COLLOQUIUM ON TEXTILE WASTEWATER MANAGEMENT

2019-09-19

MINIMISATION OF WASTEWATER EMISSIONS FROM TEXTILE FINISHING INDUSTRIES

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Informed Choice Matrix for innovative processes in the textile production and finishing

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Abstract

The textile industry uses vast quantities of water and discharges significant volumes of wastewater. This water consumption and wastewater discharge increase the problems of water scarcity and pollution of the water bodies in the producing countries.

The actual challenges in the in-house water management of the wet processing industries cannot be solved by end-of-pipe solutions alone.

An efficient reduction of volume as well as pollution load can only be achieved with a comprehensive knowledge of the processes and the used chemicals.

A comprehensive decision-making tool which provides information about latest and most efficient technologies, processes and non-toxic chemicals, is needed to enable the technical management of producers to identify best technical suitable and economical solutions.

The proposed informed choice matrix would compile and present latest technologies and technical concepts from textile finishing industries, technology providers and chemical manufactures.

1 Background

The textile industry is a water and wastewater intensive branch, nearly all applied textile finishing processes are using water. The World Bank estimates that 17-20 % of industrial water pollution stems from wet processing industries carrying out pre-treatment, dyeing, printing and final finishing processes.

Given the complexity of textile effluent, a proper understanding of textile effluent and its treatment is necessary to make the industry sustainable and pollution free.

The dominating emission mass stream from textile finishing is wastewater, and practically all inorganic and most of the organic (more than 90 %) chemical compounds are discharged with wastewater. In addition, in many parts of the globe, water availability and water scarcity respectively are of increasing concern triggering the need to avoid, minimise or recycle textile wastewater.

The actual challenges in the in-house water management of wet processing industries cannot be solved by end-of-pipe solutions alone. Process - and production -integrated measures will contribute to the development of integrated best available wastewater management practices in the textile sector. This includes the minimization of water, energy and chemical consumption by process optimization and the careful selection of chemical products not only with respect to the properties of the final textile product but also to their environmental performance. The latter means that the chemical products should be free of substances which are non-biodegradable, toxic or have a negative impact on aquatic life.

Increasing awareness of consumers, brands and retailers for sustainable production and value-added chains of the most important consumer goods like textiles and foot ware is responsible for an increasing change management by the major stakeholders of the value-added textile chain.

One of the main sources with severe pollution problems worldwide is textile wastewater containing synthetic dyes, textile auxiliaries and basic chemicals. The textile dyeing and finishing industry is the largest user of the US$14.5 billion commercial dyes and pigments industry, which is predicted to reach US$42 billion by 2021.The textile industry in turn depends on population growth and private consumer spending.
Since the discovery of synthetic dyes in 1856, today there are over 10,000 textile dyes being manufactured with an annual production in excess of 700,000 tonnes. Thirty percent of these dyes are used in excess of 1,000 tonnes per annum. Since only 50 – 95% of the dyes used are fixed on the fabric, approximately 280,000 tonnes are discharged annually – either to effluent treatment plants or directly to the environment. Practically all dyes are aerobically non-biodegradable but some of them are adsorbed

to activated sludge to a significant extent (vat, sulphur, disperse dyes, cationic dyes and organic pigments). For about 70 % (by weight) of all dyes used worldwide are azo dyes.

The textile finishing industry is a water intensive industry using large quantities of fresh water as process water. Efficient specific water consumption can range from 25 to 180 (Table 1) L/kg of fabric. Much of the water use is in cotton finishing rather than synthetic fabrics. However as seen from Bangladesh PaCT (Partnership for Cleaner Textile) experience, typical water use can be as high as 400 L/kg.

Tab. 1: Specific water consumption of fabric finishing

Fabric	**Specific consumption (l/kg)**
Cellulosic fabric	100 – 120
Synthetic fibre, yarn & fabric	25 – 70
Grey polyester fibre	30 – 40
Acrylic fibre	25 – 30
Grey viscose fibre	70 – 80
Grey cotton fibre	100 – 140
Raw wool	40 – 50
Scoured wool fibre	80 – 100
Grey cotton yarn	70 – 80
Grey cotton fabric	150 – 180
Grey polyester cotton fabric	100 – 120

Of the total water used in wet processing industries, nearly 72% of the water used is process water, which then ends up as wastewater.

The following challenges and the related solutions have been compiled as part of a position paper for the Asian Dialogues: Environment Forum for a Sustainable Production in the Textile and Garment Sector ***"**Towards a joint understanding of sustainable environmental and chemical management in the textile and garment industry in Asia".*

2 Water Efficiency and Wastewater Management

2.1 Challenges

- The textile wet processes are water intensive, possibilities to apply water efficiency measures are not sufficiently applied
- Lack of incentives for water efficiency: In many producing countries the price of intake water is zero or negligible
- Awareness concerning the pollution of natural waters is widely underdeveloped. Adequate wastewater treatment is largely missing throughout Asia (esp. in Pakistan), lack of management skills and knowhow, resistance to invest in appropriate treatment plants
- In many regions, water scarcity and competitive uses of water resources (agriculture, drinking water) require water-efficient textile production
- In general, disposal facilities for sludge from wastewater treatment are missing

2.2 Solutions

- Disseminate the knowledge about the benefits and possibilities of sound and efficient water management (water efficiency measures) and wastewater treatment
- Provide proper design of effluent treatment plant (ETPs) including zero liquid discharge in case of certain circumstances and benchmark ETPs for different types of textile finishing industries
- Promote and enforce wastewater treatment standards (e.g. ZDHC)
- Capacity development for the operation and management of ETPs and sludge treatment facilities
- Internalize the external costs of water into the production costs, as well prices of the end products
- Develop and promote sewage sludge treatment guidelines and provide sound design of common sludge incineration plants (which appears to be the best disposal option)

2.3 Wastewater characteristics

2.3.1 Total Suspended Solids, TSS

A well-functioning effluent treatment plant with a sufficient dimensioned clarifier (separation of the water from the sludge by sedimentation) can reach TSS values of 10-25 mg/l. Values of 5 mg/l TSS can only be achieved with the help of sand filtration

2.3.2 Biological Oxygen Demand, BOD_5

The textile wastewater treatment is focussing on biological activated sludge treatment processes. So far, the food-to-microorganism ratio (F/M) is lower than 0.15 kg BOD_5 / kg MLSS x day a total nitrification and nearly complete BOD_5-elimination (residual concentration < 10 mg/l) can be expected. This might be achieved with longitudinal flow reactors. The detection limit is in general 15 mg/l, at best 10 mg/l, so a 5 mg/l limit is not exactly measurable.

In the common praxis of the textile production we expect BOD_5 concentration up to 2000 mg/l at entry to sewage treatment plants, if a plant can reach an elimination up to 30 mg/l residual BOD_5 (98,5 % elimination) which can be achieved with good operating conditions.

Any further improvement of the elimination rate needs further treatment steps like adsorption or/and oxidation.

2.3.3 Chemical Oxygen Demand, COD

150 mg/l can be achieved with biological activated sludge treatment processes. Even 80 mg/l could be achieved if the used finishing chemicals and auxiliaries are biodegradable and the activated sludge treatment plant is well- designed (nitrification, longitudinal flow..) and an influent concentration not exceeding 1500 mg/l. The COD concentration in textile wastewater can rise to 4000 mg/l, especially in case of woven fabric finishing at low specific water consumption. To comply to existing standards, like ZDHC progressive or blue sign the elimination rate needs to be 98% of 4.000 mg/l, which can´t be achieved with conventional activated sludge treatment plants. This means limits of 80 or even 40 mg/l COD can only be achieved by multistage treatment plants.

2.3.4 Acidity/Alkalinity, pH

The pH value of the discharged wastewater is limited to 6 – 9, this range can be achieved by flue gas neutralization without problems

2.3.5 Temperature

The temperature of the wastewater inlet to ETPs should not exceed 35 C to avoid the degradation of the biological activated sludge performance. In case the groundwater or process water temperature is higher than 30 C it is not economically possible to keep the effluent temperature below 30 C.

2.4 Wastewater Discharge Quality Guidelines

The Textile Alliance has compiled a comparison of existing wastewater discharge standards for textile productions. The compilation considers the following standards and their limits:

- ZDHC with foundational, progressive, aspirational levels
- International Finance Cooperation - Environmental Health and Safety (EHS) Textile Manufacturing Guidelines
- Oeko-Tex
- Bluesign
- German Wastewater Ordinance, Annex 38
- Urban Wastewater Treatment Directive 91/271/EEC
- Different national wastewater guidelines for textile wastewater discharge e.g. China, India, Bangladesh, Vietnam
- Specific limits from brands and retailers like Adidas, Aldi and Levi Strauss

The variations between the different standards must be discussed within the context and goals of the different standards.

The compilation can be consulted on the web page of the Partnership for Sustainable Textiles.

<u>An international reference framework and an industrial standard for the textile and garment is still needed</u>.

2.4.1 Challenges

- National regulations exist but are not sufficiently enforced.

- Governmental structures responsible for environmental control and protection often have insufficient institutional, financial and human resources to control and advise polluting industries;
- Brands' various compliance requirements differ from one brand to another. As such, the absence of an internationally agreed regulatory framework makes necessary change management for brands and producers difficult;
- Pollution and emissions have severe effects on peoples' health and the environment, but their cost is not internalized into industry production costs.

2.4.2 Solutions

- Advise relevant government agencies on existing legal frameworks and regulations with an aim to reach the greatest harmonisation possible, using the "Best Available Techniques" (BAT) concept. Advocate for a solid legal basis for chemical management and wastewater standards;
- Strengthening governmental regulatory and enforcement structures is the basis for successful law enforcement. Capacity development for environmental protection agencies on national, regional and municipal level is needed to inspect, monitor, and advise textile producers. Beside a stringent control, a competent advisory service will be set up to assist the producers to comply with the regulations.
- Brands must agree on transparent and common standards of compliance for producers.

2.5 Plausibility check of monitoring data

2.5.1 Plausibility

Plausibility is an evaluation criteria for data and information. If data and information are judged as plausible, they are logic, understandable and comprehensive.

The review of plausibility of emission monitoring data is a challenge in the textile value-added chain. The efficient monitoring of wastewater emissions serves for the compliance of wastewater standards. The national standards are using conventional wastewater parameters like COD, BOD_5, Ammonium, total nitrogen, total phosphor, colour, pH, temperature etc. The ZDHC Wastewater Guideline also consider several dangerous chemicals, which should not be used anymore according to MRSL.

The compliance of the standards is controlled with the help of samples of the wastewater discharge to water courses. The samples are analysed by certified testing institutes. The reliability and plausibility of the presented wastewater data is challenging. Many analytical data are failing an expert plausibility check. Often the absolute concentrations of single parameters and their ratio to each other are not plausible. Many analyses are showing an unrealistic low concentration, which provokes a lot of doubts on the reliability of the results.

The initiative of the textile alliance can help the stakeholders (producers, testing houses, brands, retailers etc.) to check the reliability of wastewater analyses and to improve the quality of the results through a competent dialog within the textile value-added chain. This dialog should help to improve the control through a representative sampling and analytical methods, precise analysis of the samples and valuation of the results.

The control of the compliance in the deeper value-added chain demands a lot of efforts and the related resources and knowledge in the producing companies. The available wastewater analysis often do not allow a sufficient verification because there is no information about the sampling, as well the necessary detailed information about the finishing processes, used substrates etc.

2.6 Possible milestone of the wastewater management initiative of the Textile Alliance

Brands and Retailers are able to evaluate wastewater analysis, check their plausibility and to initiate necessary steps for improvement. Therefore relevant information is compiled and made available for the dissemination of the necessary knowledge in the value-added chain on request.

The measures initiated for the improvement of the wastewater monitoring data and their plausibility check assist the members to enforce plausible wastewater standards along the value-added chain. With the introduction of systematic approaches, their promotion as well as the dissemination of the relevant technical know-how, wastewater management initiatives contribute to an improvement of the textile production and to reduce the negative impacts on the environment.

Plausible and herewith reliable wastewater monitoring data are the target of the milestone, therefore the development and availability of a sound plausibility check is planned. Seen the large variance of the quality and reliability of the presented wastewater monitoring data, it is necessary to support the service providers to perform the necessary audits in a sufficient quality.

For these reasons the presented monitoring data must be checked with respect to sampling, analytic methods and the finishing steps (finishing processes, process sequence, substrate and used products). This information will allow conclusions from the presented results on the quality of sampling and analytics as well as on the reliability of measurements.

2.7 Sampling

Random samples of wastewater are mostly collected manually from pipes, reservoirs, rivers, streams or drains. However, samples can be taken also automatically. Each sample provides data on wastewater quality at the collection time only. Composite samples can be manually prepared by mixing single samples or can be obtained from an automatic sampler according to times or quantities. Such samples enable conclusions to be drawn about the wastewater quality over longer periods. However, in most cases, peak concentrations cannot be identified by means of such composite samples.

2.8 Applied Analytical Methods

The applied analytical methods should be standardized and reproducible. Analytical methods should be selected in a way that different methods will lead to same and comparable results. The necessary blind tests and calibrations must be documented in a transparent way.

Quality control should therefore begin during sample collection and be carried through to the final preparation and documentation of results. Here, the applicable GMP (Good Manufacturing Practice) standards for quality assurance must be applied. The aims are:

- To obtain the highest accuracy and precision of the analytical results
- To ensure that the reliability of analysis i.e. accuracy of results is maintained in the future
- Only those results having a known accuracy and precision can be compared.

3 Capacity development and knowledge management

The operating knowledge management comprises the interconnectedness between knowledge, action and competence. The awareness about which knowledge and capabilities are needed to improve the competitiveness is important to develop structures and processes to make an enterprise fit for a knowledge-based competition.

3.1 Challenges

- In many cases, producers have a substantive knowledge gap on sustainable environmental and chemical management. Especially the knowledge and experiences of up to date wastewater treatment, solid waste management and water & energy efficiency measures are insufficient.
- The assistance provided by leading brands to strengthen the capacities in the producing companies is often limited to awareness campaigning and one-day trainings, which can be barely sufficient for a substantial change process. Most of the brands capacity development activities is limited to piloting and large scale rollout is rare.
- There is a lack of competent local service providers for trainings and implementation.

3.2 Solutions

- Harmonize existing training modules based on a jointly agreed standard, publication of best available techniques and good practices to set benchmarks.
- Add wastewater treatment and waste water sludge management to the chemical management toolkit.
- Explore and evaluate the experiences of the ongoing capacity development projects to make use of the lessons learnt.
- Develop and / or make use of e-learning concepts, webinars and other forms of innovative knowledge exchange (like an informed choice matrix), seek for university cooperation.

4 Proposal for an informed choice matrix

4.1 Introduction

To facilitate the extended use of improved technologies, the decision makers should have an appropriate tool at hand, which allows them to make a correctly informed choice based on technical and economic criteria for their investment decisions.

The proposed informed choice matrix should present information of current technologies and technical concepts from textile finishing industries, technology providers and chemical manufactures.

The underlying information must be based on reliable and verified sources. The listed technical solutions and processes must have practical references. In the matrix, the in-house water management and pre-treatment options should also be compared with alternative processes, which avoid the use of dangerous chemicals.

The matrix also must include practical information about the performance of the particular technology in terms of comparable performance indicators.

Beside capacity and performance costs of investment and operation, there will be decisive parameters for decision making. So far, available information from practical applications and users about advantages and challenges should get mobilized from reference projects.

Also, the availability of respective technology providers in the producing countries is important, including the necessary maintenance and spare-part information.

The proposed matrix cannot only rely on information from technology providers and their input must be proven by independent experts based on practical experience.

The „Informed Choice Matrix“ will present the actually available technologies and processes in a comparable form for the existing commonly used fields of applications of textile wastewater treatment in a so far possible objective and neutral form. The used information is based on verified sources and the presented processes have been proven in practical applications and reference projects.

The following fields and aspects of wastewater treatment technologies will be considered:

- „End-of-the-pipe“ approaches
- Pre-treatment of individual wastewater streams

- Water saving technologies
- Practical experiences concerning treatment effectiveness
- Investment and operating cost
- Availability and applicability of processes in different sourcing countries

Based on this information the „best available treatment” can be identified as an optimal combination of processes at given framework conditions. Therefore, the compiled information will be stored and used in a SQL-databank.

4.2 Target

The target of the informed choice matrix is the development of an innovative platform, which allows the producing companies in the sourcing countries to use an appropriate tool for decision making of investment decisions for advanced textile wastewater treatment solutions. The tool considers the selection criteria of economic viability, environmental performance investment and operating costs as well availability and operationality.

4.3 Target Group

The main target group are the operating and financial managers of textile finishing companies, who are responsible for the investment decisions or its preparation.

4.4 Steps for the development of the informed choice matrix

- Holistic view of the process sequences / packages of textile chain and finishing.
- Analysis of single process steps to identify possible interfaces and alternative processes.
- Identification of innovative processes in the textile chain and finishing through investigations at leading technology providers.
  - Technologies
    - Windows and limits of application
    - Process data / practical experiences
    - Advantages and challenges
    - Practical use of the technology (dissemination)
  - Regional availability
    - Process engineering

    - Physical availability at the local market
    - Compliance with national legislation
  - Economic feasibility
    - Investment costs of the plant
    - Operating costs
    - Costs for maintenance and repair
  - Environmental advantages
    - Reduction of dangerous substances
    - Reduction of emission mass streams (emissions to water, air and soil)
    - Alternative processes or process steps
    - Compliance to legislation and guidelines
  - Preconditions for a permanent use and a sustainable operation
    - Available skilled personnel for operation
    - Technical expertise for planning and design
    - Technical operationality

- Analysis of the processes „best available treatment“ based on Key Performance Indicators (KPIs) in the respective producing countries:
  - KPIs
  - Range of application
  - Pro and Cons
- Development of logical criteria for decisions (matrix, decision tree)
- Development of a user platform with an integrated SQL-databank (Instrument)
  - User-friendly
  - Extendable
  - Ready for implementation
- Field test of the instrument with a few practical case studies from producing countries.

4.5 Focal areas of investigation and research:

- Prevention/minimisation of wastewater emissions
  - Reduction of the liquor ratio for dyeing processes.

   - Combined use of water and compressed air for the rinsing of printing screens.
   - Optimisation of rinsing and washing processes.

- Pre-treatment of segregated individual wastewater streams

   - Concentration and recovery of alkaline of mercerisation plants.
   - Recycling of dyeing and finishing liquors.
   - Minimisation of highly concentrated wastewater streams and separate discharge/disposal of the residues.

- „End-of-the-pipe“

   - Recycling (e.g. by ultrafiltration) and reuse of sizing agents with parallel reuse of the permeate for washing purposes and preparation of new sizing agent liquors.
   - Recycling of rinsing water and cooling water with low pollution loads.

- Processes for the reduction and substitution of chemicals -> MRSL / RSL

   - Reduction of the use of chemicals by revision ad optimization of recipes.
   - Preferred us of exhaust dyeing processes with optimized liquor ratio.
   - Use of heavy metal free dyes and dyes with high fixation rates to avoid higher dye concentration in wastewater.
   - Use of AOX-free dyes or with low AOX-concentrations.
   - Avoidance or reduction of the use of chemicals and auxiliaries which are heavily or non-biodegradable toxic.

- Processes for energy efficiency

   - Use and recovery of waste heat from processes by heat exchangers, both from wastewater and emissions to air. The choices of appropriate technologies as well the continuous maintenance are decision making parameters.

4.6 „Informed Choice Matrix“:

Processing step	Available best Technology/-ies	KPIs	Costs of investment	Operating Costs	Advantages	Challenges while application	References	Availability in producing countries

The essential criteria for an informed choice are the relevant key performance indicators (KPIs) like treatment capacities per unit (e.g. kg COD reduction / m³ reactor volume per day) the investments and operating costs. The comparison of these criteria will be the basis for a ranking.

The mobilization and compilation of available and reliable data and information are essential for the accuracy of the informed choice matrix. This will be the biggest challenge for the development because it needs to mobilize the relevant information and data from suppliers, users and so far, relevant researchers. The different stakeholders must be convinced of the added value of shared information and the joint target of the informed choice matrix.

The informed choice matrix will be tested with the following fields of wastewater treatment problems:

- Digital printing
- Desizing
- Dyeing and finishing
- Advanced end-of-the-pipe solutions

5 Possible next steps

Water efficiency is a critical aspect of sustainable and environmentally conscious manufacturing. While there have been efforts to create regulations by individual governments, brands and even multi-brand consortia, it still exists no single industry-standard guideline that covers all discharge criteria.

The textile wastewater expert community should continue to strive for an advanced wastewater treatment standard which is internationally accepted. The standard alone is not sufficient - there must be a campaign for knowledge and information dissemination. The options should be known to the owners and operators of the production facilities in the producing countries.

Parallel to the ongoing revision of the Textile BREF, it would be useful to improve the availability of information on advanced technologies, processes as well as chemical and non-chemical solutions. The free dissemination of such knowledge can help to improve the textile sector concerning sustainable and resource efficient production.

It should be discussed which organization might be the appropriate host for such a platform and what will be the necessary effort to compile and keep such information updated.

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Current status of textile industry wastewater treatment in China: A mini review

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Abstract

Textile industry is a significant water consumer and wastewater discharger. China has been the largest textile producer in the world over the years. Textile wastewater has become an important source of pollution that affects the water environments in China. This paper reviews the current status and challenges of the water pollution control in Chinese textile industry, including wastewater discharge, environmental risks, wastewater treatment and reuse technologies. With the stricter discharge standards, effectively method should be developed to improve pollution control and environmental sustainability.

Keywords: textile wastewater, environmental protection, discharge standards.

1 Introduction

The textile industry is China's traditional pillar industry and has clear international competitive advantages (Lu, Liu et al. 2010). At the same time, the textile industry is important in terms of people's livelihoods. The industry contributes greatly to economic growth, export earnings, and employment promotions (Li, Shen et al. 2018, Zhao and Lin 2019). The Chinese textile industry has grown rapidly with the rapid development of the country's economy. The total output value increased from USD 31.36 billion in 1997 to USD 27.43 trillion in 2014, with an average annual growth rate of 10.96%(based on the 2014 price) (Li, Shen et al. 2018).

Despite the contribution of the textile industry as an important income source in China, the environmental impacts brought by such industry cannot be overlooked since it’s traditionally one of the highest polluting industries (Robinson, McMullan et al. 2001, Wong, Yac'cob et al. 2018). Compared to other manufacturing sectors, the textile industry uses a more complicated process, which involve washing, scouring, bleaching, mercerizing, dyeing and finishing processes (Ning, Lin et al. 2014). These processes produced large quantities of highly toxic wastewater, especially for the washing and finishing processes (Li, Chu et al. 2012, Ning, Wang et al. 2015). According to the China Environment Statistical Yearbook in 2012, the discharge of textile dyeing wastewater was approximately 2.37 billion tons (Dong, Hochman et al. 2018).

The textile wastewater is difficult to dispose because it contains a high content of contaminants, such as dyes, heavy metal ions, surfactants, solvents, detergents, auxiliaries and recalcitrant compounds (Wang, Yediler et al. 2002, Lotito, Fratino et al. 2012, Liang, Ning et al. 2013). When discharged into water bodies, which could lead to disastrous effects to the aquatic ecosystem (Yusuf, Khan et al. 2017). In addition, the safety of seafood is compromised due to biomagnification and bioaccumulation effects of pollutants in the marine ecosystem (Liang, Ning et al. 2017). Transfer of these compounds into human body through ingestion of seafood could lead to undesirable and irreversible effects to human nervous systems (Oz, Lorke et al. 2011, Liang, Ning et al. 2018). The Chinese government attaches great importance to the textile industry water pollution. In response to the industry growth and sustainable development goals in China's "13th Five-Year Plan" (Ministry of Industry and Information Technology of the People's Republic of China, 2016), and in order to achieve the decoupling of the textile industry's economic growth and water environmental stress and develop in a highly efficient and sustainable way, environmental friendly and sustainability method should be developed to improve pollution control caused by textile industry wastewater.

This paper presents a brief introduction to the current status and challenges of the water pollution control in Chinese textile industry, the effective treatment methods of textile wastewater in China and future trends in the treatment of textile wastewater were also discussed.

2 Textile wastewater pollution in China

Water shortage in one of the major obstacles to economic and social development of China (Wang, Tang et al. 2009). Water resources per capita in China is 2,710 m3, which is less than 1/4 of the world's per capita water resources, ranking 88th in the world. While, the industrial wastewater discharge in China is relatively large. The textile industry is a traditional pillar industry in China and has been recognized as the most significant source of wastewater pollution. The major provinces and cities of textile industry in China are located in Zhejiang, Jiangsu, Guangdong, Fujian, and Shandong (Fig 1) (Liu, Cheng et al. 2017).

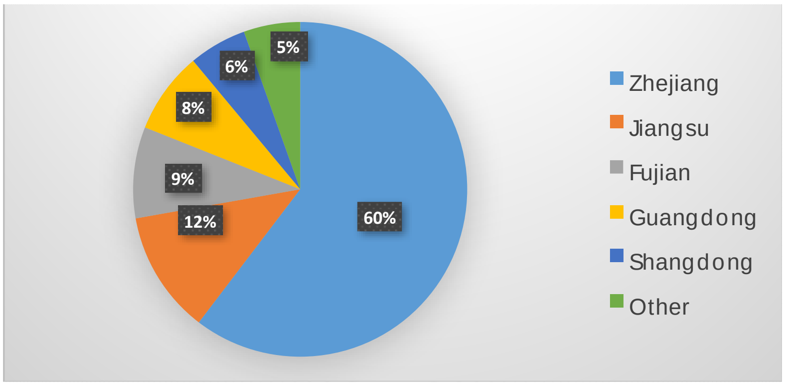

Fig. 1: Textile production in major provinces and cities in China

In 2015, approximately 1.84 billion tons of textile industry wastewater was generated, ranking third among 41 key industries in China for five consecutive years (2011–2015). In 2015, the textile industry emitted 206 thousand tons of chemical oxygen demand, ranking fourth among 41 key industries in China (Li and Wang 2019). At the same time, the recycling level of water resources in China's textile industry is on the low side. The water reuse rate in the textile industry is less than 70%, which is lower than the average level of 80% in the national industry. The water reuse rate in printing and dyeing industry is only 30% (China National Textile and Apparel Council, 2018). However, according to the textile industry development plan 2016–2020, by 2020, the water intake per textile unit of industrial added value will decrease by 23%, and the total discharge of major pollutants will decrease by 10% (Li and Wang 2019). In addition, the environmental standards implementation is also becoming more and more strict. The sustainable development of China's textile industry is facing the dual dilemma of serious water shortage and excessive wastewater discharge.

3 Textile wastewater treatment in China

Textile industry is one of the largest water-consuming in the world. Pretreatment, dyeing, printing, and finishing are the main steps in dyeing and printing process of textile industries. A large amount of wastewater is being generated by all these processes, which contains many pollutants like reactive dyes, chemicals, high chemical oxygen demand (COD), biological oxygen demand (BOD), and organic compounds.

During the past two decades, different treatment technologies have been studied to evaluate the sustainable treatment of textile wastewater (Grilli, Piscitelli et al. 2011, Fan, Li et al. 2014, Liang, Ning et al. 2018). The selection of a suitable type of technology depends on the production process and chemical usage of the textile mill, constituents of effluent, discharge standards and location, capital and operating costs, availability of land area, options of reusing/recycling the treated wastewater and skills and expertise available (Jegatheesan, Pramanik et al. 2016). Treatment technologies for textile wastewater can be divided mainly into three: physical process, biological process, chemical process (Wang, Hung et al. 2005).

There are several physical methods such as adsorption, ion exchange, and membrane-filtration processes. Adsorption is the process of collecting soluble substances which are in the solution on a suitable interface. Ion exchange can be used for the removal of undesirable anions and cations from wastewater. Most of the ion exchange resins used in wastewater treatment are synthetic resins made through the polymerization of organic compounds into a porous three-dimensional structure. Filtration is defined as the passage of a fluid through a porous medium to remove matter held in suspension. This method is normally employed after coagulation and flocculation or after biological wastewater treatment.

Biological treatment may involve the use of microorganisms in either aerobic or anaerobic conditions to degrade organic dyes by using fixed or suspended growth systems. In most cases, anaerobic biodegradation is incorporated (as a pretreatment technique) in the treatment of high strength effluents such as textile wastewater. While aerobic processes consume energy (1 kWh/kg of BOD degraded), anaerobic processes yield 0.5 to 1.5 kWh/kg of BOD degraded and comparatively produce less volume of waste sludge than aerobic processes. In general, installation of anaerobic reactors/digesters is expensive but they can absorb higher shock loads in addition to the advantages mentioned above (Jegatheesan, Pramanik et al. 2016).

Chemical treatment includes coagulation/flocculation and chemical oxidation processes. The former method is a process commonly used for removing colloidal and other suspended particles from wastewater. However, coagulation and flocculation processes often lead to toxic sludge handling and disposal problems. Hence, chemical oxidation has attracted more attention as it does not generate any secondary pollutant. Chemical oxidation processes generally involve the use of chemical reagents (such as H2O2 and O3). Usually, it can be used as a post-conventional treatment process to enhance the complete mineralization process.

4 Case study of textile wastewater treatment in China

To achieve the goals in China’s “13th Five-Year Plan” and fulfill the demand of increasingly strict regulations, the textile industry has to face the pressure to recover and reuse its wastewater. Membrane technology is an attractive method to treat and reuse textile wastewater (Ramlow, Machado et al. 2017). The membrane bioreactor-nanofiltration (MBR-NF) process, as a double membrane system combined with aerobic activated sludge process, has been used in municipal wastewater treatment to achieve discharge standard or water reuse (Chon, KyongShon et al. 2012, Kappel, Yasadi et al. 2013, Andrade, Mendes et al. 2014). By 2015, the total capacity of the membrane technology in textile wastewater treatment in China was about 662,000 m3·d–1 and the number of applications was 128 (with capacity ≥500 m3·d–1). Geographical distribution is also analyzed and most applications are located in Zhejiang, Jiangsu, Guangdong, Fujian, and Shandong (Liu, Cheng et al. 2017).

A combination of membrane bioreactor (MBR) and nanofiltration (NF) was tested at pilot-scale treating textile wastewater from the wastewater treatment station of a textile mill in Wuqing District of Tianjin (China). The MBR-NF process showed a much better treatment efficiency on the removal of the chemical oxygen demand, total organic carbon, color and turbidity in comparison with the conventional processes. The water recovery rate was enhanced to over 90% through the recycling of NF concentrate to the MBR, while the MBR-NF showed a stable permeate water quality that met with standards and could be directly discharged or further reused (Li, Jiang et al. 2016).

5 Conclusion

The application of MBR to treat textile wastewater is an emerging technology and further work should be done to reduce the cost of membrane as well as investigation the effect of EPS on fouling to achieve higher flux. In addition, as the traditional textile wastewater treatment need to add chemical for flocculation and sedimentation, which would increase the cost and produce large amount of sludge. It kind of pollution transfer other them removal. To achieve the sustainable and green development of textile industry, new concept for resource recovery from textile wastewater should be developed in the future.

Acknowledgements

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Textile wastewater treatment, recycling, and zero liquid discharge in India

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Abstract

The textile industry has evolved rapidly in the last few years. To cater to fast changing consumer needs, a single textile manufacturing plant now handles a wide variety of products with innumerable options of processing and finishing. There is a huge increase in the range of dyes and chemicals used. This has helped the textile industry to cope with frequent changes in fashion.

