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Implementation for New Dyeing Technique

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Abstract

This research project introduces a new dyeing technique using a Continuous Dyeing Machine for polyester fabric, one of the most widely used textiles. The machine design incorporates specific requirements for dyeing synthetic materials, such as high temperatures up to 135 degrees Celsius, crucial for effective dye absorption. The three-stage process involves immersing the fabric in a chemical sink for optimal dye penetration, removing excess chemicals through a padder under 2 bar pressure, and subjecting the fabric to a high-temperature treatment in the shock and furnace section. The objectives focus on reducing the current six-hour dyeing time and consolidating four processes into a single machine for improved space utilization and reducing time. The control system adheres to classic control theory principles, with component selection based on its applicability to fabric movement through the Continuous Dyeing Machine. This research represents a significant advancement in polyester fabric dyeing, offering insights into process efficiency and space optimization in the textile industry.

Keywords: dyeing process; polyester fabric; Continuous Dyeing Machine; classic control system; process efficiency; space optimization; textile industry.

1. Introduction

The textile industry has witnessed significant advancements in dyeing technologies, aiming to enhance efficiency, reduce water consumption, and minimize environmental impact. Continuous dyeing machines have emerged as a key solution in achieving these goals. This paper aims to provide an in-depth analysis of continuous dyeing machines, their benefits, and the challenges faced in their implementation.

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The idea of dyeing a substance is to give color to various materials such as textiles, paper, and leather where the addition of colors shouldn't be affected by washing, heat and light and other factors that the material would be exposed to.

1.1 Dyeing Process

The Dyeing process of fabrics is the interaction between a dye and the fiber, as well as the movement of dye into the internal part of the fiber. Generally, a dyeing process involves adsorption which is the transfer of dyes from the aqueous solution onto the fiber which is surface and diffusion the dyes diffused into the fiber. , The conventional dyeing process is often likened to a black box, wherein the quantity of dye present on the fabric remains unknown until the completion of dyeing.

Consequently, uncertainties pertaining to the fabric's shape, color, texture, and quality persist until the final product is obtained. Nevertheless, through the accumulation of field expertise and the integration of technological advancements, it is possible to attain a heightened level of predictability and expected outcomes. Notably, progress in Spectrophotometry and Computation has facilitated an indirect determination of dye quantities on fabric duri*ng the dyeing process, leveraging the principles of Beer's law [5] as represented by equation 1.*

$$A = \varepsilon bc$$ **Equation 1:** Beer's law

This Equation relates the attenuation of light to properties of a material; Where:

A is absorbance.

ε: is the molar absorptivity with units of L / mol. cm

b: is the path length of the sample, usually expressed in cm.

c: is the concentration of the compound in solution, expressed in mol / L.

Dying can be divided into two main categories:

- **Natural dyes:** The dyes are purely developed from nature.
- **Synthetic dyes:** The dyes are man-made where they are composed of chemicals.

Table 1: Methods of Dispersing Dyeing.

Method	Material	Temp (^{0}C)
Normal temperature with carrier	Polyester	80 - 100
High Temperature	Polyester	105-135
Pad roll method	Cotton	80-100
Pad Steam method	Cotton	100-120

The dyeing of Hydrophobic fibers as Polyester fibers using disperse dyes is considered as a process of dye transfer from liquid solvent to a solid organic solvent.

1.2 Dyeing Machines

The dyeing operation used currently in dyeing industry passes by Two Machines for four processes:

- Firstly, Stenter Machine (Fixation)
- Secondly, Jet Dyeing Machine (Dyeing)
- Thirdly, Jet Dyeing Machine (Washing)
- Fourthly, Stenter Machine (Finishing)

A sample enters firstly Stenter machine for heat setting taking several minutes, secondly enters Jet machine for dyeing and washing processes taking 6 to 8 hours. At last, it returns enters Stenter machine for drying [25].

