yes	No	Yellow			
Baby wipe A	No	No	Red			
Baby wipe B	No	No	Orange			

Figure 4-27 to Figure 4-31 show the normalised group efficiency of the pump (ratio of group efficiency while clogging to clear water group efficiency at the respective operating point, $\eta_{clogged}/\eta_{clear}$) during the short time performance test and the longtime performance test (for the three wastewater classes), for each of the wipes respectively (at operating point Q/Qopt = 1.0).

Both toilet wipe A and B have hardly any effect on the efficiency of the pump. Toilet wipe B leads to a slight decrease in normalised group efficiency in wastewater class 3 (WWC3) during the short time performance test, while Toilet wipe A has no impact at all – slight fluctuations in the graph are in the range of normal fluctuation during operation with clear water (2 – 3 %). During the longtime performance test neither Toilet wipe A nor Toilet wipe B has any influence on the pump's efficiency (in all three wastewater classes). This is evident from the superimposed graphs, which barely fall below 1, i.e. 100 %.

Toilet wipe C, however, leads to a substantial decrease in efficiency, due to increased energy consumption, as shown in Figure 4-29. Even with the least contaminated WWC1, the pump begins operation considerably below 100 % normalised group efficiency, for both short time and longtime performance test. This indicates that Toilet wipe C begins clogging the pump from the first moments of operation onwards. For WWC2 and WWC3 the pump efficiency is lower still, even decreasing steadily in the brief time period of the short time performance test for WWC3. The levels of normalised group efficiency during short and longtime performance test are similar for WWC1 and WWC2. Moreover, they remain fairly constant, even throughout the hour-long longtime performance tests. During the longtime performance test with WWC3 the effect on pump operation is by far the worst, as the pump loses approximately 70 % of its efficiency. The sharp decrease in efficiency during the first minutes of operation of the longtime performance tests, after which the efficiency remains at a constant low level for the remaining test, is unexpected. This indicates that despite being pumped in loop for 60 minutes, the blockage in the pump remains stable and Toilet wipe C does not break down.

As expected, the Baby wipes A + B have a much greater impact on pump performance than the toilet wipes, as they are sold as non-flushable and should not be disposed of via the toilet. Figure 4-30 and Figure 4-31 show that with each increase in contamination (from WWC1 to WWC3) the initial normalised group efficiency at the beginning of the tests is lower. During the short time performance tests the efficiency further decreases steadily in the course of the tests. Again, this indicates incipient clogging from the first wipe onwards and also that the blockage increases during test duration. During the longtime performance tests, the normalised group efficiency decreases drastically in the first minutes of operation, dropping to 20 % for Baby wipe A (WWC3) and even to 15 % (WWC3) for Baby wipe B. After the initial decrease, however, the efficiency remains stable at the minimum value, similar to Toilet wipe C. This implies a large accumulation of wipes in the first minutes of test operation (probably as many as fit into the pump), that subsequently remain in the pump for the duration of the test. Diagrams for the operating points Q/Qopt = 0.8 (part load) and Q/Qopt = 1.2 (overload) are presented in Appendix F, Figure F-1 to Figure F-5 and Figure F-16 to Figure F-20. The same general characteristics regarding WWC and type of nonwoven wipe as described for Q/Qopt = 1.0 (BEP) apply for these operating points.

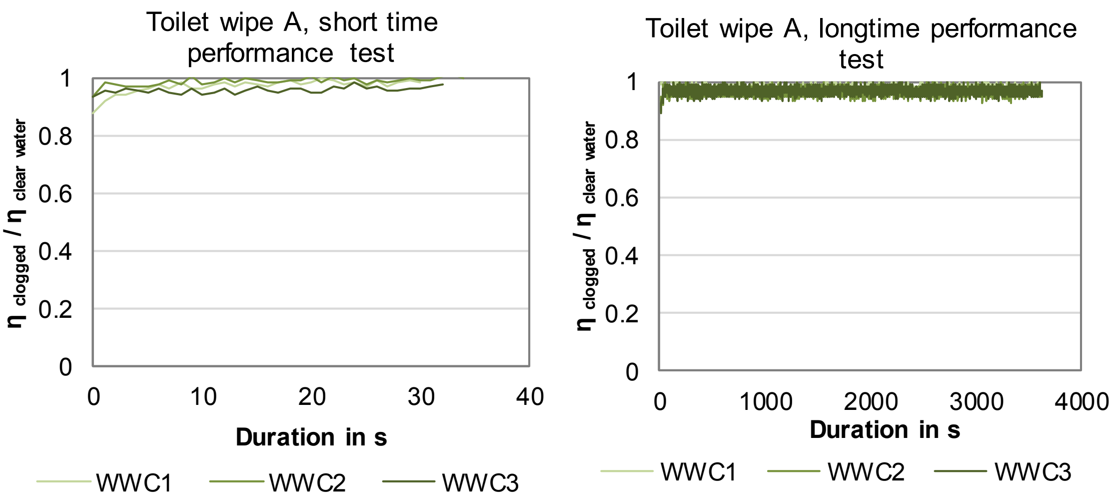


Figure 4-27: Toilet wipe A, normalised group efficiency, Q/Qopt = 1.0, WWC 1-3

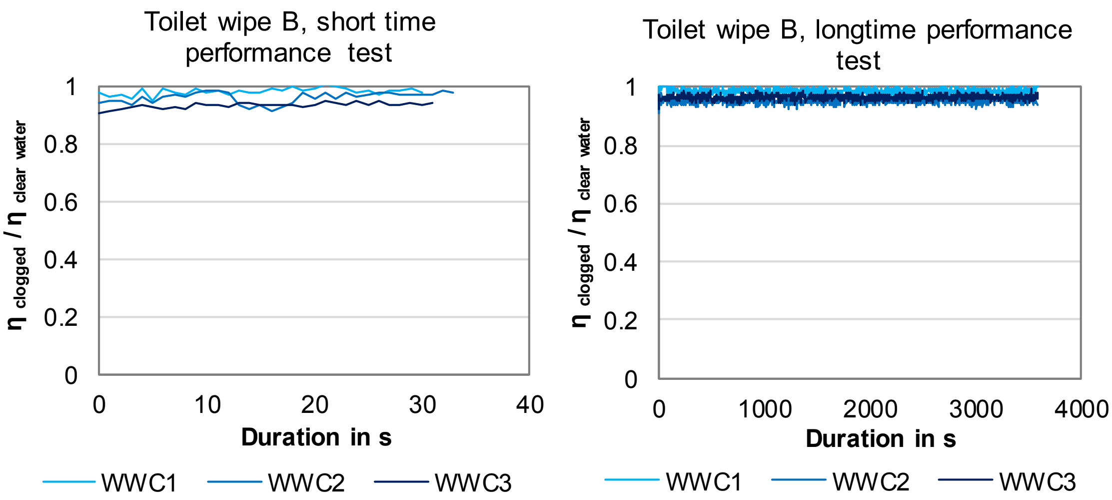


Figure 4-28: Toilet wipe B, normalised group efficiency, Q/Qopt = 1.0, WWC 1-3

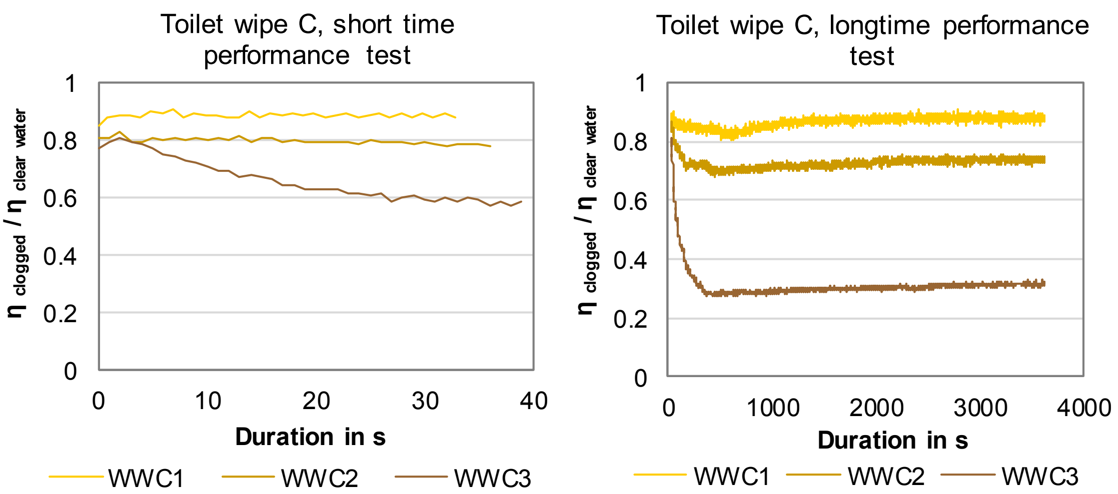


Figure 4-29: Toilet wipe C, normalised group efficiency, Q/Qopt = 1.0, WWC 1-3

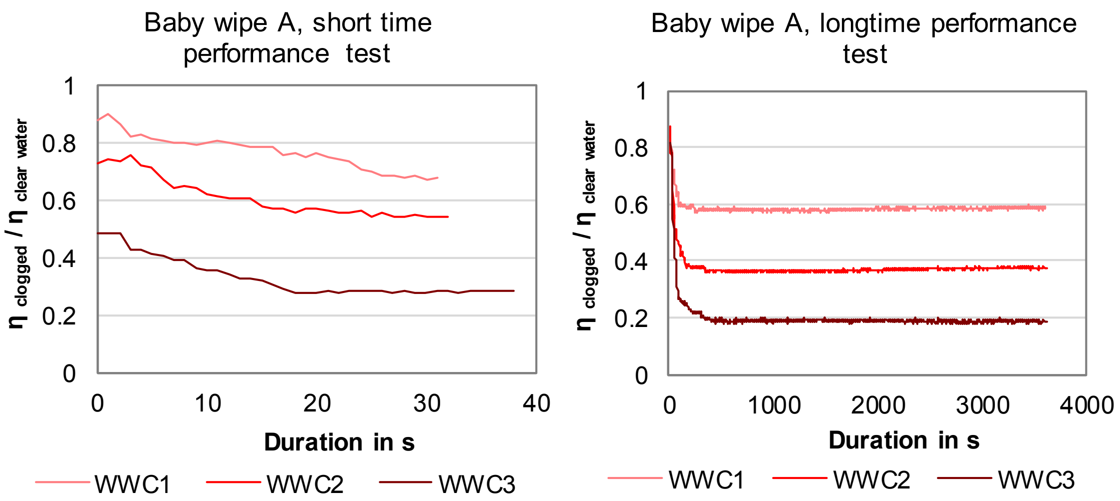


Figure 4-30: Baby wipe A, normalised group efficiency, Q/Qopt = 1.0, WWC 1-3

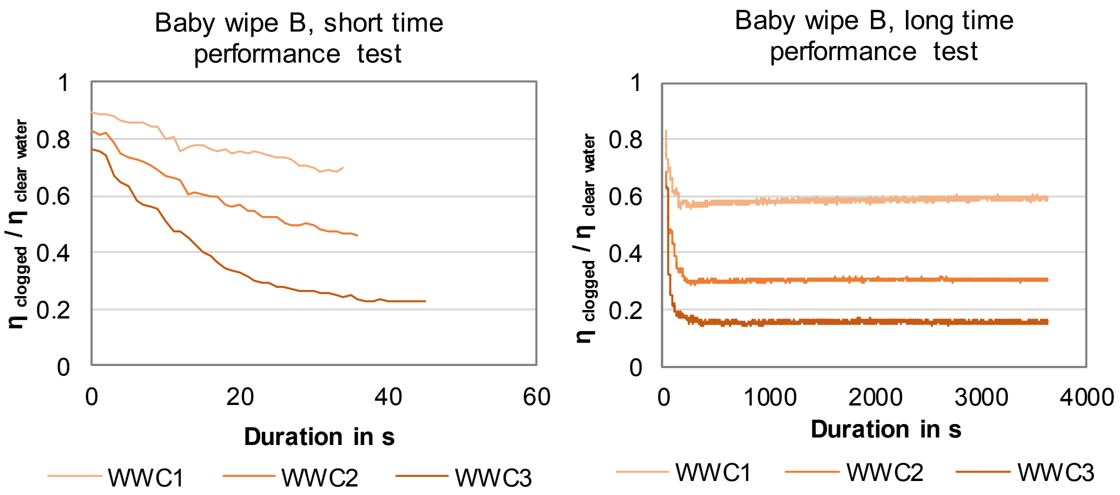


Figure 4-31: Baby wipe B, normalised group efficiency, Q/Qopt = 1.0, WWC 1-3

Figure 4-32 to Figure 4-36 show the operating points of the test pump as well as its characteristic curve during each short time and longtime performance test (at Q/Qopt = 1.0) for each investigated wipe and wastewater class. The diagrams for Toilet wipe A (Figure 4-32) and Toilet wipe B (Figure 4-33) show that these nonwoven wipes have no impact on hydraulic pump performance, neither during the respective tests, nor with increasing contamination (from WWC1 – WWC3). During both short and longtime performance tests, pump operation remains in the best efficiency point, or very close to it, indicated by the overlapping operating points for the respective WWC. Even with increasing contamination, head and flow remain constant, which can be seen by the superimposition of the operating points for the three wastewater classes.

Toilet wipe C, on the contrary, has a significant impact on the operating point during both short time and longtime performance tests. During the short time performance test with WWC1, the operating point lies slightly below the characteristic curve, but remains fairly compact. With increasing contamination, the operating point lies lower at the beginning of the test and shifts further from the BEP during the test. The operating points during the WWC1 and WWC2 longtime performance tests are similar to those of the short time performance tests. However, during the WWC3 longtime performance test, the drift of the operating point is much more pronounced. This is in line with the sharp decrease of normalised group efficiency depicted in Figure 4-29. The drifting operating points, especially during WWC2 and WWC3 tests, show that the hydraulic performance of the pump steadily decreases during the tests. The effect is worse during longtime performance tests than during short time performance tests, as due to the longer test duration, more nonwoven wipes are accumulated in the impeller.

The Baby wipes (A + B) have a stronger adverse effect on hydraulic pump performance than Toilet wipe C, especially for WWC2 and WWC3. For WWC1 the operating points for both baby wipes during both the short time and longtime performance tests remain compact and on or near the characteristic curve. The same is true for Baby wipe A and WWC2 (short time performance test). However, the operating point for Baby wipe B and WWC2 (short time and longtime performance test) shows a stronger variation and drifts further from the BEP. For both short time and longtime tests, WWC3 shows the strongest effect on the operating point (Baby wipe A + B): It shifts significantly from the BEP; more so during the longtime than the short time test. As with Toilet wipe C, these characteristics show that the hydraulic performance of the pump deteriorates with increasing contamination and also deteriorates during the tests. Again, the effect of the wipes is worse during longtime performance tests, as more nonwoven wipes can be collected by the impeller than during the short time performance test.

The fact that the operating points during short time and longtime performance tests remain on or near the characteristic curve during WWC1 tests for the clogging wipes (Toilet wipe C, Baby wipes A + B), while normalised group efficiency decreases significantly (as shown in Figure 4-29 to Figure 4-31), indicates that the pump reaches the target values for head and flow (with only negligible reductions) at the cost of increased energy consumption. An increase in contamination (from WWC1 to WWC2) leads to a further increase of energy consumption and a significant decrease in the hydraulic performance of the pump (head and flow).

Diagrams for the operating points Q/Qopt = 0.8 (part load) and Q/Qopt = 1.2 (overload) are presented in Appendix F, Figure F-6 to Figure F-10 and Figure F-21 to Figure F-25. The same general characteristics regarding WWC and type of nonwoven wipe apply for these operating points.

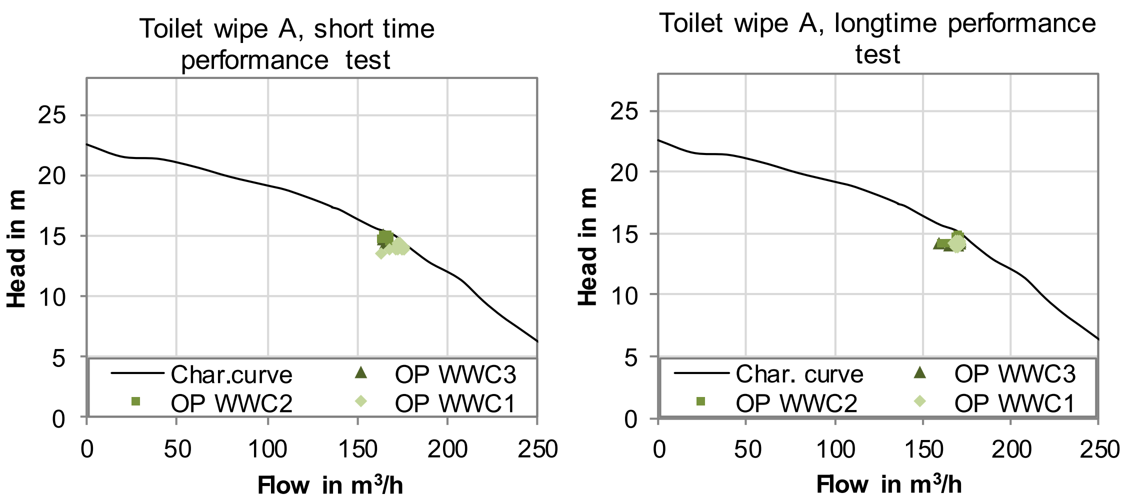


Figure 4-32: Toilet wipe A, Q/Qopt = 1.0, operating points for wastewater classes 1-3

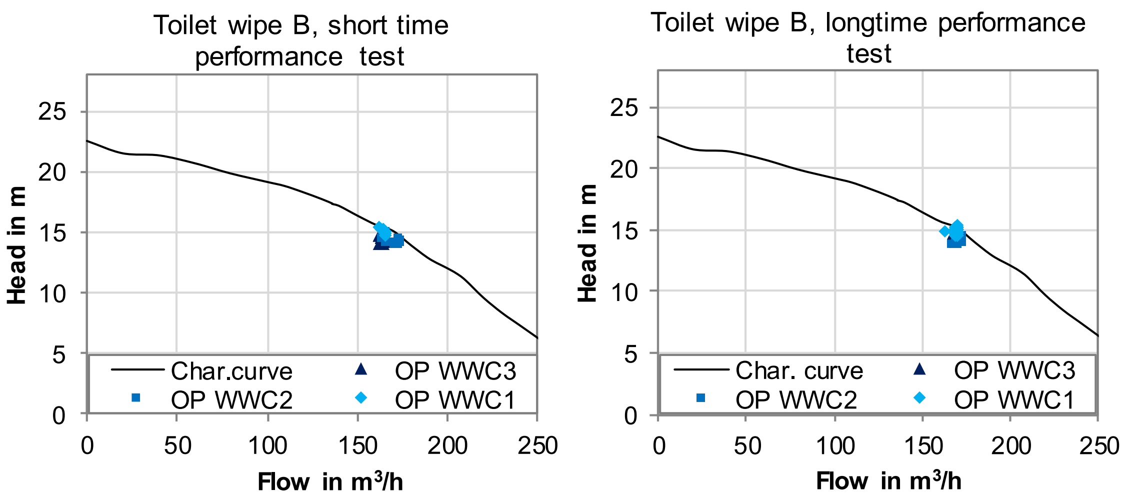


Figure 4-33: Toilet wipe B, Q/Qopt = 1.0, operating points for wastewater classes 1-3

