Recent progress of waterless technologies for Jeans washing in denim industry

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Abstract: This review focuses on the current situation of sustainable development of denim industry and analyzes the water consumption in the production process of denim. In the washing process of jeans, the dry treatment or near-anhydrous treatment is becoming a sustainable trend to replace the traditional wet treatment. From the perspective of environmental protection, this review summarizes the recent research frontiers of water-saving technologies such as recycling and utilization of printing and dyeing wastewater, foam finishing technology, ozone washing technology and laser washing technology in denim industry. With the upgrading of textile industry and the implementation of national environmental protection laws and regulations, technologies such as foam finishing, ozone washing and laser engraving have been well-developed in the field of denim garment washing processing. In the future, the denim industry will be revolutionized by the water-free manufacturing .

Key words: Denim washing; Water-free manufacturing; Cleaner production; Ozone washing; Laser washing

Sustainable textiles are environmentally friendly and should meet reasonable conditions that respect social and environmental quality by preventing pollution or installing pollution control technologies (Asim K et al. 2017). In order to reduce the damage to the environment in the production process, the concept of ecological sustainable development has been put forward in the denim industry. Ecological denim clothing refers to the denim clothing with ecological performance and quality indexes in line with the technical requirements of ecological textiles. It has five attributes, namely, friendly environmental attributes, resource-saving attributes, energy-saving attributes, healthy life attributes, and green economic attributes (Fan pan 2014). In the outline study of industrial textile power in 2020, it is pointed out that the textile and garment industry will transform from resource dependence to resource conservation, from environmental neglect to environmental friendliness, and vigorously clean production and low-carbon economy. In this review, the current situation of sustainable development of denim industry and water consumption will be discussed and summarized in the production process of denim.

1 The current situation of sustainable development of the denim industry

Sizing, dyeing and washing are the main pollution sources in the process of denim production. This production line not only requires a large amount of water, but also produces several toxic and harmful sewages containing staple fiber, pumice stone, dye, slurry(starch, PVA), chemical auxiliaries and heavy metal ions.

Li and co-workers pointed out in the study of environment-friendly denim processing technology that the main indicators of waste water generated by denim processing are: COD_{Cr}, suspended solid concentration, pH, chroma, etc (Tab.1)(Li chao et al. 2016). Water quality also varies greatly due to different processing technologies, such as the production of mercerized blue, mercerized black, ultra-dark blue and ultra-dark black products.

In the research progress of wastewater treatment for denim garment production, Wang and co-workers studied of wastewater in printing and dyeing process(Wang kaiyan 2017). Among them, printing and dyeing wastewater COD_{Cr} and chroma are higher, respectively 2,000-6,000mg/L and 1,000~2,500 times. Because

of the presence of pumice slag, staple fiber and other pollutants, the concentration of suspended substance in the wastewater can reach 2,000mg/L. Indian professor *A.K.R. Choudhury* studied the environmental impact of denim washing, including the impact of millstone treatment on the water environment (A.k.R.Choudhury 2017).

Tab.1 The wastewater indicators of denim processing produced

Indicators	The numerical
COD_{Cr}	2,200～2,800mg/L
Suspended solid concentration	300～400 mg/L
pH	11～13
Chroma	1,500～1,800 times

2 Research on production water consumption of denim industry

The main water consumption stage of denim clothing is in cotton planting, dyeing and finishing processing and consumers´ daily cleaning. The water consumption of these three stages accounts for more than 95% of the water consumption of the entire life cycle of denim. India's *H.Pal, KN.Chatterjee, D. sharma* et al. studied the water footprint of denim garment production(Pal H et al. 2017).They analyzed the water footprint of denim products and th e denim industry as a whole, and proposed standards and measurements for water footprint. The size of the water footprint of producing a pair of jeans depends on the location, irrigation techniques, farmers´ water conservation awareness, raw material content and what is involved in the production process. Dye and fabric treatment involves the use of chemicals and requires significant water consumption and wastewater treatment. Therefore, the entire denim industry, from cotton irrigation to manufacturing, has a water footprint. Showing how much water a group uses or pollutes at a particular location helps us study the use patterns of water and measure the ecological friendliness of its products to make appropriate improvements.