However, this has imposed a far greater challenge for the treatment and safe disposal of effluent generated from the textile industry. The use of a wide range of dyes and chemicals, in different proportions and combinations on a day to day basis means ever changing wastewaters.

Further, the scarcity of raw water makes it necessary to treat the effluent to an extent where one can recycle it for reuse in the process without any limitations.

The conventional lime and ferrous treatment is fast becoming obsolete due to its ineffectiveness in treating many new generation dyes and chemicals. This treatment is not able to reduce the COD (Chemical Oxygen Demand) below acceptable limits even after large quantities of lime and ferrous are dosed and a huge quantity of sludge is generated. Based on this experience, people have added a step of biological treatment. Biological treatment is natural and eco-friendly.

So far the textile industry has mainly used aerobic biodegradation for its effluents. However, aerobic biodegradation has its own limitations in reducing colour and COD in a single stage. Also, it consumes a huge quantity of power and further generates a lot of biological sludge.

A.T.E. HUBER Envirotech (AHET) understood these pain areas of the textile industry. In order to devise the right solution, AHET conducted detailed treatability studies on a variety of textile effluents. The outcome of these studies are the AAA® and SUFRO®

technologies which are successful innovations that enhance biological treatment efficiency, reduce colour, minimise sludge generation and recover maximum water at a minimum operational cost.
Subsequently, AHET could help many textile companies by successfully implementing AAA® and SUFRO® technologies for effective treatment and recycling of wastewater. AHET also conducted a detailed study of each of the full scale operating plants where AAA® and SUFRO® technologies were implemented. These studies on operating plants revealed the following:

1. Anaerobic biodegradation alone reduces color by 40-50% and COD by 30-40% (without expending chemicals or power).
2. The use of anaerobic biodegradation prior to aerobic biodegradation is especially effective and shows excellent combined colour reduction of almost 80-90%.
3. The sludge generation in anaerobic wastewater treatment is just 10% of that in an aerobic degradation process for an equivalent COD reduction. Overall there is 70% reduction in the sludge generation as compared to conventional physio-chemical process and about 20% as compared to a pure aerobic process.
4. There is a reduced power consumption by 20% by adding an anaerobic step as compared to conventional pure aerobic process.
5. SUF provides additional 10% reduction in COD and > 95% reduction in TSS from the secondary clarifier overflow water quality.
6. SUFRO® offers 40% reduction in membrane cleaning chemical consumption and 60% reduction in secondary wastewater generation (backwash and CIP wastewater) as compared to conventional UF-RO plants.

1 AAA®

1.1 Introduction

AAA® technology is a highly successful innovation from AHET that enhances biological treatment efficiency, reduces colour and minimises sludge generation for textile industry wastewaters. The treatment steps comprise of Air floatation → Anaerobic biodegradation → Aerobic biodegradation (figure 1).

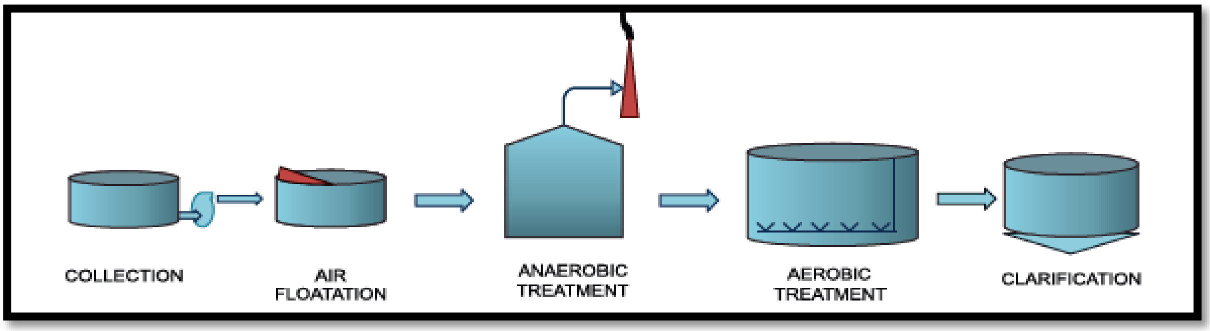


Fig. 1: AAA® technology

Salient features of AAA®:

- Dissolved Air Flotation (DAF) as a first step that eliminates floating impurities (fibres) with low chemical consumption & sludge generation
- Anaerobic biodegradation as a second step breaks down chemical bonds, reduces color, COD and improves bio-degradability
- Aerobic biodegradation as a third step completes the bio-degradation and improves dissolved oxygen level for safe disposal
- Produces consistent quality of treated wastewater

1.2 Treatment steps of AAA®

1.2.1 Air Floatation:

The wastewater after equalization and neutralization is pumped into a dissolved air floatation unit via a tube feeder. The air-saturated water is released. The micro bubbles (20 – 40 µm dia.) generated when the pressure is released and intensively mix with the suspended material in a tube feeder (special pipe-in-pipe system). The gas bubbles attach to the surface of solids. The solids/gas flocs rise to the water surface where they form a scum (or flotate) layer that is skimmed off into the flotate hopper by a scraper. The scraper joists with their special design dewater the flotate additionally. The non-clogging lamella separator increases the effective clarifier area, for maximum hydraulic loads on a small footprint. Up to 30 % of the treated effluent is recirculated for the generation of pressured water. A compressor feeds compressed air to generate small bubbles with a large surface for quick water saturation. The saturated water flows through a single pressure release valve, where the micro bubbles with a diameter of 20 to 40 microns are generated when the pressure of air-saturated water is released.

1.2.2 Anaerobic System

Fig. 2: UASB reactor

Anaerobic digestion is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen. The digestion process begins with bacterial hydrolysis of the input materials in order to break down insoluble organic polymers and make them available for other bacteria. Acid forming bacteria then convert these smaller organic molecules into carbon dioxide, hydrogen, and organic acids. Finally, methane-forming bacteria convert these products to methane and carbon dioxide.

AHET primarily used Upward Anaerobic Sludge Blanket (UASB) reactors (figure 2) for anaerobic bio-degradation. Such reactors are suitable for specific COD loading and hydraulic throughput. A flow distribution network is located at the base of the reactor. This network is designed to be suitable to distribute the flow evenly throughout the bottom of the reactor. This eliminates short – circuiting and promotes the proper formation of the sludge flocs, which is a critical factor in reactor operation. New bacterial cells formed in the reactor aggregate into tiny flocs with extremely good settling characteristics.

The gas liquid solids separator (GLSS) is provided at the treated water exit point. GLSS is designed to collect the biogas, prevent washout of solids, encourage separation of gas and solid particles, allow solids to slide back into the sludge blanket zone, and help to improve effluent solids removal. Treated effluent from UASBR is then subjected to aerobic treatment for further process.

The excess & aged sludge is discharged to dewatering equipment. Frequency of sludge discharging shall depend on MLSS (mixed liquor suspended solids) developed in the UASBR.

1.2.3 Aeration system

Fig 3: Aeration tanks

Aerobic bio-degradation is the third step of the AAA® process. The wastewater from the anaerobic tank overflows into aeration tank (figure 3). The aerobic bacteria in the aeration tank break down organic compounds. The dissolved oxygen acts as the terminal electron receiver for completing the aerobic bio-degradation. In this process the aerobic bacteria are suspended and mixed into wastewater with the help of air. Air is provided using a fine bubble diffused aeration system that helps maintain desired level of dissolved oxygen in the aeration tank. The mixed liquor from the aeration tank is fed to a secondary clarifier where the active bacterial biomass is separated from treated wastewater. The biomass is recycled back into the aeration tank so as to maintain desired concentration of aerobic bacteria in the aeration tank. Treated wastewater overflows from secondary clarifier (figure 4) and is safely disposed or fed to a water recovery system.

Fig. 4: Secondary clarifier

2 Study results

2.1 Case 1: 1.5 MLD wastewater treatment using AAA® technology for a yarn dyeing effluent using VAT dyes

2.1.1 Treatment Schematic (figure 5)

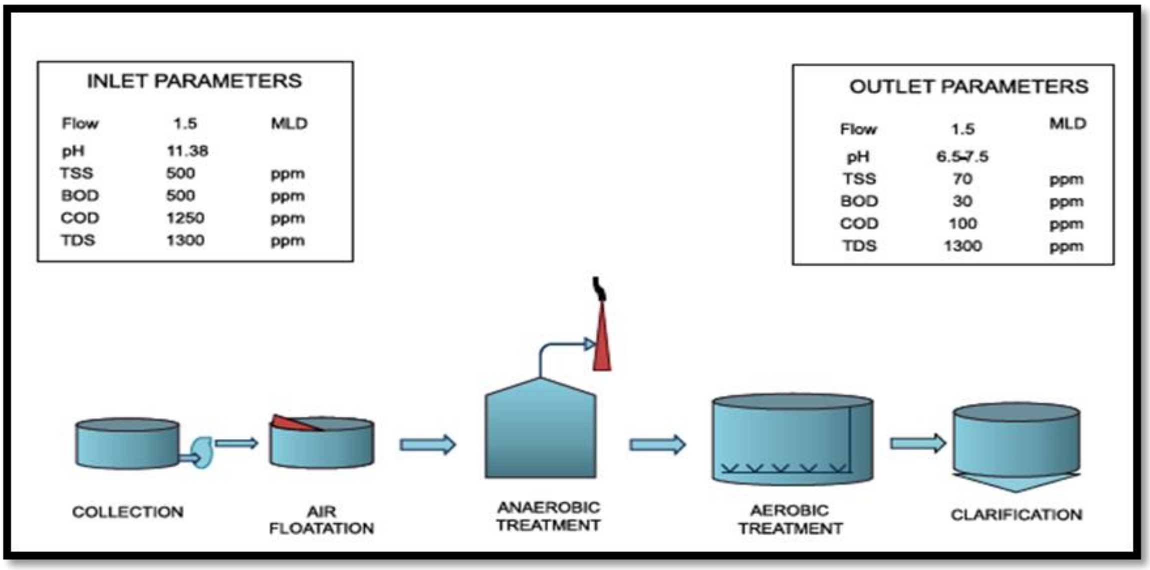


Fig. 5: Treatment scheme and feed and treated effluent parameters

2.1.2 COD Reduction (figure 6)

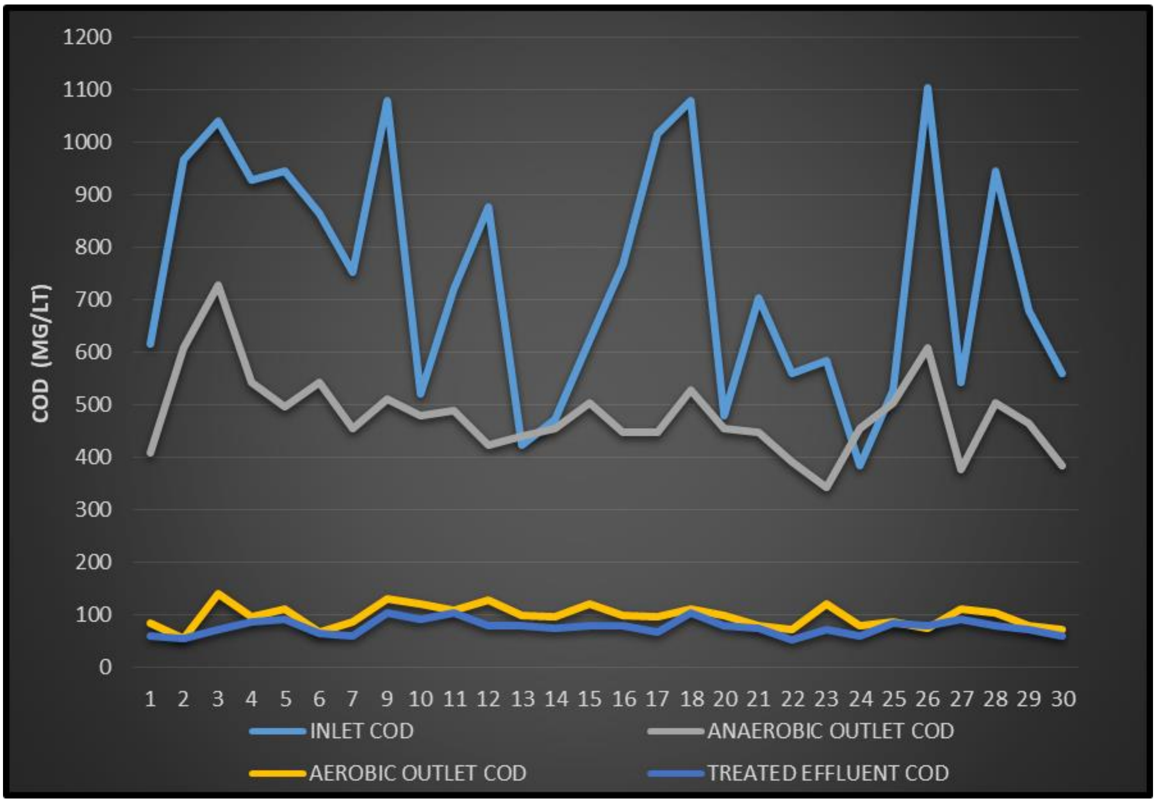


Fig. 6: COD reduction

2.1.3 Color Reduction (figure 7)

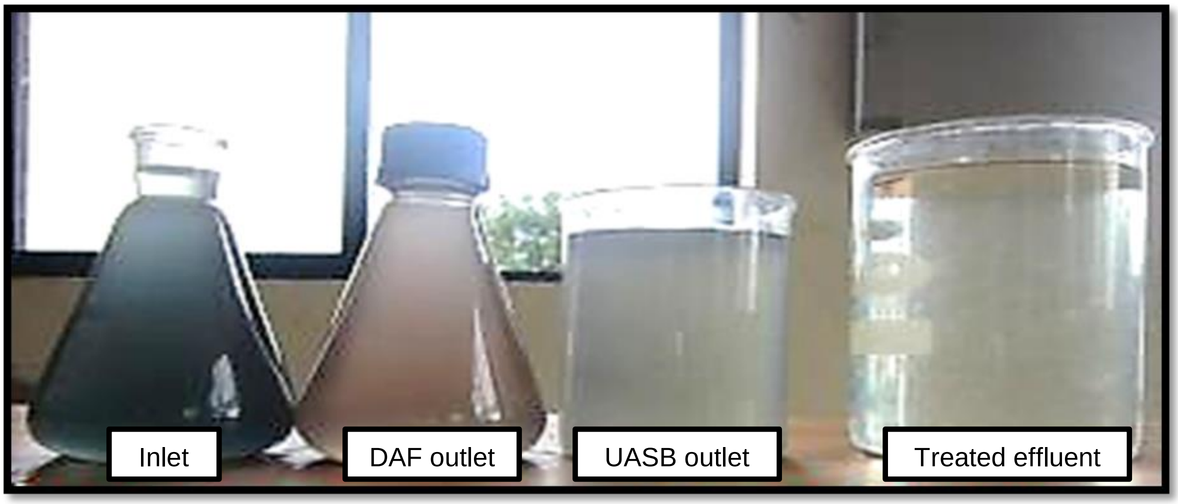


Fig. 7: Color reduction

2.2 Case 2: 1.5 MLD wastewater treatment using AAA® for a knit processing unit using reactive dyes

2.2.1 Treatment Schematic (figure 8)

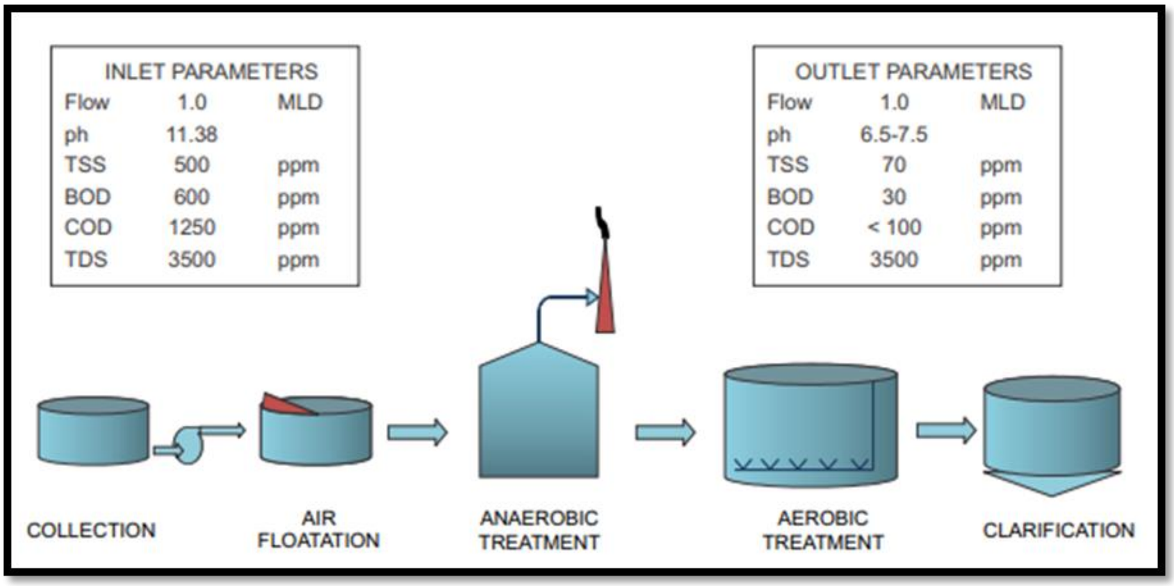


Fig. 8: Treatment scheme and feed and treated effluent parameters

2.2.2 COD Reduction (figure 9)

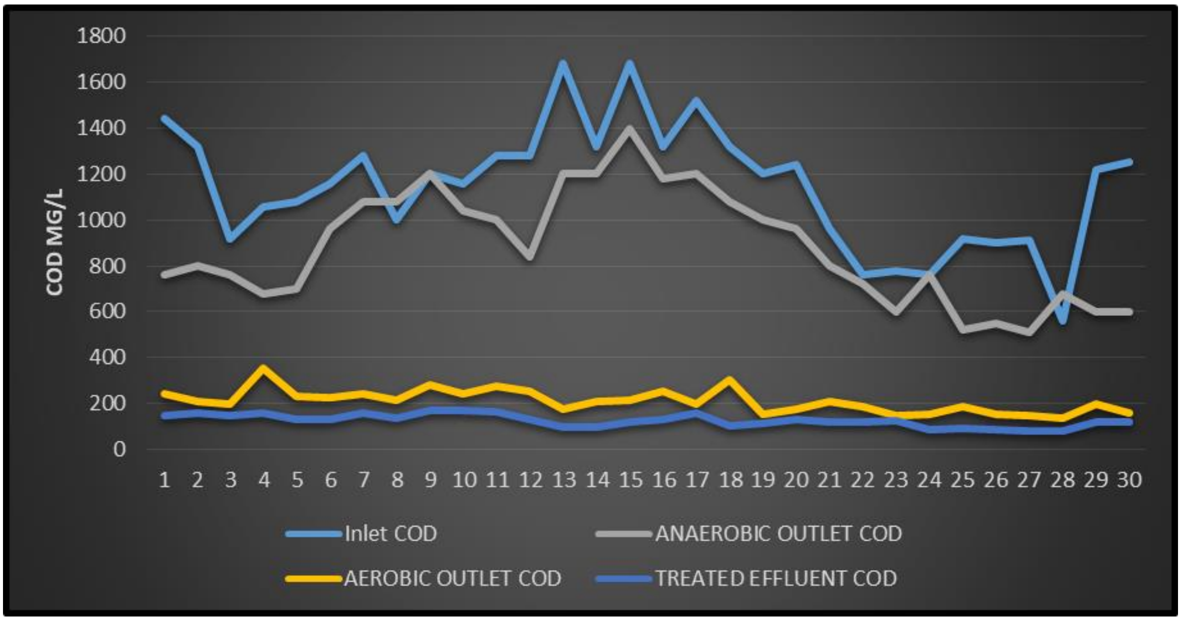


Fig. 9: COD reduction

2.2.3 Color Reduction (figure 10)

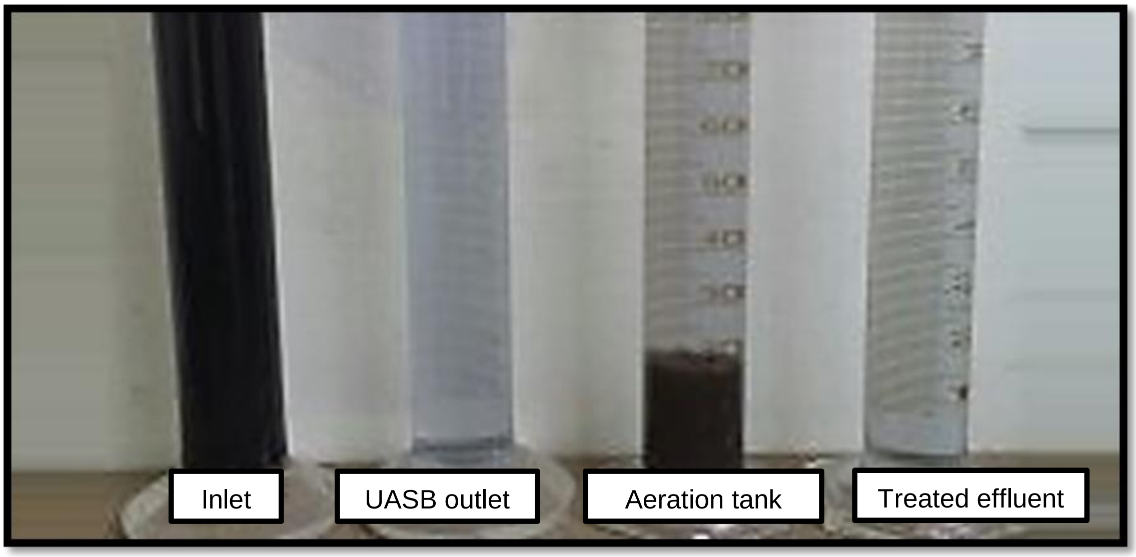


Fig. 10: Color reduction

2.3 Case 3: 1.3 MLD wastewater treatment using AAA® technology for a denim effluent

2.3.1 Treatment Schematics (figure 11)

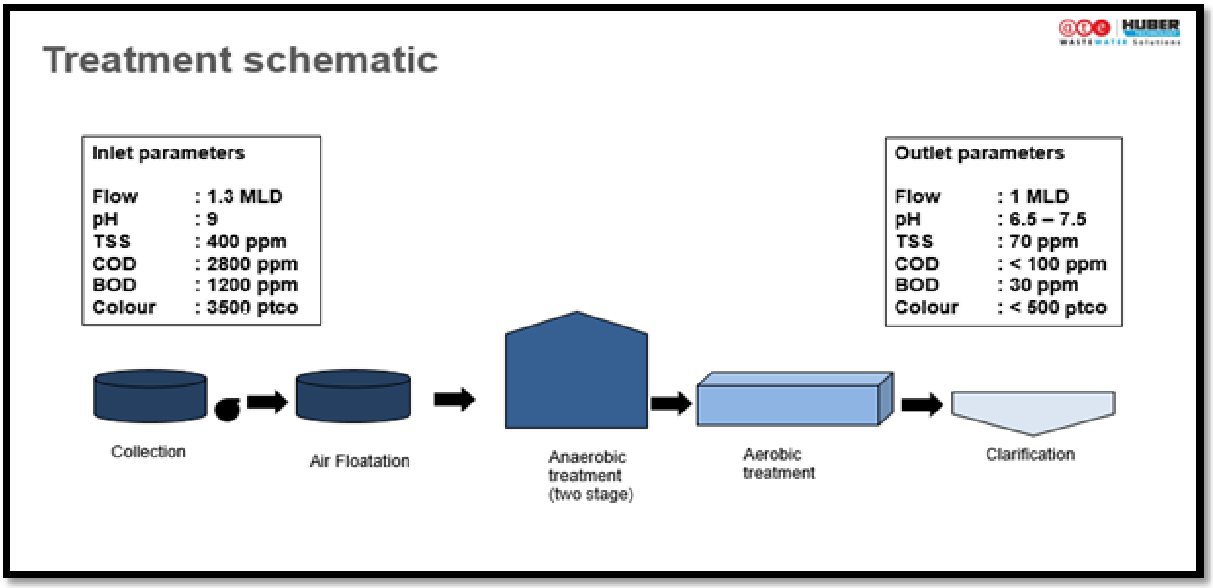


Fig 11.: Treatment scheme and feed and treated effluent parameters

2.3.2 COD reduction (figure 12)

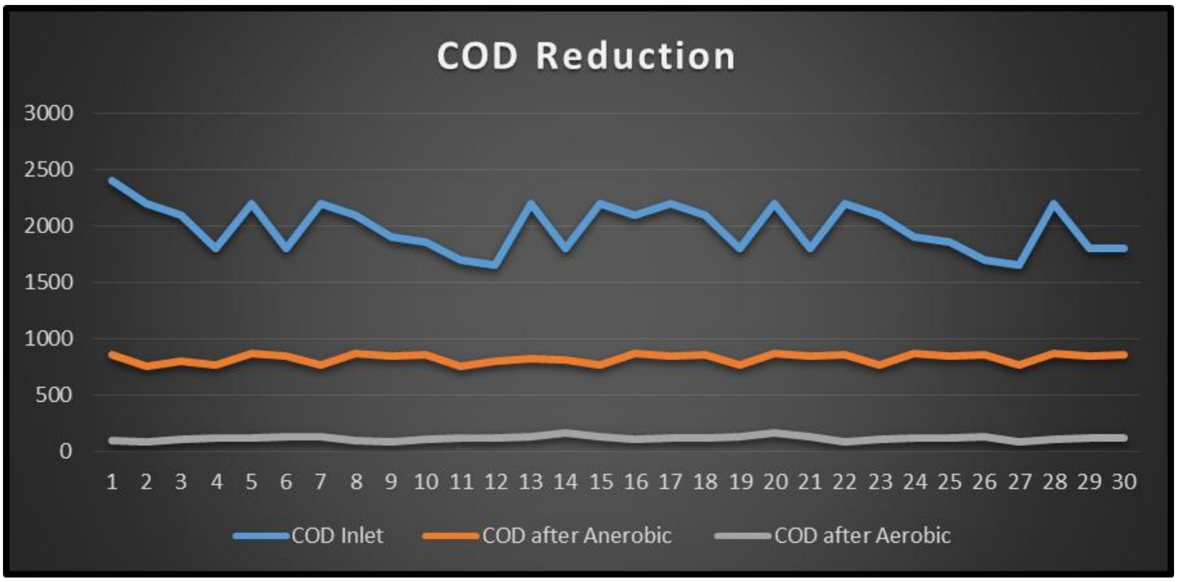


Fig. 12: COD reduction

2.3.3 Color reduction (figure 13)

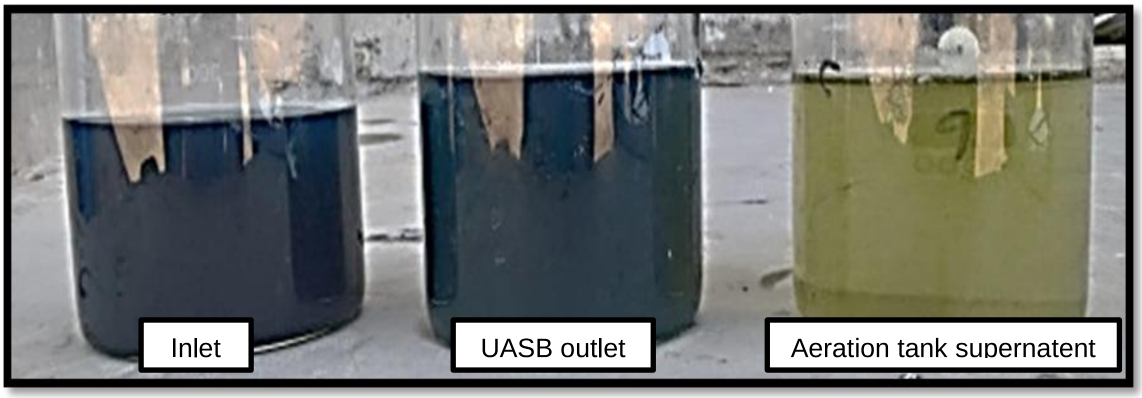
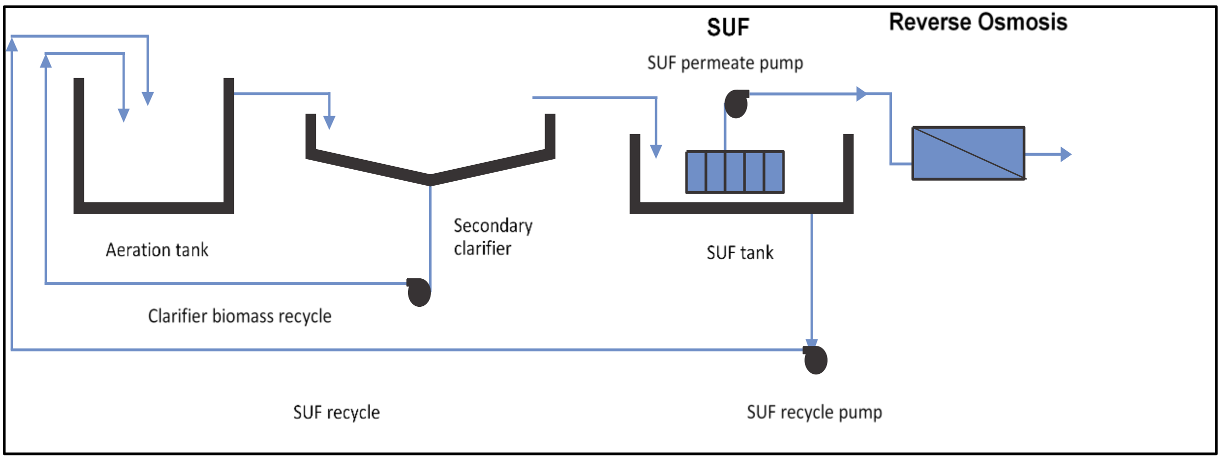


Fig. 13: Color reduction

3 SUFRO

3.1 Introduction

The SUFRO® technology consists of ultra-filtration with submerged UF membranes (a SUF) designed to pre-treat the biologically treated effluent followed by a reverse osmosis membrane system. HUBER Biomem® membranes were selected for SUF step and Hydranautics LFC and SWRO membranes selected for the RO stage of the process.



Salient features of SUFRO®:

- Compared with conventional ultra-filtration systems, SUF can withstand higher suspended solids owing to its construction.
- It eliminated the use of pressure sand filter (PSF), activated carbon filter (ACF) and basket filter, otherwise required for conventional UF.
- The biomass in the clarifier overflow (in case of any upset) is effectively retained in the SUF tank which is transferred back to the aeration tank, thus preventing biomass washouts.
- Overall hydraulic load on the wastewater treatment plant reduced as the backwash stream is not directed to the equalization tank.
- Lesser amount of chemicals and water are used in the CIP (full form?) resulting in savings in chemicals and permeate water consumption.
- Ease of operation of SUF, smaller footprint and superior treated effluent quality are other major advantages realized.
- The SUF permeate is fed directly to a 3-stage RO system without the need for any additional pre-treatment.