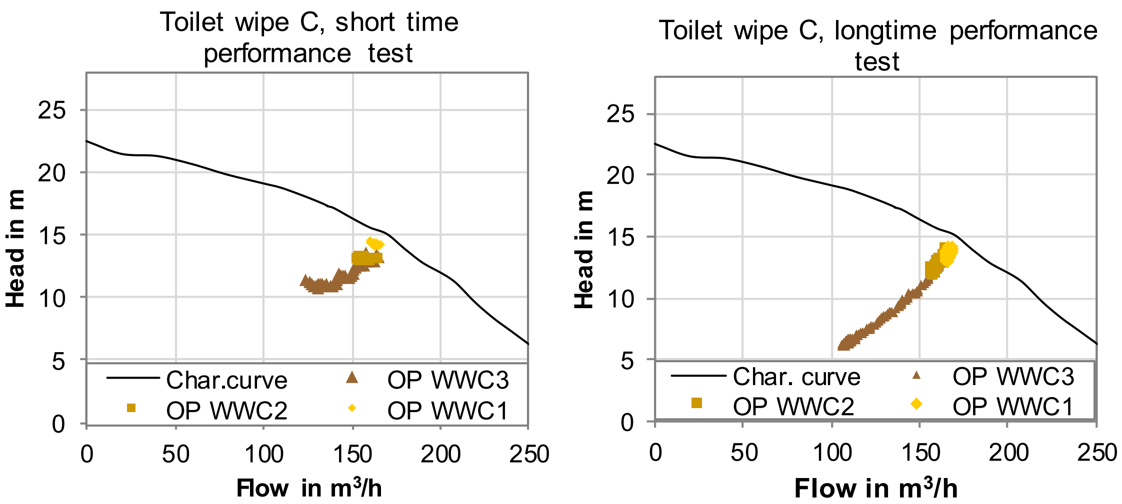


Figure 4-34: Toilet wipe C, Q/Qopt = 1.0, operating points for wastewater classes 1-3

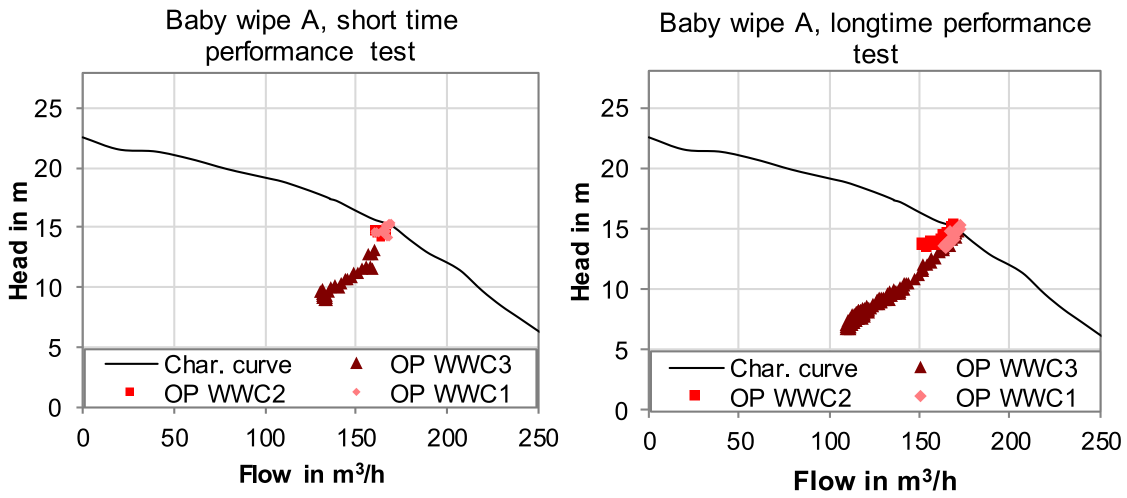


Figure 4-35: Baby wipe A, Q/Qopt = 1.0, operating points for wastewater classes 1-3

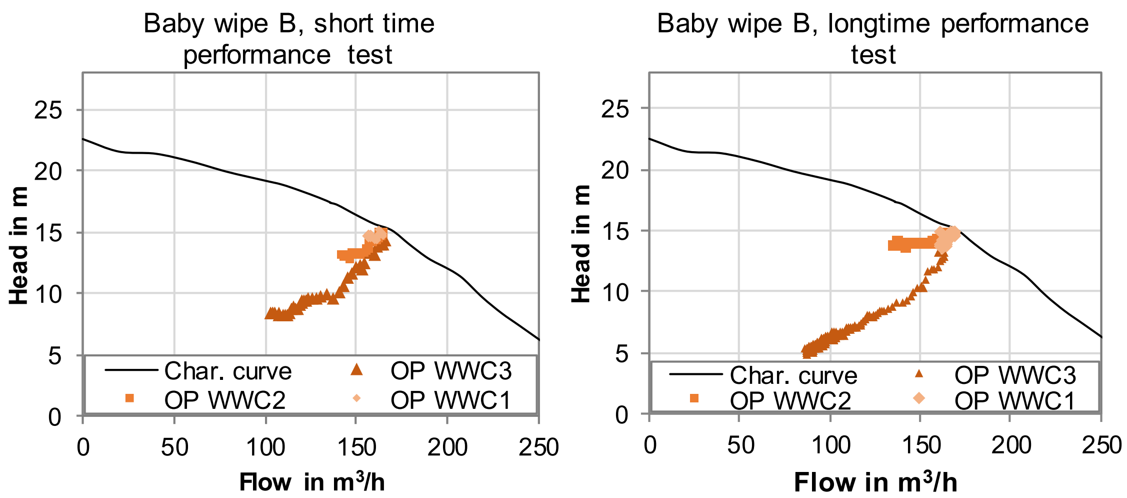


Figure 4-36: Toilet wipe B, Q/Qopt = 1.0, operating points for wastewater classes 1-3

Figure 4-38 to Figure 4-42 summarise and compare the clogging behaviour of the wipes at different WWCs. They show the average value of different evaluation criteria for each WWC for the two performance tests (at operating point Q/Qopt = 1.0).

Figure 4-38 shows the dry weight of the wipe residues remaining in the pump after each short time and longtime performance test, plotted against the degree of contamination (respective wastewater class). Figure 4-39 shows the relative amount of residues remaining in the pump (ratio of dry weight of residues found in the pump to dry weight of total pumped wipes).

During the tests it could be observed that Toilet wipe A and B disintegrate immediately, thus merely leaving separate fibres in the water. Even at the highest degree of contamination, Toilet wipe A leaves no residues and Toilet wipe B leaves merely 13 g residues in the pump (however only during the short time performance test). This corresponds to 3 % of the total added mass. However, these 13 g residues were not clogging the impeller, but lying in a small heap of fibres in the bottom of the pump, where they were likely just about to be pumped away, when pump operation was stopped (see Figure 4-37).

In contrast, Toilet wipe C clogged the pump at every concentration, despite being made of 100 % cellulose and easily tearable by hand. Even at the lowest degree of contamination (WWC1), 50 g residues were found in the pump after the short time performance test, reaching up to 170 g for the highest degree of contamination. As seen in Figure 4-39, this corresponds to nearly half of the added mass respectively (47 % and 41 %). During the longtime performance tests, even more material accumulated in the pump. In WWC3, 268 g were found in the pump, which corresponds to 61 % of the total added mass of wipes. This indicates that with increasing contamination, greater amounts of nonwoven wipes are accumulated in the impeller. The longer operating time of the longtime performance tests leads to more wipes accumulating in the pump, instead of wipes being dislodged.

As expected, the non-flushable Baby wipes (A + B) have the strongest clogging effect and cause the most residues in the pump, with a greater increase with rising contamination. This is likely due to the different material properties, compared to Toilet wipe C. While the latter is made of 100 % biodegradable cellulose and can be torn by hand, the baby wipes are made of 100 % plastic and have a high tensile strength, leading them to tangle and entwine instead of tearing. Maximum residues after the short time test are 199 g (Baby wipe A) and 291 g (Baby wipe B), which corresponds to 63 % and 64 % of total mass, respectively. As with Toilet wipe C, the Baby wipes clog the pump even worse during the longtime performance tests. Even at the lowest contamination (WWC1), nearly 100 % of wipes are caught in the pump, with a maximum of nearly 400 g after the WWC3 test. Again, similar to Toilet wipe C, these results show that with increasing contamination, greater amounts of nonwoven wipes are accumulated in the impeller. Even at low concentrations the wipes are not removed from the impeller, once they are caught there. The longer the test duration, the more nonwoven wipes are caught in the impeller, until nearly every single wipe is entwined in the clogging material.

Interestingly, the clogging effect of the non-flushable spunbonded wipes (Baby wipe A + B) was different from the clogging effect of Toilet wipe C. As often seen in the field, the spunbonded wipes form long knotted “tails” of material, which get caught by the leading edge or the hub region (due to their stretchability and high tear strength). In contrast, Toilet wipe C did not become knotted, but formed layers in the impeller, until a thick wad of material blocked the pump. This may be due to the denser material and lower permeability to air of Toilet wipe C, compared to Toilet wipe A + B (see characterisation of nonwoven wipes in Appendix E). The different clogging characteristics are shown in Figure 4-37.

Figure 4-37: Laboratory test pump clogged with different nonwoven wipes From left to right: Toilet wipe B, Toilet wipe C, Baby wipe A, Baby wipe B

Figure 4-40 and Figure 4-41 show the impact of the wipes on the hydraulic characteristic values head and flow (average value during tests) for the short time and longtime performance tests with increasing contamination. During both short time and longtime performance test with Toilet wipe A and Toilet wipe B, head and flow remain nearly constant for every WWC. This is in line with the operating points depicted in Figure 4-32 and Figure 4-33. In contrast, the three other wipes, Toilet wipe C, Baby wipe A and Baby wipe B, lead to an increasing deterioration of both head and flow with increasing contamination. However, at the lowest degree of contamination (WWC1), head and flow remain near their target values (or only decrease slightly), despite significant amounts of nonwoven wipes in the pump. This behaviour corresponds with the operating points of WWC1 tests described above. As before, it is evident that, despite substantial accumulations of blocking material in the pump, hydraulic performance of the pump is only slightly impacted at the lowest contamination. The hydraulic pump performance only begins deteriorating at higher contaminant concentrations.

Figure 4-42 shows the normalised group efficiency (average value during the tests) for both the short time and longtime performance tests plotted against the degree of contamination (WWC). Corresponding with the amount of residues found in the pump, the Baby wipes A and B have the strongest negative impact on the efficiency of the pump for every WWC. Even at the lowest contamination (WWC1), the average normalised group efficiency lies far below the maximum attainable efficiency. During the short time performance test it only reaches 78 % (Baby wipe A) and 75 % (Baby wipe B) of clear water group efficiency for the investigated operating point. During the longtime performance test it lies even lower (reaching only 59 % for both wipes). This shows that even though head and flow remain fairly constant at low contamination (WWC1), the energy consumption of the pump increases significantly due to the accumulated nonwoven wipes. At higher contaminations (WWC2 + WWC3) the Baby wipes have an even greater impact on pump efficiency. During WWC3 short time tests, on average only 47 % (Baby wipe A) and 35 % (Baby wipe B) normalised group efficiency are attained. During WWC3 longtime tests, the pump even loses more than 80 % of its efficiency (reaching, on average, only 20 % with Baby wipe A and 16 % with Baby wipe B).

Despite being sold as flushable, Toilet wipe C shows a similar effect on the pump's efficiency: The average normalised efficiency decreases sharply with increasing contamination, though overall the values are slightly better than for the baby wipes. In line with the residues in the pump described above, the impact on efficiency is worse for the longtime performance tests. For WWC1 tests, the pump reaches an average of 87 % of maximum attainable efficiency in both short time and longtime performance tests. For the highest contamination with Toilet wipe C, the pump averages 66 % normalised group efficiency during the short time performance test and only 31 % during the longtime performance test. Just as for the Baby wipes A+B, these results show that the material accumulated in the pump at low contaminations (WWC1) leads to an increase in energy consumption, while the head and flow remain at the nominal values.

As to be expected from the amounts of residues found in the pump after the tests, and in line with Figure 4-27 and Figure 4-28, Toilet wipes A and B lead to hardly any decrease in average normalised group efficiency of the pump. Even at the highest contamination, the pump remains at maximum possible efficiency, reaching an average of 96 % (Toilet wipe A) and 93 % (Toilet wipe B) of normalised group efficiency in the short time tests and 96 % (both wipes) in the longtime performance test. In conjunction with the diagrams described above, showing the operating points during the tests (Figure 4-32 and Figure 4-33) and the residues in the pump, these results show that Toilet wipe A and Toilet wipe B have no effect on overall pump performance (hydraulic characteristic values and energy consumption).

The described effects are similar for the operating points Q/Qopt = 0.8 (part load) and Q/Qopt = 1.2 (overload), as can be seen in Appendix F, Figure F-11 to Figure F-15 and Figure F-26 to Figure F-30.

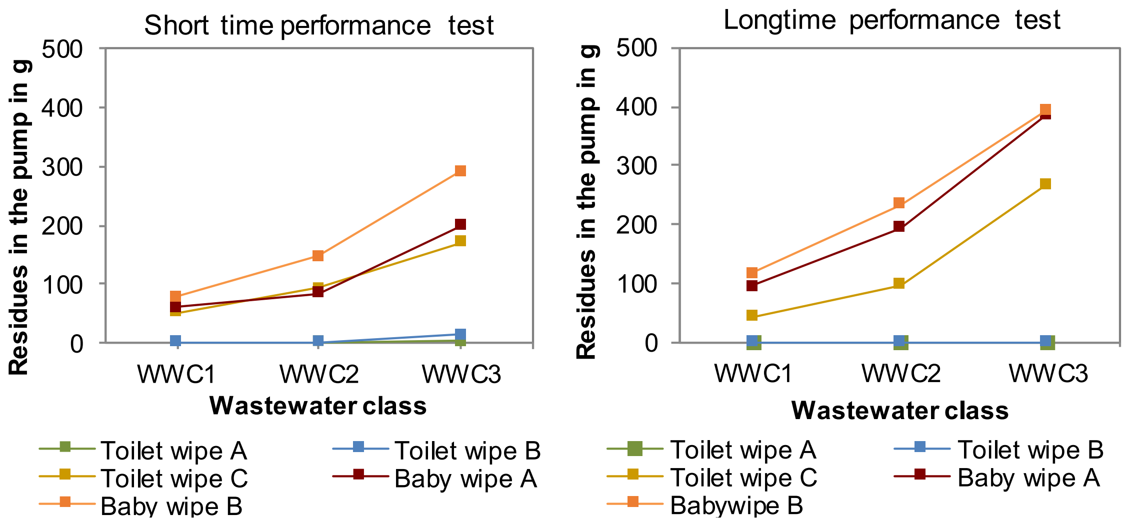


Figure 4-38: Variation of residues in the pump with increasing contamination, Q/Qopt = 1.0

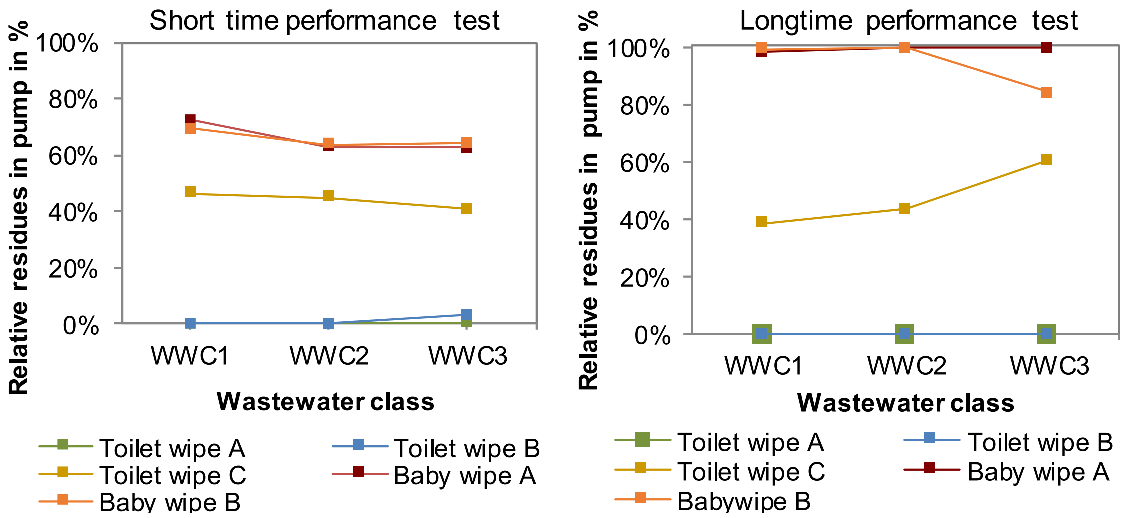


Figure 4-39: Variation of relative residues in the pump with increasing contamination, Q/Qopt = 1.0

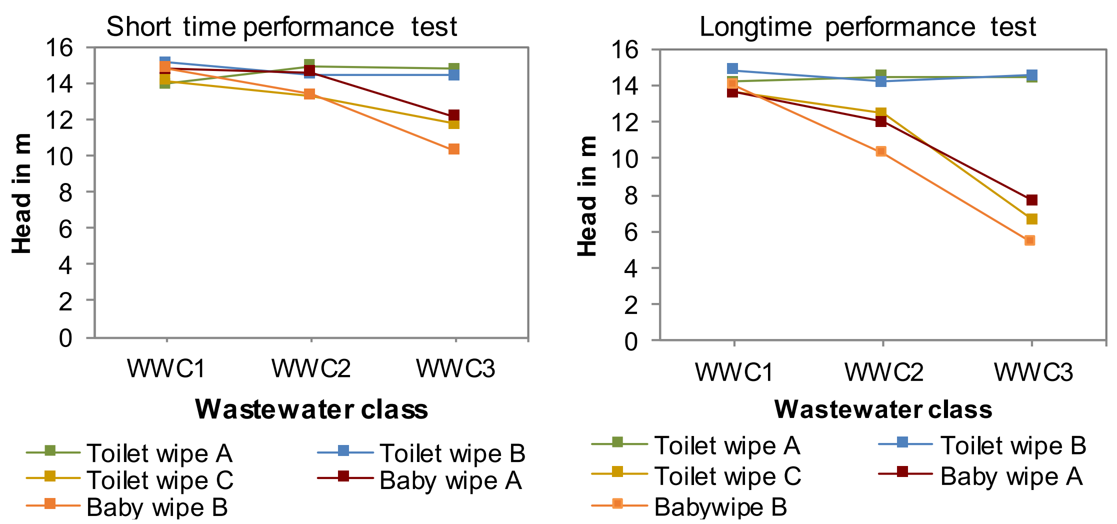


Figure 4-40: Variation of head with increasing contamination, Q/Qopt = 1.0

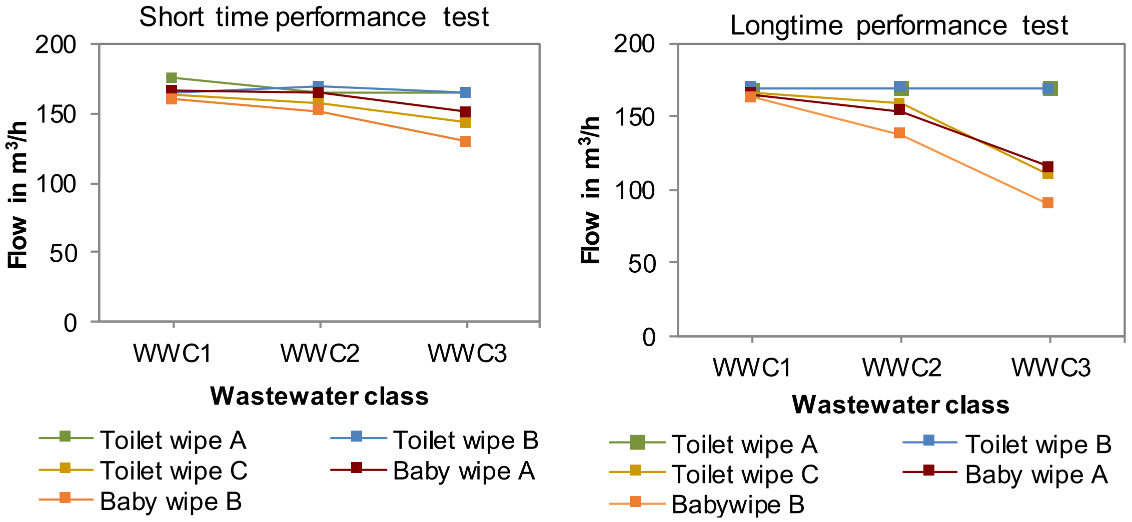


Figure 4-41: Variation of flow with increasing contamination, Q/Qopt = 1.0

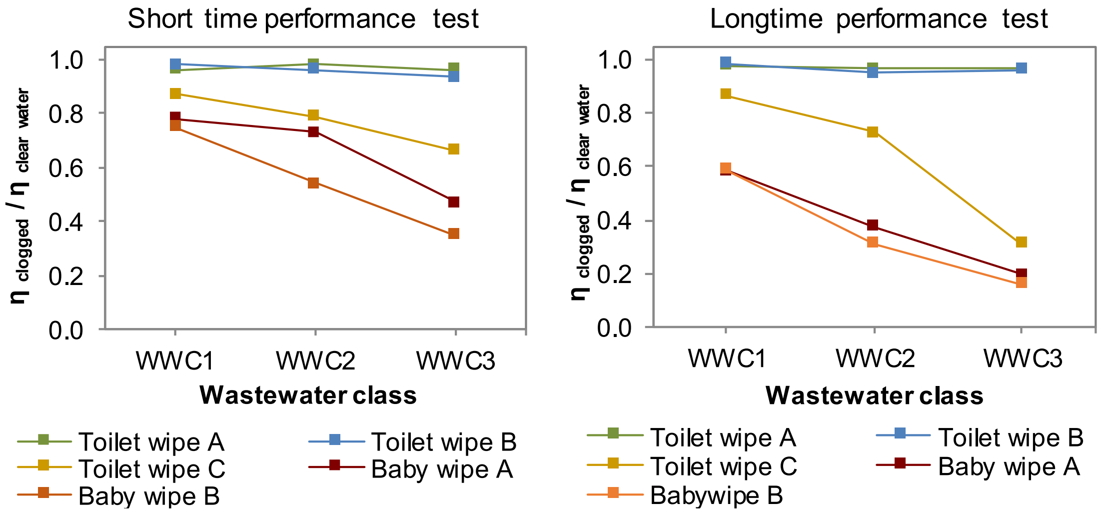


Figure 4-42: Variation of normalised group efficiency with increasing contamination, Q/Qopt = 1.0

Conclusions:

- Toilet wipe A and Toilet wipe B show no effect on the pump. They disintegrate into separate fibres and neither accumulate in the pump nor impact head, flow or energy consumption.

