Benefit of Dual Nozzle Flow Dyeing Machine for Polyester Micro Fiber Fabrics

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Abstract

It is important for researchers developing dyeing technology to improve the dyeing techniques of polyester micro fiber fabrics in terms of the time efficiency. The empirical observations have led to the deploying of the O-type dual-nozzle flow dyeing machine developed by Asia Kingdom Machinery Industry Co., Ltd. to serve such purpose. The economic advantages include reducing the liquid ratio to 1:8 and reducing the water volume required by 20~40\%. The electricity required by 48~80\% less compared to conventional upward or downward type dyeing machines. Therefore the CO\textsubscript{2} production is decreased by 60\%, demonstrating energy efficiency and environmental friendliness. The nozzle pressure of a single nozzle machine is 1.6~3.0 kg/cm\textsuperscript{2}, whereas by adjusting the flux passing front and back nozzles, the dual nozzle pressure is maintained in the range of 0.2~1.6 kg/cm\textsuperscript{2}. The reduced pressure decreases the frequency of yarn hairness occurrence, thus improving the dyeing quality. The low liquid ratio results in dye exchange increase by 1.3~1.66 fold, significantly increasing the uniformity. Despite 40 times fewer contacts between the nozzle and the fabrics (total 244 times) compared to conventional machines, similar results were observed.

Key Words: Polyester micro fiber fabrics, Flow dyeing machine, Nozzle pressure, Low liquid ratio, Clean production

1. Introduction

Economic growth and environmental protection are the two major issues in the industrial world. Scientists are now exploring the win-win solution to achieve both goals. Reducing waste on limited global resources such as water and petroleum is the focus of our research. The concept of clean production originated from the environmental development convention hosted in Brazil by the United Nations in June 1992. Clean production technology is considered the key to accomplish both economic growth and environmental protection [1].

In the textile industry, the dyeing process of fibers or fabrics required vast amount of chemicals, water, and heavy oil, electricity to achieve the desired color or functionalities, resulting in serious environmental pollution. Developing a clean dyeing process of low liquid ratio, high energy savings and high efficiency can improve the dyeing quality of polyester micro fibers.

Fibers with its single unit less than 0.5 dtex, known as micro fibers or superfine fibers, are used to produce soft textiles, which render peculiar texture and visual effects. Such textiles are soft, drapable, and comfortable with good ventilation and moisture exclusion. For example, faux chamois leather made by micro fibers is light, reproducible in unit size, with various different colors, easy to wash and maintenance, odorless and crease-free [2]. However, the dyeing process of micro fibers requires an extremely long time and imperfect outcomes can be caused by tiny operational aberrations [3]. In this study, the application of the O-type dual nozzle flow dyeing machine for polyester micro fibers is discussed in terms of the clean production efficiency.

2. Principles (theory)

2.1 Operational mechanism of flow dyeing machines

In the flow dyeing machine, the primary pump drives dye liquor to pass through the nozzle and creates flux pressure.
The polyester micro fiber fabrics are conveyed by the reel through delivery tube into the trough area to be dyed. The positions of the reel, nozzle, fabric delivery tube and trough alternate regularly [4]. Heated dye solution by a heat exchanger would bind to the fabrics under an auxiliary agent and at the proper temperature. The dyeing quality of the fabrics is influenced by the nozzle pressure, flux, fabric running speed and addition of the chemicals. In this study, we discussed 3 types of dyeing machines: upward, downward and O-type regarding the dyeing application.

2.2 Categorization of flow dyeing machines and application

High-temperature, high-pressure dyeing machines can be classified by the orientation of the fabric movement in the trough. AK-SL model (Asia Kingdom Machinery Industry Co., Ltd.), for example, is an upward dyeing machine. Fabrics are transported through the nozzle pressure upward, passing the delivery tube and moving into the trough. The movement is cyclical. Upward dyeing machines are commonly applied in dyeing procedures for general polyester fibers but less commonly in polyester micro fiber dyeing. The second dyeing machine category, downward dyeing machine, has the characteristic of fabrics passing under the nozzle (lower part of the machine) into the trough, driven by the nozzle pressure. The fabrics are dyed in the trough. When collisions occur between the fabrics and the short splashboard, two events are expected: (1) the crease of the fabric displaces, eliminating creases which might hinder the dyeing effect; (2) the surface tension of the fabric is reduced, making the fabric looser and softer. The collision is very important for shrinkable polyester fabric. AK-SQ model (Asia Kingdom Machinery Industry Co., Ltd.) is a downward dyeing machine. AK-TO model (see Fig. 1) belongs to the third category, dual-nozzle O-type dyeing machine. Each end of the delivery tube has a nozzle installed. Fabrics are transported by flux pressure generated by the front and back nozzle into the trough to be dyed. This type of machine is also called a dual-nozzle overflow dyeing machine. The bending delivery tube can be adjusted into “A” or “V” shape to optimize the conveying speed and dyeing result [5]. In the AK-TO model the delivery tube has a nozzle installed at each end. The front nozzle is designed to convey the fabric and accomplish dyeing leveling. The back nozzle is for expanding the surface area, reducing creases and enhancing dyeing leveling.