3.2 Treatment Steps

3.2.1 SUF: (Submerged Ultra-filtration)

The first step of the SUFRO® scheme is submerged ultra-filtration (SUF) (figure 14). It uses the ultra-high flow submerged UF membranes designed to pre-treat the biologically treated effluent for reverse osmosis membrane system. The SUF membranes are flat sheet membranes with a nominal pore size of 0.04 microns. The pores are small enough to prevent passage of all solids and bacteria, cells, fats, oils, colloids, macromolecules as well as most viruses. The permeate from the SUF membranes is drawn using permeate pumps controlled by variable frequency drive. The SUF membranes shall be intermittently air scoured using dedicated blowers in order to keep them clean. Occasionally, the membranes are cleaned chemically.

Fig. 14: SUF

3.2.2 Reverse osmosis

The second step is Reverse Osmosis (RO) (figure 15). A membrane-technology filtration method removes many types of large molecules and ions from solutions. The solute (large molecules and other ions) is retained on the pressurized side of the membrane and the virtually pure water is allowed to pass to the other side.

RO membranes shall be flushed/ cleaned when the pressures across the membrane increase beyond design limits. RO permeate shall be utilized for flushing and cleaning of RO membranes. SUFRO® operation shall be controlled by PLC

3.2.3 Zero liquid discharge

In case of zero liquid discharge, three to four stages of RO are required to achieve water recovery of > 90%. RO reject is sent to multiple effect evaporator and dryer to achieve a complete zero liquid discharge

Fig. 15: RO plant

4 Study results

4.1 Case 1: 200 KLD wastewater treatment using SUFRO® technology

4.1.1 Treatment Schematic (figure 16)

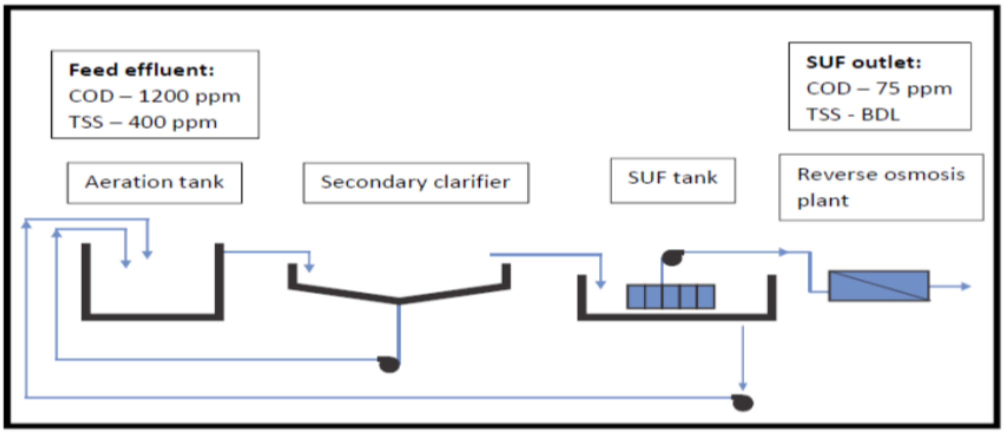


Fig. 16: Treatment scheme SUFRO®

4.1.2 COD Reduction (figure 17)

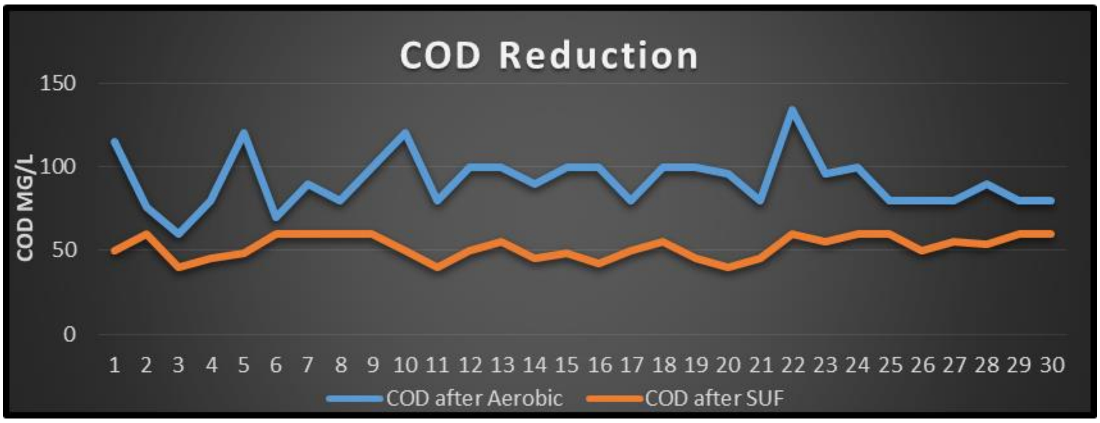


Fig. 17: COD reduction in SUF

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Water Efficiency in Textile Wet Processing Industries - A Case Study of Pakistan

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Abstract

The textile sector in Pakistan has an overwhelming impact on the economy. Pakistan is heading towards a situation of water shortage. Textile processing industries consume substantial amounts of water in their processes, particularly, the industries of Punjab province are callous in water consumption due to abundance of water availability in the province. The specific water consumption of water inefficient industries is up to six times more than the water efficient industries for woven fabric processing and up to three times for knitted fabric industries.

Water efficiency measures relevant for these industries include

i) measurement and monitoring of water consumption and its reduction,
ii) reuse of cooling water from singeing and other machines,
iii) reuse of cooling drum water,
iv) reuse of RO plant reject water,
v) reuse of multimedia washing water,
vi) reuse of ammonia chiller condenser water,
vii) reuse of vapor condensate and condenser water of caustic recovery plant,
viii) reuse of cooling water of dyeing machines,
ix) reuse of post scouring washing water as desizing washing water,
x) reuse of post mercerization washes,
xi) reuse of post neutralization washes as pre washes at bleaching machine,
xii) reuse of steamer overflow water,
xiii) reuse of water lock water from pad steam dyeing machine steamer,
xiv) installation of automatic water shut off valves at printing machines' blanket washing water supply,

xv) implementing countercurrent washing at wash boxes, xvi) heat recovery from hot process wastewater, and xvii) use of high quality water in the wet processes.

These water efficiency measures can reduce not only the water consumption but also the chemicals and associated electricity and thermal energy and water/wastewater treatment cost of the textile processing industries. The water efficiency potential of 10 industries is mentioned which were audited and supported to implement water efficiency measures under the WETI project.

1 General

The textile sector in Pakistan has an overwhelming impact on the economy. The sector contributes nearly one fourth of industrial value added and provides employment to about 40 percent of industrial labor force. Textile products have maintained an average share of about 59 percent in national exports. The export of Pakistan textile was US$ 10,042 million during July 2018 to March 2019[1].

Textile processing industries consume a huge amount of water in their processes, for pretreatment, dyeing, printing and finishing of the fabric. Water is not only used in the processes but also in the utilities, washing of floors, vessels and chemicals containers, arboriculture, firefighting, sanitary, and drinking.

Water consumption varies from industry to industry depending upon the type of the processing industry, processes, and machines employed and its production volume. Water consumption can be correlated with the above mentioned factors as under:

[1] Economic Survey of Pakistan 2018-19

Type of industry	**Type of processes**	**Type of machines**	**Specific water consumption (l/kg)**
Woven Fabric Processing	Mainly Batch	Mainly Local	High
Woven Fabric Processing	Mainly Continuous	Mainly Imported	Low to Medium
Knitted Fabric Processing	Mainly Batch	Mainly Imported	Low to Medium
Denim Processing	Mainly Batch Garment Washing	Imported and/or Local	Low
Denim Processing	Batch and Continuous (Garment Washing, Yarn Dyeing and Fabric Processing)	Imported and/or Local	Medium to High
Socks Processing	Mainly Batch (Yarn Dyeing, Socks Processing)	Mainly Imported	Low to Medium

For woven, High = >150, Medium = >100 ≤150, Low = ≤100

For knitted, socks and denim, High = >100, Medium = >75 ≤100, Low = ≤75

Note: Above ranges of specific water consumption figures are based upon the experience of the author, working in different textile industries of the Punjab province.

Pakistan is heading towards a situation of water shortage and by corollary, a threat of food insecurity. Per capita surface water availability has declined from 5,260 m^3 per year in 1951 to around 1,000 m^3 in 2016. This quantity is likely to further drop to about 860 m^3 by 2025 marking Pakistan's transition from a "*water stressed"* to a *"water scarce"* country[2].

Major clusters of textile processing industries in Pakistan are located in Punjab and Sindh provinces. These two provinces are entirely different in water availability. The estimated annual groundwater resources of Punjab and Sindh are 45 and 22.7 billion m^3 respectively[3]. Ground water resources of Punjab are about twice the resources of

[2] National Water Policy, April 2018

[3] World Bank Group, Pakistan Getting More from Water

Sindh. The reason being that the textile processing industries of Punjab are callous in water consumption due to abundance of water availability whereas the industries in Sindh province are cautious in water consumption due to water shortage. However, the water availability situation is alarming in Pakistan as a whole. Punjab province is also facing water shortage. Water efficiency is a dire need of the textile processing industries of Pakistan, particularly the industries located in Punjab, to cope with the water situation and ensure sustainability of the textile business.

2 Water consumption trend

Table 1 presents specific consumption of water[4] in 16 textile processing industries of Punjab province. These industries were audited under the GIZ project titled 'Water Efficiency in Textile Industry (WETI)' during the period of September 2016 to March 2018.

Tab. 1: Water consumption trend

Industry code	Type of industry	Specific water consumption (l/kg)
01	Knitted Fabric Processing	73
02	Knitted Fabric Processing	93
03	Knitted Fabric Processing	118
04	Knitted Fabric Processing	237
05	Denim Processing (Garment Washing)	183
06	Woven Fabric Processing	86
07	Woven Fabric Processing	96
08	Woven Fabric Processing	112
09	Woven Fabric Processing	117
10	Woven Fabric Processing	128
11	Woven Fabric Processing	138
12	Woven Fabric Processing	147
13	Woven Fabric Processing	184
14	Woven Fabric Processing	206
15	Woven Fabric Processing	501
16	Woven Fabric Processing	550

Source: WETI

[4] Specific water consumption is the total water consumption per kilogram of finished fabric

Specific water consumption trend of the above mentioned 16 industries is illustrated in Figure 1.

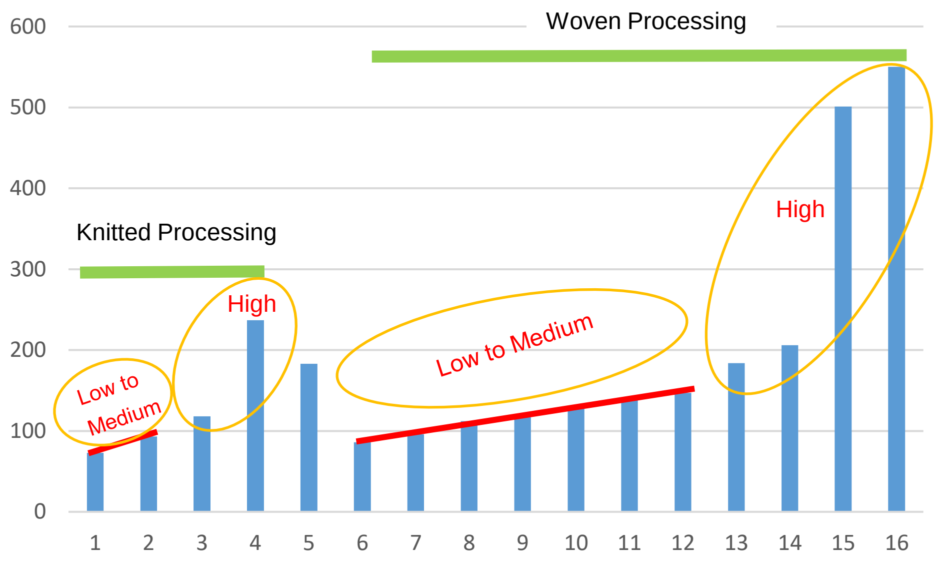

Fig. 1: Water consumption trend (l/kg)

From the above mentioned specific water consumption data, it is clearly evident that the specific water consumption varies from industry to industry. The specific water consumption of water inefficient industries is up to six times more than the water efficient industries for woven fabric processing and up to three times for knitted fabric processing industries.

Note: Generally, specific water consumption is miscalculated in the industries and its values are misleading (lower than the actual). The problem is that only the water consumed in the production process is considered while calculating specific consumption, ignoring other water consuming sources such as utilities, general uses, sanitary, drinking water, waste streams etc.

Higher water consumption is due to different reasons, as mentioned in the following section.

3 Water inefficiency – major reasons

Textile processing industries consume huge amount of water in their processes. Major reasons for high water consumption in these industries are as under:

<u>Lack of awareness:</u> Industry is not aware of the importance of water efficiency and the associated benefits. The management and floor workers are at the same mindset. There is no realization among textile industries that water quantity as well as quality affect textile processes in terms of fabric quality, chemical consumption, machine life, energy consumption and wastewater hydraulic and pollution load.

<u>Free availability of water:</u> Water is considered to be a free commodity as there are no charges, taxes, and fee imposed on water use by the Government or any other agency in Pakistan. Industries have installed their own deep well turbine pumps and have the leverage to extract as much groundwater as per their requirement without any restriction. The cost involved to this extraction is the electricity charges only which is not given due consideration. Industry's attitude is wasteful towards water consumption due to this 'water is free' psyche.

<u>Use of resource inefficient machines:</u> There are many textile industries in Pakistan that use old machines which were discarded by the European and other developed countries. These machines were discarded by these countries due to the fact that they were not designed on resource efficiency aspects. These machines consume huge amounts of energy, water, and chemicals. These machines are purchased by the Pakistan textile industries due to their cheap price without considering the resource efficiency factor.

<u>Lack of maintenance:</u> Lack of maintenance of the machines and auxiliary equipment is also one of the factors responsible for water wastage and high water consumption in the production processes. Generally, production is the first priority for the management and the workers. They are always hesitant in stopping the machines for repair and maintenance purpose and keep on running, irrespective of resource wastage, for meeting their production targets. This wastage is not given due consideration in comparison to production.

<u>Lack of measurement and monitoring:</u> There is no metering and monitoring of water consumption in the industry due to its no cost and free availability. There are only few industries which measure and monitor their water consumption in the processes and utilities. If there is no measurement and monitoring then there will be no management.

<u>Lack of external pressure:</u> There are two types of processing industries i.e. local and export. Local industries deal in Pakistan only whereas export oriented industries export their products to international markets. International buyers are imposing restrictions

on resource consumption, including water. There is a large difference of water consumption among local and export industries. Export industries are somewhat cautious in water consumption due to external pressure and moving towards water efficiency path. The local industries are under no pressure from the buyers, community and government. Generally water consumption figures of local industries are comparatively on the higher side.

4 Sources of water wastage

Following are the major sources in the textile industries responsible for high consumption and wastage of water in the production processes.

Uncontrolled use of water from water hoses: Water hoses of varying lengths and diameters are used in the textile processing industries for washing of floors, machines, chemical drums, printing machine screens etc. Mostly the length of the water hose is very large due to which it is easy for the worker to use it at a long distance from the water supply point. Workers are habitual of not closing the water supply valve after use, rather keep water hose laying on the floor due to the distant location of the valve. The water hoses keep on wasting water for many hours. Also the diameter of the water hose is very large, resulting in huge amount of water consumption and wastage.

Extensive floors, vessels and containers washing: A huge amount of water is used for floors, vessels and chemical containers washing. As water is abundantly available without any restriction, therefore, workers don’t care about its use and wastage.

No synchronization of water supply and machine operation: Mostly the water supply is not synchronized with the operation of the machine. When a machine is stopped due to any reason i.e. maintenance purpose, change over, machine’s setting etc. the water keeps on running in the machine and wasting from the drain pipe.

Extensive washing of the fabric: It is general practice in the textile processing industries to apply extensive washings on the fabric for removing unattached and unreacted chemicals and dyes. There is no criteria for deciding the extent of washing on the specific fabric. The extent of the washing is decided on the basis of past experience without any scientific basis. Extensive fabric washing is one of the major sources of water use and wastage.

Water leakages: Water leakages are also one of the sources of high water consumption and wastage. Water leakage takes place in the machines, pipes, valves, joints and pumps due to the holes in the metal part of the machines and pipes, broken seal of pumps and gaskets and malfunctioning valves. As water is considered to be a free commodity, therefore, the maintenance staff and production workers are not serious about rectifying these faults and controlling water leakages.

Wastage of cooling water: There are many equipments in textile industries where cooling water is applied. The purpose of supplying cooling water is to keep revolving parts of the equipment cool. This cooling water is not in direct contact with any contamination. It is circulated in the equipment and absorbs heat. Generally, this warm clean water stream is ultimately discharged as wastewater without its reuse.

Wastage of reverse osmosis (RO) reject water: In most of the industries, the reject water (about 30% of the total water supply) of a RO plant is not reused due to its high dissolved solid contents.

5 Benefits of water efficiency

The following benefits are associated with the water efficiency:

Low consumption of electricity: Even though water is considered to be a free commodity in the industry it still costs a lot. Mostly groundwater is used in the Punjab industries. It is extracted from the ground with the help of a deep well turbine pump. This pump consumes electrical energy while extracting water from the deep and transferring into the storage tank. This is the extraction cost. The stored water is then transported to another tank or machine through a pump which also consumes electricity. This is the transport cost. The more the water is extracted, the more will be the electricity consumption. Similarly, the more the water is transported, the more will be the electricity consumption. Hence, water efficiency reduces electricity consumption. On an average, about 0.4 kWh electricity is consumed for the extraction and transportation of one m^3 of water. In money terms, it is about Rs. 6 per m^3.

Low consumption of thermal energy: Mostly hot water is used in the textile processing industries for washing the fabric after desizing, scouring, bleaching, dyeing and printing process at a temperature of 60 to 95^oC. This water is heated with the help of steam. One m^3 of hot water (60 to 95^oC) contains about 237,600 BTU to 376,200 BTU of energy which is equivalent to 91 kg to 144 kg of steam or Rs. 200 to Rs. 316 per m^3 of hot water. The more the water is consumed in the hot washes, the more the thermal energy will be consumed. Hence, water efficiency reduces thermal energy consumption and GHG emissions (1 m^3 of hot water = 21-33 kg CO_2).

Low cost of water treatment: Generally textile industries treat the raw water extracted from the ground due to its poor quality in terms of hardness and high total dissolved solids (TDS) contents. This water is pretreated through softeners and reverse osmosis (RO) plants to reduce hardness and TDS contents respectively. This treatment involves costs due to electricity (pumping) and chemical consumption (cleaning and regeneration of membranes and resins respectively). The estimated cost of treatment for softener and RO plant is Rs. 10 and Rs. 25 per m^3 respectively. The more the water is consumed in the process, the more it will be pretreated. Hence, water efficiency reduces the costs of water pretreatment.

Low cost of wastewater treatment: About 80-90% of the water used in the processes is discharged as wastewater, mainly from the fabric washing. This wastewater is treated in the wastewater treatment plant prior to its discharge into the natural water bodies. Wastewater treatment involves cost in terms of electricity and chemical consumption. The more the water is consumed in the process, specifically in the washing, the more is the wastewater generation and treatment. Hence, water efficiency reduces not only the wastewater treatment cost (O&M cost) but also the capital cost. For low volume of wastewater, small sized wastewater treatment will be required to be constructed, resulting in reduction of the capital cost. The wastewater treatment cost varies from industry to industry based upon the hydraulic and pollution loads and the type of wastewater treatment plant technology. The average treatment cost of the wastewater is Rs. 15 per m^3.

Low consumption of chemicals and high quality products: Use of high quality water in the wet processes reduces chemical consumption and produces high quality fabric product.

Ensure sustainability of textile industry: Water is the lifeline of the textile processing industries. Textile industries use different types of chemicals in their processes including acids, alkalis, salts, detergents, dyes, pigments etc. ranging from very cheap to very expensive. Water is the most expensive chemical used by the industry. No textile processing industry can operate without water. The water efficiency will ensure sustainability of the textile industries of Punjab province. This is an urgent need that industries should focus on water efficiency so that textile business could last for many years to come.

6 Water efficiency measures[5]

This section describes various water efficiency measures which were identified for 16 textile processing industries of Punjab under the WETI project. These industries were also supported to implement these measures. These measures can be implemented by the textile processing industries to reduce their water consumption and associated cost of production.

6.1 Measurement and monitoring

Water efficiency is very important in the textile industry to reduce resource consumption and sustain textile processes. Water efficiency will only be possible if water consumption in the processes is measured, monitored and controlled. Mostly water consumption in the textile industry is not measured, monitored and managed due to its availability in abundance in Punjab with no apparent cost. The management and workers do not realize the importance of water and associated resource wastage due to its inappropriate use in the process.

Water measurement is very important by installing water flow meters at the main water turbine and different sections (production, utilities, general use etc.). After water measurement, its analysis and benchmarking is important to assess the status of water consumption in the industry that whether its consumption is optimum or consuming huge amounts of water as compared with other similar industries. Establishing water consumption benchmarking i.e. liter of water consumed per kilogram of finished fabric, and its improvement by taking water efficiency measures will improve water management in the industry.

Water monitoring facilitates production floor professionals to control the water consumption at machines. There is one example of the industry that reduced about 25% of its water at a bleaching machine just by monitoring the daily water consumption and optimizing it without any other intervention in the machine.

This measure is applicable to all the textile processing industries. The water flow meters should be selected carefully. Most of the times the water flow meters malfunction due to water quality issues. The electromagnetic type water flow meters are preferred due to their durability whereas the impeller type flow meters malfunction

[5] Most of these water efficiency measures are based upon author's own experience of working in different textile processing industries of Punjab under various resource efficiency projects.

due to clogging and scaling. The magnetic type flow meters are a bit more expensive than the impeller type. The price of the flow meter depends upon its type and size.

In woven fabric processing industries, production is recorded in terms of length (meter), not in weight (kilogram). Benchmarking or specific water consumption should be in terms of weight, not in length because length is misleading. Fabric can be light or heavy. Some industries may be using light fabric and some heavy, so if specific water consumption is measured in terms of length, then the lighter fabric will consume less water and the same length of the heavy fabric will consume more water, therefore figures for both the industries producing the same length of fabric will be misleading.

The woven fabric processing industries should convert production in meter into kilogram by multiplying it with width of the fabric in meter and GSM (gram per square meter) of the fabric and dividing it by 1,000 i.e.

(length x width x GSM)/1,000 (900 m x 1.5 m x 125 g/m^2)/ 1,000 = 168.75 kg.

Similarly denim and socks processing industries record production in garment pieces and dozen respectively. These figures should also be converted into weight (kg) for specific water consumption.

For specific water consumption, total water extracted from the ground (daily or annually) in liter should be divided by the total production in kg (daily or annually).

6.2 Reuse of cooling water of singeing machine

In the woven fabric processing industries, singeing is the first process where greige fabric is passed through the singeing machine. Singeing operation is employed to destroy singes and tufts on the surface of the fabric, by its direct exposure to the flame, for a very short time. This process is required to improve the chemical uptake of the fabric, by preventing uneven impregnation. Cooling water is continuously supplied at the rollers of the singeing machine to keep them cool. Greige fabric is allowed to pass over the open flame of the burners through rollers where loose hairy fibers protruding from the surface of the fabric are burnt. This cooling water absorbs heat of the rollers and becomes warm at about 40-45^{o}C temperature. This is a warm and clean water stream which is generally wasted from the singeing machine.

This warm water stream can be collected and reused in any of the process machines. This water can be used at the following;

- Washing water in the process
- Showering water at wet scrubbers installed with steam boiler
- Showering water at wet scrubber installed with singeing machines

Cooling water quantity varies from industry to industry. Its quantity is about 1 to 2 m^3/hr or 24 to 48 m^3/day. Mostly raw water is used as cooling water in the singeing machine. For one industry, its quantity is 47 m^3/day (15,980 m^3/yr). Its value is Rs. 1.20 million/yr (483 ton steam/yr).

6.3 Reuse of cooling water

There are many equipments in textile industries where cooling water is applied. The purpose of supplying cooling water is to keep revolving parts of the equipment cool. This cooling water is not in direct contact with any contamination. It is circulated and absorbs heat. Generally, this warm water stream is ultimately discharged as wastewater. Cooling water is used at the following locations/machines:

- Coal based boiler induced fan
- Coal feeding gate of boiler
- Coal feeding gate of therm oil heaters
- Thermosole padder’s hydraulic pump
- Therm oil pumps at therm oil heaters
- Ager therm oil pump
- Calender cooling water
- Comfort cooling water
- Gas based therm oil pump cooling water

This is non contaminated water and can be collected and reused in the process wherever convenient for the industry. The quantity of cooling water varies from industry to industry, depending upon the number of sources where cooling water is applied. Its quantity can be up to 162 m^3/day or 52,326 m^3/year. The value of this warm water is about Rs. 3.15 million/year (1,185 ton steam/year).

6.4 Reuse of cooling drum water

At most of the continuous woven fabric machines, wet fabric is first dried at drum dryers and then cooled through cooling drums for its easy handling in the subsequent stages. For this purpose, fabric is allowed to revolve on cooling drums after drum drying. These cooling drums are provided with fresh water circulation. After getting heat of hot fabric, this water is discharged as wastewater. This is a clean and warm water stream.

Generally cooling drums are attached with the following:

- Continuous bleaching machines
- Mercerization Machines
- Curing Machines
- Pad Steam Dyeing Machines
- Pad Steam Dyeing Machines attached with Thermosole
- Stenters
- Pad dryers

This clean warm water can be collected in a storage tank and reused in the process. At some industries, this cooling water is not a raw water but soft water or RO treated water which is of a very good quality water and very expensive. Cooling water quantity varies from industry to industry. Its quantity can be up to 482 m^3/day or 168,700 m^3/yr (large textile industry). The cost of this water is Rs. 8.4 million/yr.

6.5 Reuse of reverse osmosis (RO) plant reject water

Generally raw water contains a high content of dissolved solids. The use of this high dissolved solid water leads to different problems in the process. In most of the textile industries, raw water is treated in the reverse osmosis (RO) plant to reduce its total dissolved solids (TDS) and hardness to get the required quality water to be used in the processes and for boiler feed water.

As being a separation technology, the RO produces a so called permeate, which is about 70% of the total raw water supplied to RO plant. There is another water stream which is highly concentrated with the salts, called concentrate or reject water stream from RO plant which is rejected and wasted. This reject stream is about 30% of the total raw water supplied to the RO plant.

The quality of RO reject water from one industry is given as under:

pH	7.56
Total Hardness as $CaCO_3$ (mg/l)	1,475
Total Dissolved Solids-TDS (mg/l)	8,740
Total Iron (mg/l)	0.08

Reject water is high in TDS contents which cannot be used in the process but can be utilized for general purposes where high quality water is not required. It should be collected and used for general purposes such as at color kitchen for washing floors and chemical drums, showering water at coal or biomass fired boiler wet scrubber and toilets. This water can be mixed with the incoming raw water and used in the process, if volume ratio of the reject water to raw water is low. The TDS of the raw water will be increased slightly after mixing it with the reject water but it will not cause any effect in the process.

Generally the reject water stream is about 150 to 500 m^3/day or 45,000 to 150,000 m^3/year, depending upon the size of the industry and consumption of RO treated water in the processes. Mostly RO reject water is 30% of the total input to the RO plant but it can vary from industry to industry.

For one industry, its quantity is about 339 m^3/d (123,735 m^3/yr). Its value is about Rs. 0.74 million/yr.

Note: The quantity of RO reject water can be decreased by increasing the number of membranes (stages) of the RO plant.

6.6 Reuse of multimedia washing water

In most of the textile industries, a multimedia filter is installed along with the RO plant to pretreat the feeding water for the RO plant. The purpose of this multimedia filter is to remove suspended solids in the form of grit, silt, clay, ferric iron and other precipitates to protect the RO membrane. This multimedia filter is backwashed four to six times per day. The quality of the backwashed water is nearly the same as that of supply water. This water can be collected and reused in the process. This stream can also be mixed with the RO reject water or can be used separately.

This measure is applicable to all the textile processing industries where RO plants are installed and RO water is used in the processes. The quantity of this water varies from industry to industry and can be up to 50 m^3/day or 17,500 m^3/yr. Its value is Rs. 0.6 million/yr.

6.7 Reuse of ammonia chiller condenser water

Cold caustic soda solution is used at mercerization processes in some of the textile industries. The caustic soda solution is cooled through ammonia chiller. Cooling water is used at the ammonia chiller's condenser to condense ammonia gas. This cooling water is circulated in the condenser and then wasted. This is a clean water which can be collected and reused in the process. This measure is applicable to all the woven fabric processing industries where cold caustic soda solution is used at mercerization process and ammonia chiller is installed.

For one industry, the quantity of this cooling water is about 400 m^3/day or 120,000 m^3/yr. The value of this cooling water is about Rs. 0.6 million/yr.

6.8 Reuse of vapor condensate and condenser water of caustic recovery plant (CRP)

In some woven fabric industries where the mercerization process is carried out extensively, caustic recovery plant (CRP) is installed to recover caustic soda from the mercerization process waste streams. CRP is used to concentrate dilute caustic soda solution (weak lye) of 5 to 10 ^{o}Bé concentration into 20-25 ^{o}Bé concentration by evaporating water from the weak lye through evaporators. The vapors from weak lye is condensed into hot water through condensers. This hot water is at a high temperature of about 80^{o}C with alkaline pH. Generally this hot alkaline water is wasted in the industry. Also fresh water is circulated in the condensers to condense the vapors. This fresh water is also wasted. This combined water stream (vapor condensate and condenser water) is clean and slightly alkaline and high in TDS due to traces of caustic soda in it.

This water can be collected and treated in the reverse osmosis plant to reduce its TDS and alkaline effect. This RO treated water can be used in the process and in boiler as boiler feed water. This water can also be directly used as a washing water in the bleaching and mercerization machines without RO treatment.

This measure is applicable to all the woven fabric processing industries where CRP is installed. For one industry, the quantity of this combined water stream is about 600 m^3/day or 180,000 m^3/year. The value of this water is about Rs. 4 million/year.

6.9 Reuse of cooling water of dyeing machines

In the knitted fabric processing industries, dyeing of the either pure polyester fabric or polyester part of the polyester-cotton blended fabric is carried out at higher temperature of about 130°C in the dyeing machines. After the completion of dyeing, the temperature of dyeing bath is reduced to about 80°C by circulating the dye bath through a heat exchanger (attached with the dyeing machine). Fresh water is circulated in the heat exchanger to cool down the dye bath. The hot dyeing solution transfers its heat to the fresh water which gets warm. This continuous cooling water stream from the heat exchanger is wasted in the drain. This is a warm and clean water stream at a temperature of 50 to 60°C.

This water can be stored and reused in the process. For reuse, the cooling water discharge line of all the machines will be connected to the new pipeline from where the cooling water will be transferred to the storage tank. Whenever hot water is required in the process, the hot water valve will be opened and the machine will be filled with warm or hot water. In this way, water heating time and energy will be saved. The quantity of cooling water varies from industry to industry, depending upon the quantity of polyester dyed fabric production and the number of dyeing machines installed. Its quantity can be up to 150 m^3/day or 52,500 m^3/yr. The value of this warm water stream, in monetary terms, is Rs. 6.29 million/yr (2,786 ton steam/yr).

Note: Cooling water is also used in jets, yarn dyeing machines and socks dyeing machines, therefore this measure is also applicable to these machines.