Current life-cycle assessment (LCA) studies have shown that the impact of washing on the environment during the production and use of jeans is the largest(Pal H et al. 2017). Levi´s analyzed the life cycle of Levi´s 501 jeans, which require 3,781 liters of water from cotton cultivation to production, home care and disposal (www.Levi Strauss.com.2015). The consumption of water in dyeing and finishing process is particularly large, and the concentration of pollutants in the wastewater is very high. In reducing the washing of denim garments, *B. Garcia* of Spain described new technologies to reduce the water footprint. In addition to lasers, ozone, and new enzyme preparations are introduced to reduce water and chemical waste (Garcia B . 2015).

3 Water-saving technology in denim production process and its influence on industry

Water-saving technologies fall into two categories: those that recycle wastewater; and those that use less or no water. Denim production process will produce containing staple fiber, pumice, dye, pulp (starch, PVA), chemical additives, heavy metal ions and other sewage. Another method, using physical or biological methods to replace the traditional way of washing, such as foam technology, ozone washing, laser washing and decolourisation technology, biological enzyme fermentation, etc(Colomera A et al. 2015) . In years to come, denim and jeans cleaning may involve only a few dry or waterless treatments.

3.1 Recycling of printing and dyeing wastewater

In the wastewater treatment of cotton textile processing studied by *Ramesh Babu* et al., the first step to reduce the pollution of textile industry is to adopt new and less polluting chemicals and technologies to minimize the production of wastewater. The second step is to effectively treat the heavy chroma wastewater with high salt concentration to meet the specific discharge requirements, but this should be done after considering the alternative of wastewater recovery and reuse before discharge (Ramesh Babu et al. 2007).

Xu xiang et al. studied the application of ozone in the recycling of printing and dyeing wastewater, controlled the mass concentration of ozone in the ozone generator (50 mg/L) unchanged, determined the amount of ozone dosage by controlling the reaction time, sampled at a set time interval in the experiment, and analyzed the related items(Xu xiang et al. 2012). In the process of printing and dyeing, some denim fabric manufacturers use pre-reduced liquid indigo instead of powder indigo dye. This method can reduce dust pollution, and the quality of liquid dye is better than powder dye. It can reduce the value of COD and BOD, greatly reduce the use of reducing agent and other chemicals, thus reducing water pollution (Wang xinli 2018). *Zhang wei* et al. studied the application of ultrafiltration and membrane separation in the recovery of useful materials in printing and dyeing wastewater and the recovery and utilization of water resources (Zhang wei, Zhang yan 2009). *Liu jinsong et al.* also studied the deep treatment of printing and dyeing wastewater by ultrafiltration/ reverse osmosis membrane method and its reuse in dyeing process. The design of a whole set of wastewater treatment and reuse system also proves that the use of ultrafiltration/reverse osmosis membrane for printing and dyeing wastewater treatment and reuse is feasible (Liu jingsong et al. 2013). *Zhang kun* made an analysis on the deep recovery and treatment process of printing and dyeing wastewater(Zhang kun 2018). It is found that there are many problems in the treatment of printing and dyeing wastewater. *Luo daocheng et al.* studied and analyzed the existing problems of waste water treatment technology in Xiang tan textile factory (Luo daocheng 2002). The wastewater treatment process was improved by adopting the process of "secondary biological contact oxidation – sand filtration – active biochar". Wastewater treatment by this process, the water quality indicators exceed the national first-level discharge standards, water quality can be fully recycled, wastewater treatment costs decreased by about 1/3.

3.2 Foam decolorization technology

Foam finishing process is giving less liquid, dyeing and finishing technology of high energy saving. It is to pass the gas into the working liquid containing surfactant, and then generate a voluminous foam composed of many tiny bubbles after mixing and shearing. It replaces the water in the dyeing and finishing bath, and then is applied to the fabric to reduce the liquid carrying rate of the fabric, thus saving drying energy consumption (Fig.1) (Li yonggeng et al. 2008). Li studied the processing technology of textile foam dyeing and finishing, and analyzed the advantages and development prospects of foam dyeing and finishing, such as energy saving, water saving, dyeing and chemical materials saving and pollution reduction (Li ke et al. 2009).