1.2.1 Stenter Machine "Heat Setting and Drying "or "Fixation and Finishing "

Stenter is the most expensive and important fabric drying and finishing machine. It is a machine for stretching or stentering fabrics. It is also known as a 'tenter' in the woolen industry.

Figure 1: Stenter machine.

The purpose of the stenter machine is to bring the length and width to pre-determine dimensions, for heat setting and applying finishing chemicals. The main function of the stenter is to stretch the fabric widthwise and to recover the uniform width. The stenter machine consists of two endless auto-lubricated driven chains, typically 40 to 60 m in length carrying pins or clips to hold the fabric edges while passing through several hot-air chambers (3–5, each of about 3 m). Hot air is directed onto the fabric equally from above and below. A stenter has overfeeding of fabric to allow required shrinkage during heat setting of fabric while the width is increased to the precisely specified value by the chains. The stenter speed ranges from 10 m/min for heavyweight furnishing fabrics to 100 m/min for lightweight dress-goods.

1.2.2 Jet Dyeing Machine " Dyeing and washing "

Jet dyeing machine is modern machine used for the dyeing of polyester fabric with disperse dyes. In these machines, both the fabric and the dye liquor are in motion, thereby facilitating a faster and more uniform dyeing.

In jet dyeing machine, The fabric movement by only force of water. Inside the machine a strong jet of dye liquor is pumped out from an annular ring through which a rope of fabric passes in a tube called a venturi. This venturi tube has a constriction, so the force of the dye liquor passing through it pulls the fabric with it from the front to the back of the machine. The jet has a dual purpose in that it provides both a gentle transport system for a fabric and to fully immerse the fabric in liquor as it passes through it**Error! Reference source not found.**. A jet dyeing machine operates at a material velocity of up to 200–500 m/min which makes it consume so much time to complete one process that reaches 5 hours with high temperature: Up to 140°C.

1.3 Structure

As the paper introduced the dyeing process with its importance, the types of dyes and their classes. Followed by one of the most essential fabrics, which is polyester the suitable dyeing method for it as well as the traditional dyeing machine used in its dyeing process. In the following table will give an account on implemtation for dyeing technique for various types of fabrics while focusing on polyester for most through a new machine called the continuous dyeing machine.

Table 2: Dye Classes.

Dye Class	**Cellulose** (Cotton,viscose,rayon)	**Protein (wool,silk)**	**Polyester**	**Nylons**	**Acrylics**
Direct	**	*	-	*	-
Reactive	**	**	-	*	-
Sulphur	**	-	-	-	-
Vat	**	-	-	-	-
Disperse	-	-	**	*	**
Acid	-	**	-	**	-

**: The most important dye applied in dyeing

* : Less important dye applied in dyeing

- : No practical application

2. Traditional dyeing method pitfalls

As explained above dyeing process passes by two machines jet and stenter, which is the dyeing method used currently by industries world-wide. The fabric enters the stenter machine for fixation passing then through the jet machine for the adding color to the fabric this sub-process takes from three to five hours the fabric enters in a twisted rope like shape which what makes it consume so much time at last the fabric enters the stenter for color fixation. This shows that the traditional method consumes so much time, effort and money since the need to move the fabric from one machine to the other manually. Therefore the following section identifies the design of the continuous dyeing machine the idea of which aroused from the stenter machine since the fabric passes flattened passing by furnaces for color fixation the continuous dyeing machine would follow the same shape of stenter as shown in figure 2 below which is a schematic drawing for stenter machine while performing the whole dyeing process in one machine where its function is to implement a new dyeing technique for solving the fore-mentioned problem.