6.10 Reuse of post scouring washing water as desizing washing water in the bleaching machine

In the woven fabric processing industries, a continuous bleaching machine is employed to perform desizing washes, post scouring and bleaching washes. Generally, in the continuous bleaching machine, there are three sections of wash boxes. In the first section, desizing wash is carried out. In the second and third section, scouring and bleaching wash is carried out respectively. The scouring wash water can be reused as desizing wash water by directing the discharge pipeline of scouring section wash water into the supply line of desizing wash boxes. For desizing washing, high quality water is generally not required and scouring wash water can be a good option for such type of washing.

The influence of pH and fluff content should be checked for the use of scouring washing water for desizing washes. In case of fluff issue, the scouring washes should be passed through the screens prior to feeding into desizing wash boxes. The scouring wash water supply should be directly to the desizing wash boxes while bypassing the heat exchanger (if a heat exchanger is installed).

The implementation of this option will reduce water and steam consumption in the bleaching machine. For one industry, about 100 m^3/d (34,000 m^3/yr) water can be reduced in the bleaching machine. Its value is Rs. 7.21 million/yr (3,329 ton steam/yr). The potential of savings can vary from industry to industry. However, the potential is significant due to reduction in thermal energy which has substantial cost.

Note: In some industries solomatic bleaching is carried out (scouring and bleaching simultaneously in one impregnator of the machine). In this case, post solomatic washing water can also be used for desizing washing.

6.11 Reuse of post mercerization washes

The mercerization process is carried out in most of the woven fabric processing industries. The purpose of mercerization is to give strength, improve luster and increase absorption of the fabric for dyes in the subsequent processes for cotton fabric. In this process, the fabric is treated with caustic soda (NaOH) solution. Caustic soda reacts with the cellulose, swells it and imparts above properties.

In the mercerization machines, fabric is first allowed to dip into the caustic soda solution of a certain concentration (generally 22 to 28 ^{o}Bé), provided a certain time for reaction between fabric and caustic soda and then finally washed to remove unreacted caustic soda from the fabric. Generally hot washes at a temperature of 80^{o}C to 90^{o}C are applied in three to four wash boxes. The discharged washing water is alkaline and contains minor concentration of caustic soda. This water can be collected in the storage tank and reused as washing water for desizing wash, post scouring wash or post bleaching wash, generally in the continuous bleaching machine. In this way not only water but also energy will be saved.

The quantity of post mercerization hot washing water from the mercerization machine varies from industry to industry and can be up to 150 m^3/day or 45,000 m^3/yr. The value of this hot water is about Rs. 7.58 million/yr (3,753 ton steam/yr).

Note: Generally textile processing industries receive caustic soda of 50% ^{o}Bé concentration and dilute it to 22 to 28 ^{o}Bé by adding fresh water in it. Instead of using fresh water, the washing water of the mercerization machine can be used for dilution purpose which will not only reduce fresh water consumption but also the caustic soda (washing water contains traces of caustic soda).

6.12 Reuse of post neutralization washes as pre washes at bleaching machine

In the woven fabric processing industries, continuous bleaching machines are employed to perform desizing washes, scouring and post scouring washes, bleaching and post bleaching washes and neutralization of alkaline fabric with acid. There are three sections of wash boxes i.e. pre washes (02 wash boxes at 60°C), post scouring washes (03 wash boxes at 60°C) and post neutralization washing (02 wash boxes at 60°C). The post neutralization wash water can be reused as pre wash water by directing discharge pipeline of neutralization section wash water into the supply line of pre wash boxes. For pre washing, high quality water is generally not required and neutralization wash water can be a good option for such types of washing.
The quality of pre wash and post neutralization wash water is given below for a typical industry:

Parameters	Pre wash water	Post neutralization wash water
pH	8.17	7.29
Total Hardness as $CaCO_3$ (mg/l)	880	840
Total Dissolved Solids-TDS (mg/l)	5,682	6,696

The quantity of post neutralization wash water will vary from industry to industry, depending upon operational frequency of the bleaching machine and quantity of fabric bleached and neutralized. For a typical industry, its quantity is about 82 m^3/d (20,500 m^3/yr). This much water can be reduced in the bleaching machine. Its value is Rs. 2.27 million/yr (1,082 ton steam/year).

6.13 Reuse of steamer overflow water

This option is relevant for the woven fabric processing industries where fabric is bleached and dyed in continuous bleaching machine and pad steam dyeing machine respectively. In the continuous bleaching and pad steam dyeing machines, steamers are installed. Fabric is passed through steamer at bleaching and pad steam dyeing machines to provide heat treatment for the chemicals and dyes to be reacted and fixed with fabric respectively. Steamer is filled with water up to certain level. Steam is supplied in it to keep the temperature above 100°C. Steam is condensed and mixed with the water at bottom. The steam condensation increases the level of the bottom water. Water overflows from the steamer and wasted. This is a very hot water stream with a substantial amount of energy. This hot water contains traces of chemicals and dyes. It can be directly fed into the post steamer hot wash boxes to conserve water and energy.

The quantity of steamer overflow will vary from industry to industry. For one textile industry, its quantity is about 16 m^3/day or 5,168 m^3/year. Its value is about Rs. 1.11 million/year (507 ton steam/year).

Note: There are two types of bleaching machines. One type is equipped with two steamers where scouring and bleaching process is carried out separately in two separate impregnators. The other type is equipped with only one steamer where solomatic bleaching is carried out (scouring and bleaching processes simultaneously in one impregnator).

6.14 Reuse of water lock water from pad steam dyeing machine steamer

In woven fabric processing industry, pad steam dyeing machines are used for continuous dyeing of the fabric. There is one steamer installed at the machine for heating the fabric and giving reaction time for the completion of the dyeing process. There is continuous supply and wastage of fresh water at fabric exit point of the steamer. This water is supplied so that the steam vapors could not escape from the steamer along with the fabric to avoid its loss and humidity in the environment.

There are two types of dyeing carried out in the pad steam dyeing machine i.e. reactive and vat dyeing. For reactive dyeing, the water lock water is contaminated with dyes whereas for vat dyeing, the water is relatively clean. About 50% of the total water (if both types of dyeing are carried out in the machine) is clean which can be collected and reused in the pad steam dyeing machine wash boxes for subsequent washing of the fabric.

The quantity of water lock water will vary from industry to industry depending upon the quantity of dyeing in the pad steam dyeing machine. Its quantity can be up to 115 m^3/day or 37,145 m^3/year. Its value is Rs. 0.74 million/year.

6.15 Installation of automatic water shut off valves at rotary and flatbed printing machines' blanket washing water supply

Rotary and flatbed printing machines are employed for the continuous printing of woven fabric in woven fabric processing industries. The printer table blanket is washed with forced water jets, by means of two or three rows of multiple nozzles, placed underneath the table in cross direction, to remove the stains adhered to the blanket during printing operation. Generally, the blanket washing water at the printing machines is kept on running and wasted during machine stoppage (due to maintenance or change over). This water wastage can be avoided by installing automatic water shut off valves at the machines. Whenever the printing machine is stopped, the blanket wash water will automatically be stopped, avoiding its unnecessary use and wastage.

The quantity of blanket washing water wastage will vary from industry to industry, depending upon the number of printing machines, frequency and duration of stoppage due to maintenance or change over. For one industry, its quantity is about 90 m^3/d (29,070 m^3/yr). Its value is about Rs. 0.44 million/year.

6.16 Countercurrent washing

In the woven fabric processing industries, fabric is washed in many wash boxes in continuous machines. Generally the number of wash boxes of the machine vary from two to eight. Following are the continuous machines where fabric is washed in wash boxes:

- Bleaching
- Mercerization
- Pad steam dyeing
- Soaper
- Washing

The modern machines are designed on countercurrent washing mode in which all the wash boxes are interconnected and washing water of one wash box is used in other wash box and so on. In the countercurrent washing mode, water and energy consumption is reduced substantially. The water and energy of the machine is reduced three to four times in case if three to four wash boxes are interconnected and operate in countercurrent mode. The locally manufactured machines are not designed on countercurrent washing mode and each wash box is operated independently with separate supply of water in each wash box which is heated through steam and then wasted as overflow water. There is a substantial amount of water and energy consumption in such types of arrangements. Countercurrent washing is based upon the principle that the dirty fabric is in contact with dirty water and clean fabric is in contact with clean water.

In some cases, even though the machine is equipped with countercurrent washing arrangement the operators disconnect this arrangement and operate the machine without countercurrent sequence due to their own ease.

It is a resource efficient way to operate machines on countercurrent washing mode to save water and energy.

The quantity of water and energy reduction will vary from industry to industry depending upon number of wash boxes to be interconnected, flow rate of water supply, temperature of washing water and operational frequency of the machine. For one typical industry where two bleaching machines operate without countercurrent washing mode, the water and energy saving in monetary terms will be Rs. 28.69 million/yr. Water conservation will be 590 m^3/d (177,000 m^3/yr) and steam reduction will be 58 ton/d (17,400 ton/yr).

6.17 Heat recovery from hot process wastewater

Extensive hot washes are carried out in the textile industries to wash impurities, undesired chemicals and unfixed dyes and pigments. Hot wastewater from these washes contain a substantial amount of thermal energy which costs millions of rupees per year.

These wastewater streams are discharged at a temperature of 60-95^{o}C from various processes, given as under:

- Desizing washing water
- Scouring and bleaching washing water
- Hot chemical bath discharged from kiers
- Mercerization hot washing water
- Dyeing hot washing water discharge
- Washing water from soapers

Thermal energy from the hot wastewater streams can be recovered. It is not practicable to recover energy from all the hot wastewater streams but there are few streams from where energy can be recovered effectively. Major factors for evaluating the viability and effectiveness of heat recovery are the temperature and the flow of the stream under consideration.

Heat energy of the hot washes can be recovered by installing plate type or shell and tube heat exchanger. For the implementation of this option, hot washes will be first collected in a small covered storage tank. It will then be pumped into the heat exchanger while passing through the strainer, in the tube side, whereas fresh water will flow in the shell side (in case of shell and tube type heat exchanger). Fresh water will be heated and used in the washings. Under such an arrangement, less quantity of steam will be required to heat the washing water up to the required temperature as it is already hot.

The energy contents of hot wastewater will vary from industry to industry. It depends upon the volume and temperature of the wastewater. For one industry, the value of the energy of the hot wastewater from the bleaching machine is Rs. 13 million/yr. About 70% of this energy can be recovered by installing a heat exchanger. Before the exchanger, a well-designed fibers/fluff removal device will have to be installed to protect the exchanger against clogging and malfunctioning. The energy of the value of Rs. 9 million/yr, equivalent to 23 ton steam/d or 6,900 ton/yr can be saved.

6.18 Use of high quality water for wet processing

Generally the groundwater used in the textile industries of the Punjab is not of good quality water for the wet processing. It contains dissolved solids of mostly calcium, magnesium and sodium metals. These solids are in the form of carbonates, bicarbonates, chlorides, sulfates etc. These dissolved solids can be measured in terms of hardness (mg/l as $CaCO_3$) and total dissolved solids (TDS in mg/l). These dissolved solids affect wet processing in a number of ways.

The textile dyes for each fiber are designed to have low solubility in water and these become difficult to dissolve in very hard water. Due to insufficient solubility, the dye shade becomes weaker and may also produce spots on the dyed fabric. Further on heating or on coming in contact with alkalis during dyeing and soaping, calcium and magnesium ions are precipitated on fabrics as whitish carbonates and hydroxide particles.

Dyes of low solubility and printing pastes are also precipitated even in the soft water of high TDS. The presence of an excessive amount of sodium ions also gives a damp and limp handle to the finished fabric due to their tendency to hold water.

The dissolved solids in water can also result in precipitation of soaps, re-deposition of dirt and insoluble soaps on washed fabric (resulting in yellowing of fabric and uneven dyeing), formation of scale on equipment, boilers and pipelines, decreased solubility of sizing agents, coagulation of some types of printing paste and decomposition of bleaching baths.

The use of high quality water containing low concentration of dissolved solids can improve fabric quality, reduce water, chemical and energy consumption and improve the life of the equipment. High quality water can be achieved by treating raw water through softeners and reverse osmosis (RO) plants to reduce hardness and TDS respectively and used in the wet processes to produce high quality fabric with less resource consumption.

6.19 Summary of water efficiency measures

The summary of water efficiency measures for textile processing industries of Punjab province is given in Table 2. These savings are also illustrated in Figure 2.

Tab. 2: Summary of water efficiency measures

#	Water efficiency measure	Annual saving			
		Water (m^3)	**Electricity (kWh)**	**Steam (Ton)**	**Rs. Million**
1	Measurement and monitoring	-	-	-	-
2	Reuse of cooling water of singeing machine	15,980	6,392	483	1.20
3	Reuse of cooling water	52,326	20,930	1,185	3.15
4	Reuse of cooling drum water	168,700	67,480	-	8.4
5	Reuse of RO reject water	123,735	49,494	-	0.74
6	Reuse of multimedia washing water	17,500	7,000	-	0.6
7	Reuse of ammonia chiller condenser water	120,000	48,000	-	0.6
8	Reuse of vapor condensate and condenser water of caustic recovery plant (CRP)	180,000	72,000	-	4.0
9	Reuse of cooling water of dyeing machines	52,500	21,000	2,786	6.29
10	Reuse of post scouring washing water as desizing washing water in the bleaching machine	34,000	13,600	3,329	7.21
11	Reuse of post mercerization washes	45,000	18,000	3,753	7.58
12	Reuse of post neutralization washes as pre washes at bleaching machine	20,500	8,200	1,082	2.27
13	Reuse of steamer overflow water	5,168	2,067	507	1.11
14	Reuse of water lock water from pad steam dyeing machine steamer	37,145	14,858	-	0.74
15	Installation of automatic water shut off valves at rotary and flatbed printing machines' blanket washing water supply	29,070	11,628	-	0.44
16	Implementation of countercurrent washing	177,000	70,800	17,400	28.69
17	Heat recovery from hot process wastewater	-	-	6,900	9.0
18	Use of high quality water for wet processing	-	-	-	-

1 m^3 = 0.4 kWh

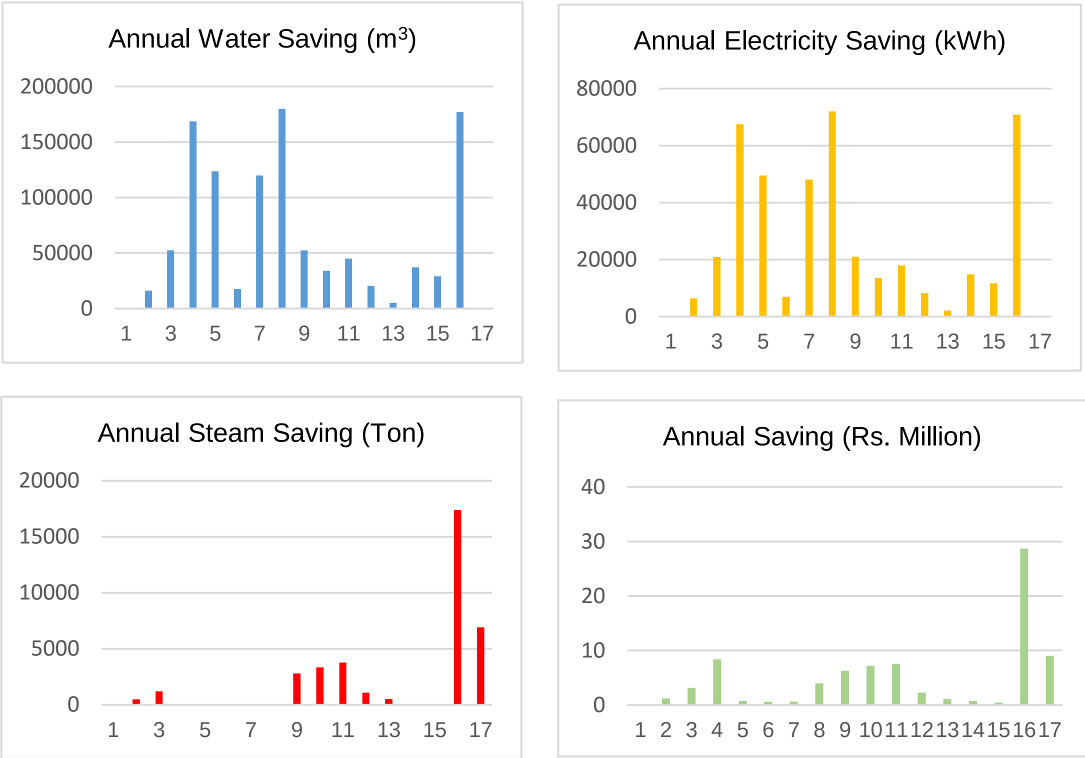

Fig. 2: Annual savings from water efficiency measures

7 Water efficiency potential of textile processing industries of Punjab

Table 3 summarizes the water efficiency potential of 10 textile processing industries of Punjab which were audited and supported to implement water efficiency measures under the WETI project.

The water saving potential is in the range of 10 – 50%. These measures can reduce not only 3 million m^3 (3.4 cusec[6]) of water but also the associated electricity of 1.4 million kWh (1,398 MWh) and 93,560 ton of steam annually. The annual saving potential in monetary terms will be Rs. 228.54 million.

[6] Cusec = Cubic feet per second

Tab. 3: Water efficiency potential of textile processing industries of Punjab

Industry code	Specific water consumption (l/kg)			Annual saving			
	Before	After	% Reduction	Water (m^3)	Electricity (kWh)	Steam (Ton)	Rs. Million
1	73	54	26	111,900	55,883	3,465	7.76
2	93	59	37	253,871	80,416	6,162	8.38
3	118	106	10	33,959	5,723	5,977	9.57
6	86	72	16	223,634	223,634	13,905	31.12
8	112	81	27	304,174	182,504	5,154	15.54
10	128	78	38	512,924	307,755	3,682	15.74
11	138	108	22	226,118	113,059	3,726	25.34
12	147	74	50	628,500	157,125	36,258	80.95
15	501	390	22	260,750	91,264	8,319	17.96
16	550	381	31	487,200	181,020	6,912	16.18
Overall	**73 – 550**	**54 – 390**	**10 - 50**	**3,043,030**	**1,398,383**	**93,560**	**228.54**

Source: WETI

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Design and operation of textile wastewater treatment plants and water recovery in India and Bangladesh

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Abstract

The best practices for the treatment of the textile wastewater consent the recovery and reuse of this water. The present publication identifies the critical parameters for the design of wastewater treatment. It describes the available technologies for the water recovery and the Zero Liquid Discharge (ZLD). The ZLD process consists of a multi-stage treatment. The first part of the treatment reduces the organic load (biological degradation process) and the second part is carried out with a series of filtration processes. The concentrate produced by filtration section must be treated by evaporation. Finally, we compare the operation of two different processes, both based on membrane filtration, for a case-study of 6,000 m^3/day plant for the treatment of cotton yarn dyeing effluent. The first process that is analyzed includes the sequence of purification steps listed: 1. Screening; 2. Homogenisation; 3. Cooling Tower; 4. biological unit; 5. Multimedia filters; 6. Capillary Ultrafiltration; 7. Softener; 8. Multistage Reverse Osmosis; 9. Multi-Effect Evaporator. The second process that is analyzed includes the sequence of purification steps listed: 1. Screening; 2. Homogenisation, 3. Cooling Tower; 4. MBR; 5. Softener, 6. Multistage Reverse Osmosis; 7. Multi-Effect Evaporator. The operation and the running costs are described in detail. Which technology do you prefer between a conventional biological plant combined with multimedia filters and capillary ultrafiltration or MBR? The answer cannot consider only running costs but also other decisive factors (available space, process flexibility, membrane replacement cost, membrane cleaning).

1 Textile industry

The textile industry is an ever-growing market. Global Textile Market will reach 1,207 Billion USD by 2025 (data from Zion Market Research). China, European Union, India and United States dominate the global textile industry. China is the leading textile manufacturing country and is almost worth 1/4th of the global textile. The textile industry of the European Union has Germany, Spain, France, Italy and Portugal on the forefront with a value of more than 1/5th of the global textile industry. India is the third largest textile manufacturing industry. India is responsible for more than 6% of the total textile production globally.

The textile sector is highly competitive, sales prices are moderate, and the margin is very low. The adoption of technological solutions that aim to save resources, such as the recovery and reuse of process water, is useful to increase competitiveness and margin.

1.1 Indian textiles industry

India’s textiles sector is one of the oldest industries in Indian economy and it is one of the largest contributors to India’s exports with approximately 11 per cent of total exports. The Indian textiles industry, currently estimated at around 108 billion USD, is expected to reach 223 billion USD by 2021. The industry is the second largest employer after agriculture, providing employment to over 45 million people directly and 60 million people indirectly. The Indian Textile Industry contributes approximately 5 per cent to India’s Gross Domestic Product (GDP), and 14 per cent to overall Index of Industrial Production (IIP).

India is the second largest producer and exporter of cotton in the world at 6.3 billion USD, marginally close to China. India has emerged as the largest producer of cotton in the world with the production of 345 lakh bales in 2016-17 and second largest exporter after China. India is the largest producer of jute in the world and it is the second largest producer of silk in the world, producing around 18 per cent of the world's total silk.

For more than a decade the legislation in force in India for new production sites has forced companies, in most of the country, to install ZLD plants for the recovery and reuse of wastewater.

1.2 Textiles industry in Bangladesh

The importance of the textile industry in the economy of Bangladesh is very high. Some economic data follows to understand the textile industry in Bangladesh:

- Investment in the Primary Textile Sector: over 6 billion USD.

- Textile sector contributes around 13% in Gross Domestic Product (GDP).
- Over 86% of the export earning comes from Textiles & Textile related products.
- Around 85-90% yarn demand for knit Readymade Garment (RMG) and 35-40% yarn demand for woven RMG are met by Primary Textile Sector (PTS).
- Local fabric demand & the yarn demand for handloom are also met by Primary Textile Sector (PTS).
- Total Export of the country 37,000 million USD (July 2016 to June 2017). Out of 37,000 Textile & Clothing export is 31,273 million USD which is around 84.52% of the total export.
- The legislation in force in Bangladesh for new production sites does not oblige companies to install ZLD facilities for the recovery and reuse of wastewater. This option is only a proposal for a new law and the political discussion is still ongoing.

1.3 Textiles industry pollution

The textile industry is composed of a wide number of sub-sectors, covering the entire production cycle from the production of raw materials (man-made fibers) to semi-processed (yarn, woven and knitted fabrics with their finishing processes) and final products (carpets, home textiles, clothing and industrial use textiles).
In the above cases, the contributions to pollution are:

- Air pollution
- Process water pollution
- Chemicals consumption
- Energy consumption
- CO_2. emissions

In this publication, we deal with the process water pollution, among the most important of those listed.
When the treated wastewater is drained, the process water volumes must be daily restored with fresh water. Normally the water used comes from surface sources or freshwater wells. The depuration, recycling and reuse of the same water in the production process make it possible to reduce this contribution.
In normal condition, the recycling allows the water recovery from 50% of process water up to Zero Liquid Discharge, which is the best result and the topic of this publication.
The variety of raw materials (cotton, wool, silk, synthetic fibers), of treatments and processes, of dyes and additives requires the wastewater treatment plant to be

designed on a case by case basis. Despite this complexity, it is possible to identify the critical and determinant parameters of the wastewater for the design of a ZLD plant: temperature, COD, color, salinity. Case by case, in wastewater there are: dyes and auxiliaries (e.g. dispersing and levelling agents), sizing agent (PVA), spinning lubricants and knitting oils, impurities removed from the fabric, chemicals from previous processes, detergents and other auxiliaries used during washing, organic halogenated solvents.

In this publication we present our ZLD solutions in the case-study of 6,000 m^3/day plant for the treatment of cotton yarn dyeing.

2 ZLD: basic process stage-by-stage

The ZLD process consists of a multi-stage treatment. The first part of the treatment reduces the organic load (biological degradation process) and the second part is carried out with a series of filtration processes. The concentrate produced by reverse osmosis concentration must be treated by evaporation.

The sequence of steps of the wastewater depuration is listed below. In this publication two different solutions are presented, both provided on membrane filtration processes. The two solutions differ only in the phase of separation of biological sludge and following filtration, upstream of the reverse osmosis. In the first solution, which we will later call conventional, there are the following steps:

a. sedimentation
b. a safety pre-filtration with multimedia filters (MMF)
c. a capillary ultrafiltration (UF)

The second solution utilizes the MBR technology, Membrane BioReactor. The MBR section does the same function just in one step replacing the three steps listed above.

The conventional solution includes the complete sequence: 1. Screening; 2. Homogenisation; 3. Cooling Tower; 4. Conventional Biological unit; 5. Multimedia filters; 6. Capillary Ultrafiltration; 7. Softener; 8. Multistage Reverse Osmosis; 9. Multi-Effect Evaporator.

The MBR solution includes the complete sequence: 1. Screening; 2. Homogenisation, 3. Cooling Tower; 4. MBR; 5. Softener, 6. Multistage Reverse Osmosis; 7. Multi-Effect Evaporator.

2.1 Screening

The aim of this section is the separation of the gross solid content, to avoid sedimentation and obstruction in the following process steps.
The wastewater, coming from the textile production, before arriving to the collecting pit, undergoes to a coarse screening followed by a fine screening.
The fine screening unit is normally an automatic self-cleaning, brush type. In the fine screening unit, **the filtration is done through a mesh with circular holes**. This conformation with the circular holes is the most suitable geometric conformation to retain the suspended fibrous solids, typical for the textile industry. The required filtration degree is 2 mm.

2.2 Homogenisation

This step of the process is simple but very important, as its aim is to keep as much constant as possible the feeding to the oxidation phase with reference to polluting parameters and flow.
In this section, air is used to move and mix the whole wastewater as well as to avoid the development of anaerobic fermentation areas inside the accumulation unit, which may produce bad smell.

2.3 Cooling Tower

The wastewater from textile industry is normally hot, up to temperature of 65 °C.
A cooling tower regulates the temperature to the optimal value (less than 38 °C) for subsequent treatment with activated sludge.

2.4 Activated sludge biological plant

Feeding to the biological step is realised by means of a pump system that transfers the water assuring during the 24 hours at constant flow rate. This constant feeding lets the biological unit to work in the better way.
The feeding with nutrients salts consists of a feeding station with nutrients salts of phosphor and/or nitrogen, necessary for the life of microorganisms in the oxidation unit.
The flow, that comes from the homogenisation step, is mixed with the activated sludge which depurates the wastewater into the oxidation tank. In this tank the pollutants are oxidised by the activated sludge thanks to the oxygen given by the blowers and turn it

to carbon dioxide. In the activated sludge tank, a new biomass grows and periodically must be evacuated (excess sludge).

The necessary oxygen is supplied through a net of air-diffusers, generating air-fine bubbles, getting a high yield of dissolved oxygen.

At the same time, the rising air bubbles create a whirling movement and a complete mixture between the bacteria and the wastewater.

The blown-in air comes from blower units with adjustable flow that can grant the right quantity of oxygen.

A further advantage of blown-in air is that it does not create any aerosol effect; therefore, it does not produce bad smell.

An oxygen transmitter that automatically varies the quantity of blown-in air controls the process. So, it avoids both anoxemia and high oxidation that would have negative consequences for the bacterial flora and for the outlet water quality. Furthermore, we can always keep a constant quantity of dissolved oxygen, even when the polluting organic load varies.

This section allows the water preparation for membrane treatment; in particular, this section reduces the COD, TSS and TOC parameters.

The aerobic process is not very efficient in reducing colours, in particular reactive colours. **In case of the ZLD plant, our experience demonstrates that that the colour removal after this step is not a critical parameter for the subsequent membrane filtration step. Therefore, in a ZLD plant it is not essential to dose decolorizing reagents at this phase of the treatment.**

Another very important feature for the design of the aerobic process of the textile wastewater is the low ratio BOD / COD. Biological processes biological processes must be sized with a **low F / M ratio**, in the range 0.07÷0.09 kg BOD / kg MLSS per day.

2.5 Sedimentation (conventional solution)

The aim of this step is to clarify the effluent coming from the oxidation tank and to allow the settled sludge recirculation.

After biological oxidation phase the mixed liquor arrives by gravity to the final circular sedimentation tank provided with scraping bridge.

The biological sludge deposits by gravity at the tank bottom and from there it is conveyed by the bottom blade of the scraping bridge into the central hopper, connected to the sludge recirculation pit where the sludge recycling pumps are positioned.
The depurated waters that separate in the upper side of the sedimentation tank are collected in a peripheral channel and then discharged by gravity.

2.6 Multimedia filters (conventional solution)

In this treatment step, the filtration is carried out through a granular bed of quartz sand with dimensions of 1 mm. These are suitable for the specific purpose of selectively retaining suspended substances for the ultrafiltration membrane protection.

2.7 Capillary ultrafiltration (conventional solution)

This technology is used for the total suspended solids removal.
The ultrafiltration process is a pressure-driven process that achieves separation through size exclusion depending on the pore size in the membranes. The ultrafiltration unit separates fine particles, suspended solids, colloidal matter, microorganisms and low molecular weight substances. Capillary ultrafiltration membranes reject solutes ranging in size from 0.03 microns approx.

Fig. 1: Capillary ultrafiltration unit

2.8 MBR system (alternative to 2.5, 2.6 and 2.7)

In the MBR system the ultrafiltration membranes are submerged, and the biological sludge is filtered directly.

The separation of biological sludge with membranes can be done with membranes with different degrees of filtration. **For the ZLD plant, it is important to use ultrafiltration membranes and not microfiltration membranes, although also this second type of membrane is used for the realization of MBR systems.**

2.9 Softening and Dealkalinisation

After the ultrafiltration step (conventional or MBR), to minimize running costs, the multistage reverse osmosis must concentrate as much water as possible. Therefore, it is necessary to condition the water so that there is no scaling (precipitation of insoluble salts) on the membranes using a softening and dealkalinisation unit.

This unit is composed of filters loaded with ion exchange resin of the weak cationic type. This type of resin guarantees the achievement of our aim with the minimum possible consumption of regenerating product. A positive impact is thus obtained on the overall mass balance, reducing the amount of water to be evaporated.

2.10 Multistage reverse osmosis

This section allows the total solids removal and concentration. It produces a permeate with low TDS, completely colorless and directly reusable in the production process. The main aim is the maximum possible recovery with minimum energy consumption. For this purpose, we have developed a series of reverse osmosis units, called multistage treatment. Normally, in these units the concentration sequence is performed in three sequential stages with increasing pressure. In the case study, we will see that this solution allows to obtain a very low energy consumption. The latter is the most significant parameter of running costs.

We produce machines with total recovery up to 92-93%. The critical parameters for the aim are: silica, COD less than 160 ppm, hardness and alkalinity.

Fig. 2: Three stage reverse osmosis unit

3 Conventional bioreactor+MMF+UF+ vs MBR

Tab. 1: Conventional bioreactor + MMF + capillary UF vs MBR

Characteristics	Conventional bioreactor + MMF + capillary UF	MBR	Notes
Footprint	-	+	NOTE1
Civil cost	-	+	NOTE1
Sludge carryover	-	+	NOTE2
Process flexibility	++	-	NOTE3
Running cost	+	-	NOTE4
Membrane replacement cost	++	-	NOTE 5
Membrane cleaning flexibility	++	-	NOTE 6
Plant modularity: possible expansion feasibility	+	-	
Capital cost	+	-	NOTE 7

LEGEND:

- Disadvantage
+ Advantage
++ Really good

NOTE1 – FOOTPRINT AND CIVIL COST: MBR membrane tanks are smaller than tanks of conventional configuration. With MBR technology adoption, the installation of MMF and capillary UF machines can be avoided.