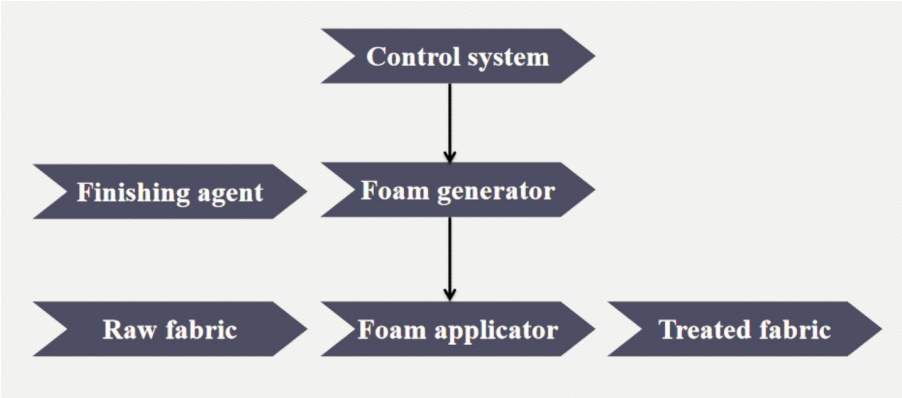

Fig.1 Schematic diagram of foam finishing system

Foam finishing process is mainly used for denim mercerization and dyeing. The alkali-containing foam that contacts the fabric during foam mercerization quickly ruptures into a strong alkali solution that is absorbed by the fibers through the capillary effect, and the impact force generated when the foam ruptures also contributes to the penetration of the alkali solution into the fibers. As a result, foam finishing reduces the amount of lye used, with better lye penetration and reduced water consumption and wastewater discharge compared to conventional filamentation. By using the characteristic of poor penetration of foam dyeing, the colored denim fabric can be developed. The low bath ratio of foam dyeing makes the process water-saving, energy saving and dyeing material saving, which can reduce sewage discharge and has significant ecological and environmental advantages (Chen ying et al. 2013). In the research of foam finishing of denim fabric, the foaming agent was prepared according to the need of technology, and its foaming, stability, alkali resistance and compatibility were tested. Due to the low liquid content, the foam softener can reduce the moisture content of the fabric, so the energy consumption of drying is small and the softener utilization rate is high.

3.3 Ozone decolorization technology

Ozone (O_3) has strong oxidation ability to various objects and is an oxygen molecule easily soluble in water. On the one hand, ozone can directly decompose pollutants in water through its own oxidation. On the other hand, pollutants are degraded indirectly by producing a chemical. The oxidative property of ozone enables it to have chemical interaction with the chromophore group in organic matter, break the chemical bond of organic matter, and gradually reduce the macromolecules in sewage into colorless small molecules so as to eliminate pollutants. This technology is easy to operate, so ozone oxidation technology is widely used in industrial wastewater treatment (Ren xueting et al. 2007).

Chemical substances used in traditional bleaching technology can cause water pollution, and the uniformity of bleaching is difficult to control. The fading rate of indigo dye depends on the proportion of dye in the fiber and its solubility, as well as the diffusion of ozone in the fiber (Gabr BG et al. 2016). *Chi-wai Kan*, hing-fu Cheung, Queenie Chan et al.* studied the discoloration of dyed cotton treated with plasma induced ozone (Kan C W et al. 2015). The results show that the fading effect of jeans can be controlled and the steps and costs can be reduced by using proper parameters. Traditional processes require three steps of flushing with water, each of which requires two flushing cycles. Plasma ozone treatment requires two rinsing steps and water, and only one rinsing cycle is required for each rinsing step (Fig.2). Therefore, plasma treatment of jeans can save water, eliminating the use of chemical agents such as

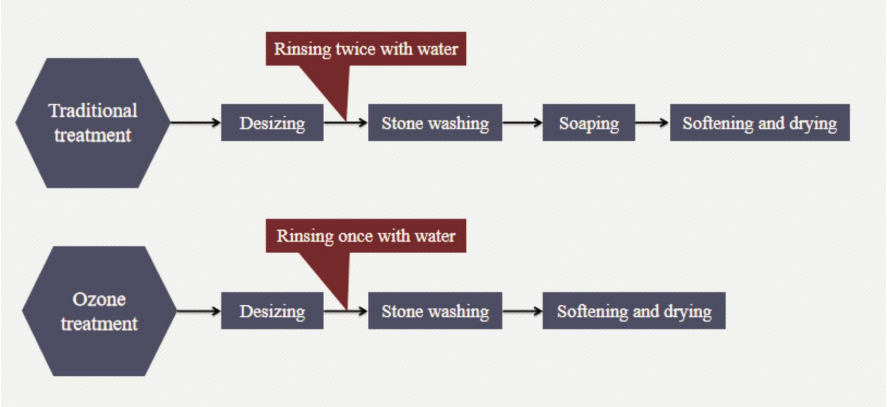

Fig.2 Conventional treatment process and plasma induced ozone treatment process

dispersant and defoaming agent, and the fading effect is good. Plasma-induced ozone treatment greatly reduces the use of electrical, water, and chemical components in denim products. Therefore, plasma induced ozone treatment has a broad application prospect in denim garment processing.