2.3 Characterization of dye circulation, flux and uniform dyeing

The mechanical properties associated with fabric dyeing are correlated to the dyeing variety and dye circulation. The equation proposed by Carbonel describe such correlation: \( F = \frac{E}{C} = \frac{100}{C \cdot D} = \frac{100 \cdot B}{A \cdot D} \), where \( F \) represents minimal dyeing period (min), \( E \) represents the number of completed cycles (times), \( A \) represents flux (l/kg/min), \( B \) represents liquid ratio (l/kg) and \( C \) represents the cycle frequency (times/min), \( D \) represents the dye adsorption per cycle (%/cycle) [6, 7].

From the perspective of fabrics, the contact frequency between fabrics and the nozzle is the most important factor for dyeing leveling (Fig. 2). In single nozzle dyeing machines, such frequency is affected by the flowing speed of fabrics and the length of fabrics [8]. When the fabric flowing speed and dye circulation double in number, the contact frequency between fabrics and dye are increased accordingly, enabling the goals of increasing heating speed, reducing dyeing time and promoting dyeing leveling [9].

Figure 3 shows the effect of flux on uniform dyeing [8]. Liquor flow rate and bath circulation are important parameters in dyeing procedures, given that \( C = \frac{LF}{LR} (\text{min}^{-1}) \).

![Fig. 1 Dual-nozzle O-type flow dyeing machine.](image)

![Fig. 2 Impact of contact frequency between fabrics and the nozzle on uniform dyeing.](image)

1 The mechanical effect factor of liquor flow dyeing machine is also based on speed of fabric, that is the relatively contact frequency=fabric speed/fabric length, the degree of effect as the Fig. 2 shown.
For example, the liquor flow rate equals 6 times/min if the liquid ratio is given as 1:5 and flux as 30 l/min. In other words, there are 6 contacts between fabrics and the nozzle per minute. In dyeing procedures using conventional dyeing machines, low liquid ratio will result in more contacts than high liquid ratio. For example, by calculating the liquor flow rate and bath circulation, it is concluded that liquid ratio of 1:10 results in 3 times higher contacts than the ratio of 1:30.

3. Materials and methods

3.1 Materials

3.1.1 Polyester micro fiber fabric

(1) 100%PET
(2) Warp density 142 fibers/in × woof density 84 fibers/in: 72d/72f × 75d/144f SD, width: 62 inch, gray cloth weight: 165 g/m² (240 g/yard)
(3) Thickness: 0.18mm
(4) Application: faux peach-skin flannel

3.1.2 Dye recipe and combinations

(1) Color: black tone
(2) Recipe: 0.5% RESOLIN Red K-2BLS 200%
    1.0% RESOLIN Dark Blue K-RLS 300%
    9.0% RESOLIN Black K-BLS 300%
    2.0 g/l PERSOFTAL (dispersing agent)
    pH−value = 4~5
(3) The dyeing procedures are shown in Figs. 4, 5 and 6

3.2 Optimization of dyeing procedures

The dyeing results of micro fiber fabrics from 3 different types of high-pressure, high temperature dyeing machines were compared.

3.2.1 High-pressure, high-temperature upward dyeing machine

The conditions for machines with 300 kg fabric load are set as (1) Motor power of the major pump: 20 HP, flux: 2400 l/min (2) Nozzle pressure: 1.6 kg/cm² (3) Liquid ratio 1:12 (4) Fabric flowing speed 200 yards/min, (5) Fabric loading rate: ~60% (180 kg) with width of 750 yards and duct length of 375 yards (6) Dye volume 2160 l (Fig. 4) [10, 11].

3.2.2 High-pressure, high-temperature downward dyeing machine

The conditions for machines with 300 kg fabric load are set as (1) Motor power of the major pump: 40 HP, flux: 3200 l/min (2) Nozzle pressure: 3.0 kg/cm² (3) Liquid ratio 1:10 (4) Fabric flowing speed 475 yards/min, (5) Fabric loading rate: ~72% (216 kg) with width of 900 yards and duct length of 450 yards (6) Dye volume 2160 l (Fig. 5) [10, 11].

3.2.3 High-pressure, high-temperature dual-nozzle O-type dyeing machine

The conditions for machines with 300 kg fabric load are
set as (1) Motor power of the major pump: 30 HP, flux: 3200 l/min (2) Nozzle pressure: 1.6 kg/cm² at the front and 0.2 kg/cm² at the back with 1/3 valve opening (3) Liquid ratio 1:8 (4) Fabric flowing speed 380 yards/min, (5) Fabric loading rate: ~80% (240 kg) with width of 1000 yards and duct length of 500 yards (6) Dye volume 1920 l (Fig. 6) [10, 11].