NOTE2 – SLUDGE CARRYOVER: Normally, when the biological process conditions cause a sludge carryover, the same conditions cause a flow reduction in the MBR configuration. Biological process conditions do not depend on MBR or conventional adopted technology.

NOTE3 – PROCESS FLEXIBILITY: In case of biological process disturbs, the conventional configuration allows more flexibility: some chemical dosing like sodium hypochlorite, decolourant etc. in the clarifier feeding stream can control for instance the bulking / colour / sludge carryover etc. phenomena and trials can be conducted without effecting the flow. In the MBR configuration we can’t use any chemicals without a careful membrane impact analysis, and we can’t push the production above some limits, even for short time, because the MBR membranes operate under vacuum. The capillary UF membranes allow to increase the filtration pressure in a wider range, because they operated under pressure.

NOTE4 – RUNNING COST: The specific energy cost per cubic meter of treated water for the MBR compared with conventional configuration are normally higher.

NOTE5 – MEMBRANE REPLACEMENT COST: Considering a life cycle of 3 years only (normally the life cycle is longer) for the capillary UF membranes and of 8 years for the MBR membranes, the MBR membranes replacement specific cost for cubic meter of treated water are more expensive.

NOTE6 – MEMBRANE CLEANING FLEXIBILITY: The recovery chemical cleaning of the capillary UF membranes is totally automatic, it is executed in 2÷3 hours and the service water consumption is minimal. The recovery chemical cleaning of the MBR membranes is a procedure with an intensive time (8÷10 hours) and manpower consumption, even the amount of service water required is higher (the membranes lodging tanks must be totally filled with cleaning solution and washing solution).

NOTE7 – CAPITAL COST: Even if in case of MBR technology adoption we don't install the MMF and UF machines, the MBR is more expensive, in the range 5÷10%.

4 Case-study: 6,000 m^3/day ZLD plant

We present our case-study for the design and operation of a treatment plant of cotton yarn dyeing 6,000 m^3/d in India. We list the inlet water critical parameters for the design of ZLD plant and we analyse in detail the calculated running costs.

4.1 Inlet water characteristics

Tab. 2: Inlet water characteristics

Parameters	Values
Temperature	50 °C
pH	9÷12
COD	2,200 ppm
BOD	900 ppm
TSS	700 ppm
TDS	600 ppm
Total Alkalinity	2,000 ppm $CaCO_3$

4.2 Running costs: conventional bioreactor + MMF + capillary UF vs MBR

Tab. 3: Energy consumption

Energy consumption	Conventional configuration [kWh/m³]	MBR [kWh/m³]
Homogenisation and bioreactor	1.72	1.92
Multimedia filters	0.14	
Ultrafiltration machine	0.12	
Softening and alkalinisation	0.11	0.11
Multistage reverse osmosis machine	1.28	1.28
Evaporator	0.50	0.50
TOTAL ENERGY CONSUMPTION	3.87	3.81

For evaporator costs it is also necessary to add steam in the range 18-20 kg / m^3 of effluent.

Tab. 4: Chemical consumption

Product	Conventional configuration [ppm]	MBR [ppm]
Sulphuric acid	1,128	1,128
Hydrochloric acid	525	520
Polyelectrolyte	6	6
Sodium hypochlorite	20	13
Citric acid	0	5
Chemical for membranes cleaning	5.5	5.5
Nutrients	0	0
Sodium hydroxide	42	37
Sodium metabisulfite	3	3
Antiscalant	3	3
Biocide	0.5	0.5

Tab. 5: Consumables costs

Consumables	Conventional configuration [USD/day]	MBR [USD/day]
UF membranes	230.137	361.644
RO – safety pre filtration cartridges	55.000	55.000
RO – I stage	151.233	151.233
RO – II stage	87.123	87.123
RO – III stage	58.082	58.082
Total specific consumables cost USD/m^3	0.097	0.119

5 Conclusions and future goals

5.1 Conclusions

In this publication we wanted to share our experience in the construction of ZLD plants for the textile industry. We compared the two treatment processes we developed and that currently, in different forms, are the most adopted in the market. Analyzing the running costs in detail, we can see that the two solutions do not present substantial differences in energy consumption. The most critical points of the entire treatment process regarding energy consumption are the biological oxidation section and the reverse osmosis section. Also, regarding the consumption of chemical products there are no particular differences. As far as the impact of the membranes is concerned, there is a slight advantage of the conventional system which, however, has the disadvantage of having a greater footprint.

In any case, the ZLD is not an "impossible" technology. Installation and running costs are consolidated. In some scenarios the scarcity or the high price of water can make this process an interesting option also from an economic point of view and not only from the point of view of environmental compliance. In the case study analyzed, with the specific costs of the Indian market for electricity and consumption of chemical products, the running cost is 1.20 USD/m^3 (sludge disposal excluded).

5.2 Future goals: recovery of mixed salts

Our next goal is to achieve an effective and efficient treatment of mixed salts, outlet of the multi-effect evaporator. We are studying new techniques for the recovery and reuse of the salts themselves and the reduction of the quantity of pollutants to be disposed of.

We are studying the advantages of recovering NaCl salt with membrane filtration processes and recovering Na_2SO_4 salt with fractional crystallization.

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Energy- and water-efficient exhaust dyeing with reactive dyestuffs

Markus Böhme

CHT Germany GmbH, Tübingen

CONTENT

- Facts about water resources
- Saving water / energy in cotton exhaust dyeing
  - Low liquor ratio
  - Requirements dyestuffs / auxiliaries
  - Process
- Project InoCottonGROW
  - Trials in pretreatment / dyeing
  - Results / savings
- Outlook

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LIFE CYCLE ASSESSMENT

LCA is the ecobalance of a product from “cradle to grave”, from raw material to recycling

For textile production

- Cotton cultivation
- Spinning / knitting
- Pretreatment / dyeing / finishing
- Clothing

impact

- Water footprint (water in m^3)
- Carbon footprint (CO_2 in to)
- Ecosystem (Eutrophication in to N)
- Natural sources (land in m^2)
- Human health

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FACTS ABOUT OUR WATER RESOURCES

- Water consumption has been increased 6 times within last 70 years.
  This is due to a drastic increase of world population and doubling of average water consumption per capita.
- In developing countries 70% of industrial waste water is discharged without any kind of treatment
- The groundwater level e.g. in Pakistan reduces every year 40-60 cm – estimated that it will reduce down to around 180 m!
- Water shortage in many specially fast growing cities like Chennai India
- WEF is reporting in their last forum in Davos that the global water crisis stands in the first place of economic risks - even before the budget crisis, terrorism or unemployment

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THE PROBLEM IS ON THE TABLE

- 30% of the world population has no access to clean drinking water
- Water consumption in textile industry is huge
- 1 kg cotton needs 11.000 liter water

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VIRTUAL WATER – CO TEXTILE

- ~40% GREEN VIRTUAL WATER rainwater, stored in the soil and be absorbed by plants depending on growing area
- ~ 40% BLUE VIRTUAL WATER : groundwater and water from river, lakes used for watering plants
- ~ 20% GREY VIRTUAL WATER : polluted water e.g. by production process, not being reused

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SAVING ENERGY- AND WATER IN TEXTILE PRODUCTION

- Change from exhaust to continuous process
  - Semi-continuous process growing: CPB
  - Continuous process (PDPS) only for big batches / woven fabric
- New processes in exhaust?
  - CO_2 dyeing
  - Salt free dyeing
- Saving potential in exhaust dyeing

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ENERGY- AND WATER-EFFICIENT EXHAUST DYEING WITH REACTIVE DYESTUFFS

- Reduction of water
  - Low liquor ratio machines
  - Use water at the right step, avoid overflow rinsing, specially rinsing features of machine
- Reduction of energy
  - Reduced temperature in bleaching, dyeing, soaping, rinsing
- Shorter process
  - Less process steps, less energy / water demand
- Re-use water
  - In developement

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SHORT LIQUOR RATIO IN DYEING

State of the art, LR 1:6 to 1:4 for dyeing cotton in exhaust

- Less water consumption
  - Less water costs
- Less waste water
  - Less liquor to be treated in effluent treatment plant
- Reduced energy demand
  - Less steam required
  - Smaller heat exchangers required
  - Smaller circulation pumps necessary and therefore less electricity consumption

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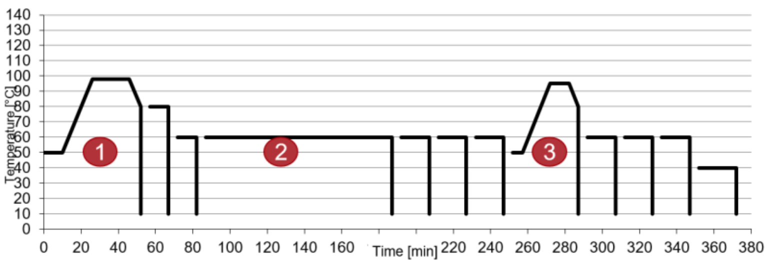
SHORT LIQUOR RATIO



- **PRETREATMENT**
  - Higher contamination in the liquor, from residuals, oil from greige
  - Higher concentration of released hardness from greige cotton in liquor
- **DYEING**
  - Solubility of dyestuff
  - Higher import of cotton accompanies hardness / tenside
  - Reduced dosing time
  - Reduced migration properties due to short liquor
- **SOAPING**
  - Less water – less washing effect
  - High fixing grade required – less unfixed dyestuff to be washed out
  - High carry over

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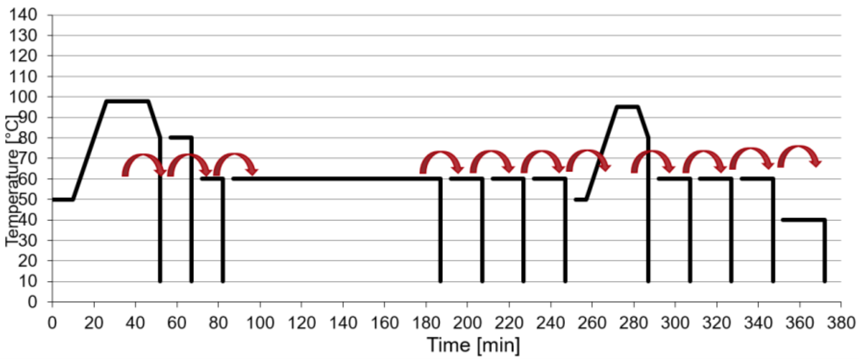
RINSING IN LOW LIQUOR RATIO

- Best drain / fill, try to avoid overflow rinsing
- Variable liquor ratio
- Various systems to optimize the washing effect depending on machine supplier
- Dyestuff with high fixing rate (low amount of unfixed dyestuff)
- Number of rinsing bathes also depend also on soaping agent
  - salt content
  - backstaining

CARRY OVER



	carry over 250% - **salt in g/l**				
LR	dyeing	1st rinsing	2nd rinsing	3rd rinsing	4th rinsing
1:15	80	13	2		
1:10	**80**	**20**	**5**	**1**	
1:6	80	33	14	6	2
1:3	80	67	56	46	39

	carry over 250% - **dyeing liquor in %**				
LR	dyeing	1st rinsing	2nd rinsing	3rd rinsing	4th rinsing
1:15	100%	17%	3%		
1:10	**100%**	**25%**	**6%**	**2%**	
1:6	100%	42%	17%	7%	3%
1:3	100%	83%	69%	58%	48%

CHT TAKES PART

SPONSORED BY THE

Federal Ministry of Education and Research

project head.
Research Institute for Water and Waste Management at RWTH Aachen

Hochschule Niederrhein
University of Applied Sciences

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TEXTILMASCHINEN Thies

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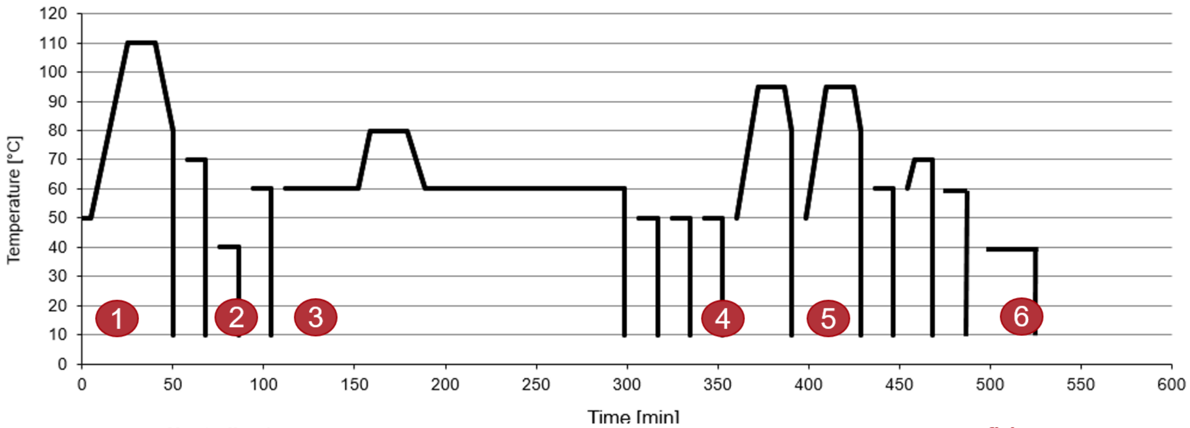
STATE OF THE ART CUSTOMER - 2018



Neutralise / peroxide killer

neutalise

fixing

Bleaching 110°C

Reactive dyeing 60°C

Double soaping 98°C

with migration step at 80°C (mixed alkali) plus biopolish

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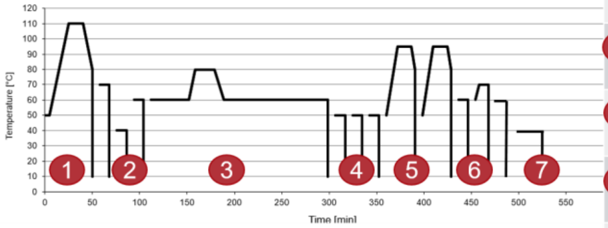
SAVING POTENTIAL



	actual	improvement
1	Peroxide bleach 110°C	Peroxide bleach 80°C
2	Rinsing / neutralising / peroxidekiller: 3 baths	Number of baths: Reduction possible?
3	Dyeing 60°C (migration step 80°C)	Dyeing 40°C (migration 60°C)
4	3 rinsing baths after dyeing	Number of baths: Reduction possible?
5	Double soaping at 98°C	Temperature reduction possible?
6	3 rinsing bathes after soaping	Number of baths: Reduction possible?
7	fixing	

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4SUCCESS

- **VARIO BLEACH 3E** - pretreatment
  - Low temperature bleach
- **SARABID MIP** – dyeing auxiliary
  - Controlled dyeing of cellulosic fibres
  - Sequesting / dispersing properties
  - pH control
  - Masking nonionics
- **BEZAKTIV GO** - dyestuff
  - Low tempature dyeing at 40°C possible
  - Shorter process
- **COTOBLANC SEL-** soaping
  - Vario soaping
  - Working independant on salt content
  - Clear reduction of backstaining

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BEZAKTIV GO

- **High fixing rate, > 90% !**
  - Less hydrolysed dyestuff after fixation
  - Reduced bath contamination in each washing and soaping step
- **High concentrated dyestuffs**
  - Lower dyestuff concentration / less problems with solubility issues
  - Lower salt amount required
- **Suitable for 40°C dyeing**
  - Little higher amount of alkali required
  - Shorter process
  - Level build up

COTOBLANC SEL

conventional

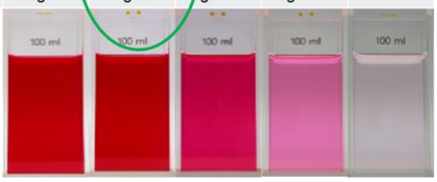
	1.wash	2. wash	3 wash	Soap	5. wash	6. wash	7.wash
temp	40 °C	60 °C	60 °C	98 °C	80 °C	70 °C	40 °C
salt	33 g/l	14 g/l	6 g/l	2 g/l			

First:
Elimination of residual salt below 2 g/l before soaping

COTOBLANC SEL

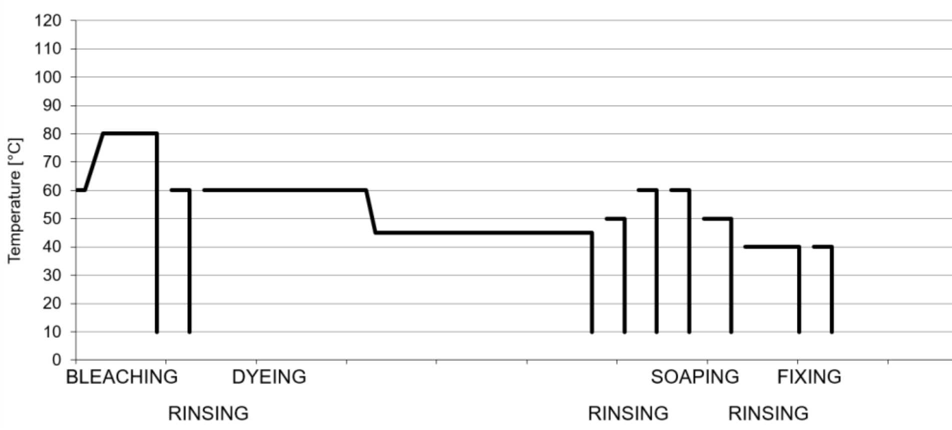
	1.wash	Soap	3. wash	4. wash	5. wash
temp	40 °C	98 °C	80 °C	70 °C	40 °C
salt	33 g/l	14 g/l	6 g/l	2 g/l	

Soaping in presence of salt



LR 1:6
salt in dye bath: 80 g/l

IMPLEMENTED TRIALS 4SUCCESS



1	FELOSAN FOX	2,8 g/l
	BIAVIN DFG	1,8 g/l
	VARIO BLEACH 3E	1,5 ml/l
	peroxide 50%	3,50 ml/l
	caustic soda 50%	4,0 ml/l
2	acetic acid	1,5 ml/l
	CHT CATALASE BF	1,5 ml/l
3	BIAVIN DFG	1,8 g/l
	MEROPAN DPE	1,0 ml/l
	SARABID MIP	1,5 ml/l
	COMMON SALT	x g/l
	BEIZYM SPELL	1,5 ml/l
.	BEZAKTIV SCARLET GO	x %
	BEZAKTIV RED GO	y %
	BEZAKTIV NAVY GO	z %
.	soda ash	2 g/l
.	soda ash	3 g/l
	caustic soda	x g/l
4	COTOBLANC SEL	2.0 g/l
.	COTOBLANC SEL	1.5 g/l
5	acetic acid	1.0 ml/l
	REWIN ACP	3.0 %

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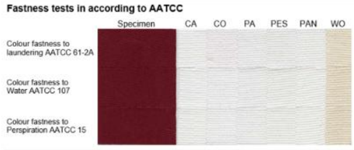
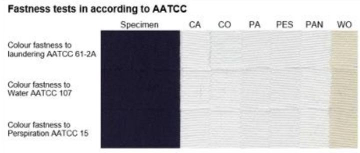
CUSTOMER IMPLEMENTED 4SUCCESS IN BURGUNDY/ NAVY /BLACK

Fastness tests in according to AATCC



Evaluation	Colour change	Staining					
		CA	CO	PA	PES	PAN	WO
Colour fastness to laundering AATCC 61-2A	5	5	4-5	5	5	5	5
Colour fastness to Water AATCC 107	5	5	5	5	5	5	5
Colour fastness to Perspiration AATCC 15	5	5	5	5	5	5	5

Fastness tests in according to AATCC



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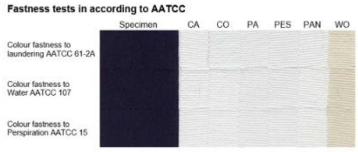

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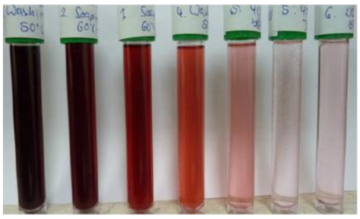
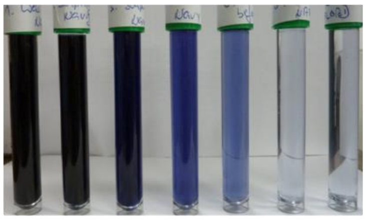
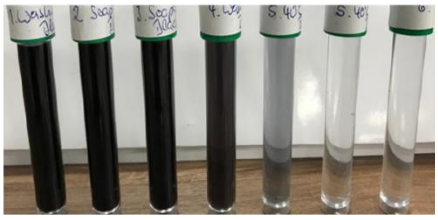
Colour fastness to Perspiration AATCC 15	5	5	5	5	5	5	5







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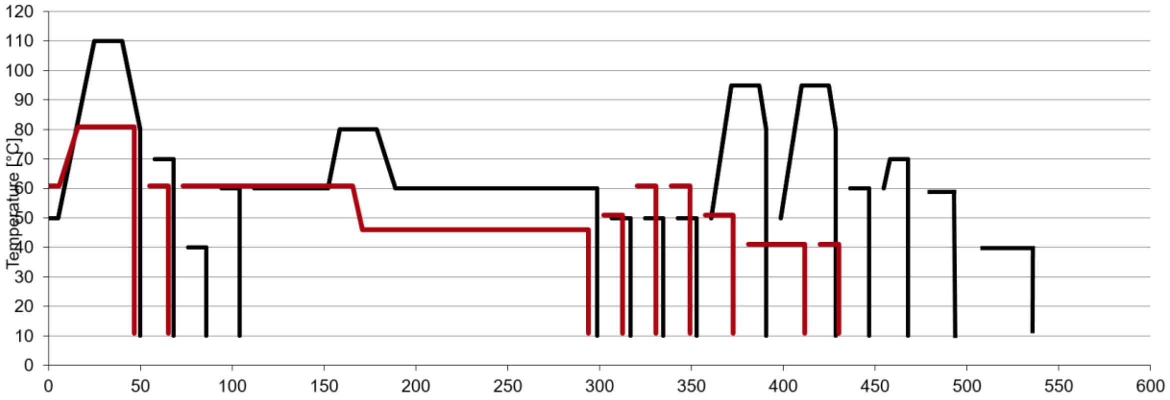
IMPLEMENTED PROCESS 4SUCCESS



BLEACHING RINSING DYEING RINSING SOAPING RINSING FIXING

BLEACHING DYEING SOAPING FIXING

RINSING RINSING RINSING

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SAVINGS

	Customers process	4success	savings
Process time (min)	542	426	-21%
Water (l/kg)	55	38	-31%
Steam (kg/kg)	4,22	1,44	-66%
Energy (kWh/kg)	0,293	0,219	-25%

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POTENTIAL WATER SAVING FOR TOTAL PRODUCTION

- Calculation of approx. 55t dyed fabric per day - water consumption of 54-56 l/kg = 2.970.000 l
- Calculation 4SUCCESS of approx. 55t dyed fabric per day - water consumption of 38 l/kg = 2.090.000 l
- Water saving per day = 880.000 l
- Water saving per month = 26.400.000 l
- Calculation of estimated money saving per month* = 72.600 €

*Cost for process water, water treatment includes all facility, item labour and energy.

Cost of water treatment in Europe is in the range of 2,5 - 5,0 €/m3 depending on contamination of water - high contaminated dyehouse water with organic sludge dyestuff, fixing, finishing etc.

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NEXT STEPS

- Implementation at customer for further colors
- 4 additional customer in Pakistan start trials in InoCottonGROW Project
- Project of reducing water/energy in Bangladesh, in coorperation with BUTEX, Dhaka with CHT support
- CHT B&R in contact with brands

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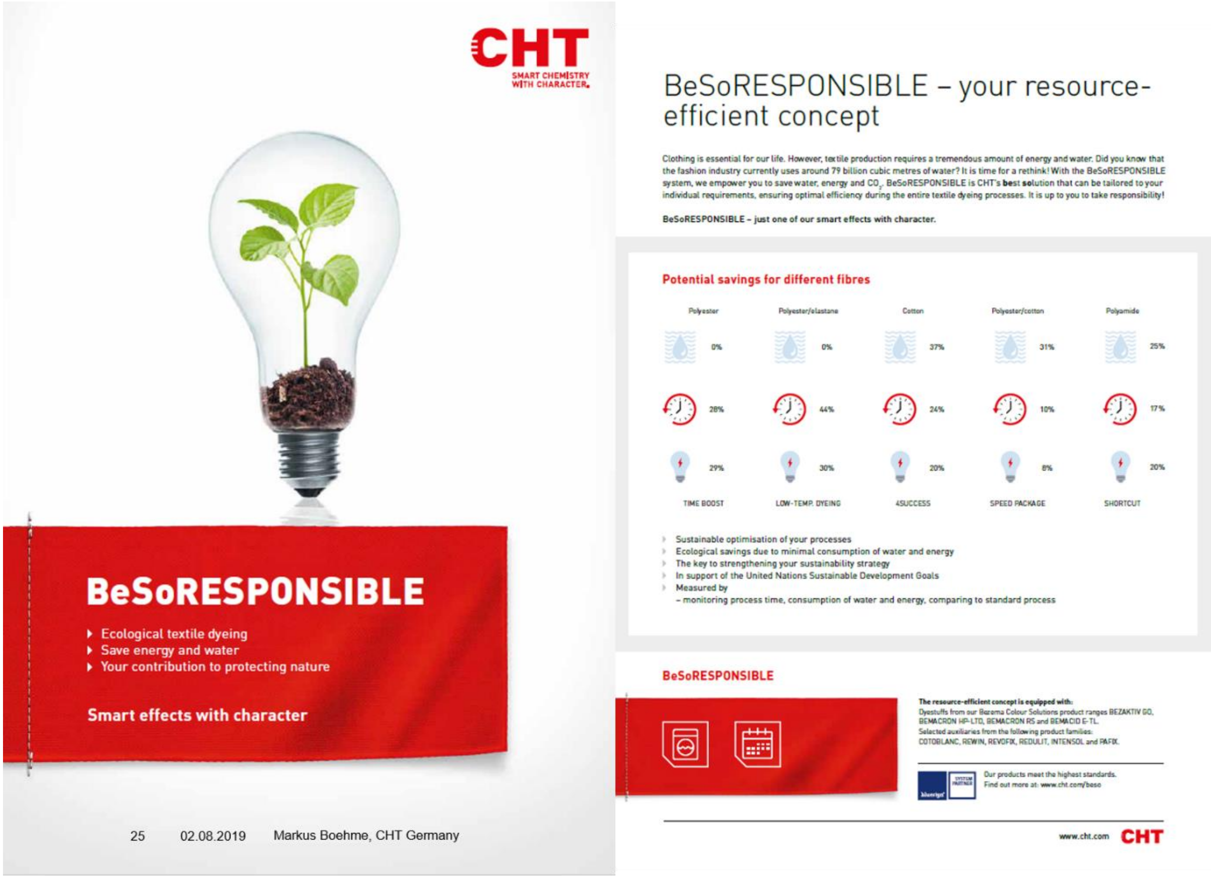

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Chemicals management and water pollution prevention in textile finishing industries

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Abstract

For textile finishing, a huge variety of chemical products are used which can be grouped into dyestuffs/organic pigment, textile auxiliaries and basic chemicals. Especially textile auxiliaries are formulations which are produced from different components. Each component consists of different chemical compounds. Counting also isomers and by-products, these products may consist of hundreds of different chemical substances. Biodegradability/bioeliminability is usually determined from the formulation and is presented as one figure, i.e. x %. In this contribution, basic information about biodegradability/bioeliminability is provided to understand better the information concerned in material safety data sheets.

1 Introduction

Textile wet processing, also called textile finishing, is associated with the use of manifold chemicals. On the European market, there are about 7000 – 8000 textile auxiliaries with 400 – 600 main active ingredients (Enquete-Kommission, 1994) available; worldwide, the number may be more than 10,000. Globally, there are more than 10,000 Colour Index (CI) generic names assigned to commercial colorants; approximately 4,500 are in use, and over 50 % of these belong to the azo class (Chudgar, 2000). The chemical products used for wet processing can be grouped into dyestuffs / organic pigments, textile auxiliaries[1], and basic chemicals[2]. The textile

[1] Formulations which contain mainly organic compounds as active ingredients

[2] all inorganic compounds, all aliphatic organic acids, all organic reducing and oxidising agents, and urea

auxiliaries can be subdivided into auxiliaries and finishing agents for fibres and yarns, pretreatment agents, textile auxiliaries for dyeing and printing, agents for final finishing, and technical auxiliaries for multipurpose use in the textile industry (predominantly surfactants). Thus, the chemical products can be grouped as follows:

- Auxiliaries and finishing agents for fibres and yarns
- Pretreatment agents
- Textile auxiliaries for dyeing and printing
- Agents for final finishing
- Technical auxiliaries for multipurpose use in the textile industry
- Basic chemicals
- Dyestuffs and organic pigments

In textile finishing industries with a long process sequence such as finishers of cellulosic woven fabric with pre-treatment, exhaust, semi-continuous and continuous dyeing processes, reactive printing and final finishing, the specific consumption of chemicals products is up to 1 kg/kg fabric processed. However, this figure includes the water content of aqueous formulations which are frequently used.

Medium sized textile finishing industries apply 150 – 300 chemical products (all products are counted with an annual consumption of more than 10 kg). As shown in Figure 1, in a textile finishing industry with the full sequence of processes (pre-treatment, dyeing and/or printing, final finishing), about 80 % of the annual consumption of textile auxiliaries are covered by only about 20 % of the chemical products used.

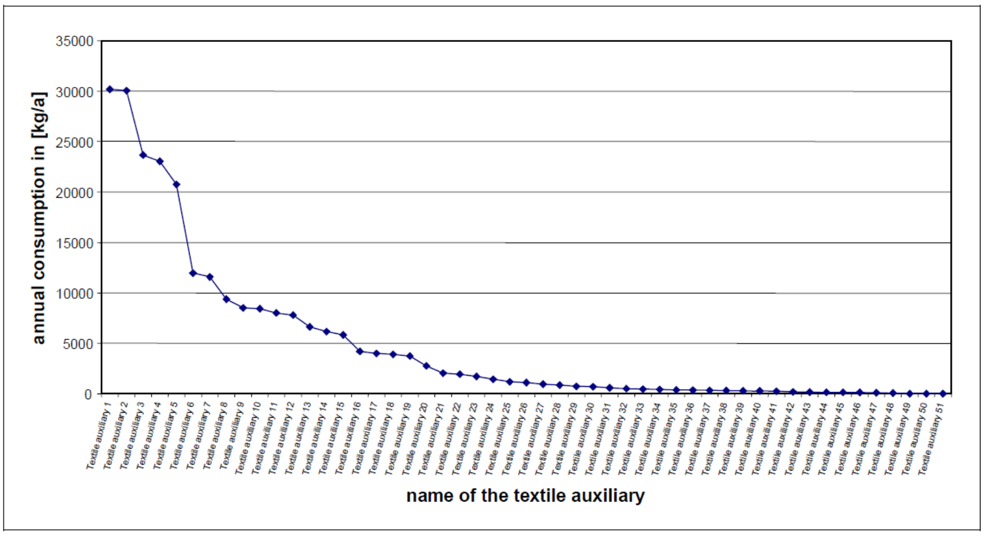

Fig. 1: Typical pattern of textile auxiliaries consumption of a textile finishing industry

Usually, a similar hyperbolic curve is typical for the annual consumption of dyestuffs (Figure 2).