- Toilet wipe C has a clear adverse effect on the pump performance (head, flow and energy consumption), even at the lowest concentration. This effect increases with increasing contamination. The clogging effect is worse during longtime performance tests. This indicates that Toilet wipe C does not break down during the hour-long test duration. Rather, increasing amounts of wipes are accumulated in the pump during operation and are not dislodged again.

- Baby wipe A and Baby wipe B have a stronger negative impact on pump operation (head, flow and energy consumption) than Toilet wipe C. Increasing concentrations of the baby wipes lead to increasingly worse pump operation. Again, the impact of the wipes is stronger during the longtime performance test than during the short time performance test. In the case of the Baby wipes A + B, nearly all the wipes accumulate in the pump during the longtime test and cannot be removed during pump operation.

- At low concentrations, the clogging wipes (Toilet wipe C, Baby wipe A + B) lead to a significant increase in energy consumption of the pump, but hardly impact hydraulic performance (head and flow). This behaviour will vary from pump to pump, depending on pump hydraulics.

4.4.1 Interim summary and conclusions from the laboratory experiments

The laboratory investigations into the clogging behaviour of different nonwoven wipes showed that a clear distinction between different types of wipes regarding their clogging effect on the test pump can be made.

As expected, the baby wipes, which are spunbonded nonwovens designated for disposal via the household waste, are not compatible with pumping systems at all. Due to their textile physical characteristics (high tensile strength) they had a significant negative effect on pump operation, even at the lowest investigated concentration. From the first moments of operation onwards, wipes began clogging the impeller. During the longtime tests, partly 100 % of wipes added to the system were accumulated in the pump and were not removed during pump operation. This affected the hydraulic performance of the pump and increased energy consumption drastically. Partly, pump efficiency was reduced by over 80 %. Concrete values and clogging characteristics may vary from pump to pump, as pump impeller technology can influence clogging. However, it can be concluded that spunbonded nonwoven wipes are more likely to clog the pump, and with a worse effect, than nonwoven wipes sold as flushable. It is evident that they should never be disposed of via the toilet and can lead to equipment failures in wastewater systems. Apart from their clogging behaviour, their high content of synthetic polymers also makes them incompatible with this disposal route, as they will lead to microplastic fibres in the environment.

In contrast, the INDA/EDANA compliant flushable Toilet wipe A and Toilet B showed no adverse effect on the pump. They disintegrated immediately, leaving only separate fibres in the water. Even at high concentrations, hydraulic performance and energy consumption of the pump remained unaffected. This is an interesting insight, as to date the potential pumping system safety of INDA/EDANA FG compliant flushable wipes has not been demonstrated in a scientific investigation.

The most interesting distinction could be made between INDA/EDANA FG compliant flushable wipes and INDA/EDANA FG non-compliant flushable wipe, Toilet wipe C. Despite being labelled as flushable and consisting of 100 % biodegradable cellulose, this wipe nonetheless had a strong negative impact on pump operation – comparable, though slightly lower, to that of the non-flushable (plastic) baby wipes. Toilet wipe C clogged the pump at every investigated concentration, leading to an increase in energy consumption and a deterioration of pump hydraulic performance. Even during the longtime test, this “flushable” wipe did not disintegrate, but remained stable inside the pump, causing up to 70 % reduction in pump efficiency. This proves that flushability is not only dependent on using biodegradable fibres made of natural polymers, but is also influenced by web formation and bonding. Moreover, it also indicates that the staple fibre nonwovens identified in the pump blockages in the field experiments were not merely “caught up” in the blockage, but can clog pumps of their own accord.

In summary, these results show that in line with the labelling on the package, wipes designated for the household waste should never be flushed down the toilet, as they have an extremely negative impact on pump operation. They also indicate that flushable wipes complying with INDA/EDANA Flushability Guidelines are pumping system safe. In contrast, INDA/EDANA FG non-compliant flushable wipes can impact pumping systems, causing hydraulic pump performance and efficiency to deteriorate. Moreover, important insights are given as to why some nonwoven wipes using natural fibres clog pumps and others do not.

In this study only few samples could be investigated. To ascertain whether all INDA/EDANA-compliant flushable wipes are pumping system safe, further research is necessary. To this end, more wipe samples should be investigated, perhaps also using different types of pumps. It would also be of great interest to link the central disintegration test of the INDA/EDANA Flushability Guidelines (Slosh Box Disintegration Test) to pumping system safety. If all wipes passing the Slosh Box Test were pumping system safe, then a separate pump test (which is included in the guidelines) would be unnecessary.

5 Summary and discussion of results

The aim of this study was to gain a deeper insight into the operational problems in wastewater systems caused by nonwoven wipes. In particular, the distinction between non-flushable nonwoven wipes and those sold as flushable was of importance, as well as identifying sewer system compatible nonwoven wipes. For this purpose, four research questions were defined and investigated. In the following, the results gained in the study are evaluated and discussed in the context of the research questions and weaknesses and uncertainties are summarized.

5.1 Summary of results in the context of the research questions

RQ1: How do nonwoven wet wipes in sewer systems impact German wastewater utilities?

To identify and characterise wipe-related operational problems in German wastewater systems, a survey was conducted among German wastewater utilities. The results of the survey confirmed the relevance of the issue. Occurrence, location, type of operational problems, and, to an extent, financial impacts arising from the problem could be identified. It was shown that nearly all wastewater utilities are affected by wipe-related operational problems. The wastewater pump was identified as the system element most impacted by the nonwoven wet wipes, due to blocking and clogging. The additional costs arising from the wipe-related operational problems were identified as increased personnel costs, mainly due to the time-consuming elimination of pump blockages. It could also be shown that wastewater utilities demand binding criteria for products that are sold as "flushable" and want to participate in the development of these criteria.

Overall, the results of the survey answer RQ1 satisfactorily and constitute a strong basis for the following research aspects. Whether non-flushable nonwoven wipes or those sold as flushable cause the operational problems could not be answered in the context of this survey. This important issue was investigated for RQ3 and RQ4.

RQ2: How are nonwoven wet wipes being used and disposed of among the general public in Germany?

After investigating the effects of sewer system incompatible nonwoven wipes for RQ1, RQ2 focusses on gathering information regarding the use and disposal of nonwoven wipes by the general public, to gain an insight into which wipes are actually being flushed. For this purpose, a second survey was conducted, this time among the general population. The results of the study showed the importance of nonwoven wet wipes as convenience products in daily life, especially for young parents with young children. The types of nonwoven wipes being used were identified (mainly moist toilet wipes and baby wipes) as well as the intended use and the frequency of use of different wipe products. Moreover, the disposal habits and the understanding regarding flushability were examined. The results showed that apart from moist toilet wipes, which are sold as flushable, mainly baby wipes were being flushed. Contrary to expectations, the baby wipes were not only flushed after nappy changing of small children, but mainly after toilet hygiene for small children and also after adult toilet hygiene. A general interest for the issue of sewer system compatibility of flushable nonwoven wipes could be determined, as well as a willingness to pay more for truly sewer system safe wipes. User requirements regarding sewer system compatibility are in line with those demanded by the wastewater utilities. In conclusion, the results of the survey answer RQ2 comprehensively and give important impulses for solutions on the consumer side of the issue of wipe-related problems in wastewater systems.

RQ3: Which types of nonwoven wet wipes can be identified as causing problems in sewer systems?

Which nonwovens wipes are the cause for operational problems in wastewater systems – non-flushable wipes or those sold as flushable – is a central aspect of the issue. Past studies in other countries have given an insight into the types of nonwoven wipes identified in pump blockages. However, to investigate the issue of wipe-related operational problems in Germany, and to improve on the methodology of previous studies, an investigation in a German catchment area was necessary. To this end, three pump blockages from an inner city pumping station in Berlin, Germany, were collected and analysed.

The results of the investigation showed that non-flushable wipes designated for disposal via the household waste (spunbonded nonwovens) were the main cause for the blockages. However, a second important finding was that a significant amount of nonwoven wipes sold as flushable could also be identified in the clogging material. These findings are in line with the above mentioned studies, though the amount of flushable wipes identified in this investigation was higher. The results answer RQ3 and, again, important insights into possible solution strategies can be gained from the outcome.

RQ4: Do different types of nonwoven wet wipes have different pump clogging effects and can this be demonstrated in the laboratory?

After identifying the types of wipes found in pump blockages in the field, the fourth part of the study focussed on investigating whether different clogging characteristics of nonwoven wipes can be reproduced in a laboratory setting. In addition to confirming differences between non-flushable wipes and those sold as flushable, it was of interest to gain an insight into the flushable wipes found in pump blockages. To this end, it was important to find out whether INDA/EDANA FG compliant flushable nonwoven wipes and INDA/EDANA FG non-compliant flushable wipes could be distinguished according to their clogging behaviour. For this purpose, three moist toilet wipes (among them two compliant with INDA/EDANA Flushability Guidelines) and two baby wipes were investigated.

The results from the laboratory investigations confirmed the clogging behaviour of the non-flushable baby wipes, which was previously indicated by findings from the field and experiences from wastewater system operators. These wipes clogged the test pump at every investigated concentration and impacted pump hydraulic performance and energy consumption. A clear distinction could be made between the INDA/EDANA FG compliant flushable moist toilet wipes and the flushable wipe not complying with these guidelines. The compliant moist toilet wipes were demonstrated to be harmless for pump operation. They disintegrated sufficiently fast into separate fibres and did not clog or otherwise impact the pump, even at the highest investigated concentration. In contrast, the non-compliant moist toilet wipe had an adverse effect on the pump, similar to that of the baby wipes, but not quite as severe. It, too, clogged the pump at every investigated concentration and affected pump hydraulic performance and energy consumption. Hence, these results give a comprehensive answer to RQ4. They are also an important basis for advancing the compliance of products sold as “flushable” with INDA/EDANA Flushability Guidelines, which were heretofore greatly criticised as being insufficient, especially by wastewater system operators.

Taken together, the results of this study give a comprehensive insight into the operational problems caused by sewer system incompatible nonwoven wipes in wastewater systems. The problem was investigated from the point of view of all relevant stakeholders. The importance of the topic for wastewater utilities and the extent of their problems was determined, as was the consumer behaviour regarding the use and disposal of different nonwoven wipes. The major cause of the pump blockages in the field could be identified. Finally, it was demonstrated in the laboratory that not all nonwoven wipes contribute equally to the operational problems, but that there are clear differentiation possibilities. In addition, it was established that the INDA/EDANA Flushability Guidelines are most likely suitable for distinguishing pumping system safe nonwoven wipes from those that lead to blockages and that sewer system compatibility does not only depend on the use of biodegradable fibres. Based on these results, important conclusions and recommendations regarding the issue of wipe-related operational problems in wastewater systems can be drawn, which are presented in the following chapter 6.

5.2 Summary of uncertainties and weaknesses

The uncertainties and weaknesses of this study warrant consideration, as they influence the quality of the results. This includes limitations arising from the methodical approach of the surveys, as well as field and laboratory experiments.

With regard to the two surveys, it was not possible to collect truly representative data, since (1) the total number of wastewater utilities in Germany was unknown (and the concentration of wastewater utilities varies greatly from one federal state to another) and (2) the population of people with internet access, buying and using nonwoven wipes, in Germany is unknown. Therefore, the results are limited in terms of their representativeness. Also, the distribution mode of the user survey (only online and distribution beginning in Berlin) led to uneven distributions in age and geographical locations (and perhaps also sex) of the respondents. Moreover, the respondents' behaviour regarding use and disposal of nonwoven wet wipes was not observed in reality; rather they assessed their own behaviour. Thus, there may be a gap between the behaviour in reality and how it is reflected by the respondents in the answers of the survey. In addition, the pre-formulated answers limit the possible answers of the respondents. The survey among wastewater utilities partly requested specific information that might not have been known by some respondents. This may have led to a falsification error.

Due to the inhomogeneity of wastewater it is not possible to collect representative data regarding pump clogging material. For this reason, this study was limited to the collection of three samples in an urban catchment. Since the goal was to verify or refute existing results from other studies, this sample size is considered sufficiently large. In addition, the aim was to show that nonwoven wipes sold as flushable are also found in pump blockages. Again, this was achieved. Moreover, the three samples did not vary greatly in their composition. A larger variance in constituents would have necessitated further sampling. Nonetheless, a more extensive field campaign than was possible within the scope of this study would have provided more comprehensive results and should be conducted in the near future. This should include other areas and cities in the country as well as other pumps.

The mass of different wipe products on the market makes a representative survey of the clogging behaviour of nonwoven wipes impossible. For this study, the investigation was limited to two types of wipes which were found to be most relevant (based on results from previous studies and results from the user survey): two types of baby wipes and three types of moist toilet wipes. Among the three moist toilet wipes, two were INDA/EDANA-compliant and one was not. Thus the sample size was very small. The results of the moist toilet wipes, in particular, can only be seen as indications. More comprehensive investigations are necessary to verify whether there is a positive link between INDA/EDANA-compliance and pumping system safety of wipes. As the testing methodology used in this survey was very extensive and time-consuming, it was not possible to investigate further samples. However, for the scope of this study, the sample size was sufficient, as it could be demonstrated that different nonwoven wipes, even among those sold as “flushable”, have different clogging characteristics.

6 Conclusions and recommendations

Wipe-related operational problems in wastewater systems affect nearly all wastewater utilities in Germany. They disrupt the operation of the critical infrastructure, cause equipment failures and large additional expenditures. Therefore, these problems are a relevant issue that has to be dealt with. Contrary to the perception of the issue by wastewater utilities, the majority of operational problems are caused by users wrongly disposing of wipes designated for the household waste (“non-flushable” wipes) via the toilet. However, this study also shows that some wipes labelled as “flushable” can adversely affect wastewater pumps too, despite being made of 100 % biodegradable fibres. How large the share of sewer system incompatible wipes is among those products that are sold as “flushable” is unfortunately unclear. To ensure a comprehensive and long-lasting solution of the problem, the involvement of all relevant stakeholders is necessary.

Education of and communication with users

Foremost, the problem should be dealt with at its point of origin: the user and disposer of nonwoven wet wipes. In line with investigations from other countries, this study demonstrated that the major cause of pump blockages are non-flushable spunbonded wipes that were wrongly disposed of via the toilet. As these products are designated for the household waste, flushability criteria are not considered in their design. Therefore it is of great importance to educate users about adhering to disposal guidelines on product packages and about the effects of wrongly flushed items in wastewater systems. Good examples for education campaigns can currently be found in Dresden, Germany ([95]) and New York, US ([5]). Education campaigns such as these have the added benefit of educating people on other non-sewer items that can cause problems in the system, such as feminine hygiene products or food waste.

The results of this investigation suggest that baby wipes, in particular, are wrongly disposed of via the toilet. The users flushing them are mainly young adults (more females than males) with young children (aged 0 – 5). Therefore, clear educational messages for this target group in particular are necessary, for example directly at the point of sale in the stores. Further target groups should include institutions and people working with nonwoven wipes, such as care facilities (children, health and old people). Possible communication measures are summarised in Table 6-1.

It is unclear who can and should shoulder the responsibility and cost of these education and communication measures. As the customers of the wastewater utilities are the ones who are wrongly disposing of these products, the utilities should be at least partly responsible for educating their customers. However, the support of the nonwovens industry (manufacturers, retailers and industry associations) with regard to funding and contents is advisable, as to date wastewater utilities dismiss all nonwoven wet wipes as incompatible with wastewater systems and advocate their prohibition.

Table 6-1: Possible communication measures

Target group	Measure	Implementation frame
Care facilities (health, children, old people)	Posters, stickers and leaflets for “high risk” facilities	Short-term
General	Information leaflets for landlords and renters	Short-term
General	Education campaigns from wastewater system operators, e.g. “The toilet is not a trash can”	Medium-term
General	Collaboration with information programmes for children and adults	Medium-term
General	Online content for YouTube, Facebook and other channels	Medium-term
Parents of young children	Specific baby-wipe related information on disposal at point of sale	Medium-term
General	Creation of a national website on flushability with up to date information and product recommendations	Long-term
General	TV and print advertisements, advertising sewer system compatible flushable products (once flushability certification is in place)	Long-term

Ensuring reliable sewer system compatibility

Secondly, the reliable sewer system compatibility of wipes sold as “flushable” has to be ensured. The results of this investigation provided compelling evidence that not all so-called flushable wipes can be safely disposed of via the toilet (and subsequently pumped), even if they are made of 100 % biodegradable fibres. What is more, “flushable” products containing plastic fibres can also be found on the market [2]. Only if the label “flushable” can be relied upon to ensure true sewer system compatibility, can consumers make the right purchasing choices and will utilities be prepared to concede that these products can be flushed into the sewer system.