4. Result and discussion

Microfiber fabrics were dyed using 3 different types of high-pressure, high temperature dyeing machines which were conventional upward, downward and dual-nozzle flow. Five steps, loosening, dyeing, washing, reducing and neutralizing, were conducted during the procedure. The results are compared in the table listed below.

(1) The dual-nozzle dyeing machine is equipped with one more nozzle than the conventional single-nozzle dyeing machine, enabling more dyeing leveling. Additionally, bundled fabrics can be loosened up better when passing its nozzle, resulting in potential reduction of liquid ratio. The result of dyeing experiments suggests that the dual-nozzle dyeing machine is superior.

Table 1 Effect of flow dyeing machines on dyeing polyester micro fiber fabrics.

<table>
<thead>
<tr>
<th>Type</th>
<th>Upward</th>
<th>Downward</th>
<th>Dual-nozzle flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>AK-SL (Asia Kingdom)</td>
<td>THIES company</td>
<td>AK-TO (Asia Kingdom)</td>
</tr>
<tr>
<td>Motor power (HP)</td>
<td>20</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Load (kg)</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Nozzle type</td>
<td>Single (Diameter 100mm)</td>
<td>Single (Diameter 90mm)</td>
<td>Front: 80mm  Back :2/3 sliding degree</td>
</tr>
<tr>
<td>Liquid ratio</td>
<td>1:12</td>
<td>1:10</td>
<td>1:8</td>
</tr>
<tr>
<td>Dyeing procedure</td>
<td>Procedure Fig. 4</td>
<td>Fig. 5</td>
<td>Fig. 6</td>
</tr>
<tr>
<td>Flowing speed</td>
<td>200</td>
<td>450</td>
<td>380</td>
</tr>
<tr>
<td>Time (min)</td>
<td>210</td>
<td>270</td>
<td>160</td>
</tr>
<tr>
<td>Loosening time</td>
<td>40</td>
<td>--</td>
<td>40</td>
</tr>
<tr>
<td>Water consumption (l/kg)</td>
<td>48</td>
<td>40</td>
<td>32</td>
</tr>
<tr>
<td>Liquor flow rate (dyeing)</td>
<td>700</td>
<td>1440</td>
<td>1066</td>
</tr>
<tr>
<td>Fabric/nozzle contact frequency (dyeing)</td>
<td>129</td>
<td>285</td>
<td>244</td>
</tr>
<tr>
<td>Quality analysis</td>
<td>AATCC61-IIA</td>
<td>Color fading: degree 4-5</td>
<td>Color fading: degree 4-5</td>
</tr>
<tr>
<td>Surface uniformity</td>
<td>excellent</td>
<td>excellent</td>
<td>excellent</td>
</tr>
<tr>
<td>Crease</td>
<td>Slight longitudinal crease</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>1000 kg of dried fabrics</td>
<td>CO₂ emission (kg) [12]</td>
<td>849(100%)</td>
<td>837(98.5%)</td>
</tr>
<tr>
<td>Petroleum consumption(l)</td>
<td>211(100%)</td>
<td>175(82.9%)</td>
<td>158(74.9%)</td>
</tr>
<tr>
<td>Electricity (degree)</td>
<td>460(100%)</td>
<td>600(130.4%)</td>
<td>310(67.4%)</td>
</tr>
</tbody>
</table>
(2) Fabric/nozzle contact frequency (dyeing step): Despite that the dual-nozzle flow dyeing machine had 244 contacts between the nozzle and fabrics, which was less than the contacts of the downward dyeing machine (285), the dyeing result was comparable. Furthermore, fabrics have a smoother surface as a result.

(3) Liquor flow rate: The dual-nozzle and downward dyeing machines both demonstrate independent and well-defined functionalities in dyeing polyester microfiber woven textile.

(4) The dual-nozzle dyeing machine performed well in washing regarding its physical properties. Its excellent performance in washing by reducing agents and detergents has enormous positive impacts for dyeing engineering.

(5) CO2 emission, one of the clean production indices, is comparable between conventional upward and downward dyeing machines. On the other hand, CO2 emission of the dual-nozzle dyeing machine is only 72.6% compared to the other two types because of its low liquid ratio.

5. Conclusion

In response to the sophistication of fiber production and diversified development of a variety of O-type dyeing machine for polyester micro fibers, dyeing machines are expected not only to serve the purpose of dyeing fabrics but also to achieve quality improvement, energy saving and environmental reservation. The dual-nozzle overflow dyeing machine is designed in a similar fashion to the conventional dyeing machines with similar power requirement. However, the modification made based on liquor flow principle and fabrics/nozzle contact theory enhances the dyeing leveling and accomplishes the goal of low liquid ratio, dyeing time reduction and clean production. It is noteworthy that the technology used here is distinct from the one applied to the design of air-flow dyeing machine, where highly pressurized air is used to unfold bundled fabrics. It is expected that the technology used in dual-nozzle dyeing machines will be the focus of future research. For instance, it is of high interest to increase the loading rate for current 80% to 100% by developing control systems to adjust the front and back nozzles.

References