3.4 Laser washing and decolourisation technology

Lasers work by generating a wide range of heat, in which a material in a small region is subjected to intense heat, which can also cause the material to melt due to a phase transition from solid to liquid. The optimal characteristics of laser make it widely used in many fields such as medicine, industry and military (Nourbakhsh S et al. 2012).Later, laser was applied to laser cutting clothing(Xu xiaoxiao et al. 2018), innovative design of clothing fabrics (Du qun 2014; Ni ran et al. 2018) and denim laser printing (Fig.3)(Li ming 2013; Samanta K K 2017).

Fig.3 Laser engraved cat whiskers on jeans and hole-punching effect

Laser technology replaces manual sanding, potassium permanganate spraying, oxidation, washing and other high pollution processes by means of light, machine and electricity, greatly reducing the discharge of wastewater(Fig.4). It takes just 1.6 minutes for a piece of clothing to be worn out and the engraving and graphics to be laser processed. No matter from the production cost, efficiency and the quality of washing

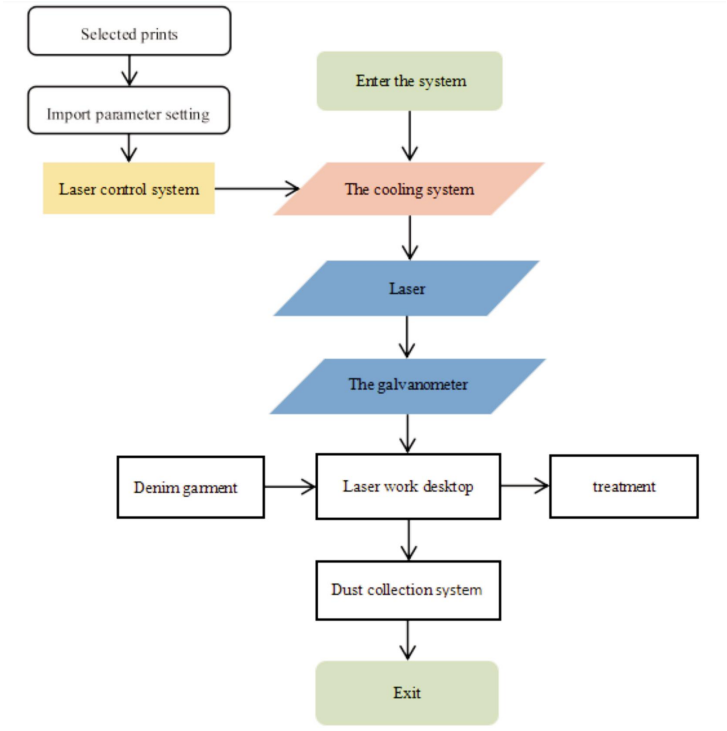

Fig.4 Denim laser carving process flow chart

water, laser processing to replace the traditional washing process is an irreversible trend. CO_2 laser treatment has been widely used in different fields of textiles in recent years due to its advantages such as short time of surface pattering, high precision and no great damage to the inherent volume performance of textiles. Lower energy waste leads to less heat generation, smaller and cheaper cooling systems and less water consumption(Ortiz-Morales M 2003). Because in the production process of denim fabric, the sizing of the slurry is a necessary link, and the desizing also needs water. Therefore, the development of a laser-based slurry discoloration method would be attractive as it would further save the washing cycle (Khalil E 2015) .

4 Summary and prospect

In the denim production process, the production process should be improved and the use of environmentally friendly dyes, such as advanced technology(foam washing, ozone, laser) to reduce pollutant emissions in green production. Ozonation technology will play a huge role. With the strengthening of environmental protection awareness and the progress of science and technology, the application scope of ozonation technology will be broader. Laser engraving hardware equipment is constantly improved, laser engraving technology is widely favored by denim garment processing enterprises for its unique advantages. Especially for the jeans washing, which has a high pollution discharge, there is a large space for the realization of clean production. With the application and popularization of ozone technology, laser technology and other high and new technologies in the field of denim washing, the denim washing industry will get rid of the pollution bottleneck, realize the waterless manufacturing, and usher in new development opportunities.

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