To this end, several steps are necessary. On the one hand, a consensus regarding criteria for sewer system compatibility has to be reached. Despite criticism from wastewater utilities, the results from this study indicate that INDA/EDANA Flushability Guidelines are able to distinguish sewer system compatible nonwoven wipes from those that are not – at least with regard to pumping system safety. Thus, the INDA/EDANA Flushability Guidelines seem a good first step to ensure sewer system compatibility. However, additional criteria demanded by German wastewater system operators (see the results of this investigation as well as demands from the German Association for Water, Wastewater and Waste, DWA [8]), such as plastic free wipes and environmentally safe coating lotions, should also be included in the near future.

On the other hand, the compliance with these (or other suitable) flushability requirements has to be ensured. To date, the adherence to INDA/EDANA Flushability Guidelines is only a voluntary self-commitment of the associations' members. Thus the label "flushable" on products cannot be trusted by consumers or wastewater utilities, which is to the detriment of those manufacturers already complying with the requirements. A legal obligation to conform to flushability criteria is desirable, however seems unlikely for the time being [91]. If Germany were to follow the example of Belgium and Spain and were to pass flushability legislation, the process may take years. For this reason, too, the promotion of public awareness of the issues surrounding sewer system incompatible wipes sold as "flushable" is of importance. The public awareness can lead to public pressure to solve the problem, which in turn can be a high enough incentive for manufacturers and retailers to comply with existing flushability criteria.

Correct and consistent labelling of flushable and non-flushable nonwoven wipes

Along with a reliable adherence to the flushability criteria, the labelling of flushable and non-flushable nonwoven wipes must be consistent and comprehensible. The associations of nonwovens manufacturers, INDA and EDANA, have already made suitable product labelling requirements for non-flushable products in their Code of Practice (COP [79]), as described in chapter 2.3.2. However, as the COP is not legally binding, but only a voluntary self-commitment, full implementation in the market, at least in Germany, is not accomplished to date.

Since no uniform and mandatory labelling requirements are to be expected at either national or European level, a positive label or flushability seal, as is being currently discussed in the German DWA working group on flushability (DWA AG ES-7.8), may be a good alternative or addition. A positive flushability seal can make consumers aware of the fact that these nonwoven wipes can be safely disposed of via the toilet, since they have been tested by independent testing institutes according to the specifications of the wastewater utilities. A positive seal can also be attractive to manufacturers and retailers, as it can be a good selling point with regard to a public that is aware of the flushability issue. Moreover, the results of this study have shown that, at least in principle, the consumers of flushable nonwoven wet wipes would be willing to pay more for reliably sewer system compatible wipes. However, the implementation of a uniform and trustworthy flushability seal would again require consistent flushability criteria and an independent testing organisation. Currently (summer 2019), the German working group on flushability (DWA AG ES-7.8) is discussing the certification of sewer system compatible nonwoven wipes with the German TÜV (Technischer Überwachungsverein, English: Technical Inspection Association), which provides inspection and product certification services.

In the coming years, the labelling of nonwoven wipes will also be influenced by the so-called “Single-Use Plastics Directive” [96], adopted by the European Parliament and the Council in June 2019. It requires certain products, including nonwoven wet wipes, to have labels explaining the appropriate waste handling options. For example, nonwoven wet wipes packaging must inform consumers of the presence of plastic in the wipes and the damage caused to the environment if they are not disposed of in the correct manner. The EU Member States have two years to adopt the legislation into their national and local law.

Future research

The following topics have been identified as subjects for further research, since they could not be included within the scope of this study:

- To monitor the further development of the issue and the progress of solution strategies (and thus, hopefully, the reduction of wipe-related operational problems), additional surveys among German wastewater utilities are necessary. These should concentrate on the type, frequency and cost of problems. To be able to determine whether the frequency of the problems, e.g. pump blockages, is reduced over the next years, the German Association for Water, Wastewater and Waste (DWA) should encourage their members to continuously track and record the relevant data.

- To monitor the disposal practice of nonwoven wipes and the understanding of flushability issues, further surveys among the general population and the people working with nonwoven wet wipes (especially in care facilities for children, sick people and old people) should be conducted. This can give insights into the effect of communication and education measures.
- To track possible changes in the composition of clogging material (for example regarding the presence of non-flushable wipes as well as flushable wipes) further investigations of pump blockages are necessary. These should be conducted in different catchment areas in different regions of the country.
- To date, only insufficient research on suitable flushability criteria has been conducted. Future research should include investigations into an appropriate disintegration test (as the INDA/EDANA Slosh Box Disintegration Test and its parameters are criticised by wastewater utilities). It should also be determined whether a suitable disintegration test makes a separate pump test superfluous, as suggested by the results of this study. Many existing alternatives to the INDA/EDANA Flushability Guidelines already believe a pump test to be unnecessary. Moreover, the so-called Municipal Pump Test in the INDA/EDANA Flushability Guidelines is also heavily criticised by wastewater utilities. For this purpose, further INDA/EDANA compliant and non-compliant wipes should be investigated with a suitable pump test stand, such as in this study. Results can be compared with the INDA/EDANA Municipal Pump Test. Lastly, research into an appropriate biodegradability test for sewer system compatible products should be conducted. Currently, many different biodegradability tests are listed in existing flushability specifications, none of which is truly suitable for nonwoven wipes in wastewater (such as OECD 301B test method, OECD 311 method, MONS test and others).

7 Outlook

Nonwoven wipes enable consumers to perform necessary hygienic activities quickly and efficiently in an increasingly fast-moving time. Given our habits and lifestyles, these products will likely not disappear from the market in the near future. Therefore, it should be the long-term aim to make them as environmentally friendly and sustainable as possible. This includes ensuring sewer system compatibility of nonwoven wipes sold as flushable, as well as ensuring a low environmental impact of wipes designated for disposal via the household waste. Nonwoven wipes made of plastic should be made obsolete as soon as possible, even if they are not sold as flushable. Innovative production techniques, environmentally conscious consumers and the new EU Single Use Plastics Directive [96] will hopefully support the paradigm shift away from environmentally harmful products towards sustainable and biodegradable nonwoven wet wipes. Indeed, the first products, 100 % biodegradable baby wipes made from renewable raw materials, are available on the market today.

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Appendices

Appendix A

Table A-1: Comparison of IWSFG and INDA/EDANA Slosh Box Disintegration Test

Experimental parameter	Requirement by IWSFG	Requirement by INDA/EDANA
Pre-conditioning of sample	Flush in toilet and hold for 30 minutes in the drainline (w/o water)	Rinse off lotion
Sample	Single sheet	Single sheet
Water volume (L)	4	2
Temperature of water (°C)	15 ± 1	20 ± 3
Mixing speed of Slosh Box (in rotations per minute)	18	26
Mixing time (hours)	0.5	1
Rinse time (4L/minute) (seconds)	60	120
Perforation of sieve (mm)	25	12.5
Expected ratio of disintegration to pass (% of initial dry mass)	95	60

Appendix B

Befragung zu Betriebsproblemen im Abwassersystem aufgrund von Feuchttüchern

Seit einigen Jahren verzeichnen Betreiber zunehmend Betriebsstörungen durch Feuchttücher im Abwassersystem. Die DWA Arbeitsgruppe AG ES-7.8 „Störstoffe in Entwässerungssystemen“ hat den Auftrag, einen Arbeitsbericht zum Thema vorzulegen. Mit der Teilnahme an unserer 10-minütigen Befragung können Sie uns dabei unterstützen, ein umfassendes Verständnis von der Problemlage und damit einhergehend möglichen Lösungsansätzen zu erstellen. Die Umfrage deckt unterschiedliche Themenbereiche ab. Falls Sie zu bestimmten Gebieten keine Antworten wissen, dann bitte einfach auf "keine Angabe" klicken.
Die ausgewerteten Ergebnisse stellen wir Ihnen zur Verfügung.
Unter allen ausgefüllten Fragebögen werden drei Teilnahmen zum nächsten DWA Fachaustausch zu Feuchttüchern verlost.

Vielen Dank im Voraus für Ihre Unterstützung!

Bei Fragen, Problemen oder Anmerkungen zur Befragung können Sie uns gern kontaktieren:
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Hinweise zum Datenschutz:
Ihre Teilnahme an dieser Befragung erfolgt auf freiwilliger Basis. Diese Befragung dient ausschließlich wissenschaftlichen Zwecken, eine gewerbliche Nutzung Ihrer Daten ist ausgeschlossen. Die erhobenen Daten werden unter keinen Umständen an Dritte weitergegeben.

Umfrage beginnen

Befragung zu Betriebsproblemen im Abwassersystem aufgrund von Feuchttüchern

Figure B-1: Landing page of utility survey

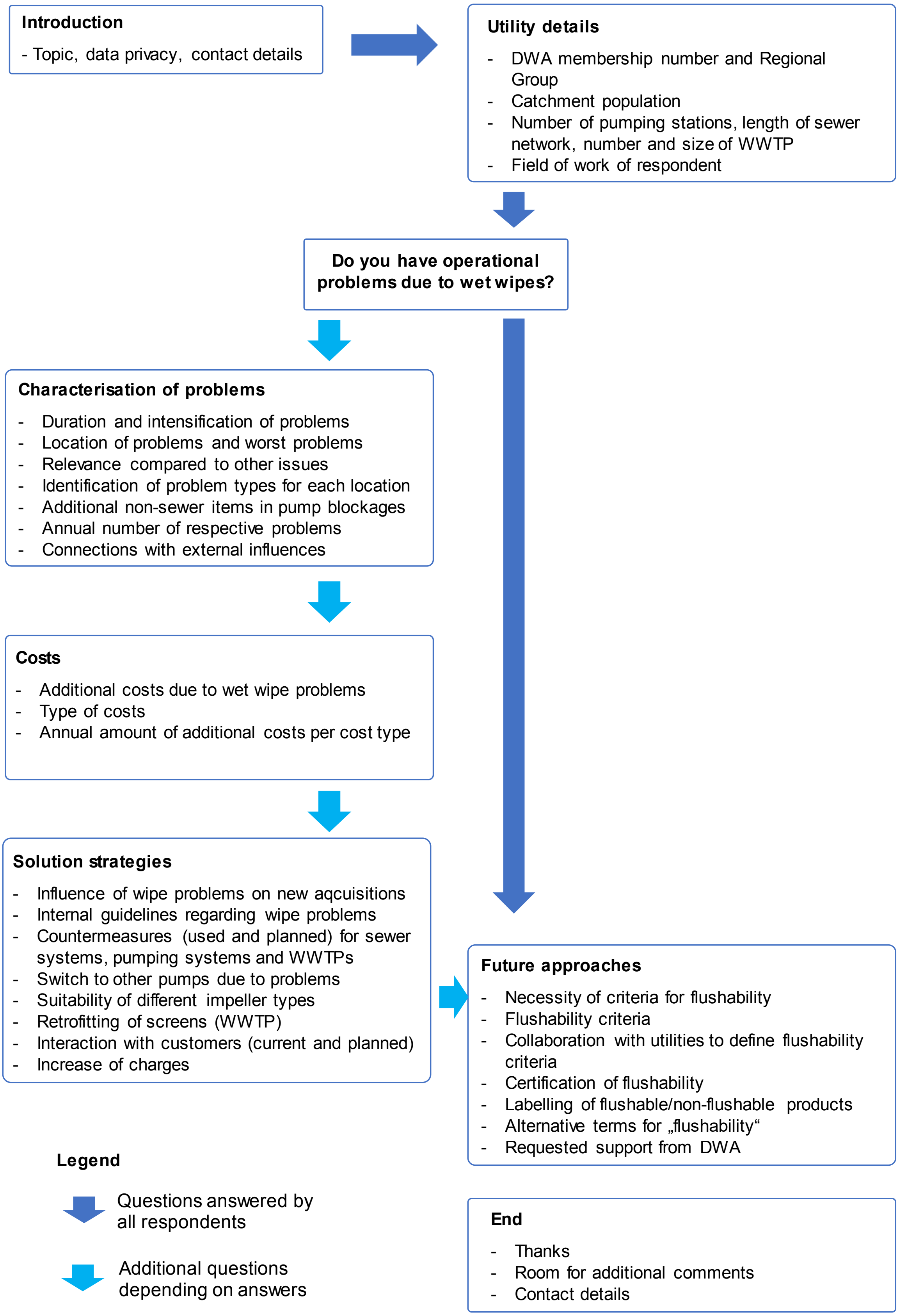

Figure B-2: Overview of the survey among utilities regarding operational problems due to nonwoven wet wipes (English translation)

Appendix C

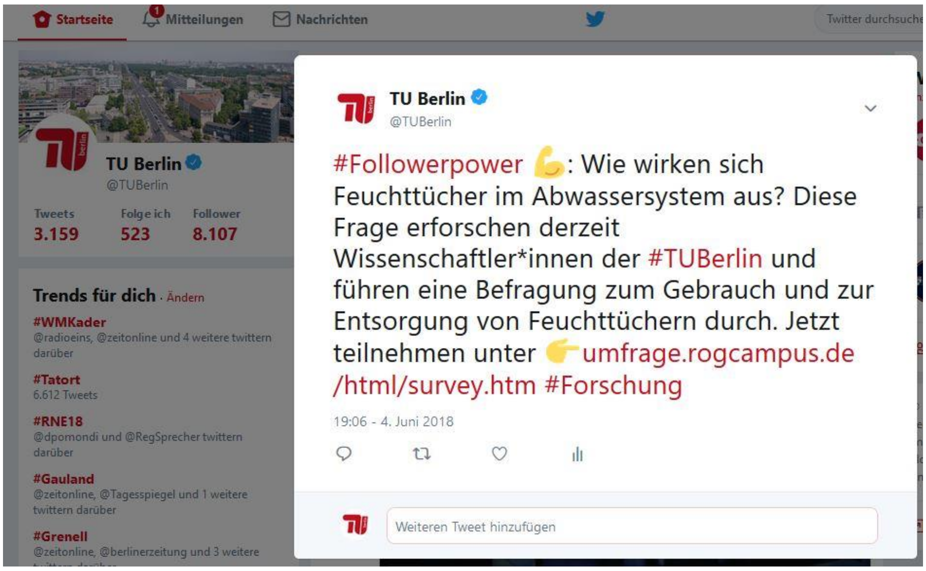

Figure C-1: Tweet on TU Berlin Twitter channel with appeal to participate in the survey


Unterstützen Sie unser Forschungsprojekt zu Feuchttüchern im Abwassersystem!

Mit Ihrer Teilnahme leisten Sie in nur 5 Minuten einen wichtigen Beitrag zu unserem Forschungsprojekt, mit dem Ziel, das Verhalten von Feuchttüchern im Abwassersystem besser zu verstehen.

Es gibt keine richtigen oder falschen Antworten. Uns interessiert, wie Sie Feuchttücher verwenden und entsorgen!

Link zur Umfrage:
http://umfrage.rogcampus.de/data/tu-berlin/Feuchttuch_Gebrauch/

QR Code zur Umfrage:

Figure C-2: Flyer distributed to students and interested members of the public

Befragung zum Gebrauch und zur Entsorgung von Feuchttüchern

Herzlich willkommen zu unserer Befragung zum Gebrauch und zur Entsorgung von Feuchttüchern!
Mit Ihrer Teilnahme leisten Sie in nur 5 Minuten einen wichtigen Beitrag zu unserem Forschungsprojekt, mit dem Ziel, das Verhalten von Feuchttüchern im Abwassersystem besser zu verstehen.
Es gibt keine richtigen oder falschen Antworten. Uns interessiert, wie Sie Feuchttücher verwenden und entsorgen!
Am Ende der Befragung können Sie an einer Verlosung von 50 dm-Gutscheinen im Wert von je 10 € teilnehmen.

Hinweis: Feuchttücher sind in eine Lotion oder eine Flüssigkeit getränkte Vliesstofflappen, die für den einmaligen Gebrauch gedacht sind (z.B. Babytücher, feuchtes Toilettenpapier oder Kosmetiktücher). Sie sind jederzeit griffbereit und praktisch zu verwenden.

Vielen Dank im Voraus für Ihre Unterstützung!

Bei Fragen, Problemen oder Anmerkungen zur Befragung können Sie uns gern per E-mail kontaktieren: raja-louisa.mitchell@tu-berlin.de

Umfrage beginnen

Hinweise zum Datenschutz: Ihre Teilnahme an dieser Befragung erfolgt auf freiwilliger Basis. Diese Befragung dient ausschließlich wissenschaftlichen Zwecken, eine gewerbliche Nutzung Ihrer Daten ist ausgeschlossen. Ihre Daten werden anonymisiert verwendet und zu statistischen Kennzahlen zusammengefasst, so dass keine Rückschlüsse auf Ihre Person möglich sind. Die erhobenen Daten werden unter keinen Umständen an Dritte weitergegeben. Es erfolgt keine Speicherung Ihrer IP-Adresse.

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Technische Universität Berlin

Befragung zum Gebrauch und zur Entsorgung von Feuchttüchern

1

Figure C-3: Landing page of user survey

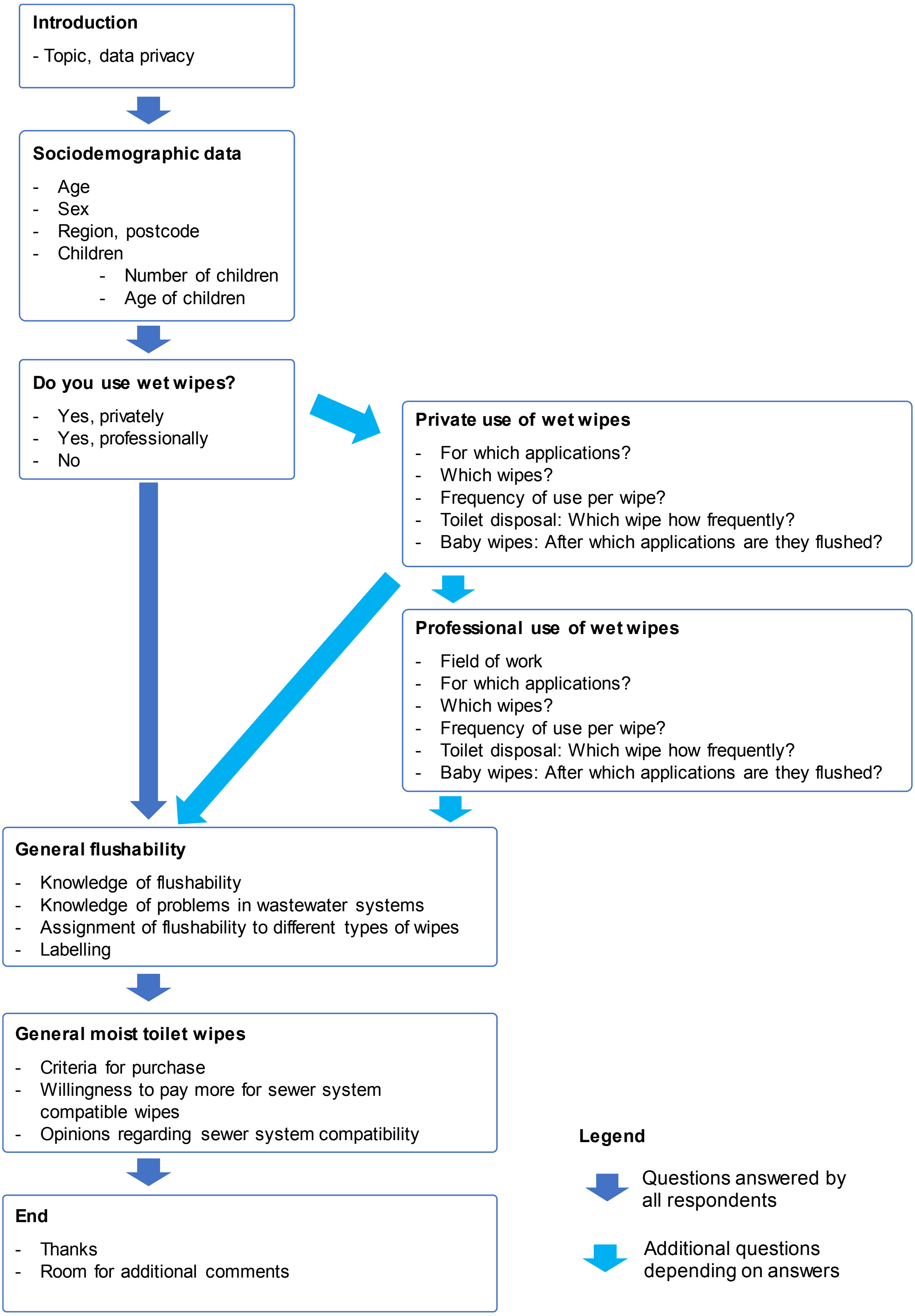

Figure C-4: Overview of the survey among the general public regarding use and disposal of nonwoven wet wipes (English translation)