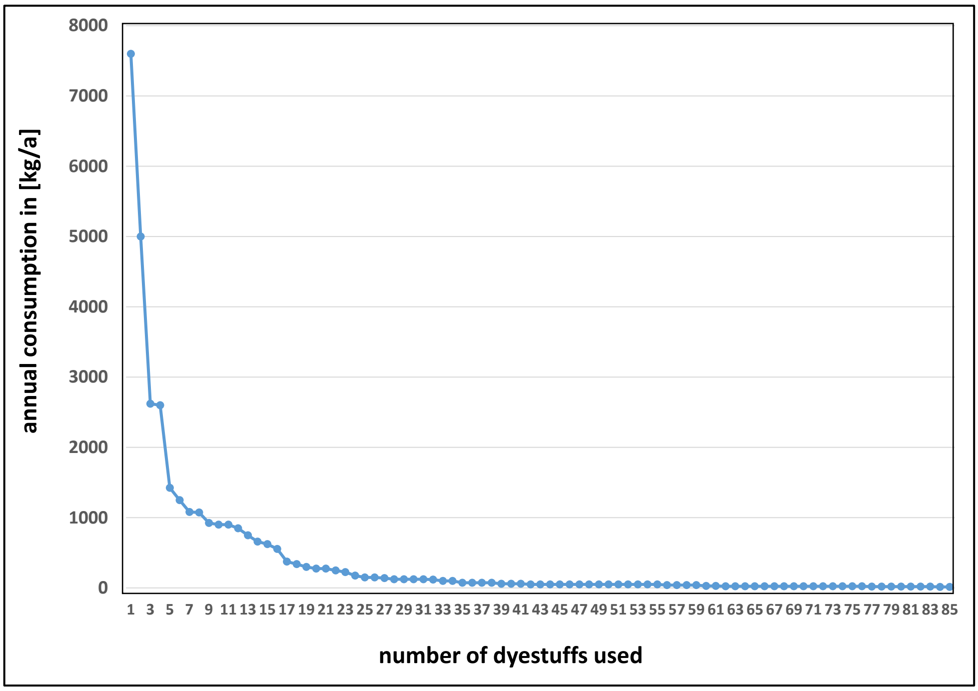

Fig. 2: Typical pattern of dyestuffs consumption of a textile finishing industry

It is important to compile all chemical products used in a systematic way. For this purpose, they should be grouped as indicated above using a certain template. A first version was already proposed in 2003 (Textile BREF, 2003) it was developed further in 2017/2018 (Figure 3). In 2019, it was further detailed. Now, there are 25 columns which, due to readability, cannot be shown here in the form of a table. Consequently, all 25 headings of the excel table are listed below.

Form 3

List of used chemicals

sorted according to annual consumption quantities

Name of the textile finishing industry

Year:

3. Textile auxiliaries for dyeing and printing

3.1 Dyestuff solubilizing and hydrophobic agents		
3.2 Dispersing agents and protective colloids	3.11 Bonding agents for pigment dyeing and printing	3.20 Mordants
3.3 Dyeing wetting agents, deaeration agents	3.12 Printing thickeners	3.21 Brightening and stripping agents
3.4 Levelling agents	3.13 Emulsifiers for gasoline printing	3.22 Fibre-protective agents
3.5 Carriers	3.14 Agents to remove printing thickeners	3.23 pH-regulators, acid and alkali dispensers
3.6 Crease-preventing agents	3.15 Printing and edge adhesives	
3.7 Dyestuff protecting agents, boildown protecting agents	3.16 Oxidizing agents	
3.8 Padding auxiliaries	3.17 Reducing agents	
3.9 Fixing accelerators for continuous dyeing and printing	3.18 Discharging agents and discharging assistants	
3.10 Aftertreatment agents for fastness improvement	3.19 Resist agents	

No.	Commercial name	Chemical characterisation	Process, application	Annual consumption [kg/a]	GHS Hazard	Cont. haz. Substances according to SVHC, ZDHC and……[mass-%]	Biological degradation respect. bioelimination [%] and testing method	spec. COD-value [mg O_2/g]	spec. BOD_5-value [mg O_2/g]	Heavy metal content [mg/g]	Org. halogen content [mg/g]
1.											
2.											
3.											
4.											
5.											
6.											
7.											
8.											
9.											
10.											
11.											
12.											
13.											
14.											

Fig. 3: Form for listing of textile auxiliaries for dyeing and printing along with the environmental information for their evaluation (Schönberger, 2018)

Headings of the current excel table for listing the chemical products used:

1. No.
2. Commercial name
3. Producer
4. Chemical characterisation
5. Known Chemical Abstract Service number (CAS no.)
6. Process, application
7. Annual consumption in [kg/yr]
8. Material safety data sheet (MSDS), available yes/no and date of issue
9. Globally Harmonised System (GHS) – hazard classification
10. Containing hazardous substances according to SVHC, ZDHC, contains persistent, bioaccumulative and toxic substances (PBT) and very persistent and very bioaccumulative substances (vPvB) in [weight-%] for individual substances
11. Ionogenic character
12. Biological degradation/elimination of the whole product (formulation) and individual substances in [%] and test duration [d] and test method
13. Specific COD value [mg O_2/g]
14. Specific BOD_5 value [mg O_2/g]
15. Heavy metal content [mg/g]
16. Organic halogen content [mg/g]
17. Total nitrogen content [mg N/g]
18. Total phosphorus content [mg P/g]
19. Classification according to wastewater relevance scheme
20. Toxicity on bacteria, EC50 [mg/L]
21. Toxicity on algae; EC50 [mg/L]
22. Toxicity on daphnia [mg/L]
23. Toxicity on fish, LC50 [mg/L
24. Maximum quantity stored [t]
25. Classification concerning storage

Chemicals management in textile finishing industries comprises different aspects such as

- labelling according to the Globally Harmonised System (GHS)[3],
- proper unloading and storage,
- proper handling of chemicals for wet textile processing,
- systematic listing of all chemical products used,
- adequate use of material safety data sheets,
- careful selection of textile auxiliaries and basic chemicals, also with respect to their environmental properties.

This contribution concentrates on the careful selection of chemicals with respect to their biodegradability/bioeliminability. As a source of information, textile finishing industries usually only use material safety data sheets.

2 Biodegradability/bioeliminability

2.1 Typical information in MSDS

In Chapter 12 MSDS contain information about biodegradability and bioeliminability respectively. Figure 4 shows four examples from four different MSDS.

[3] The Globally Harmonized System of Classification and Labelling of Chemicals (GHS) is an internationally agreed-upon standard managed by the United Nations that was set up to replace the assortment of hazardous material classification and labelling schemes previously used around the world. "GLOBAL HARMONIZED SAFETY SYSTEM for CLASSIFIED CHEMICAL LABELLING" - Core elements of the GHS include standardized hazard testing criteria, universal warning pictograms, and harmonized safety data sheets which provide users of dangerous goods with a host of information. The system acts as a complement to the UN Numbered system of regulated hazardous material transport. Implementation is managed through the UN Secretariat. Although adoption has taken time, as of 2017, the system has been enacted to significant extents in most major countries of the world (see https://www.unece.org/trans/danger/publi/ghs/implementation_e.html). This includes the European Union, which has implemented the United Nations' GHS into EU law as the CLP Regulation, and United States Occupational Safety and Health Administration standards (Wikipedia, 2019).

Product 1

Information related to the product itself:

Biodegradability :	62 % (28 d, BOD/CODX100) Readily biodegradable. Method : OECD 301F * 1992 * Manometric respirometry 93 % (28 d, DOC) inherently biodegradable Method : OECD 302B * 1992 Zahn-Wellens/EMPA (inherent)
Chemical oxygen demand (COD) :	1.644 mg/g Method : DIN 38409-H41
Biochemical oxygen demand (BOD5) :	599 mg/g Method : OECD 301F * 1992 * Manometric respirometry 5 d

Product 2

Information related to the product itself:

Biodegradability :	< 18 % (28 d, DOC) Method : OECD 302 B
Chemical oxygen demand (COD) :	190 mg/g Based on the components.

Product 3

Biodegradability: 41 % (BOD/CODX100)
Method: OECD 301C * 1981 Mod. MITI (I) (ready)

Product 4

Product:

Biodegradability :	Type of test: DOC-CO2 measurement Biodegradation: 70 % Exposure time: 28 d Method: OECD 302 B with CO2 (mineralisation) Type of test: DOC-CO2 measurement Biodegradation: > 75 % Exposure time: 28 d Method: OECD 302 B with CO2 (elimination) According to the criteria of OECD, the product is "inherently biodegradable"
Biochemical oxygen demand (BOD) :	65 mg O2/g Incubation time: 5 d, method: DIN EN 1899-1 (H 55)
Chemical oxygen demand (COD):	520 mg O2/g Method: DIN 38409-H-41

Fig. 4: Four examples for typical information on biodegradability/bioeliminability in MSDS

The proper understanding and interpretation of this information requires expert knowledge and starts with the understanding of the abbreviations such as "28 d, BOD/CODx100", "OECD 302 B", "with CO2 (mineralization)". To interpret the results, the test methods have to be known. So, in the following, important background information is submitted in order to provide a better understanding of the information contained in MSDS. This also includes basics on the character of biodegradability.

2.2 Character of biodegradability

The term “biodegradability” is a term describing a system rather than being a property of a chemical or of a matrix of various chemicals such as wastewater. In many cases, the system conditions determine whether a chemical compound is degraded therein or not, such as the temperature, pH, salt content, redox potential, degree of adaptation, availability of nutrients or other conditions (Figure 5).

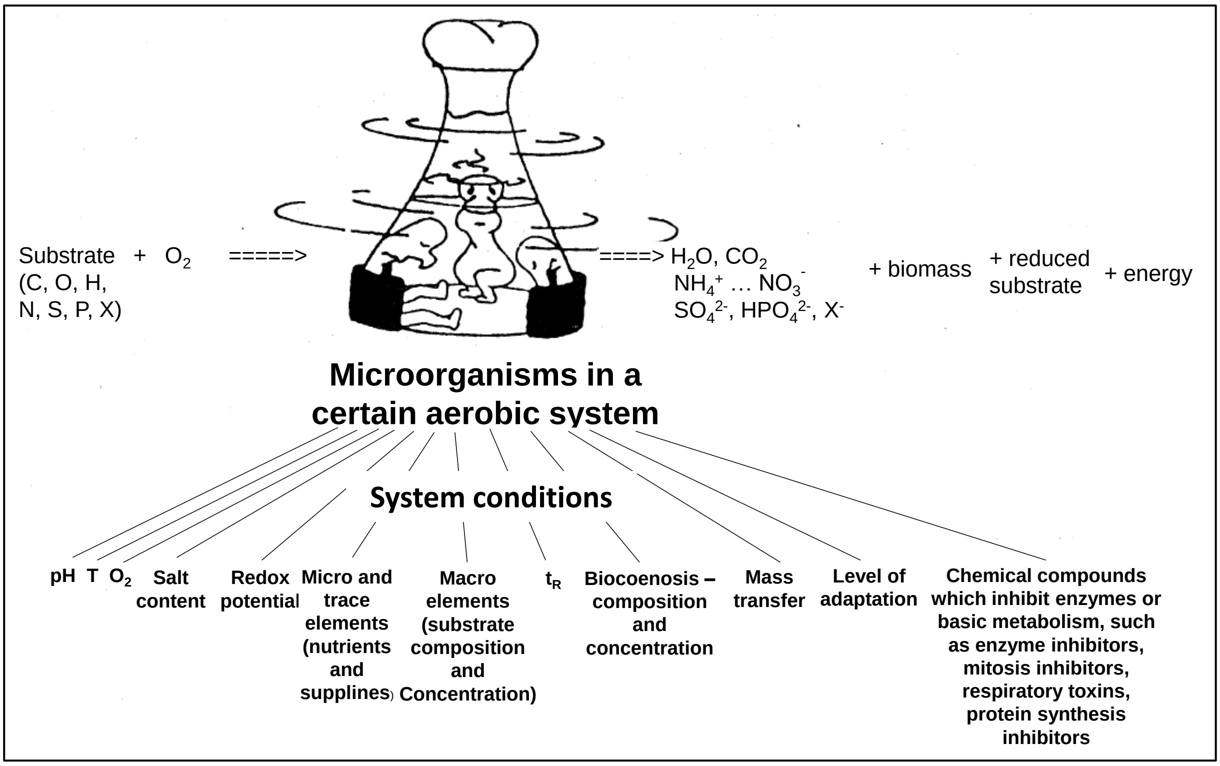

Fig. 5: Strongly simplified scheme for aerobic biodegradation

As a consequence, the statement “…the chemical compound x is biodegradable ….” is often useless without mentioning the system conditions. With respect to systems for testing the biodegradability, the question always emerges whether the results can be transferred to other systems such as municipal or industrial real wastewater treatment plants (WWTP) or water bodies such as lakes, rivers, sediments, underground passages or the sea.

2.3 Test methods for the determination of biodegradability/bioeliminability

In practice, for the assessment of results from biodegradation tests and their transferability to other systems, especially to real WWTP, the OECD strategy from

1981 is still valid which groups the available test methods into three categories (Figure 6)

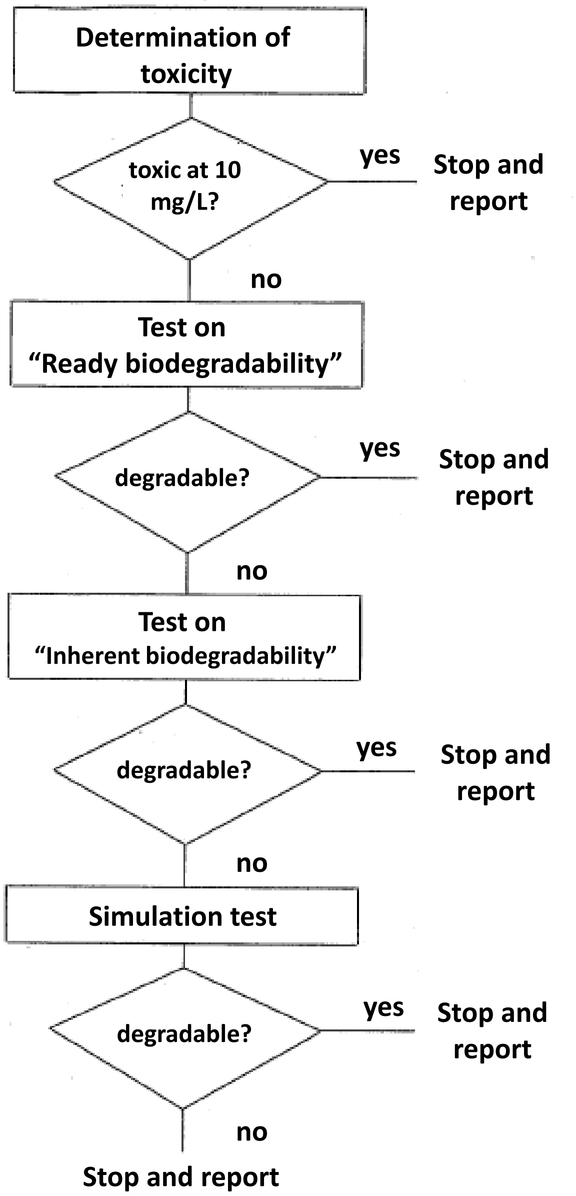

Fig. 6: OECD strategy for the determination of biodegradation/bioelimination

This strategy was primarily developed for the testing of chemical substances. However, it can also be applied for wastewater. The three categories are as follows:

- Test on "Ready Biodegradability"
- Test on "Inherent Biodegradability"
- Simulation tests

2.3.1 Tests on “Ready Biodegradability”

These are tests with restrictive conditions for bacteria such as low bacteria concentration, non-adapted inoculum (bacteria culture) and limited substrate level. If there are positive results under these conditions, it is expected that the results can promptly be transferred to other systems such as municipal or industrial WWTP. There are a number of tests for this level known as OECD 301 tests such as OECD 301 A (DOC die-away Test), OECD 302 B (CO_2 Evolution Test), OECD 301 C (MITI Biodegradation Test), OECD 301 D (Closed bottle Test), OECD 301 E (Modified OECD Screening Test), or OECD 301 F (Manometric Respirometry Test). This explains some of the abbreviations in Figure 4.

2.3.2 Tests on “Inherent Biodegradability”

These test methods have much more favorable conditions for biodegradation such as high biomass concentration, long retention time, comparatively high substrate concentrations and adapted microorganisms (if the inoculum is taken from the WWTP the investigated wastewater is discharged to). They are abbreviated with “OECD 302”. If there is no or little biodegradation under these conditions, at first sight, it can be expected that the chemical compound concerned or the mixture of many compounds (wastewater) is heavily biodegradable. However, if the result is positive, one cannot conclude that it can be transferred to any environmental compartments such as the water phase of a river or a lake, or the sediments of rivers or lakes. Today, the modified Zahn-Wellens-Test is usually used and recommended (Schönberger, 1991): This test is abbreviated as “OECD 302 B”. Many MSDS contain results for this test method (see also Figure 4). Therefore, some information will be presented below.

2.3.3 Simulation tests

These tests simulate conventional WWTPs. They are abbreviated with “OECD 303”. The most important simulation test is the “Coupled Units Test” (OECD 303 A). MSDS rarely contain results from this test method.

2.3.4 Zahn-Wellens-Test

Today, this test is normally used for the determination of “inherent biodegradability”. Under the conditions of this test, the biodegradation rates are significantly higher compared to BOD_5 (which is similar to the Closed Bottle Test according to

OECD 301 D). Usually, the test results can be transferred to real WWTPs, especially if the activated sludge (inoculum) for the test is taken from the WWTP the wastewater investigated is discharged to. It is important to note that the Zahn-Wellens-Test comprises all elimination mechanisms also occurring in an activated sludge system which is the most important biological treatment technique. The elimination mechanisms are stripping of volatile compounds to air, adsorption to the biomass and biodegradation. This is the reason why the terms “bioelimination” or “bioeliminability” are used. Especially adsorption to sludge often plays an important role and thus, the terms “biodegradation” (refers to the biochemical degradation of organic compounds) and “bioelimination” (comprises biodegradation but also adsorption and in some cases also stripping to air) should be carefully used. As a consequence, the test result from a Zahn-Wellens-Test should be called bioelimination rather than biodegradation. Nevertheless, chemical suppliers mostly call it biodegradation in their MSDS (see Figure 4).

2.3.4.1 Description of the Zahn-Wellens-Test

The Zahn-Wellens-Test was published in 1974 (Zahn/Wellens, 1974). Six years later, a report about further experience was issued (Zahn/Wellens, 1980) and later on, further results on mono- and di-substituted benzene derivatives were presented (Wellens, 1990). In 1981, OECD introduced the test as “Modified Zahn-Wellens-Test (OECD, 1981). In Germany, the test was published as DIN Norm in 1984 (DIN 58412, 1984) and has been introduced as DIN EN ISO Norm in 1999 (DIN EN ISO 9888, 1999).

The Zahn-Wellens-Test is a static test. In principle, four batches are required to test a chemical or a wastewater. However, more than one chemical or wastewaters can be tested at the same time. Figure 7 shows the different batches.

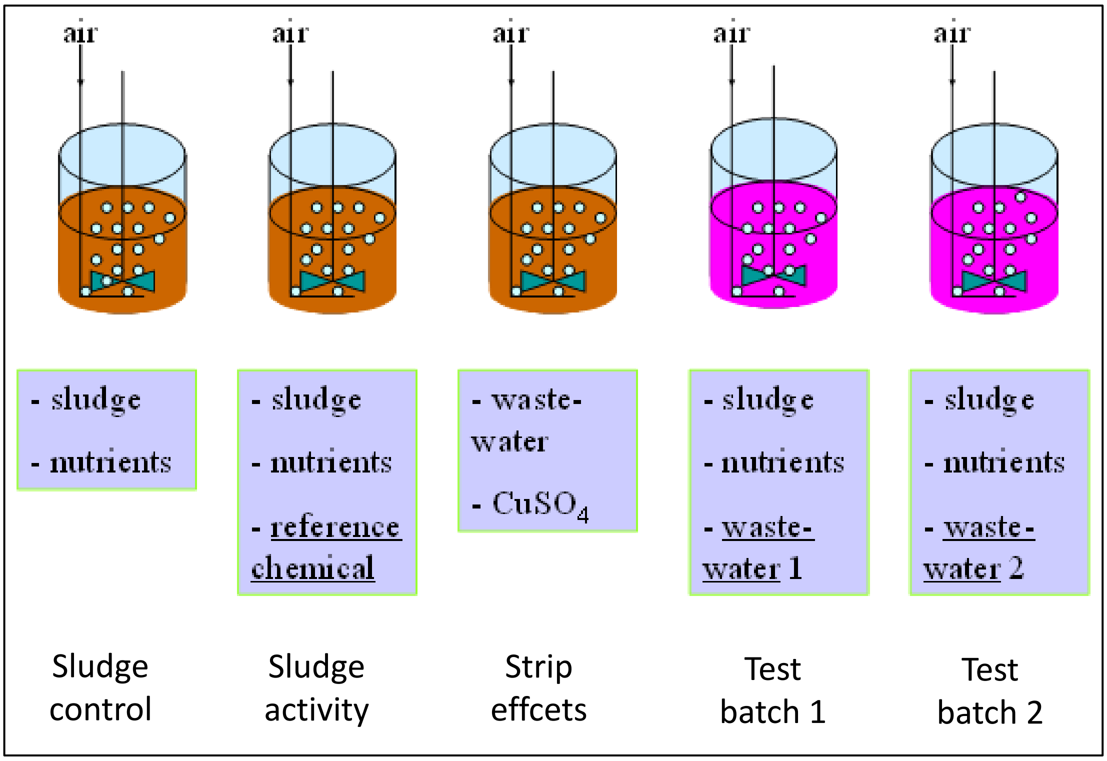

Fig. 7: Principle batches of a Zahn-Wellens-Test (the batches for sludge control, sludge activity and strip effects are needed in addition to the test batches)

From the test batches, the first sample is taken after 3 hours for TOC or COD analysis to see the adsorption to sludge. Then, every day, a sample is taken to determine the elimination rate. The batch “sludge control” is to determine the contribution of the sludge to the elimination rate (usually very minor) and the batch “sludge activity” is to see whether the sludge is fully active which is the case if the biodegradation of diethylene glycol follows the well-known curve. The batch “strip effects” is only needed if the presence of volatile compounds such as volatile organic solvents is assumed or can be expected. For instance, for textile wastewater this is rarely the case and thus, the batch “strip effects” often is not carried out.

2.3.4.2 Further development of the Zahn-Wellens-Test

Urs Baumann has developed the Zahn-Wellens-Test further by determination the mineralisation rate also. For this purpose, closed bottles for the test batches are taken and aerated by CO_2 free air (Figure 8) (Baumann, 2001). The CO_2 formed as a consequence of biodegradation is caught from the off-gas of the biodegradation/bioelimination batches by adsorption in a diluted caustic soda solution.

Form this solution a sample is taken every day to determine how much caustic soda has been neutralised and thus, the mineralisation can be determined. So far, very few institutes and chemicals suppliers have introduced this significant improvement of the test. Also, the DIN EN ISO Norm has not been adapted so far. The determination of mineralisation confirms whether an observed bioelimination is really biodegradation or is due to adsorption only.

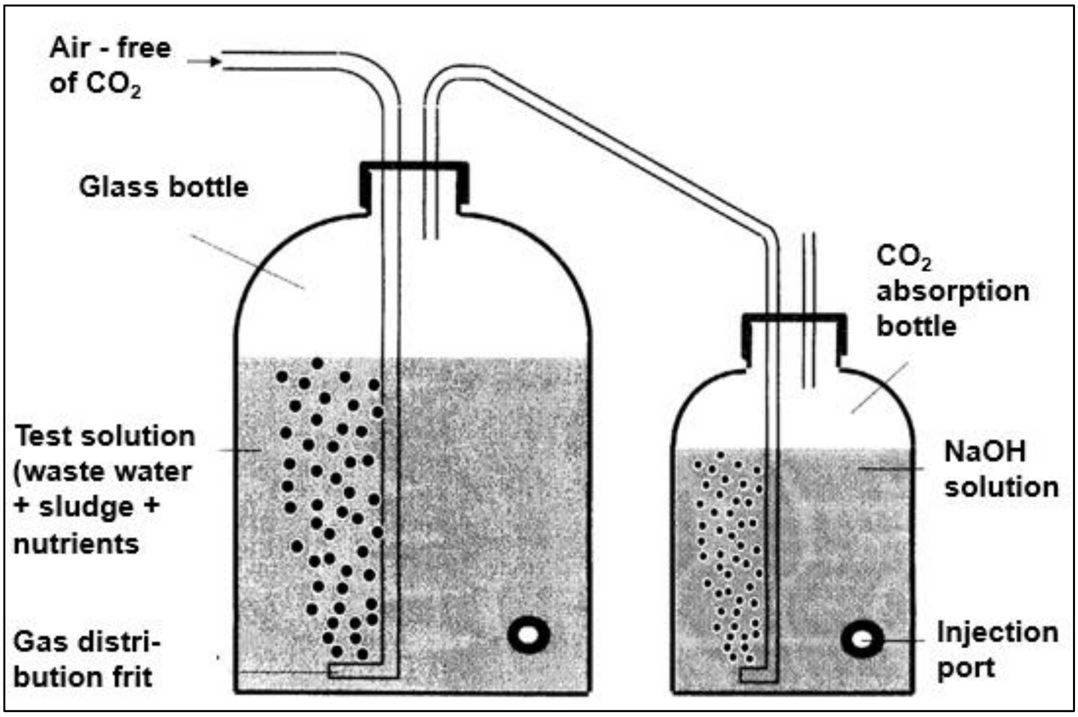

Fig. 8: Zahn-Wellens-Test with determination of mineralisation (Baumann, 2001)

This important improvement of the Zahn-Wellens-Test explains the term “Method: OECD 302 B with CO2 (mineralisation)” in Figure 4.

2.3.4.3 Test time

The modification of the Zahn-Wellens-Test was the introduction of the possibility to choose another concentration of sludge and related substrate concentration and to increase the test period from maximum 14 days to “up to 28 days”. The latter modification is important. As shown in Figure 4, the test period is often 28 days (sometimes also called “exposure time”). However, the testing time is important with respect to the transferability of the results. The question is whether the elimination rate after 28 days is also reached in real industrial or municipal WWTPs. There are very strong doubts that this is the case. If sludge is taken from the WWTP the wastewater to be investigated is discharged to, a testing period of 28 d appears to be far too long. In case of testing individual chemicals with an inoculum taken from a WWTP which is not adapted to that chemical, it may be meaningful to run the test for 28 days to see whether adaptation may occur. However, in case of investigating wastewater using inoculum from the WWTP the wastewater is discharged to, adaptation – if it occurs – is already there. Thus, the testing time should follow the time where the same elimination rate as in the real WWTP concerned is reached. Investigations at WWTPs operated at nitrifying conditions (<0.15 kg BOD_5/kg MLSS x d) showed that the elimination rate of the real WWTP is reached in the Zahn-Wellens-Test after 2-3 days (Killer/Schönberger, 1993). The inoculum concentration has an influence: i.e. the higher the inoculum concentration is the shorter the time of the Zahn-Wellens-Test is to reach the elimination rate of the WWTP. Against this background, a result after 28 days may be significantly higher compared to that which can be achieved in the real WWTP. In practice, this knowledge is often not considered. To be on the safe side, the German Wastewater Ordinance stipulates to take the elimination rate not after 2-3 but after 7 days (Abwasserverordnung, 2018)[4]. This is much shorter than a test period of 28 days which is often reported (see Figure 4). In addition, as also shown in Figure 4, only the elimination rate after the test period is reported but no intermediate values. It is often useful to know the elimination curve which shows all daily values. Two examples of bioelimination curves are illustrated in Figure 9 showing that the elimination rate after 28 days is much higher than after 7 or 14 days (curve on the right) and after 14 days is much higher than after 7 days (curve on the left).

[4] Annex 1 of the German Wastewater Ordinance mentions all related analysis and measuring methods. In No 408 of this annex (Aerobic degradability (eliminability) of the filtered sample from biological treatment plants), it is stated that the elimination rate refers to a test time of maximum seven days.

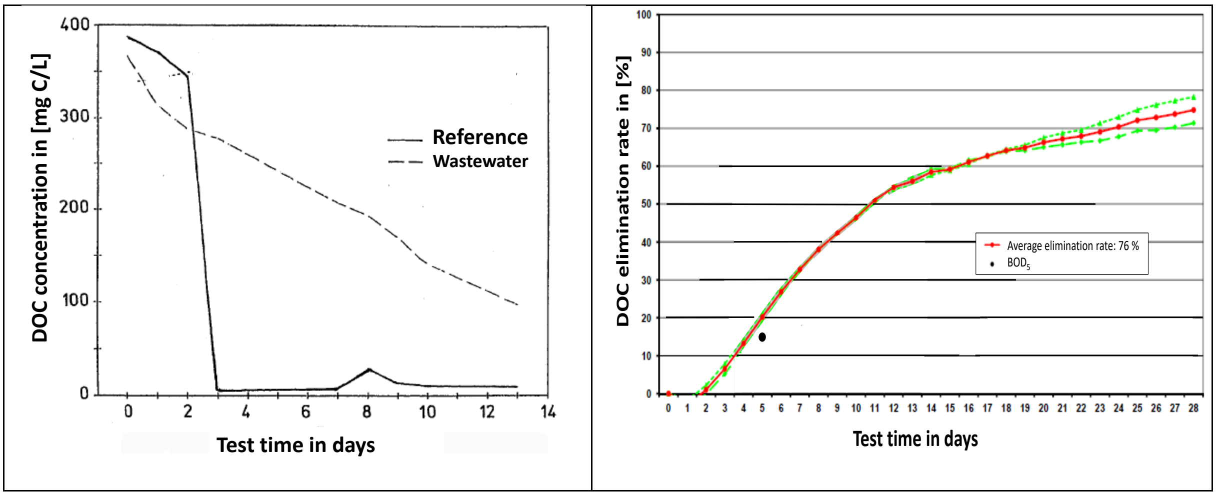

Fig. 9: Two examples of bioelimination curves determined by means of the Zahn-Wellens-Test, one with determination of mineralization (note that the curve on the left is showing the absolute DOC concentration whereas the curve on the right shows the DOC elimination rate)

2.3.4.4 Adaptation

There are chemicals which need adaptation to be biodegraded. A well-known example in the textile sector is polyvinyl alcohol (PVA)[5].In this case, the required enzymes have to be induced first. In practice, this induction happens if PVA is regularly discharged to the WWTP and certain system conditions are maintained (see footnote 5). In case of an activated sludge with no contact with PVA at all, the adaptation time may take three weeks. This means that for three weeks no biodegradation at all can be detected but after that time the biodegradation takes place (see curve WWTP Teufen in Figure 10). In contrast, in case of an activated sludge fully adapted to PVA (see curve Habis Textil in Figure 10), the biodegradation immediately starts.

[5] The specific COD of PVA is about 1700 mg/g and the specific BOD_5 is about 50 mg/g. At first sight, PVA does not appear to be biodegradable or is at least heavily biodegradable but under certain system conditions (low food-to-microorganism ratio, temperature above 15 °C and adaptation – see Schönberger et al., 1997 a and b), it is well biodegradable.

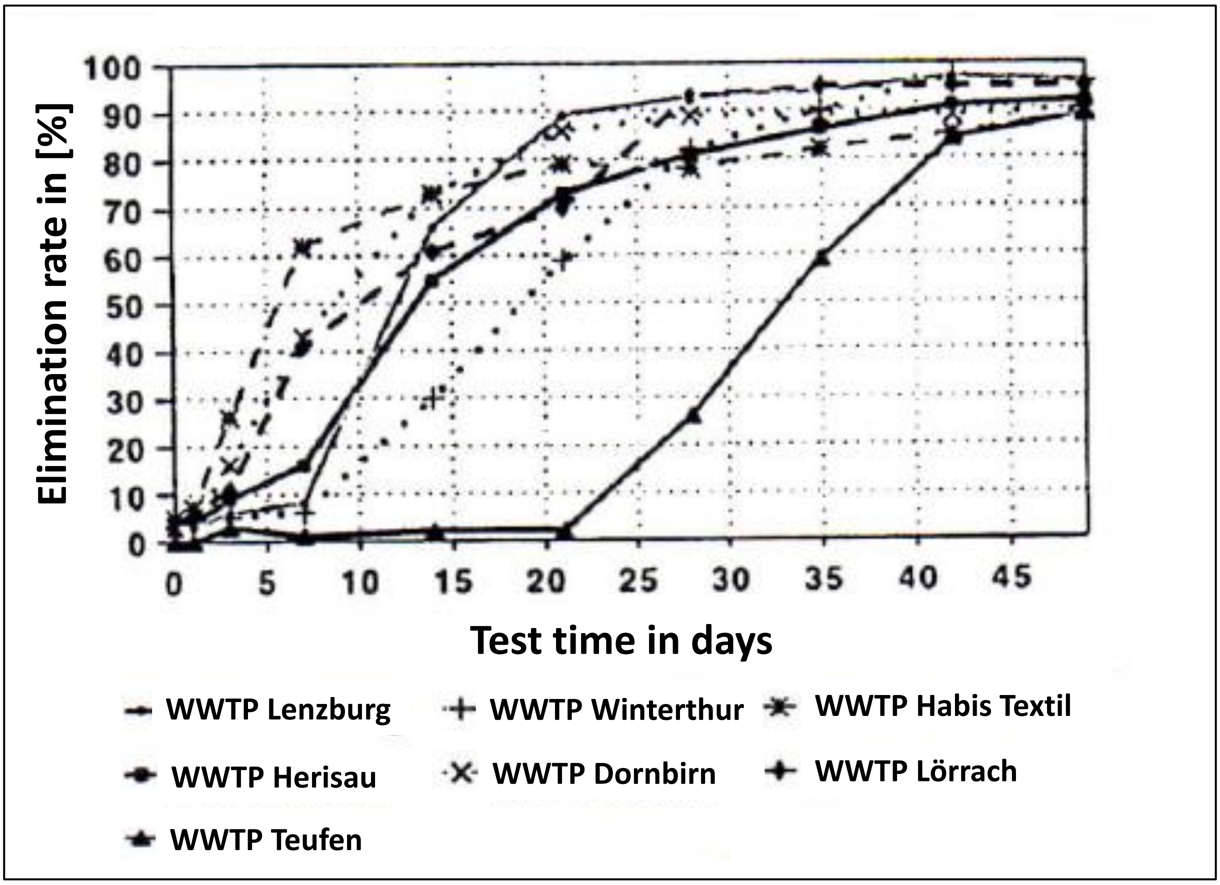

Fig. 10: Zahn-Wellens-Test results for polyvinyl alcohol (PVA) with activated sludges with different adaptation levels (Schönberger et al., 1997a and b): WWTP Teufen only receives domestic sewage and had no contact with PVA (no PVA adaptation at all), WWTP Habis Textil is a treatment plant of a textile company fully PVA adapted, the other WWTPs are municipal WWTPs receiving textile wastewater as well and show different degrees of PVA adaptation

It is important to stress that adaptation can occur but not necessarily for any chemical. Of course, there are cases where no adaptation happens such as for polysubstituted naphthalene derivatives as contained in many azo dyestuffs.

2.3.4.5 Investigation of formulations

MSDS often contain results on biodegradability/bioeliminability for formulations, i.e. for a mixture of different chemical compounds. An example is shown in Table 1.

Tab. 1: Composition of a textile auxiliary which is a formulation of different components

- Water	45 – 47 %
- D-Gluconic acid	16 – 18 %
- Phosphonate	5 – 7 %
- Polyacrylic acid	3 – 5 %
- Copolymer on acrylic acid basis	3 – 5 %
- Sodium gluconate	0.5 – 1 %
- Inorganic salt	19 – 23 %

The different components have different biodegradability/bioeliminability. Whereas D-gluconic acid and sodium gluconate are easily biodegradable, the phosphonate is not. The latter is water-soluble and does not adsorb to activated sludge. Polyacrylic acid and the copolymer on acrylic acid basis are also non-biodegradable. It can be expected that the copolymer does adsorb to activated sludge to a significant percentage. The adsorption rate of the polyacrylic acid present is not known.

As a consequence, the bioelimination curve shows that there are biodegradable but also non-bioeliminable components (Figure 11). As there is also the mineralization curve, one can be sure that there is a significant percentage of biodegradation (which can be expected because of the D-gluconic acid and sodium gluconate). But there must be also components which cannot be eliminated which can be explained by the aforementioned chemicals. However, in practice, in most cases, the composition of a formulation is not known but only the elimination rate of the whole formulation. Then it will not be possible to interpret and to understand.

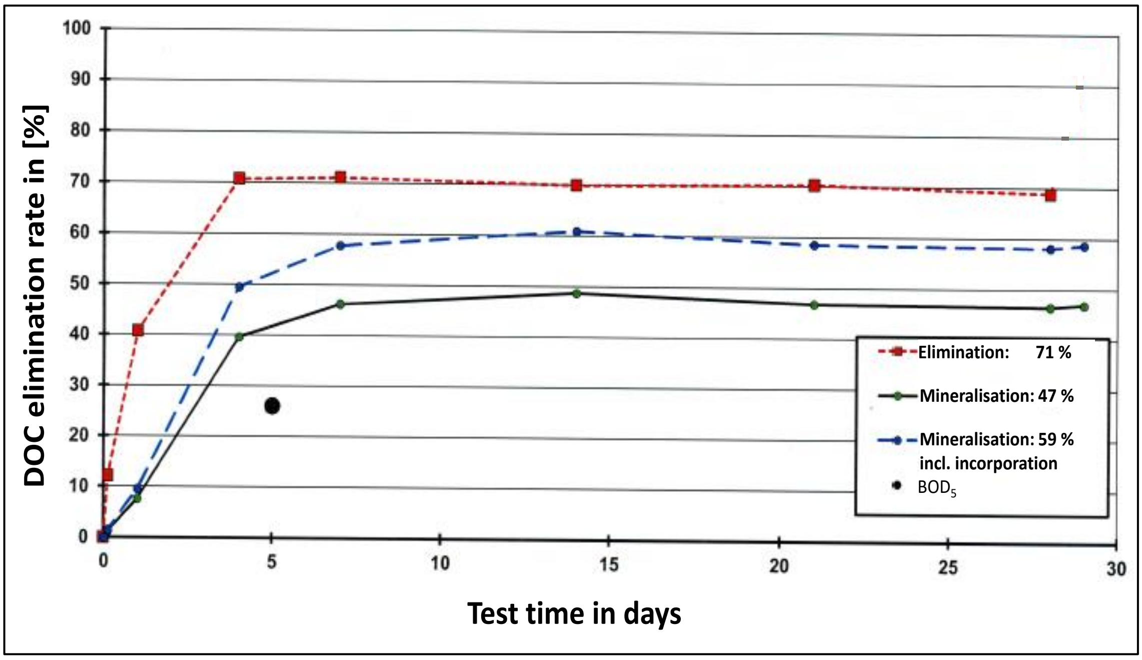

Fig. 11: Zahn-Wellens-Test with determination of mineralisation (Baumann, 2001)

2.3.5 COD/BOD$_5$ or BOD$_5$/TOC ratio

For a long time, it was common to assess the biodegradability by means of the COD/BOD$_5$ ratio. If the difference between COD and BOD$_5$ (whereas the BOD5 is a test according to OECD 301 – see 2.3.1 above) is big, i.e. the ratio is higher than 4:1 – 5:1, is was concluded that the chemical compound, chemical formulation or wastewater is heavily or non-biodegradable. The aforementioned PVA is a well-known example for that.

Against this background, it was interesting to compare this ratio with results from the Zahn-Wellens-Test. In a publication concerned, not the COD/BOD$_5$ ratio was used but the BOD$_5$/TOC ratio. However, in principle it is the same approach as TOC comprises all organic compounds and BOD$_5$ only the easily biodegradable ones. But as BOD$_5$ is the numerator, low BOD$_5$/TOC ratio indicate probable low biodegradability. It is very interesting to see that the correlation may be different depending on the test time of the Zahn-Wellens-Test. For 128 different wastewater streams from the chemical industry it could be shown that after 3 days only a few wastewater streams showed high bioelimination (values on the bottom right in Figure 12) whereas low BOD$_5$/TOC values correlated with low bioelimination rates in the Zahn-Wellens-Test.

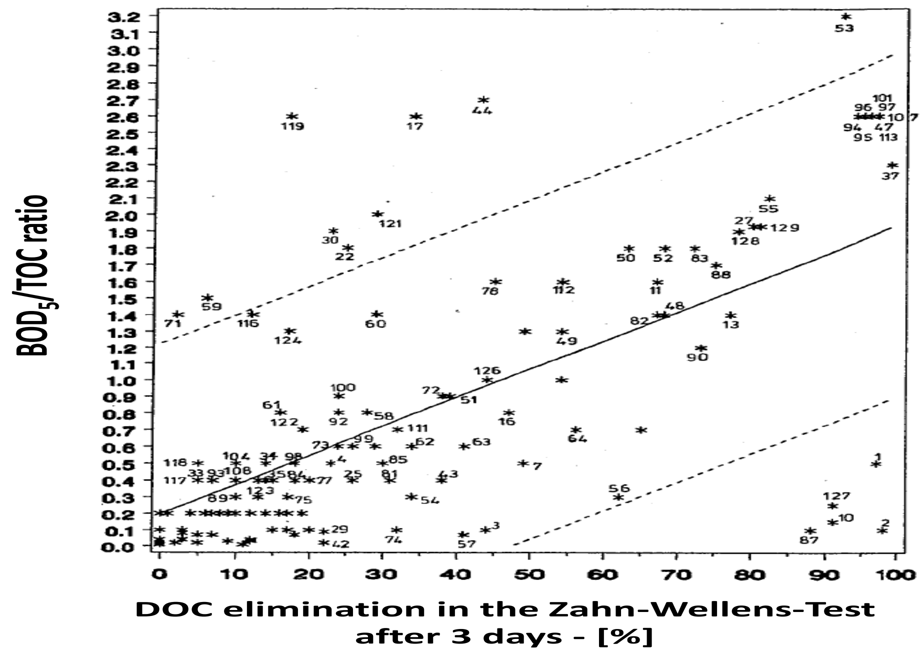

Fig. 12: Comparison of results of Zahn-Wellens-Tests after a test period of 3 days of wastewater from chemical production processes with the BOD_5/TOC ratio (Schönberger, 1991)

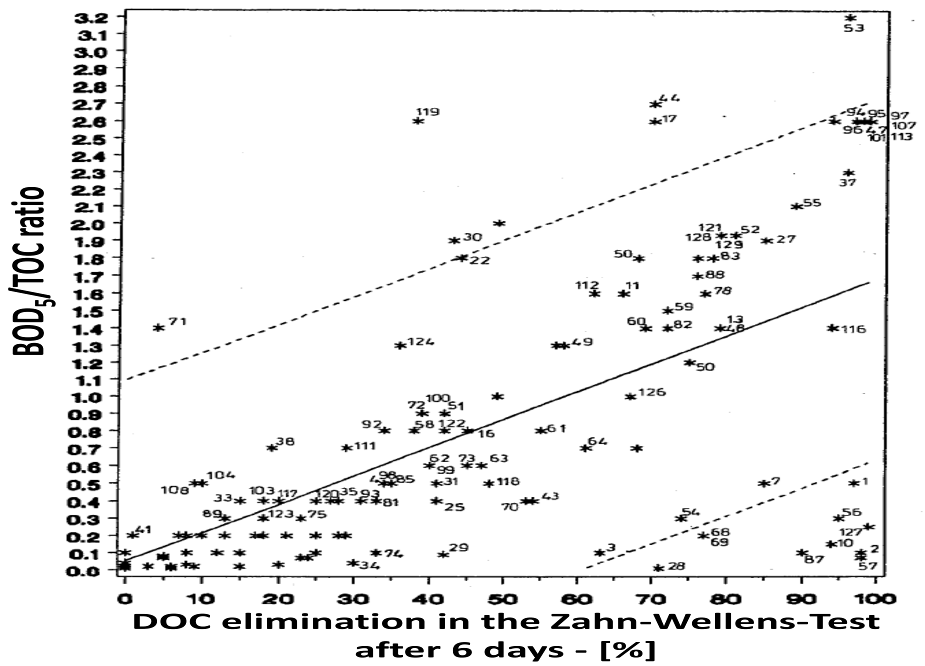

Fig. 13: Comparison of results of Zahn-Wellens-Tests after a test period of 6 days of wastewater from chemical production processes with the BOD_5/TOC ratio (Schönberger, 1991)

However, after 6 days (Figure 13), much more streams showed high bioelimination rates and even more after 13 days (Figure 14). This is due to adaptation (see also 2.3.4.4). However, many values remain in the corner on the bottom left indicating wastewater streams which contain chemical compounds which are heavily or non-biodegradable.

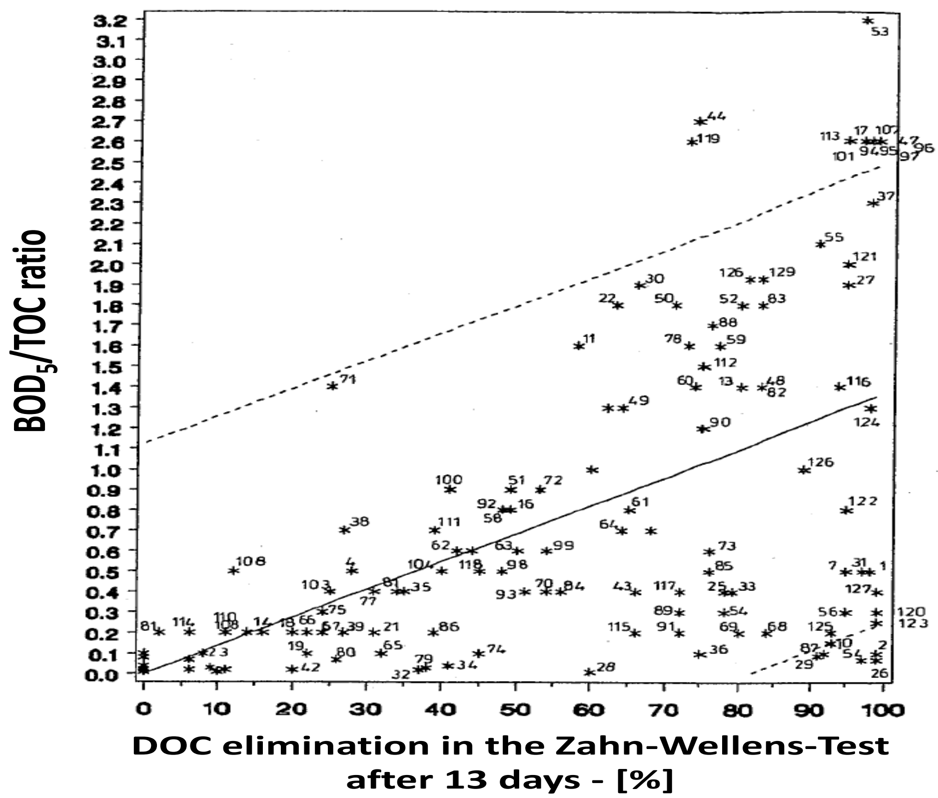

Fig. 14: Comparison of results of Zahn-Wellens-Tests after a test period of ***13 days*** *of wastewater from chemical production processes with the BOD_5/TOC ratio (Schönberger, 1991)*

3 Conclusion

The understanding and interpretation of data on biodegradability/bioeliminability need expert knowledge which has to be carefully applied. This paper shall contribute to develop it.

Concerning the testing of biodegradability and bioeliminability respectively, one has to distinguish between the testing of chemicals and wastewater. For wastewater with inoculum taken from the WWTP the wastewater investigated is discharged to, the test period should not be longer than 7 days as otherwise the test result is too positive and cannot be transferred to the WWTP concerned.

For a better understanding of the result from a Zahn-Wellens-Test, it is helpful to see the bioelimination curve and not only to consider the value after the test time.

Adaptation can be assumed if the inoculum is taken from the WWTP the wastewater investigated is discharged to. This is also a justification not to run Zahn-Wellens-Tests for wastewater longer than seven days (maximum 14 days).

The COD/BOD_5 or BOD_5/COD ratio do not reflect adaptation. Thus, in case of biodegradation of chemicals or wastewater which need adaptation, i.e. certain system conditions, the BOD_5/COD or BOD_5/COD cannot be directly used to conclude on low biodegradability.

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Fundamentals on the design of activated sludge systems and excess sludge formation

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1 Biological treatment principles

The goals of biological wastewater treatment are the removal of biodegradable (oxygen-depleting) organic carbons and the elimination of nitrogen and phosphorous fertilizers through the metabolic activity of microorganisms.
Biological wastewater treatment uses processes that occur naturally in bodies of water. In wastewater treatment plants, however, the processes are accelerated and controlled by means of higher microorganism density and injection of additional oxygen via aeration.
If large volumes of wastewater were discharged into natural waters without prior treatment, it would lead to a severe disruption of the natural balance. There would not be enough oxygen available for natural self-purification, and an oxygen deficit and eutrophication (over-fertilization) would result. In extreme cases, high fish mortality occurs.
Biological treatment of municipal wastewater and of many types of industrial wastewater is undertaken with the aid of aerobic processes. This requires an adequate amount of oxygen in the water to degrade contaminants.

The basic principle for aerobic decomposition of organic compounds is:

Substrate + O_2 → decay products + bacterial growth

A sufficient level of concentration of oxygen in the aeration tank is crucial. The oxygen content may not sink below 1 mg/l. The optimum concentration lies in the range of 2 to

3 mg/l O_2. It must be ensured that not only the biological oxygen needs but also the wastewater specific oxygen transfer factor is taken into consideration.
Bacteria oxidise a part of the energy-rich organic substances during energy metabolism under O_2 consumption into inorganic end products such as H_2O and CO_2. Through the oxidation, the energy stored in the organic materials is set free and used by the bacteria. This energy gain is high, resulting in a high growth rate or rather a low sludge age. The other part is converted during the anabolism, the building-up of biomass, as the bacteria grow and multiply. Each of the processes converts approx. 50% of the available substrate. Therefore, a lot of excess sludge arises from aerobic metabolism.

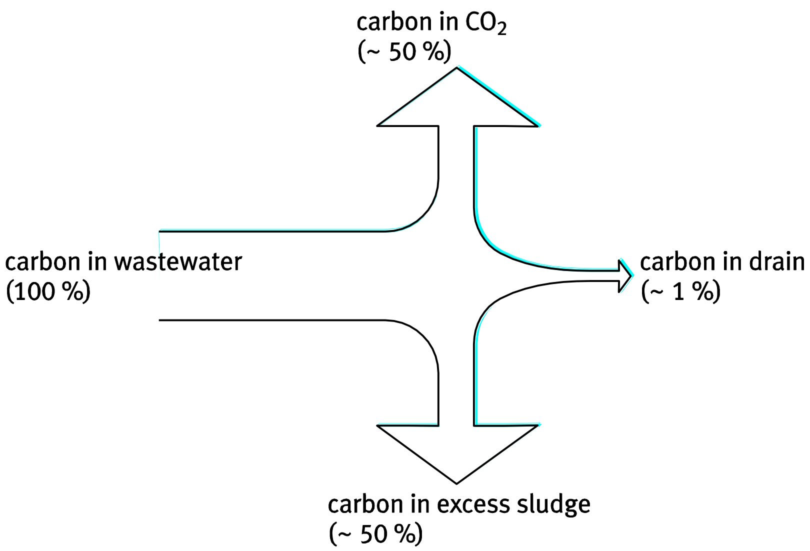

Fig. 1: Schematic carbon balance for aerobic metabolism

The following prerequisites must be fulfilled to successfully carry out wastewater treatment in a technical scale with optimized conditions:

- Increased biomass concentration
- Ensuring increased O_2 requirement is met, due to the increased metabolic rate (basic principle)
- Optimum contact between bacteria, substrate and oxygen (air)

It must be assumed that the respective available mixed biocenosis (symbiosis) of different bacteria adjusts itself to the nutrient conditions through the available

substrates. Interference in the microbial composition is usually not necessary, apart from damage to the biocenosis, e.g. through a blast of poison.
The activated sludge process is the one most commonly used in wastewater treatment plants.

1.1 Biological treatment – degradation and respiration

The biological degradation is done by bacteria. During this process the number of bacteria is increasing, CO2 and water are produced. If there is sufficient substrate in a batch reactor, first the bacteria adapt themselves to this substrate starting degrading substrate and producing energy and CO2. After that the number of bacteria is increasing with a constant exponential rate. If the substrate is mostly degraded the growth rate is decreasing and the mass of bacteria will be constant for a while. After this stage of stationary the bacteria will die with a small but constant rate (death phase). The specific curve is shown in the following figure:

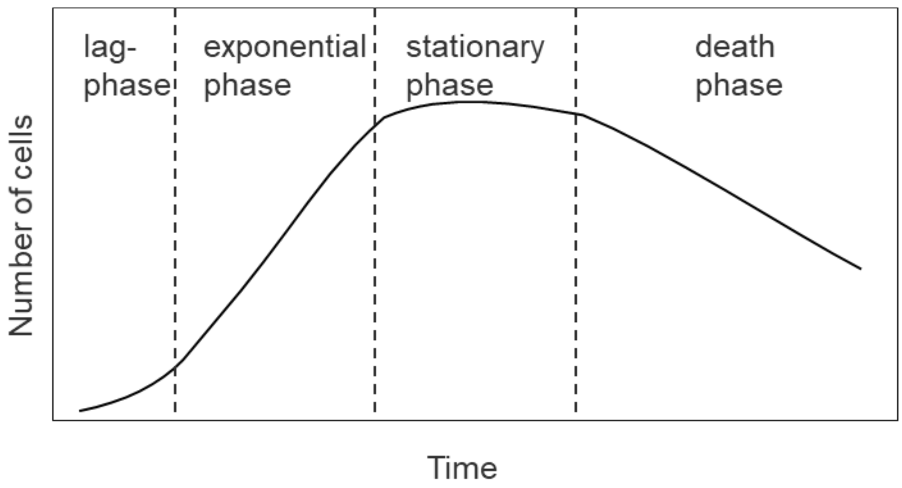

Fig. 2: Specific curve of bacteria growth and decay

The growth rate is following Monods law and is only depending on the level of substrate, the temperature and the type of bacteria. The following figure shows two curves of growth rate depending on temperature with sufficient substrate all the time.

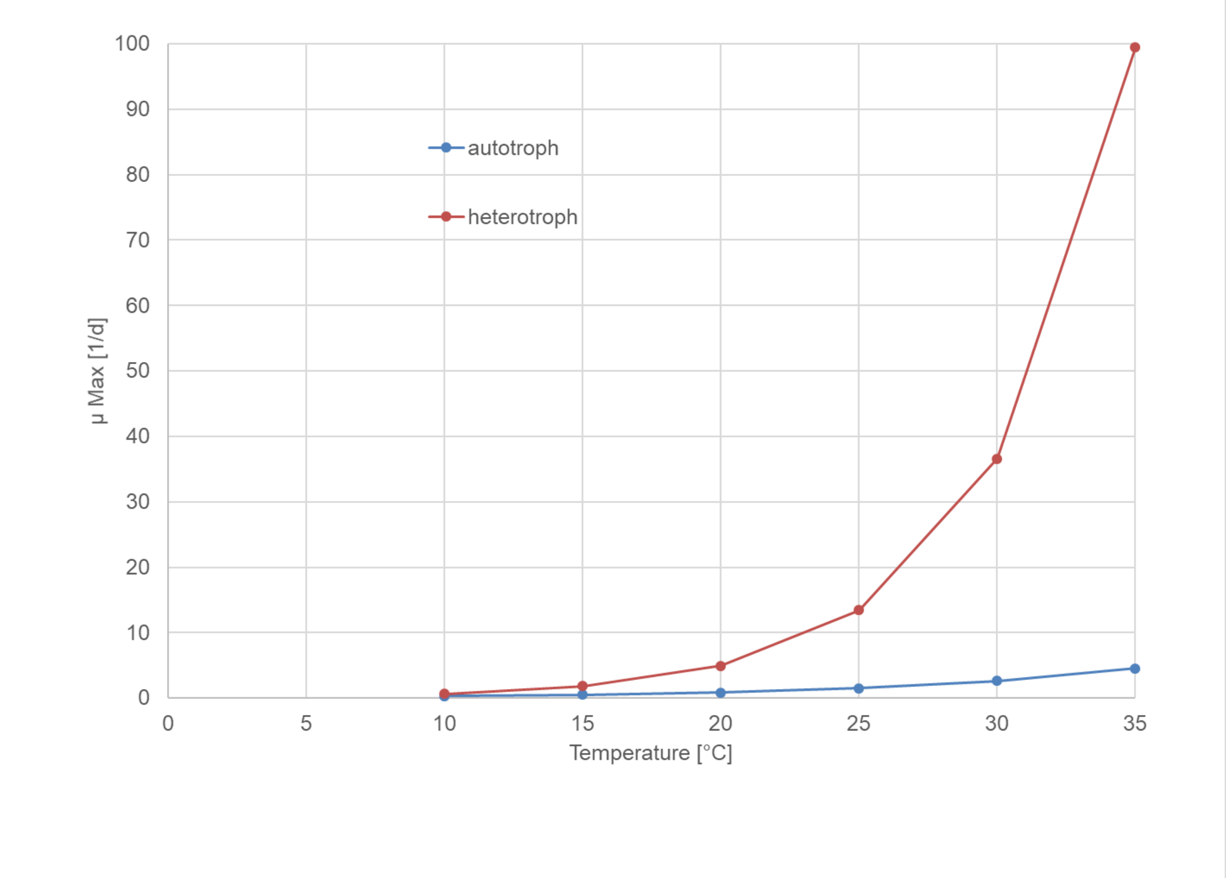

Fig 3: Growth rate in order of temperature

The growth rate of heterotrophic carbon degrading bacteria is much higher than of autotrophic ammonia degrading bacteria. With this difference of growth rate it is possible to control the sort of bacteria in a waste water treatment plant. If the sludge retention time is lower than the growth rate for one type of bacteria these types will be flushed off the system.

1.2 Bacteria growth – sludge retention time

The growth rate of most slowly increasing bacteria is relevant for the needed sludge retention time.

The growth of bacteria mass can be calculated out of the feed load, the temperature, the yield of substrate and the decay factor. To keep the amount of sludge in an aeration tank constant it is necessary to daily take off as much sludge as is produced in one day. The sludge age is not measurable. But the existing sludge age can be calculated out of the bacteria mass in the aeration tank and the daily amount of excess sludge. The existing sludge age in the tank is calculated according to the following equation:

$$SRT = \frac{V \bullet MLSS}{Q_{ES} \bullet MLSS_{ES}} = \frac{total\ Microorganism}{daily\ Excess\ Sludge}$$

with

SRT	= Solid Retention Time	d
Q_{ES}	= Volume of daily Excess Sludge	m^3
$MLSS_{ES}$	= Mixed Liquor Suspended Solids in Excess Sludge	kg/m³
MLSS	= Mixed Liquor Suspended Solids	kg/m³

The degradation rate is depending on the retention time in the reactor and the bacteria concentration. This means that the more bacteria are suspended and the longer the substrate is staying in the reactor the higher the degradation rate will be. The so-called food to mass or microorganism ratio is responsible for the efficiency of degradation of substrate. If the F/M ratio is low there is a lot to eat for the bacteria and the growth rate of bacteria is high. If the F/M ratio is low in the same tank the efficiency of the degradation is high and the growth of bacteria is low.
Therefore the sludge production and within this the excess sludge rate is depending on temperature and sludge age according to the following graph:

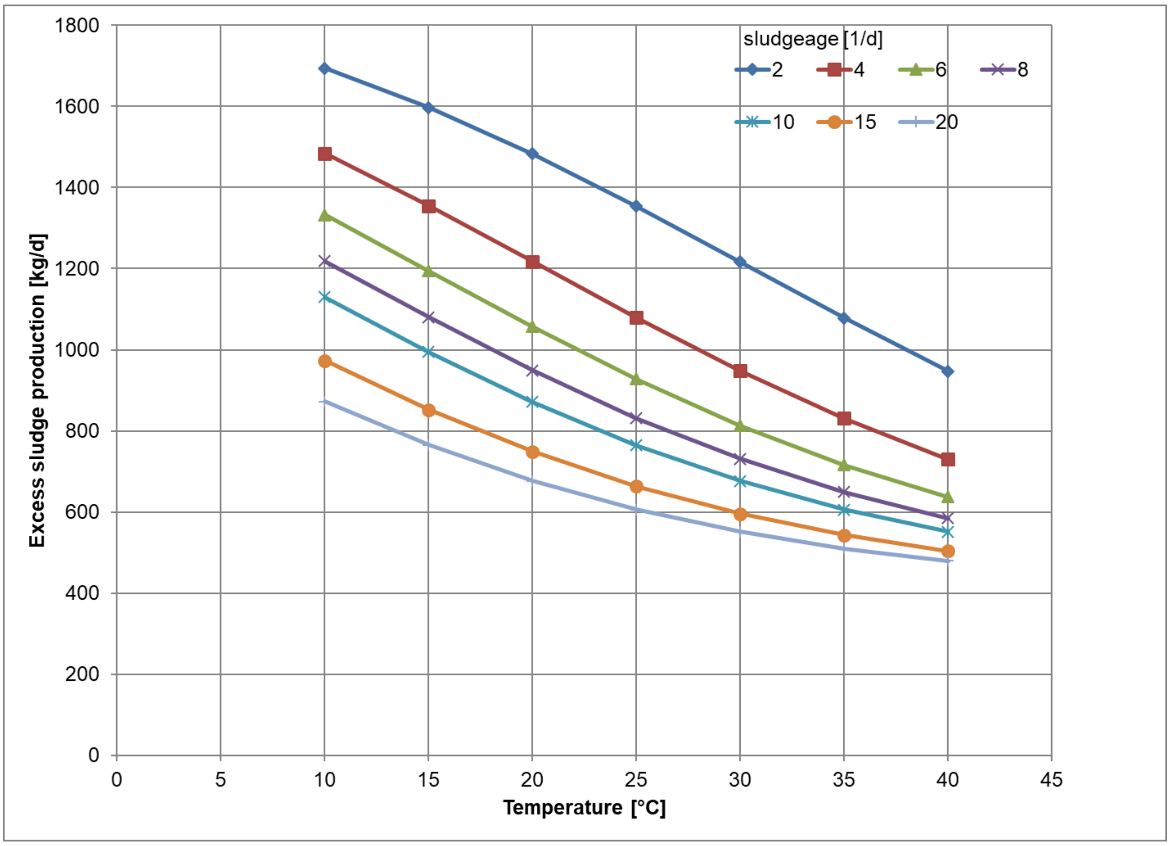

Fig. 4: Excess sludge production in order of temperature and sludge retention time

These graphs are calculated with the same reactor size, the same daily flow and load of COD.