Appendix D

Table D-1: Characterisation of respondents

Sex of respondents		**Male**		**Female**	
		386		555	
Age groups of respondents in years	**<=24**	**25-34**	**35-44**	**45-59**	**>59**
	91	387	202	193	74
Age groups of females in years	**<=24**	**25-34**	**35-44**	**45-59**	**>59**
	49	205	124	128	49
Age groups of males in years	**<=24**	**25-34**	**35-44**	**45-59**	**>59**
	41	180	77	64	24
Children of respondents		**yes**		**no**	
		507		439	
Children's age groups in years	**0-5**	**6-10**	**11-15**	**>15**	
	237	122	66	205	

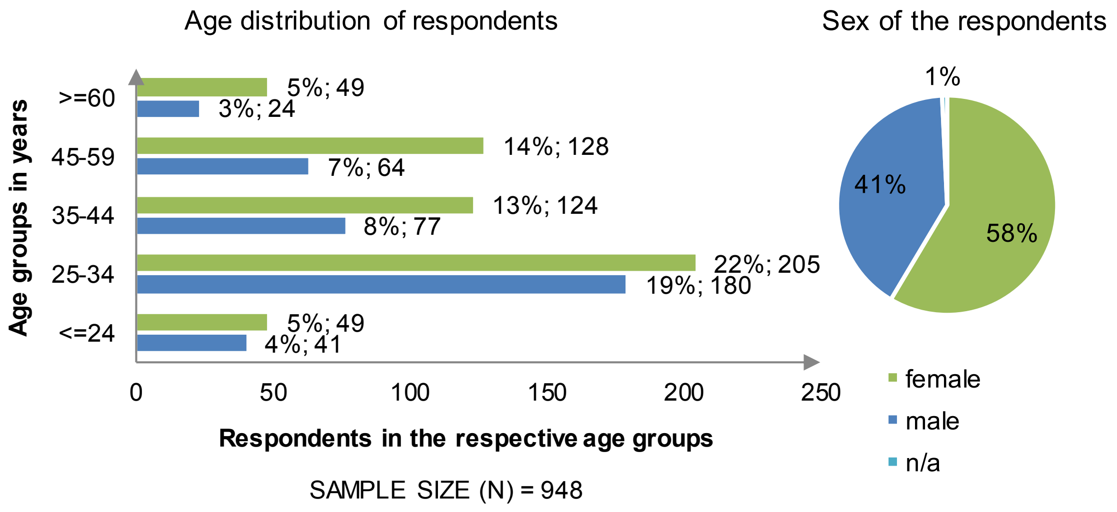

Figure D-1: Distribution of sex and age groups of respondents

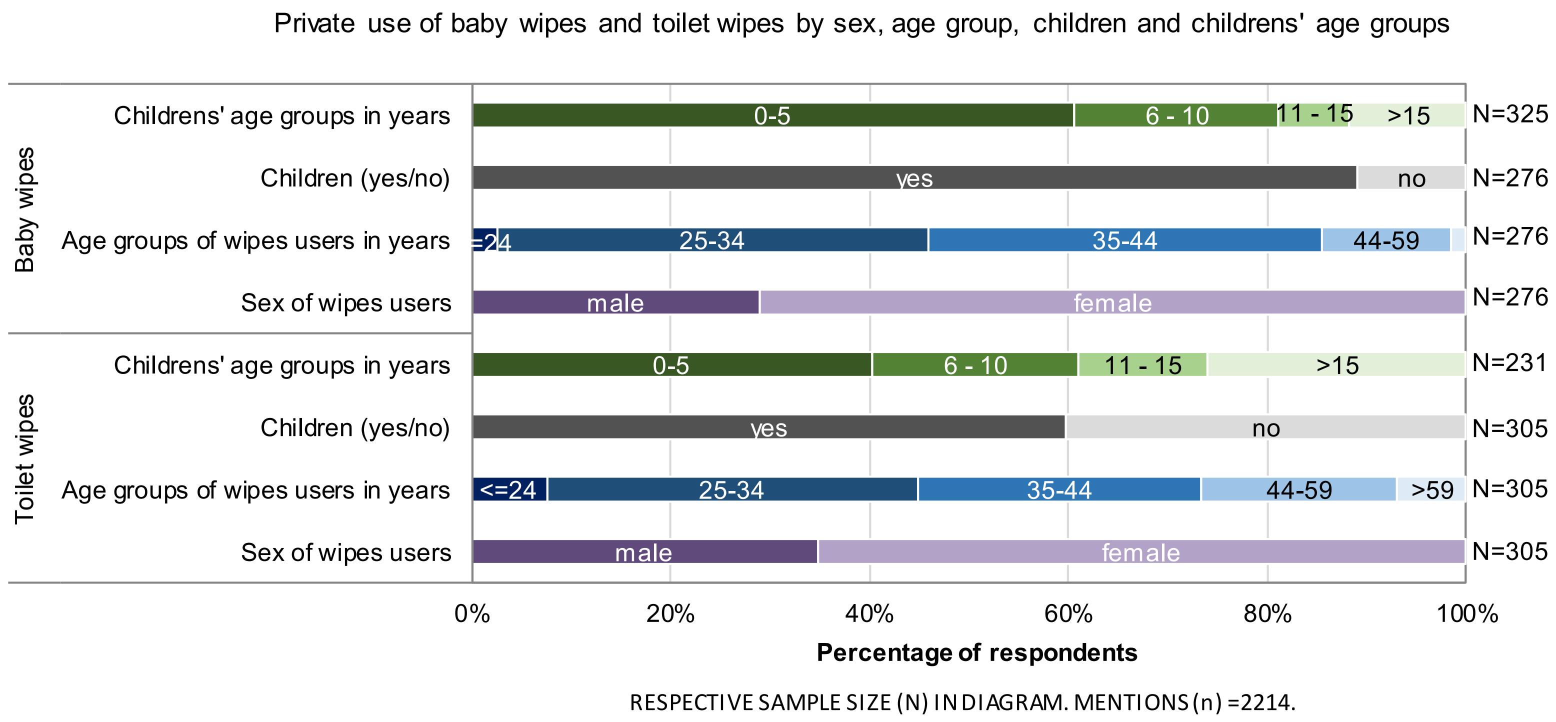

Figure D-2: Characterisation of baby wipes and toilet wipes users by sex, age and children

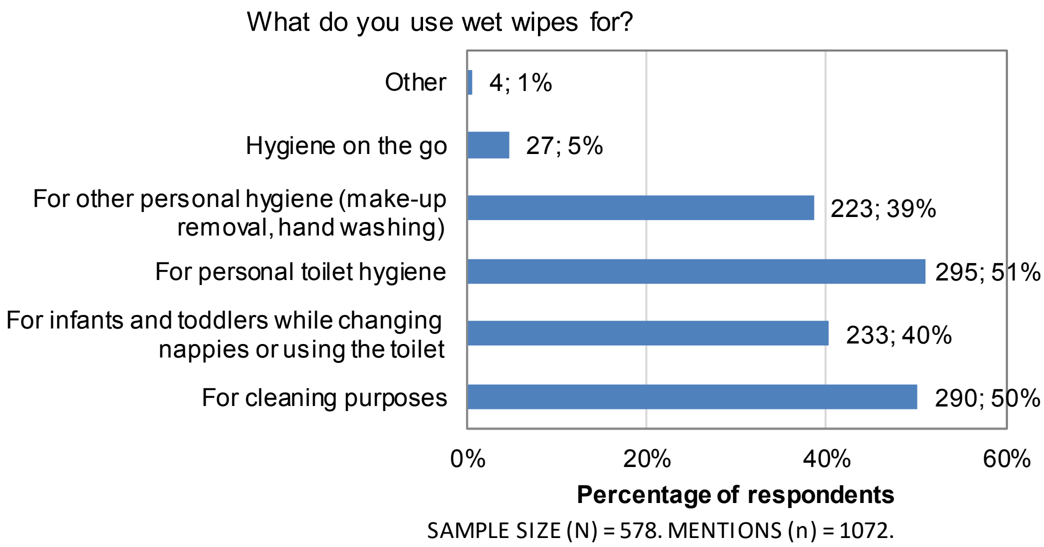

Figure D-3: Distribution of use types for nonwoven wipes

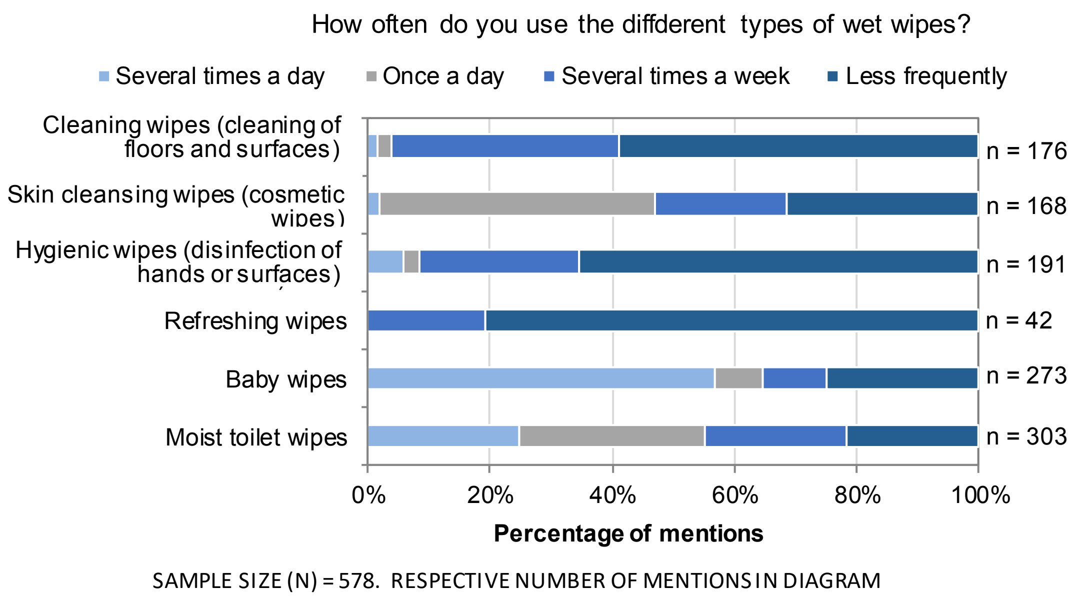

Figure D-4: Frequencies of use of different nonwoven wipe products

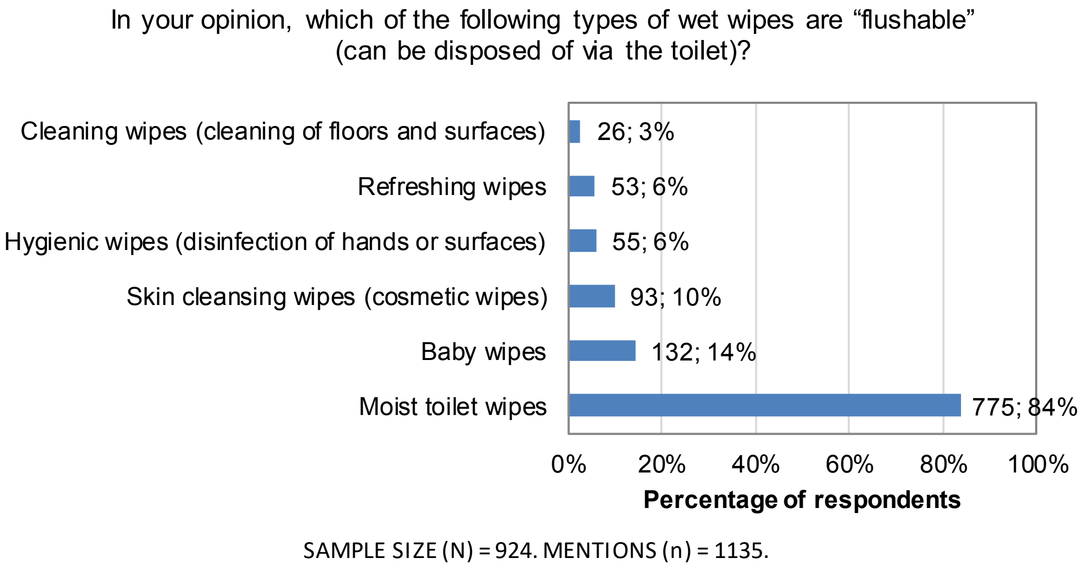

Figure D-5: Assessment of flushability of different nonwoven wipe products by respondents

Appendix E

The following tables and figures characterise the nonwoven wipes used in the laboratory investigations. Figure E-1 gives an overview of four of the investigated wipes. Table E-1 summarises the values determined by own measurements or provided by the wipe manufacturers. Unfortunately, the retailers of Toilet wipe C and Baby wipe A did not disclose the manufacturer. Thus details regarding fibre material and bonding could only be estimated. Table E-2 and Figure E-2 summarise the values determined by Esslinger in her master's thesis, jointly supervised by the author of this study [97]. Toilet wipe B could not be investigated within the scope of the master's thesis. The difference in tensile strength between the baby wipes and the toilet wipes was expected, due to textile properties (fibres, web formation, and bonding). However, it is interesting to note that the tensile strength of Toilet wipe A and Toilet wipe C are very similar (wet and dry), despite the fact that Toilet wipe C has a significant clogging effect and Toilet wipe A disintegrates immediately. The only significant difference between the two toilet wipes is their permeability to air, as seen in Figure E-2 bottom right hand side. The clogging Toilet wipe C has a much lower permeability than Toilet wipe A. This indicates that, in addition to the fibre material and length, web formation and bonding can influence the textile properties of nonwoven wipes to a degree that determines whether they are sewer system compatible (and thus flushable) or not.

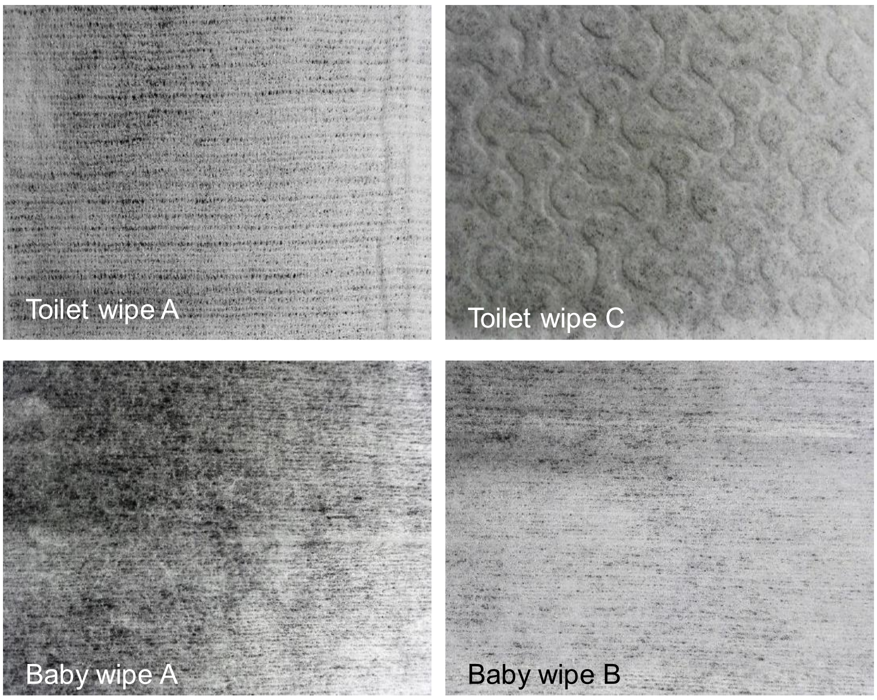

Figure E-1: Close-up view of the investigated wipes [97]

Table E-1: Characterisation of nonwoven wipes from laboratory investigations, data provided by manufacturers or from own measurements

	Toilet wipe A	Toilet wipe B	Toilet wipe C	Baby wipe A	Baby wipe B
Type of nonwoven fabric	Fibre nonwoven	Fibre nonwoven	Fibre nonwoven	Spunbond nonwoven	Spunbond nonwoven
Fibre material	Cellulose, viscose (10-20 %)	80% cellulose, 20% viscose	Cellulose and/or viscose	Not known, likely 100 % PET	20% viscose, 80% PET
Web formation	Wetlaid	Wetlaid	Airlaid	Spun-bonded	Spun-bonded
Bonding	Hydroen-tanglement	Hydroen-tanglement	Calen-dered	Not known	Hydroen-tanglement
Weight per wipe in g	1.26	1.5	1.57	1.38	1.66
Length per wipe in mm	185	180	200	200	190
Breadth per wipe in mm	118	130	130	170	175
Area per wipe in cm^2	218.3	234	260	340	332.5

Table E-2: Characterisation of nonwoven wipes used in laboratory tests, data from [97]

		Toilet wipe A	Toilet wipe B	Toilet wipe C	Baby wipe A	Baby wipe B
EN ISO 9073-18:2008	**Dry tensile strength MD in N (75 mm, n=10)**	15.95		21.72	71.14	116.9
	Wet tensile strength MD in N (75 mm, n= 10	7.42		8.33	69.4	119.71
	Elongation wet MD in % (75mm, n=10)	37.91		11.78	33.45	32.7
	Elongation dry MD in % (75mm, N=10)	9.93		9.88	33.69	32.39
DIN EN ISO 9073-2	**Thickness dry in µm (n=10)**	771		559	630	639
	Thickness wet in µm (n=10)	629		492	590	633
DIN EN ISO 9237	**Permeability to air in mm/s (20 cm^2, n=10)**	1347		854.6	3292	2840
DIN EN 29073-1	**Mass per unit area dry in g/m^2 (n=10)**	66.04		61.62	47.83	50.72
	Mass per unit area wet in g/m^2 (n=10)	426.33		282.79	239.22	298.45