1.3 Reactor design – F/M ratio

The correlation between bacteria mass and treatment efficiency is visualized in figure 5.

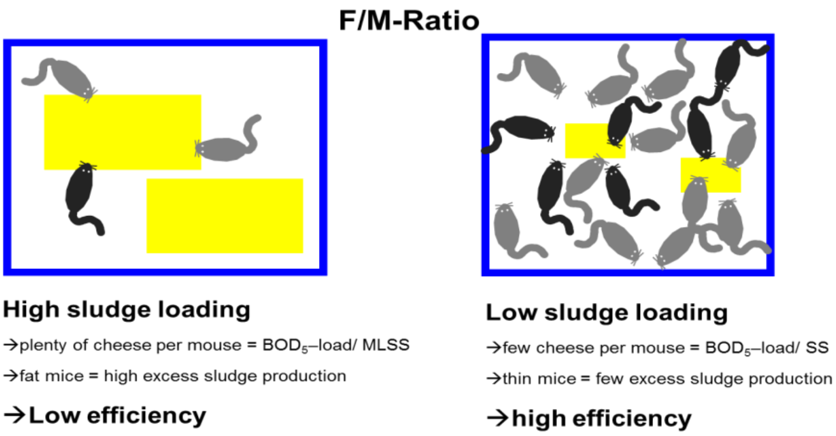

Fig. 5: Food to mass ratio

Assuming the sludge production and the sludge retention time, we know the total amount of biomass in the reactor.

$$M_{SS,AT} = td_{SS,dim} * Q_{ES\ d}$$

With the suspended dry matter in the aeration tank, which is belonging to the efficiency of the secondary sedimentation it is possible to calculate the reactor volume of the aeration tank.

$$V_{AT} = \frac{M_{SS,AT}}{SS_{AT}}$$

$M_{SS,AT}$ = mass of suspended solids in aeration tank
$td_{SS,dim}$ = dimensioned sludge age
$Q_{ES\ d}$ = daily excess sludge production
SS_{AT} = suspended solids in aeration tank

To control the calculation it is helpful to cross-check the sludge load in the aeration tank.

$$\frac{F}{M} = \frac{B_{d,BOD_5}}{V \bullet MLSS} = \frac{Food}{Microorganisms}$$

F/M	= Food/Microorganism- ratio	kg BOD_5/(kg MLSS*d)
$B_{d,BOD5}$	= Daily BOD_5 load in influent	kg/ m^3
V	= Volume of tank	m^3
MLSS	= Mixed Liquor Suspended Solids	kg/m³

The following table allows to bring the results of the sludge load calculation in correlation with experimental results and experience of many years of plants in work.

Tab. 1: Treatment targets and resulting sludge load, biomass concentration and sludge age

Treatment Target	Type of System	Sludge Loading	Biomass Conc. SS_{AT}	Sludge Age t_{SS}
		kg/(kg•d)	*kg/m³*	*d*
Part Treatment	High Loaded	≥ 1.0	1.5 – 2.0	≤ 1
BOD_5-Removal	Medium Loaded	0.25 – 0.50	2.0 – 3.0	2 - 4
Nitrification	Low Loaded	0.10 – 0.15	3.0 – 5.0	7 - 12
Nitrification and Denitrification	N-Elimination	0.07 – 0.09	3.0 – 5.0	12 - 15
Aerobic Stabilization	Extended Aeration	0.04 – 0.07	3.0 – 5.0	15 - 30

DIN EN 12255-6 (4/2002)

All these results are for biological treatment of municipal wastewater and a temperature of about 15°C. If the sludge load is lower than 1 kg BOD/kg sludge a sludge age of max 1 d is to be implemented to keep the sludge content stable. Below a load of 0,5 kg/kg the BOD is totally removable and the sludge age should be between two and four days. Lower load leads to higher sludge age and autotrophic bacteria are able to survive. The result is partial or total nitrification.

2 Example: The biological treatment plant Dulal Brothers in Bangladesh

The daily wastewater flow is 7.200 m³/d with a BOD concentration of 300 mg/L (1000 mg/L COD). The BOD load is 2.160 kg/d, COD load = 7200 kg/d
The volume of the aeration tank is 15.000 m³ with MLSS of 2 g/L. The biological mass is 30.000 kg in the reactor. This means that the sludge load in the reactor is BSS = 2.160 /30.000 = 0,072 kg/kg. The temperature in the reactor is between 32°C and 35°C, i.e. with a sludge age of more than 15 d there will be an excess sludge production of about 500 kg/d.

Within the same reactor it would be possible to treat a COD load of 60.000kg/d or BOD 30.000 kg/d. The sludge load is BSS = 0,5 kg/kg and depending on the sludge retention time the sludge production will be three times higher.

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Disposal of sludge from textile wastewater treatment in cement plants

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Abstract

Textile sludge can be disposed of in a cement kiln. Since some of the sludges contain a high percentage of organic compounds, they must never be mixed with the raw material, but must be incinerated. This means that such sludge must be added either to the primary or secondary firing. This requires, however, that the sludge used has certain homogeneity. Excessive fluctuations in the calorific value would cause disturbances in the kiln system.

With the exception of mercury, heavy metals are no problem with regard to emissions to air and the quality of the clinker. Some textile sludges can deliver a fairly large additional proportion of emissions. The mercury content of the sludges must therefore be monitored and sludges with excessively high contents excluded from use.

1 Introduction

In Asia, wastewater from wet processing of textile is increasingly treated. The reduction of the organic load is usually carried out by means of biological treatment, mainly in activated sludge systems. This is associated with significant amounts of sludge. As a rule of thumb, bacteria of activated sludge convert about half of the degraded organic compounds into biomass. This means that 1 kg of the biochemical oxygen demand results in about 0.5 kg of biomass (as dry matter). In plants with extended aeration, i.e. they are operated at low food-to-microorganism ratio (F/M) (< 0.05 – 0.1 kg BOD_5/kg MLSS x d), the biomass generation can be significantly lower (about 0.25 – 0.35 kg biomass (as dry matter) per kg BOD_5 degraded) and almost zero at F/M lower than 0.05 kg BOD_5/kg MLSS x d and at F/M lower than

0.1 kg BOD_5/kg MLSS x d if, at the same time, the wastewater temperature is high, i.e. higher than 30 °C. In addition, fibers present in textile wastewater can increase the sludge quantity. The same is true if organic agents for decoloration are used. In case a precipitation/flocculation stage using mainly inorganic chemicals (iron or aluminum salts) is applied prior to biological treatment, the additional sludge generation can be significant.

Against this background, increasing amounts of sludge have to be tackled in an environmentally-friendly manner. Repeatedly, the option of co-incineration in clinker[1] production plants is proposed for doing so. However, this option is often not well understood. Therefore, the subject of this study is to closely look into the possibility of disposing of textile sludge in a clinker (cement) production plant and to define adequate conditions concerned. For this purpose, it is assumed that this sludge should be used in a cement kiln system with a preheater but not in a wet or semi-wet kiln.

2 Relevant Data

2.1 Chemical data

The composition of textile sludge is determined by the manufacturing processes and treatment processes of textiles and the chemicals used.

As these processes are constantly changing, the concentrations of organic compounds, heavy metals and other compounds can vary over a wider range. For an assessment of an application in a cement plant, therefore, the analyzed contents of 21 textile sludges analyzed by EcoMetrix in April/May 2011 (EcoMetrix, 2011) are used.

[1] Clinker is produced by sintering of limestone and aluminosilicate materials such as clay and other materials in rotary kilns. Together with additives such as fly ash or blast furnace slag, it is ground to produce cement.

Tab. 1: Comparison of the analysis results of 21 textile sludge samples from Bangladesh (EcoMetrix, 2011) with analysis results from thousands of municipal sludge samples in Germany (UBA, 2018)

		Textile sludge - values from 21 Bangladeshi sludge samples (EcoMetrix, 2011)			Municipal sludge in Germany - ranges from (UBA, 2018) from thousands of samples
		Minimum	Maximum	Average	Minimum - maximum
Moisture	[%]	36.1	92.6	70.4	65 - 75
Dry Matter	[%]	7.4	63.9	29.6	30
Loss on Ignition	[%]			90*)	45 - 80
Ammonium-N	[%]	0.005	0.55	0.1	
TOC	[%]	1.1	44.7	11	33 - 50
AOX	[mg/kg]	4.3	2200	263	200 - 400
Arsenic	[mg/kg]	2	25	4.5	4 - 30
Cadmium	[mg/kg]	0.2	8.9	0.9	1.5 - 4.5
Chromium	[mg/kg]	17	140	56	50 - 80
Cobalt	[mg/kg]	3	21	10	6.5
Copper	[mg/kg]	9.2	1100	173	300 - 350
Lead	[mg/kg]	9	280	32	70 - 100
Manganese	[mg/kg]	43	2000	560	600 - 1500
Mercury	[mg/kg]	0.05	1.6	0.2	0.3 - 2.5
Molybdenum	[mg/kg]	2	3.8	2.2	3.9
Nickel	[mg/kg]	8.7	94	25	30 - 35
Thallium	[mg/kg]	0.1	0.2	0.1	0.2 - 0.5
Tin	[mg/kg]	1	44	9.2	30 - 80
Vanadium	[mg/kg]	3	100	26	10 - 100
Zinc	[mg/kg]	200	4100	916	100 - 300

*) Only one value

2.2 Chemical data

The term "textile sludge" is a collective term for sludges from the textile industry, whereby the composition of the sludges depends on the production process, the substances used, etc. The chemical composition of the sludges can therefore be quite different.

In a co-combustion of textile sludge, the organic substances of the sludge and thus also the organic pollutants must be destroyed. An important parameter is therefore the calorific value or the loss on ignition, which indicates a high organic content in the sludge. Another important parameter is the water content, since the water content reduces the calorific value of the sludge.

As Table 1 shows, textile sludges can have quite different moisture contents. The large proportion of dry sludge is volatile organic compounds and little ash, which is also confirmed by the published calorific value (Anwar et al., 2018) of 17.9 MJ/kg and the loss on ignition values (“weight loss”) of 80 % (Iqbal et al., 2014).

The calorific value of the wet sludge is a function of the calorific value of the dry sludge minus the corresponding evaporation heat of the water. Figure 1 shows the calorific value in function of water content and for different calorific values (parameter) of the dry sludge.

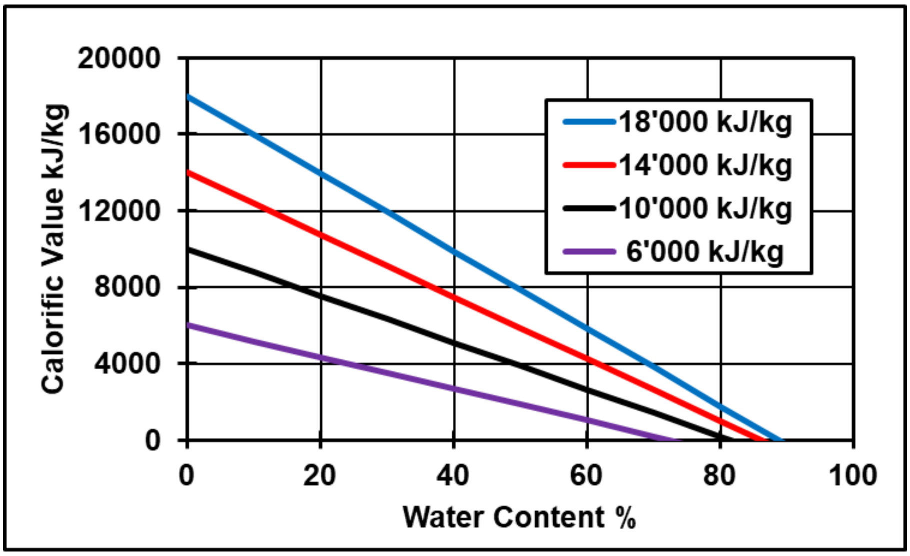

Fig. 1: Calorific value in function of water content and the caloric value of the dry substance (Parameter)

3 Suitability of sludges

3.1 Required homogeneity

In a cement kiln, the raw material used must have a certain homogeneity (chemical composition), and the same applies to all fuels used.

The required homogeneity of such sludge depends on the following factors:

1. Fluctuation of the heat value in the sludge (short term: minutes)
2. Fluctuation of the mass flow of the sludge into the kiln (given by the quality of the dosing system; short term: minutes)
3. Substitution rate

The combined influence of the first two factors produces the fluctuation of the heat input into the kiln by the sludge. The fluctuation of the total heat input into the kiln needs to be below a certain level.
As a rule of thumb, the following formula applies:

% Fluctuation (heat input) x % Substitution < 100 %
where:

% Fluctuation ~ (maximum – minimum) / average x 100
% Fluctuation (heat input) = fluctuation heat value + fluctuation mass-flow
% Substitution = % of heat consumption of kiln

If the fluctuations are higher, impacts caused by the inhomogeneity have to be expected (e.g. CO formation, increased heat consumption, reduced production capacity …)
Examples:

20 % Substitution: < 5 % fluctuation of heat input to avoid negative impacts
10 % Substitution: < 10 % fluctuation of heat input to avoid negative impacts
5 % Substitution: < 20 % fluctuation of heat input to avoid negative impacts

3.2 Homogeneity of the sludge

The measured dry matter and water content of the 21 samples from April/May 2011 vary in a very large range (EcoMetrix, 2011). However, this also means that the calorific values fluctuate accordingly.
This textile sludge with such a variation in the water content respectively in the calorific value must under no circumstances be placed in a cement kiln. Kiln fluctuations and disturbances are to be expected which would not be acceptable under any circumstances. The sludge should not be used without homogenization and/or prior drying.

3.2.1 Dry textile sludge

One possibility, however, would be to dry and homogenize this sludge to a residual moisture of 10% or less, whereby the fluctuation of the calorific value should be as small as possible.

3.2.2 Wet textile sludge

If this sludge is to be used wet, it must be homogenized. This means that sludge with acceptable average water or solids content must be formed and this value may only vary within a certain range, e.g. 20%. From the measured sludges, for example, a homogenized sludge of approximately 30 % dry matter (average value) could be produced without further heat and with some effort the variation respectively the calorific value could be kept below 20 %. Considering the input fluctuations (fluctuation of the input device) in a cement plant, an input of 3 to 4 % of the total heat consumption of the kiln could be possible. (cf. 3.1).

4 Disposal of the sludge in a cement kiln

The cement kiln has three input points for waste (Figure 2), namely:

- the main burner at the rotary kiln outlet end (1)
- the secondary firing (2) for which a number of different versions exist (see the list below)
- the raw material route (3)

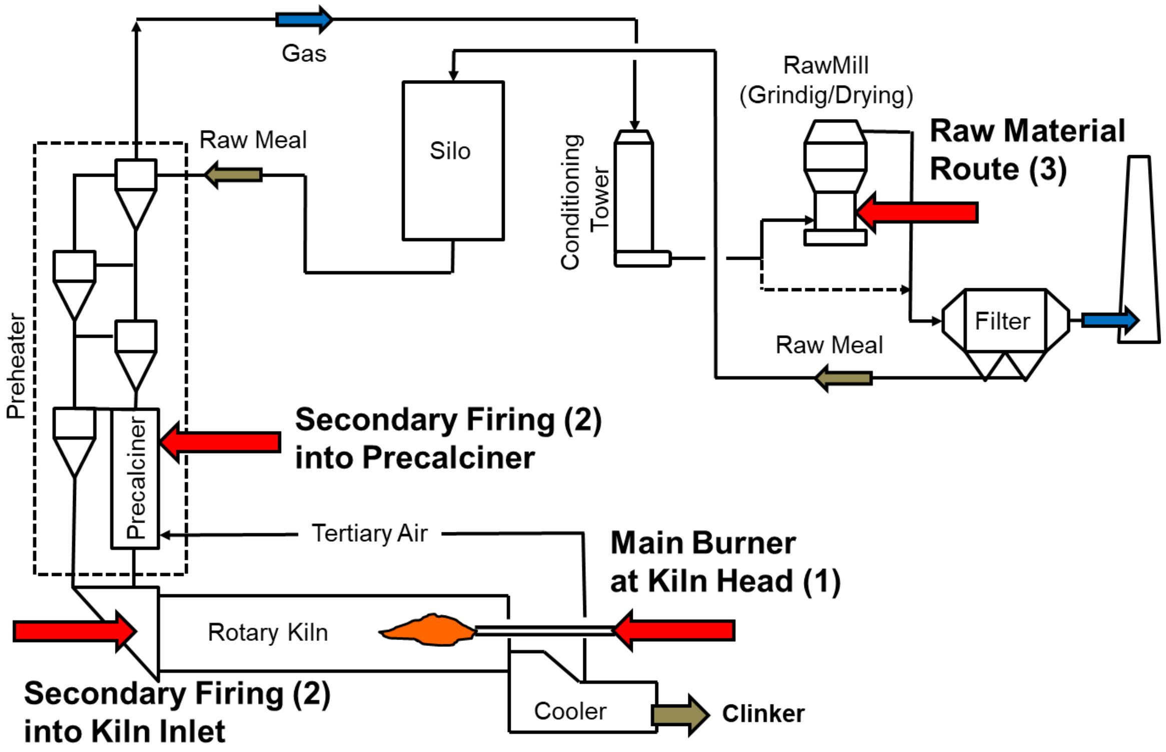

Fig. 2: Overview of a cement plant with the indication of the basic points (numbers 1, 2 and 3) for the feeding of waste-derived fuels and (waste-derived) raw materials.

Concerning the secondary firing, the following feeding points exist in practice:

- via a feed chute at the transition chamber at the rotary kiln inlet end (used for lumpy fuels such as waste tires)
- via secondary burners to the riser duct
- via a precalciner without a burner (so-called flameless combustion)
- via a precalciner equipped with a burner
- via a pre-combustion chamber, that is not equipped with a burner (so-called flameless combustion), prior to the precalciner
- via a combustion chamber, equipped with a burner, prior to the precalciner
- via circulating fluidized bed prior to the precalciner

4.1 Primary (or main) flame

4.1.1 Firing conditions

The maximum temperature in the flame is about 2000 °C and in the rotary part of the furnace the gas stays above 1200 °C for at least 6 seconds. Due to the clinker quality, the burning process in the area of the sintering zone (flame) must be operated with excess air. Therefore, it is expected that the organic substances in this zone will be completely oxidized.

Own investigations at the kiln inlet (transition part rotary kiln / preheater) at several furnaces without secondary firings have shown that all organic substances were oxidized and no organic compounds, in particular no chlorinated organic compounds, could be detected.

4.1.2 Incineration of dry textile sludge

It would be possible to burn this sludge via the main burner. This would have the advantage that all organic compounds would be oxidized and there would be no additional emission of organic substances at the stack.

The condition for an input on the main flame, however, would be that the sludge is dried in advance to a remaining water content of 10% or less and homogenized so that the fluctuations in the calorific value are less than about 5%. Wet textile sludge with high water content should not be fed to the main flame anyway. These fuels reduce the flame temperature due to their low calorific value and this can have a negative effect on the temperature required for clinker formation.

The amount of (dry) textile sludge that can be added via the main flame depends strongly on the burner construction. With an optimal construction, experience with dried sewage sludge has shown that up to about 10 % of the heat requirement can be burnt in the main flame. However, the mass flow of sludge with calorific values below approximately 10’000 kJ/kg] should be limited to approx. 4 t/h.

Assumed kiln characteristic

- Production: 2400 t/day or 100 t/h
- Raw meal mass flow: 165 t/h
- Heat consumption: 3.8 MJ/kg Clinker

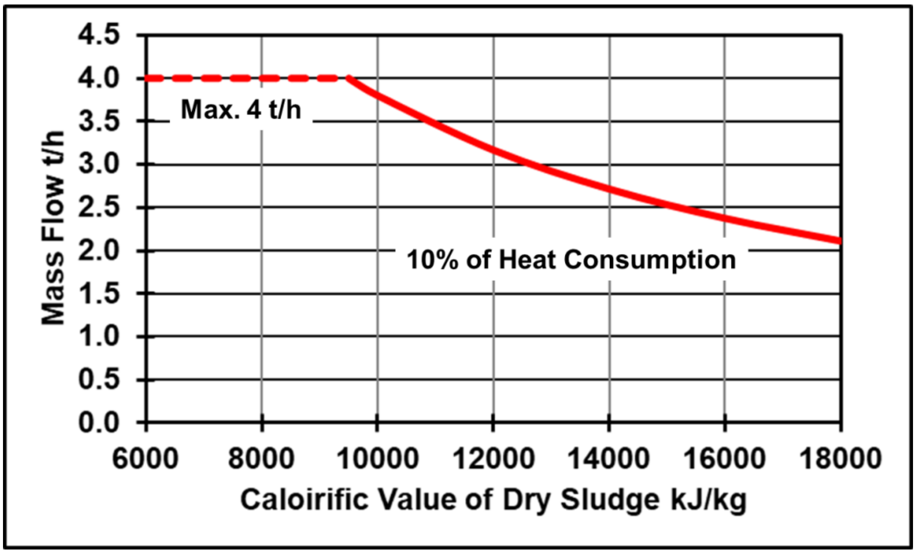

Fig. 3: Maximum input of dried sludge (water content < 10%) for a 10 % replacement of heat consumption of the kiln

4.2 Secondary firing

4.2.1 Firing conditions

In terms of secondary firing, a distinction must be made between the direct input of fuel to the kiln (e.g. tires) and the input of fuel to a special combustion chamber, the calciner. A maximum of about 20 % of the total heat consumption of fuels can be fed into the kiln inlet. The input to the calciner is 40 to 60 %, depending on the design.

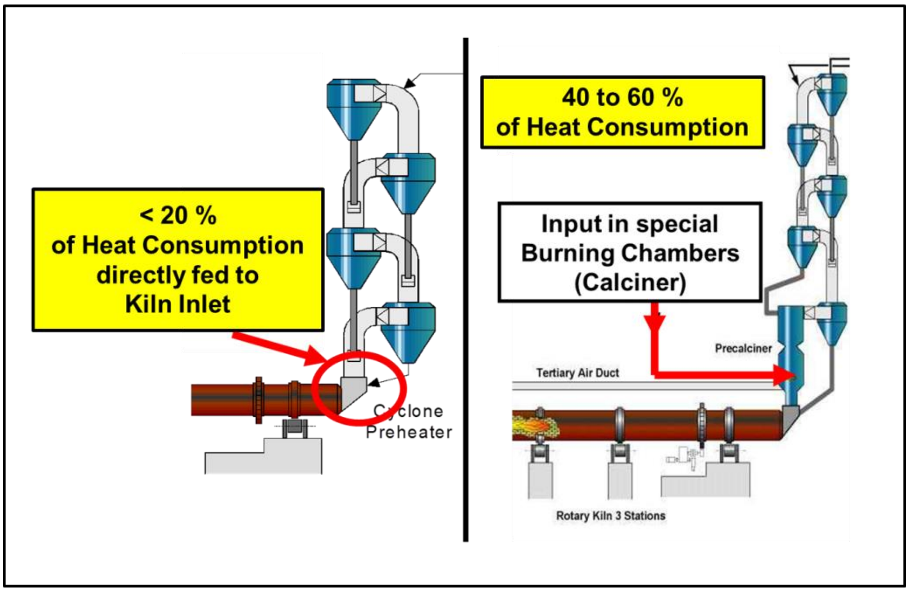

Fig. 4: Fuel Input in Secondary Firings

4.2.2 Co-incineration of textile sludge

Assuming that the sludge can be homogenized up to a variation of the water content below 20 % of the average and that the feed system causes few fluctuations, this corresponds to 3 to 4 %, in the optimal case 5 % of the heat consumption of the kiln. For a kiln described below, the possible mass flow (in t/h) of the textile sludge as a function of the heat input was calculated as a percentage of the total heat consumption of the kiln and as a function of the calorific value of the dry sludge and shown in Fig.4.

Assumed kiln characteristic

- Production: 2400 t/day or 100 t/h
- Raw meal mass flow: 165 t/h
- Heat consumption: 3.8 MJ/kg Clinker

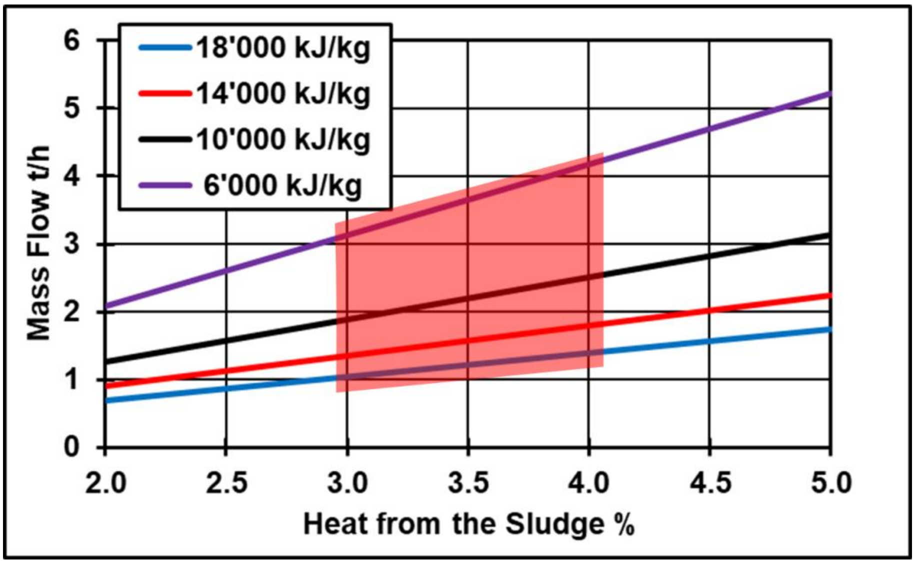

Fig. 5: Mass of sludge in function of heat input of sludge and calorific value of substance; red = recommended range fuel input in secondary firings

In secondary firing, the combustion conditions are much less rigid compared to the kiln when waste-derived fuels, such as sludge, are fed via the main burner. The gas temperature level is much lower (850 - 1100 °C) and the retention time can be less than one second. As a consequence, the incineration can be incomplete. There are cases known where the incineration conditions are highly incomplete resulting in high emissions of carbon monoxide, volatile organic carbon, also including hazardous substances such as benzene. However, in well-designed and well-operated calciners, the incineration conditions can be almost complete which is indicated by resulting carbon monoxide concentrations below 500 mg/Nm^3 and only traces of organic compounds at the outlet of this burning zone.

4.3 Input via raw material route

The addition of this sludge to the raw material would be the easiest way of disposal. **But this method is not a thermal disposal of the sludge and should not be made.** The organic compounds in this sludge are only adsorbed. Adsorption is the attachment of atoms, ions or molecules from a gas, a liquid or a dissolved solid to a surface. That is, the organic substances are only slightly embedded in the base material. A reaction with the base material (absorption) usually does not take place.
When such slurry is mixed in the raw material, it will be slowly heated in the kiln system and the organic compounds evaporate below about 400 °C and are emitted. So critical organic substances do not get into temperature zones where they are oxidized.

5 Heavy metals

The textile sludge contains some heavy metals. In the following, the emission factors EF published by the VDZ (VDZ, 2018) or my own factors (Mo and Zn) are used to calculate the possible emission and integration into the clinker for a sludge the maximum (dry) mass flow of 4 t/h.

Tab. 2: Emission and Input into the Clinker from the Textile Sludge

Heavy Metals	**Max. Content mg/kg**	**Factor EF %**	**Input g/h**	**Emission mg/m^3_N**
Arsenic	25	0.023	99	0.0001
Cadmium	8.9	0.17	260	0.0003
Chromium	140	0.012	288	0.0003
Cobalt	21	0.019	68	0.0001
Copper	1100	0.0093	1756	0.0018
Lead	280	0.05	2403	0.0024
Manganese	2000	0.018	6180	0.0062
Molybdenum	3.8	0.01	27465	0.0000
Nickel	94	0.03	7	0.0005
Thallium	0.2	1.3	484	0.0000
Tin	44	0.074	45	0.0006
Vanadium	100	0.052	559	0.0009
Zinc	4100	0.01	893	0.0070

5.1 Influence on stack emission and on clinker

The calculated emission is generally well below the detection limit of the corresponding element. The influence of the textile sludge is therefore marginal. Also an increase of the input over the assumed maximum mass flow of 4 t/h does not change this statement. A comparison of the influence of textile sludge with the detection limits (VDZ, 2018) and with the Swiss limits for clinker produced with waste (VVEA, 2018) shows a negligible influence. Quality problems with the clinker can thus be excluded, even if the input would be increased over the assumed 4 t/h.

Tab 3: Assessment of the calculated values

Assessment of Values	Influence on Emission		Influence on Clinker	
	Detection Limit mg/m^3_N (VDZ, 2018)	Emission mg/m^3_N	Limit mg/kg Clinker (VVEA, 2018)	Input mg/kg Clinker
Arsenic	0.0011	0.0001	15	0.0010
Cadmium	0.0001	0.0003	5	0.0004
Chromium	0.0017	0.0003	250	0.0056
Cobalt	0.0002	0.0001	125	0.0008
Copper	0.0013	0.0018	250	0.0440
Lead	0.0030	0.0024	250	0.0112
Manganese	0.0050	0.0062	---	0.0800
Nickel	0.0013	0.0005	250	0.0038
Thallium	0.0003	0.0000	---	0.0000
Tin	0.0001	0.0006	50	0.0018
Vanadium	0.0003	0.0009	---	0.0040
Zinc	0.0050	0.0070	750	0.1640

5.2 The emission of mercury

The element mercury is an exception. Here, influences of the textile sludge can be expected. The following values were calculated under the condition that all mercury is emitted and nothing is discharged from the system via a dust outlet.

Tab 4: Influence of Mercury (Hg)

Hg-Values	**Content mg/kg**	**Emission mg/m^3_N**
Maximum	1.6	0.0275
Average	0.2	0.0034
Minimum	0.05	0.0009

Compared with the German emission limit values (17. BImSchV, 2013) of 0.03 (daily average value) or 0.05 mg/m³ (half-hourly average value), textile sludges can deliver a fairly additional large proportion of emissions; even exceeding the limit values is possible.

The mercury content of the sludges must therefore be monitored and sludges with excessively high contents excluded from use.

6 Conclusions and recommendations

Textile sludge can be incinerated in the cement plant, but the following conditions must be met:

- Use in the main flame: Only dry sludge (moisture < 10 %) can be used here and a maximum of about 10 % of the heat consumption of the kiln can be replaced. In any case this input point guarantees complete oxidation of all compounds.
- Use in secondary firing: Wet sludge can also be used here, but the humidity respectively the calorific value must not fluctuate by more than 20%. Under these conditions, a replacement of the heat requirement of 5% is then possible.
- Addition to the raw material: Under no circumstances must the sludge be disposed of via the raw material path. The organic compounds evaporate in this way and are emitted at the chimney.

With the exception of mercury and thallium, all heavy metals are largely incorporated into the clinker. Thus not only the calorific value of the sludge is used, but at the same time all heavy metals of the sludge are completely "disposed of".

Sludges with high mercury contents may cause emission problems and should not be incinerated.

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