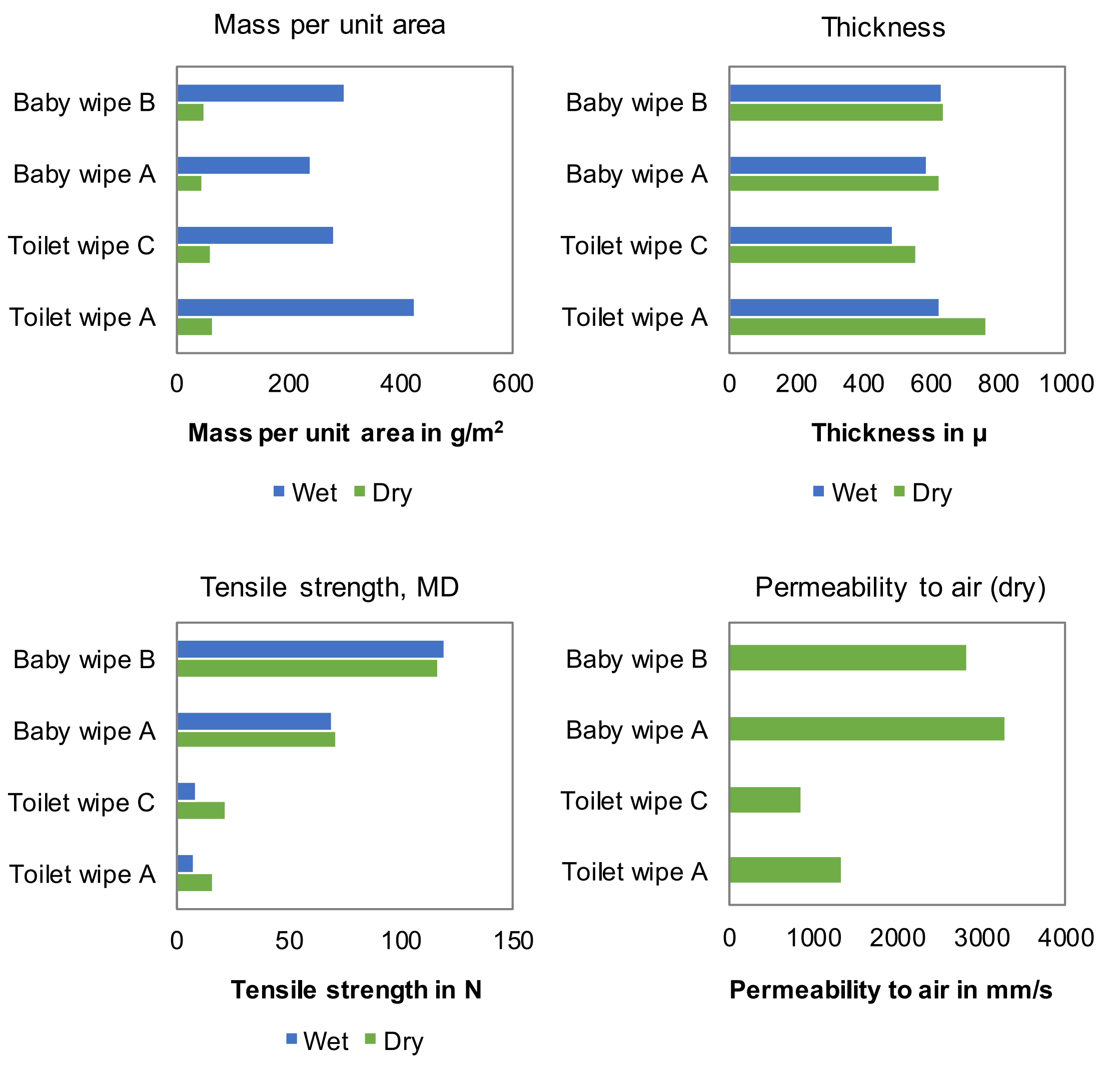

Figure E-2: Characterisation of nonwoven wipes used on laboratory tests, own diagrams with data from [97]

Appendix F

Normalised group efficiency at operating point Q/Qopt = 0.8 for all tested wipes in short time performance test and longtime performance test for the three wastewater classes

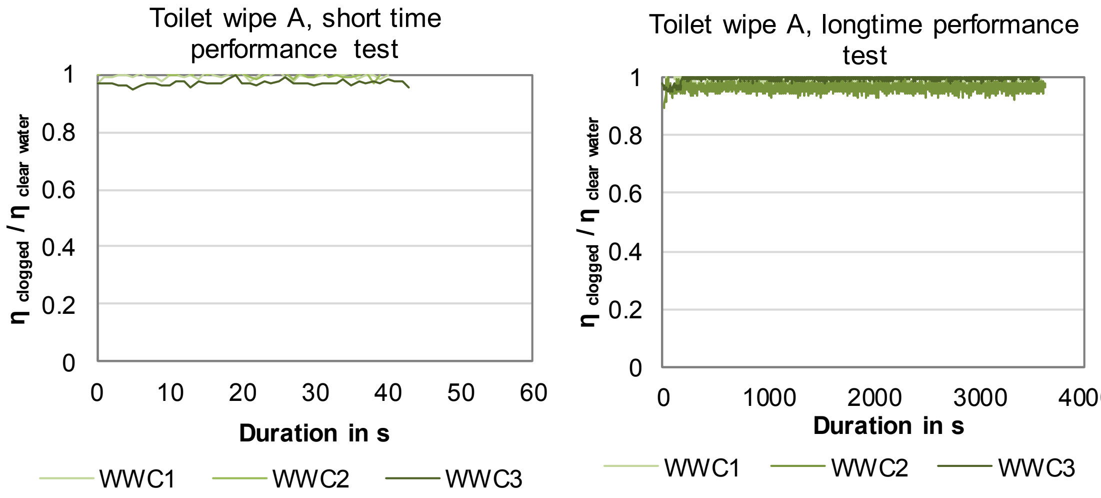

Figure F-1: Toilet wipe A, normalised group efficiency, Q/Qopt = 0.8, WWC 1-3

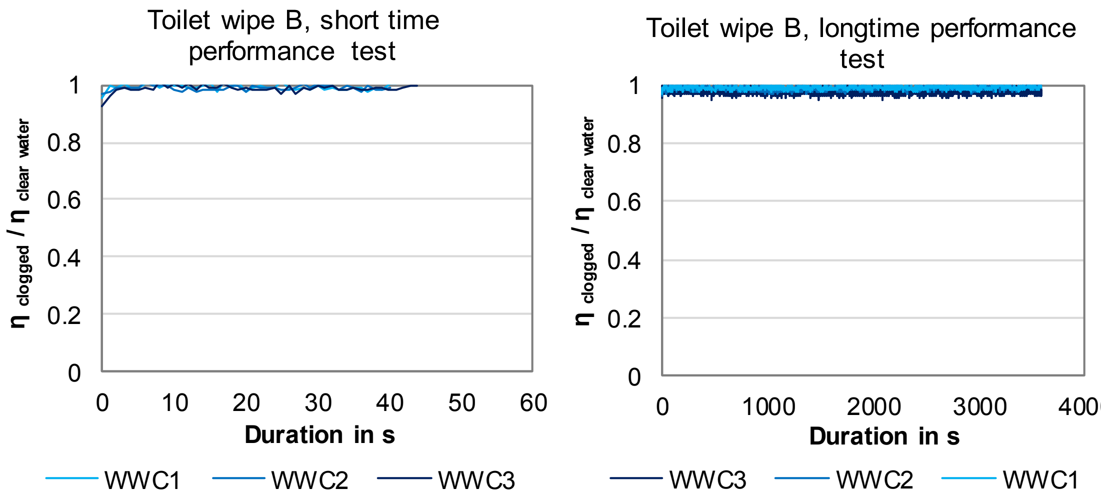

Figure F-2: Toilet wipe B, normalised group efficiency, Q/Qopt = 0.8, WWC 1-3

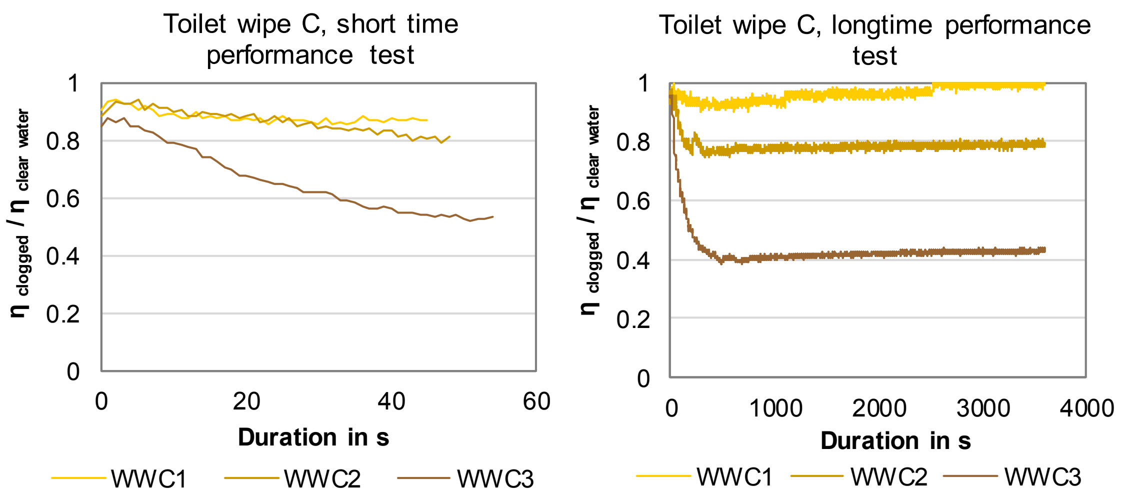

Figure F-3: Toilet wipe C, normalised group efficiency, Q/Qopt = 0.8, WWC 1-3

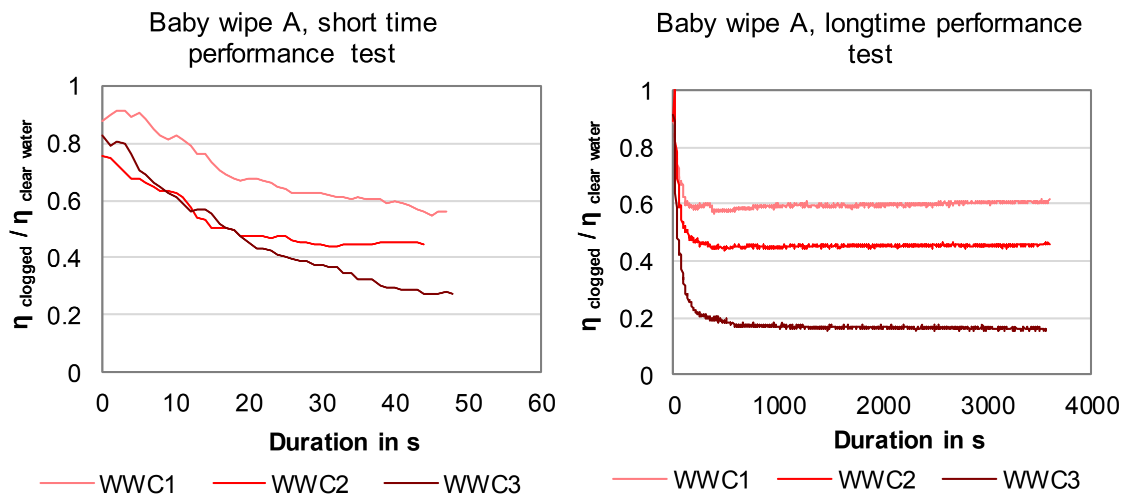

Figure F-4: Baby wipe A normalised group efficiency, Q/Qopt = 0.8, WWC 1-3

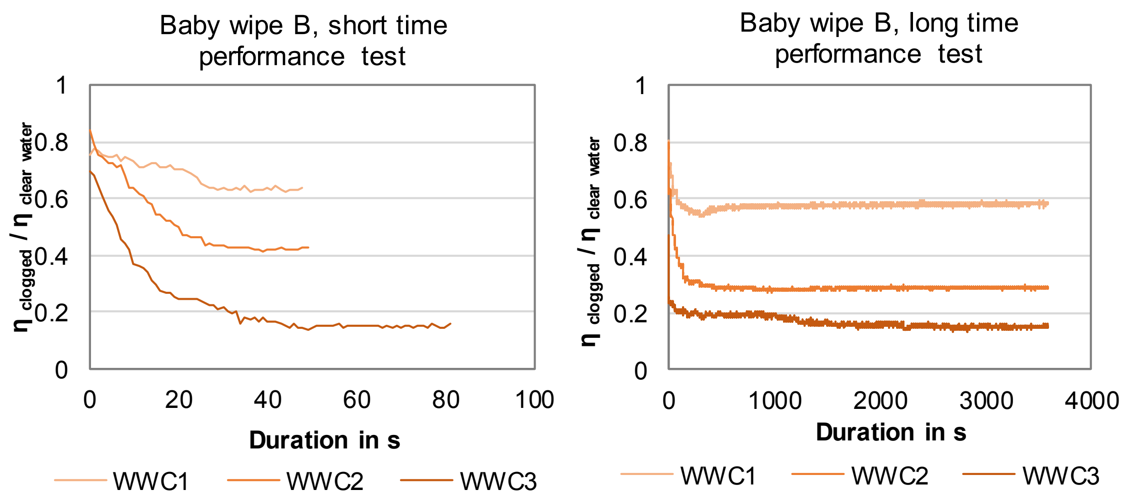

Figure F-5: Baby wipe B normalised group efficiency, Q/Qopt = 0.8, wastewater classes 1-3

Operating points during short time and longtime performance tests for Q/Qopt = 0.8 and the three wastewater classes

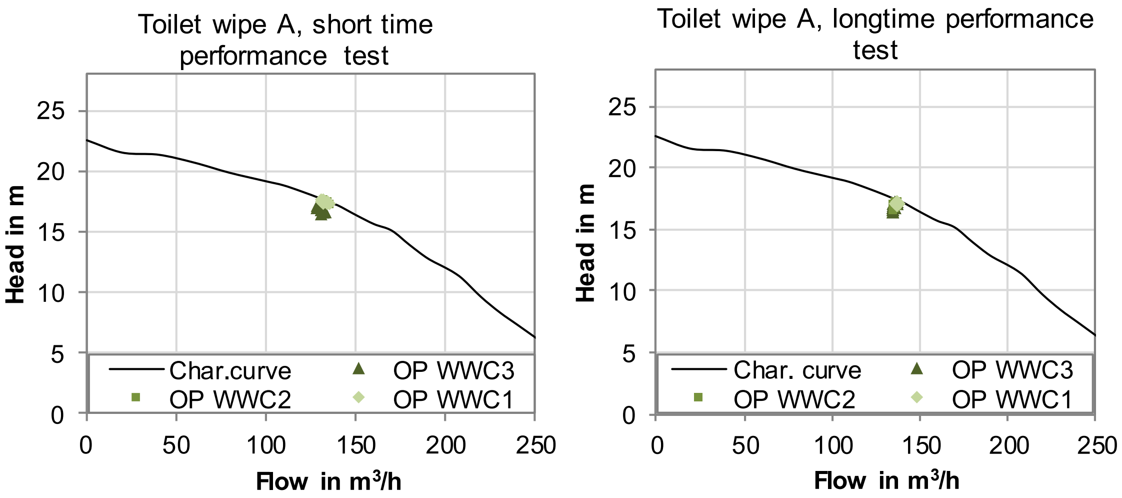

Figure F-6: Toilet wipe A, Q/Qopt = 0.8, operating points for WWC 1-3

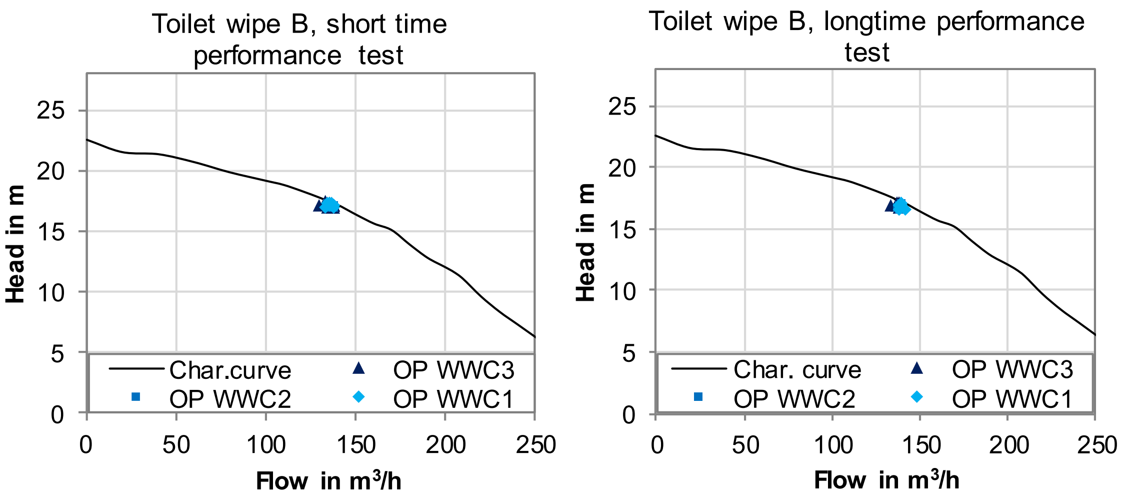

Figure F-7: Toilet wipe B, Q/Qopt = 0.8, operating points for WWC 1-3

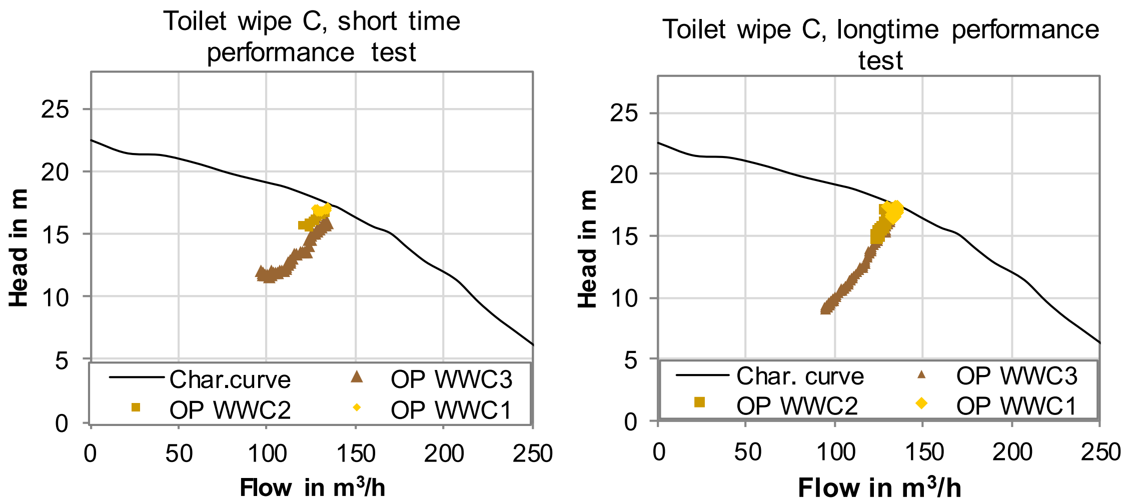

Figure F-8: Toilet wipe C, Q/Qopt = 0.8, operating points for WWC 1-3

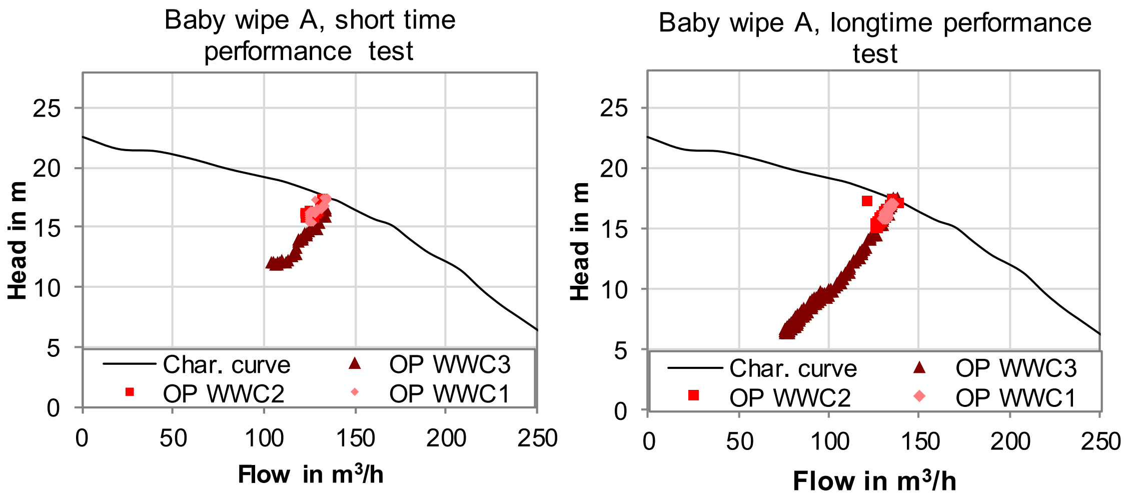

Figure F-9: Baby wipe A, Q/Qopt = 0.8, operating points for WWC 1-3

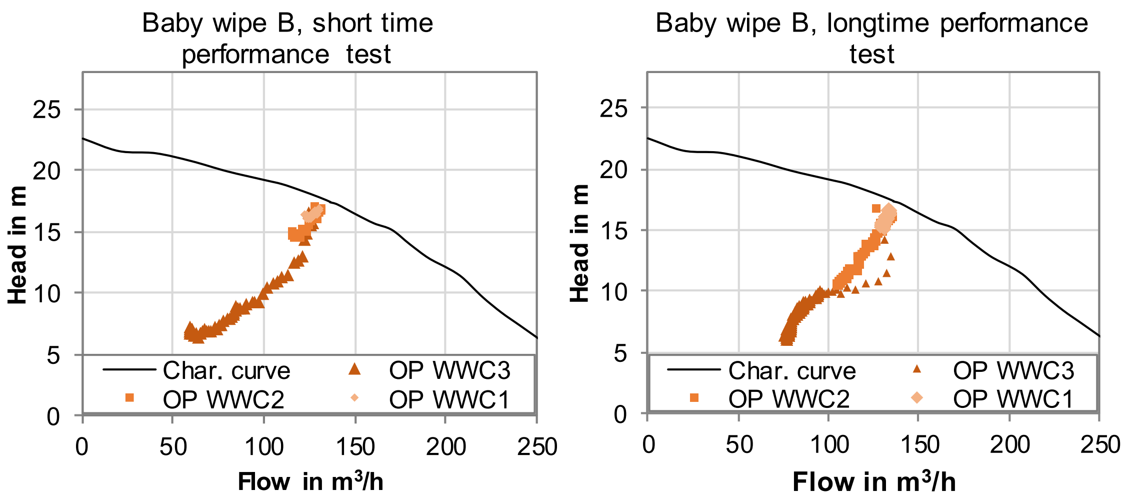

Figure F-10: Baby wipe B, Q/Qopt = 0.8, operating points for WWC 1-3

Variation of normalised group efficiency, head, flow and residues in the pump with increasing contamination at operating point Q/Qopt = 0.8

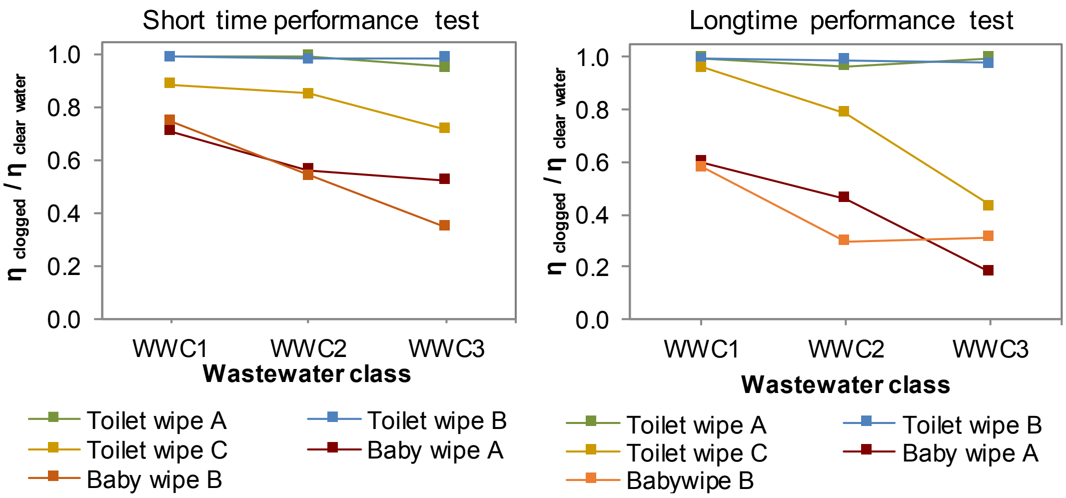

Figure F-11: Variation of normalised group efficiency with increasing contamination, Q/Qopt = 0.8

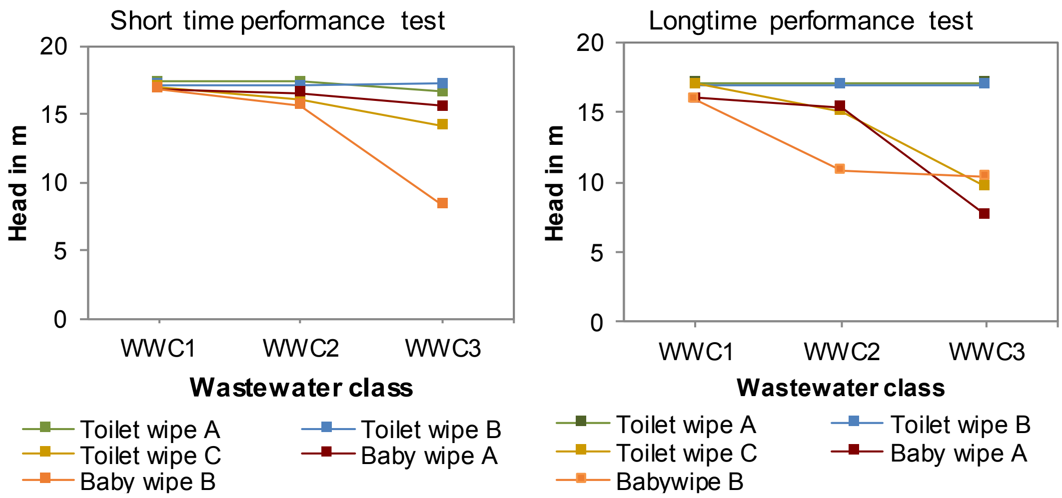

Figure F-12: Variation of head with increasing contamination, Q/Qopt = 0.8

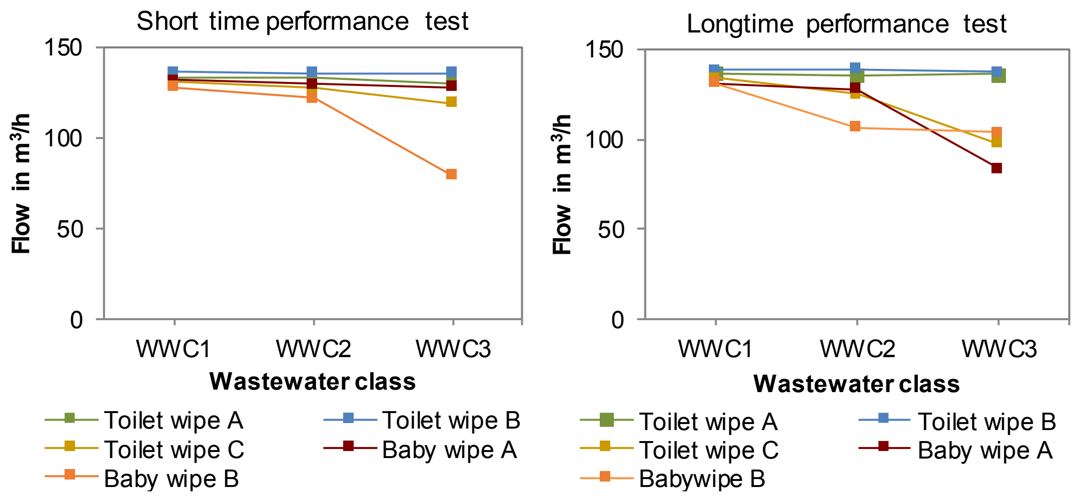

Figure F-13: Variation of flow with increasing contamination, Q/Qopt = 0.8

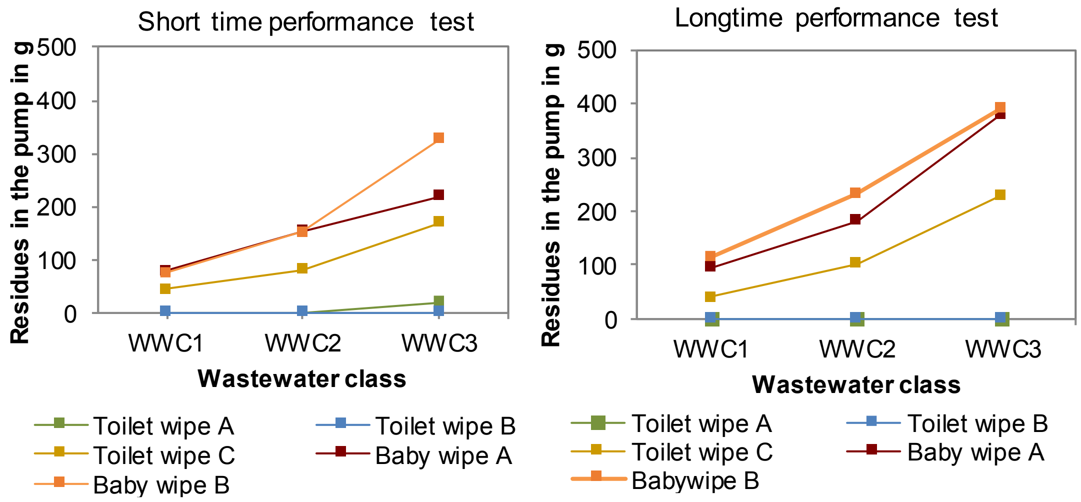

Figure F-14: Variation of residues in the pump with increasing contamination, Q/Qopt = 0.8

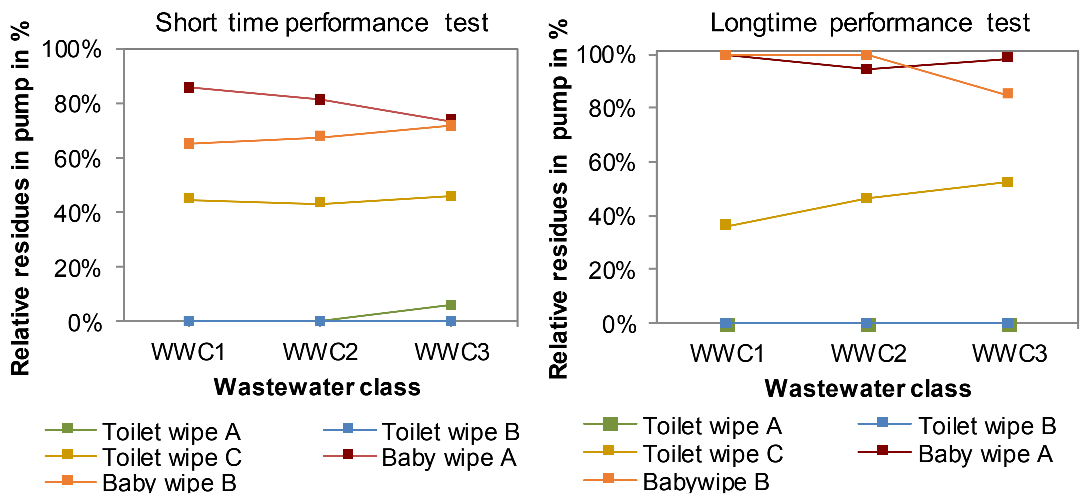

Figure F-15: Variation of relative residues in the pump with increasing contamination, Q/Qopt = 0.8

Normalised group efficiency at operating point Q/Qopt = 1.2 for all tested wipes in short time performance test and longtime performance test for the three wastewater classes

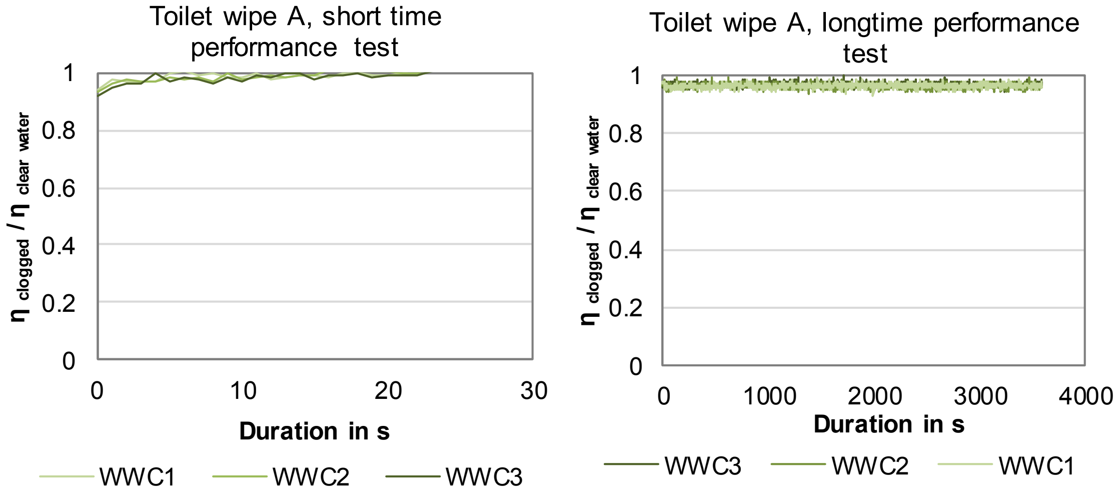

Figure F-16: Toilet wipe A, normalised group efficiency, Q/Qopt = 1.2, WWC 1-3

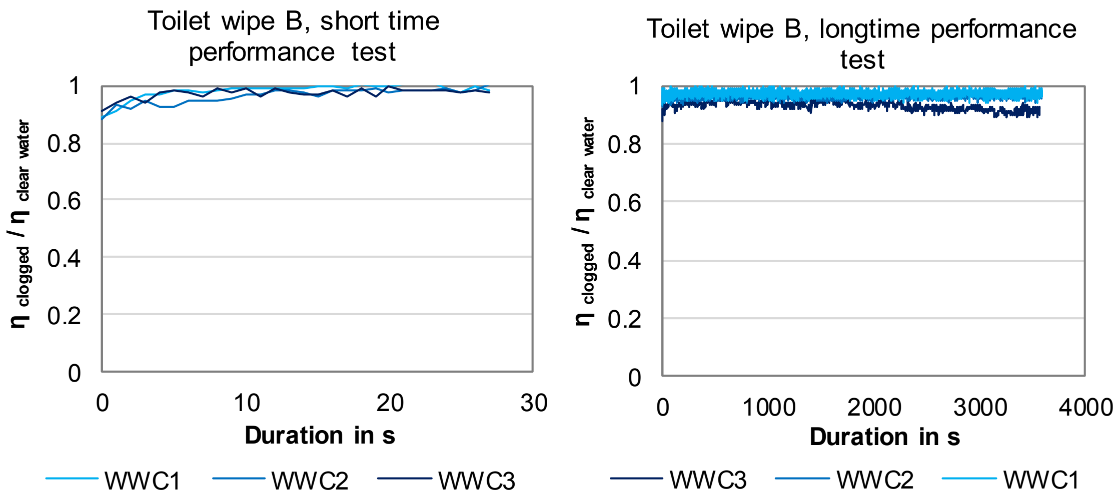

Figure F-17: Toilet wipe B, normalised group efficiency, Q/Qopt = 1.2, WWC 1-3

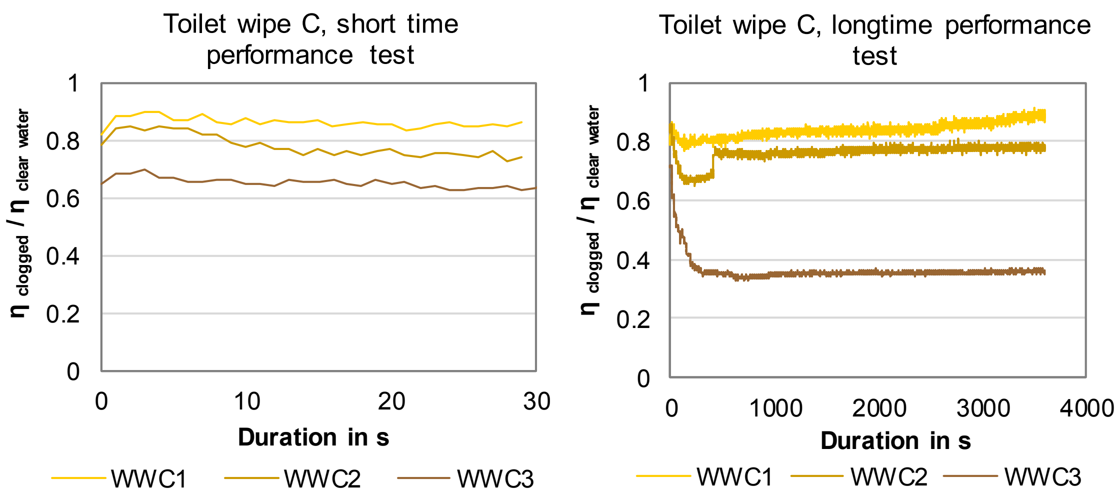

Figure F-18: Toilet wipe C, normalised group efficiency, Q/Qopt = 1.2, WWC 1-3

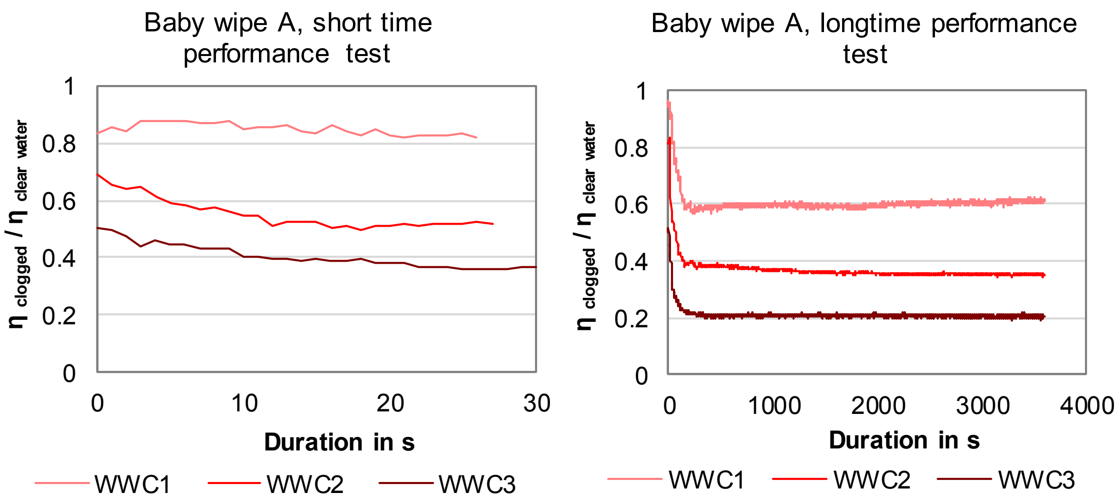

Figure F-19: Baby wipe A, normalised group efficiency, Q/Qopt = 1.2, WWC 1-3

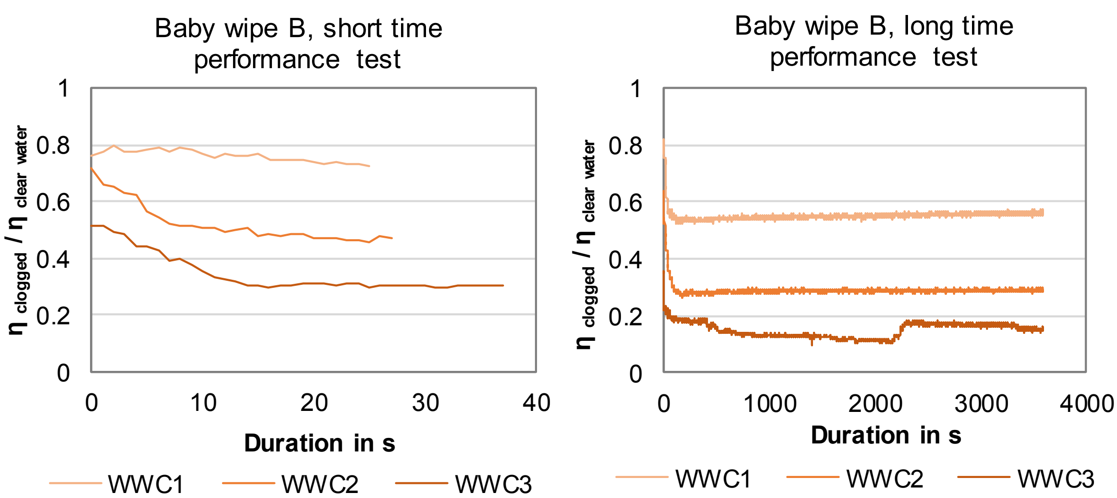

Figure F-20: Baby wipe B, normalised group efficiency, Q/Qopt = 1.2, WWC 1-3

Operating points during short time and longtime performance tests for Q/Qopt = 1.2 and the three wastewater classes

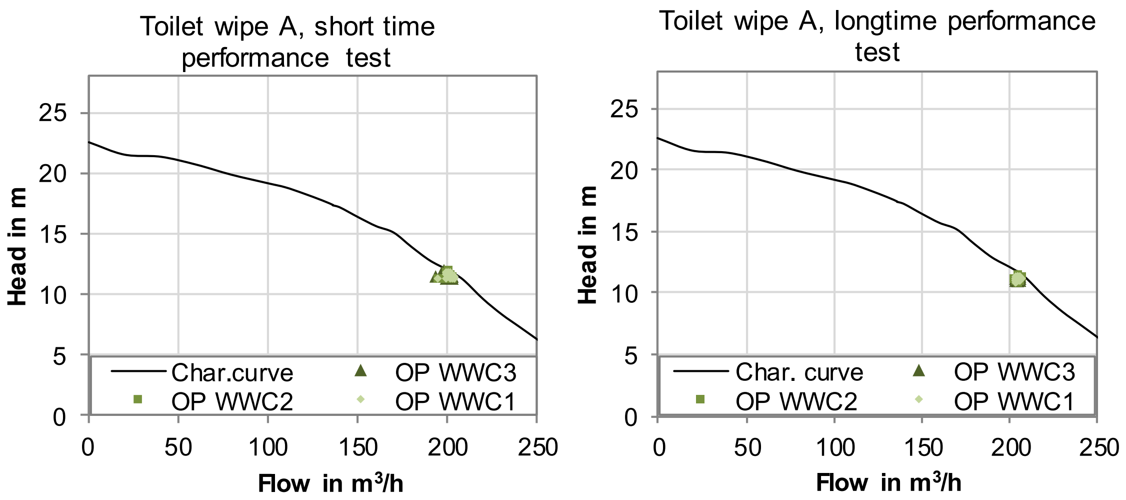

Figure F-21: Toilet wipe A, Q/Qopt = 1.2, operating points for WWC 1-3

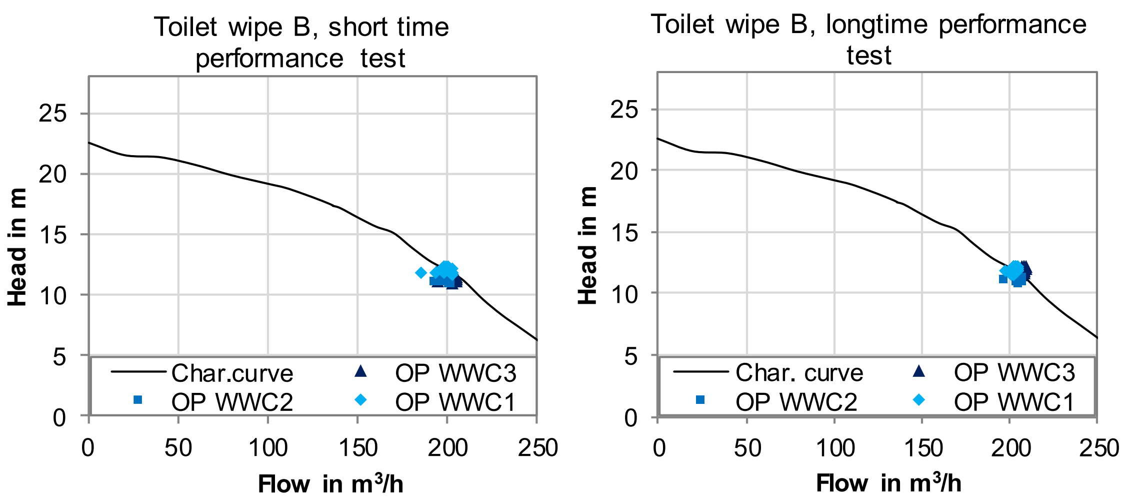

Figure F-22: Toilet wipe B, Q/Qopt = 1.2, operating points for WWC 1-3

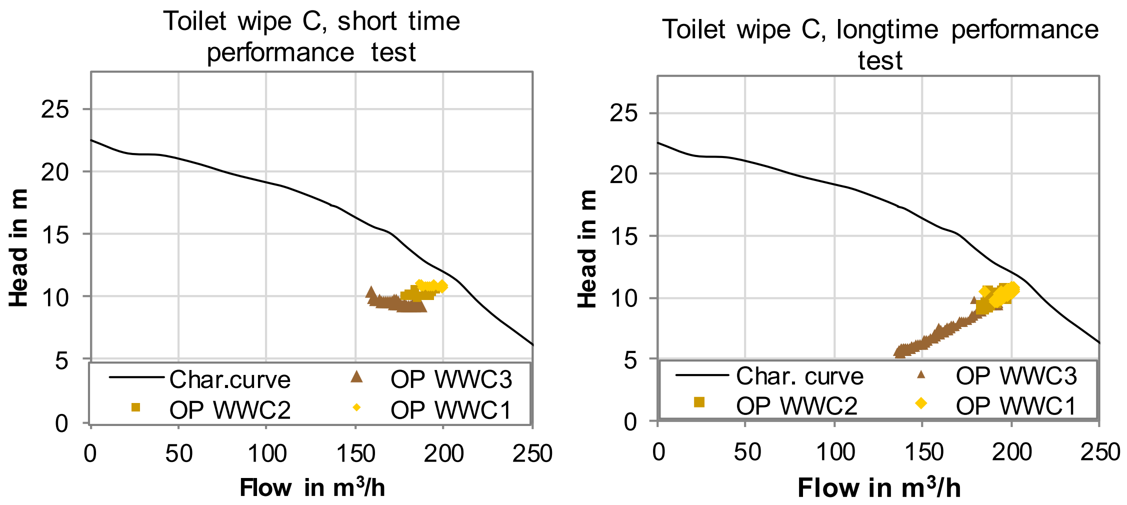

Figure F - 23: Toilet wipe C, Q/Qopt = 1.2, operating points for WWC 1-3

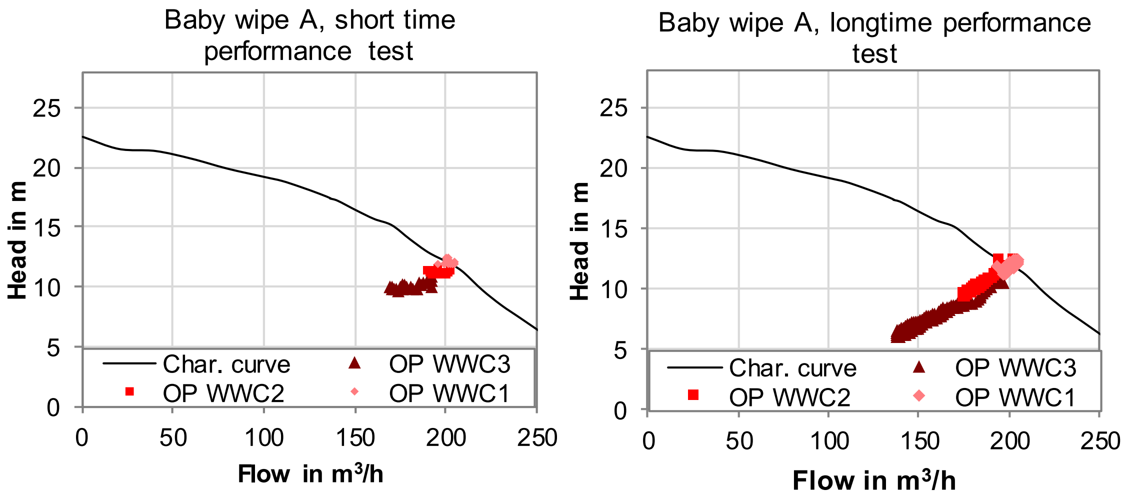

Figure F-24: Baby wipe A, Q/Qopt = 1.2, operating points for WWC 1-3

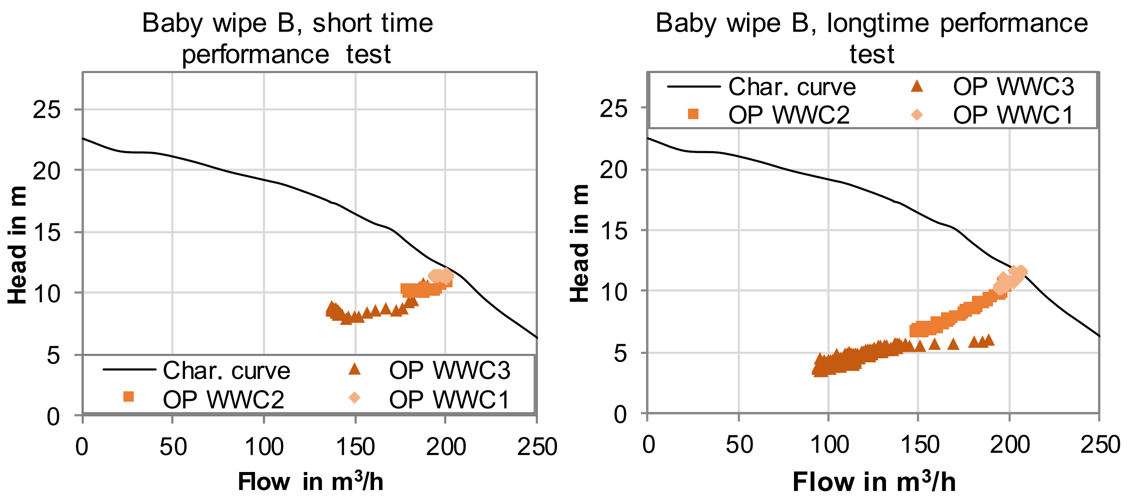

Figure F-25: Baby wipe B, Q/Qopt = 1.2, operating points for WWC 1-3

Variation of normalised group efficiency, head, flow and residues in the pump with increasing contamination at operating point Q/Qopt = 1.2

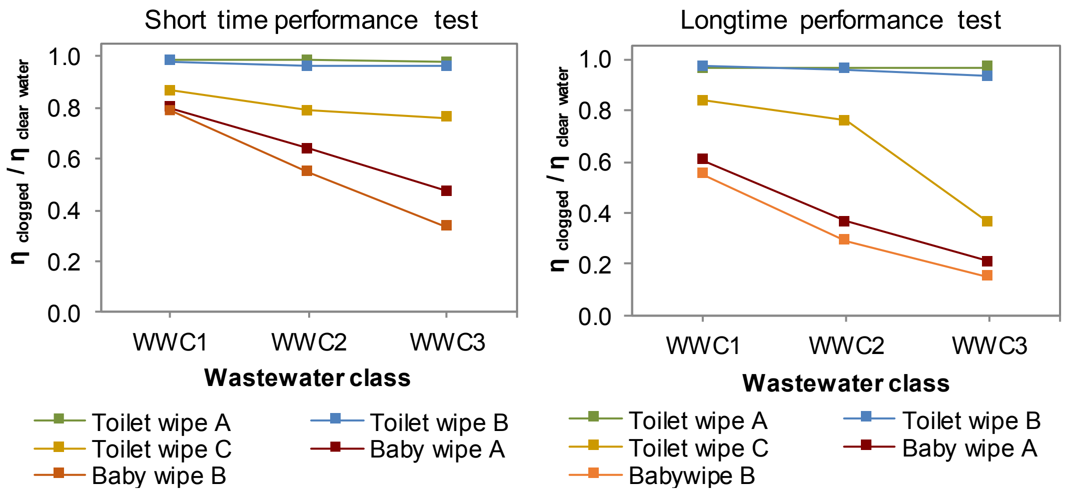

Figure F-26: Variation of normalised group efficiency with increasing contamination, Q/Qopt = 1.2

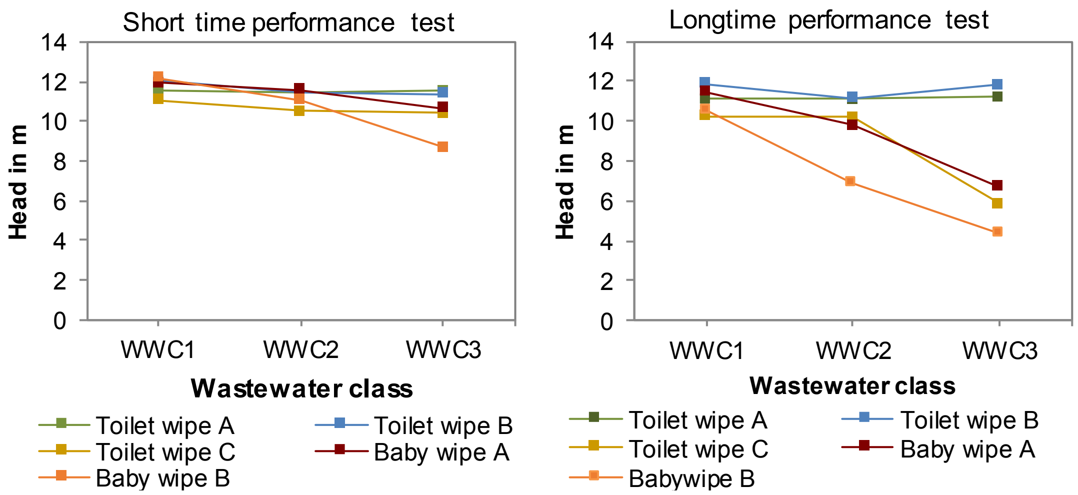

Figure F-27: Variation of head with increasing contamination, Q/Qopt = 1.2

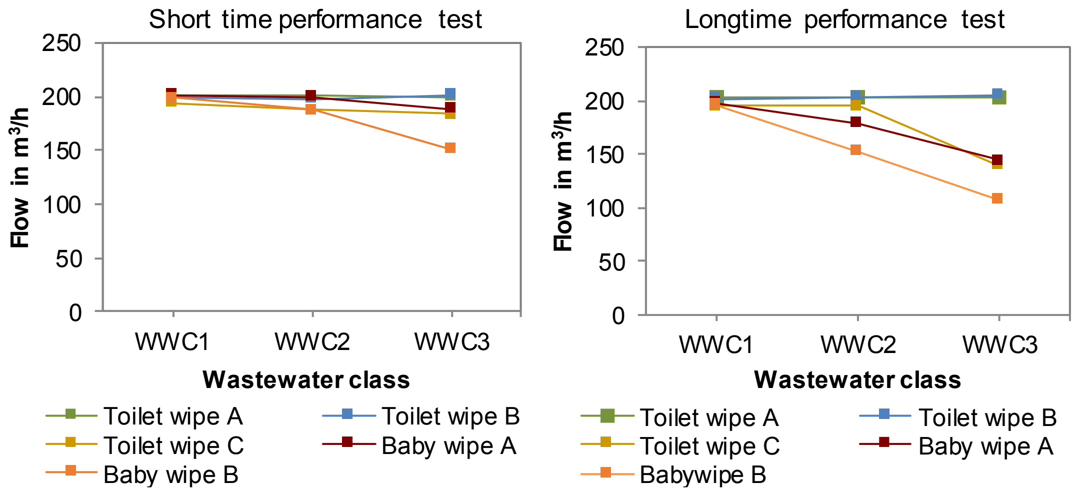

Figure F-28: Variation of flow with increasing contamination, Q/Qopt = 1.2

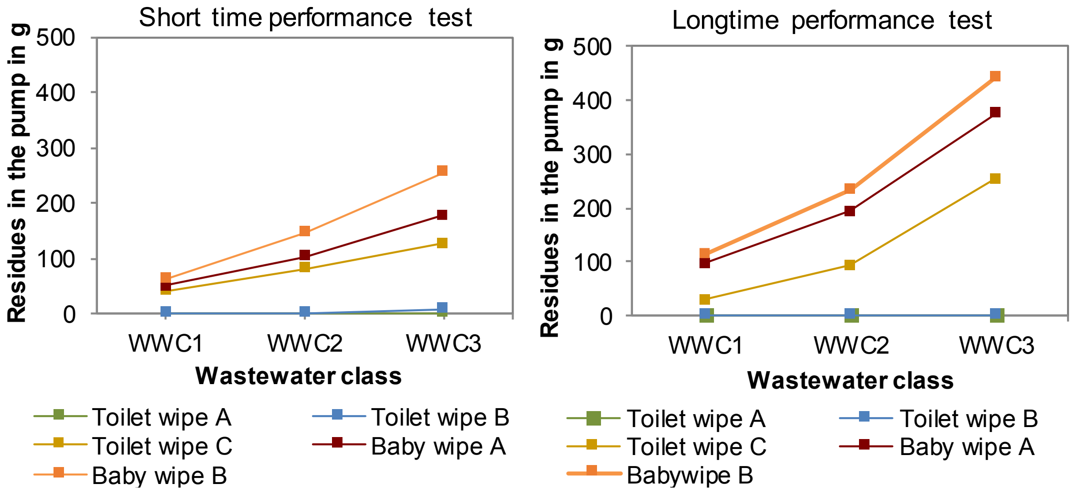

Figure F-29: Variation of residues in the pump with increasing contamination, Q/Qopt = 1.2

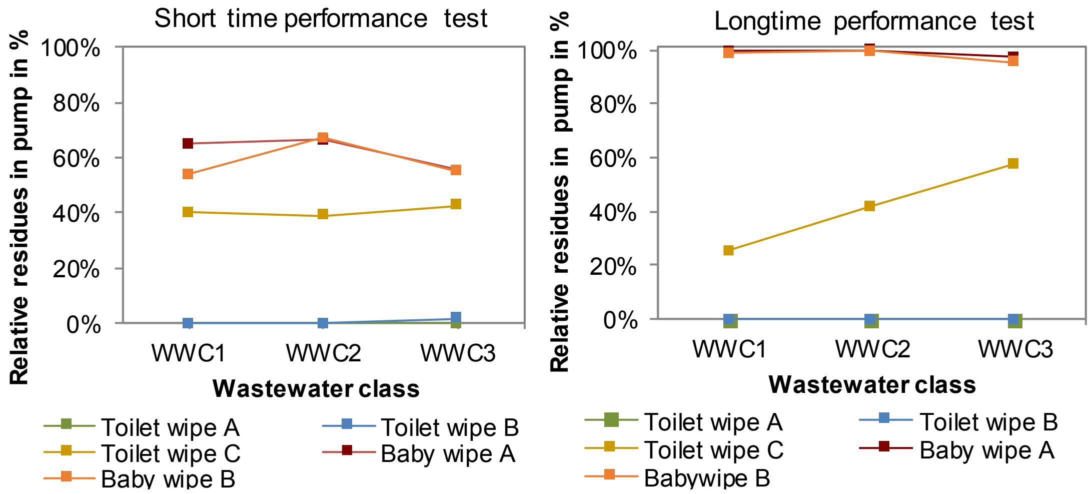

Figure F-30: Variation of relative residues in the pump with increasing contamination, Q/Qopt = 1.2