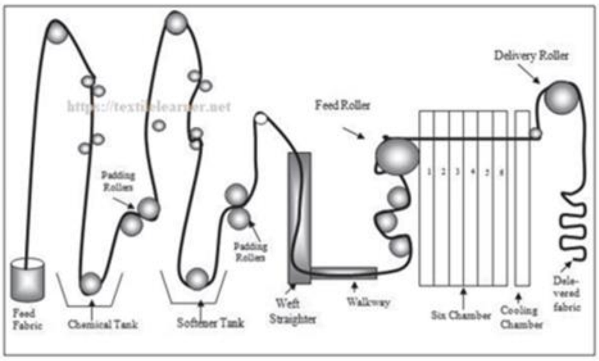


Figure 2: Schematic representation of continuous dyeing machine.

3. Continuous Dyeing machine design

Function of machine is Dyeing fabric continuously with Pressure, Temp, and chemicals by reducing the time than the traditional method also without the need to move the fabric from one machine to the other as the whole

process is done in this machine.

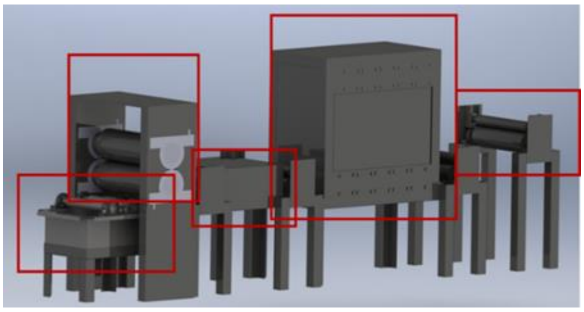
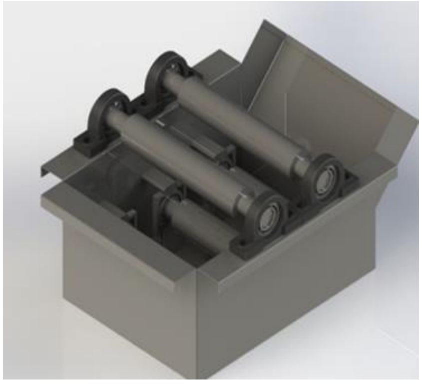


Figure 3: Continuous Dyeing Machine Stages.

Figure 4: Continuous Dyeing Machine Stages.

Stage 1: Chemical Sink Deep container contains Chemical substance which responsible for dyeing process. It includes two shafts at the bottom and three shafts at the top which help textile material to pass by three paths in the sink as shown in figures below. Chemical Sink is made of stainless steel



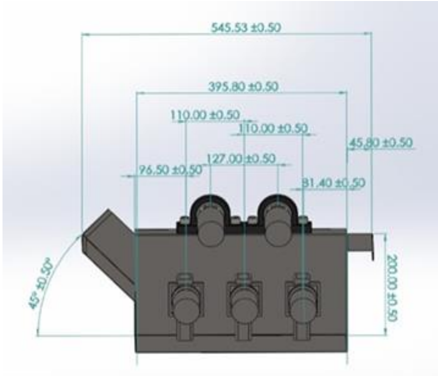
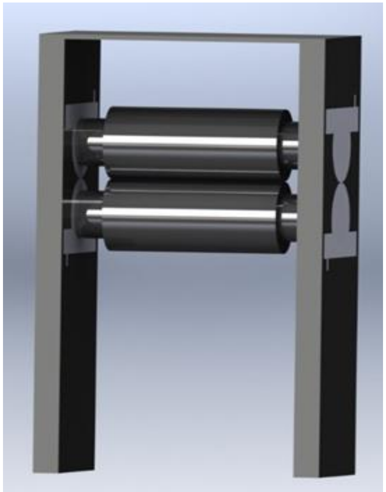


Figure 5: Chemical Sink Sketch. **Figure 6:** Chemical Sink Section. **Figure 7:** Chemical Sink.

Stage 2: Padder Equipment to roll the textile after passing through the chemical sink, the textile would be socking in chemicals, so the rolling shafts remove all excess chemicals from the fabric as shown in figure 4.6 – 4.7. Made ST-37



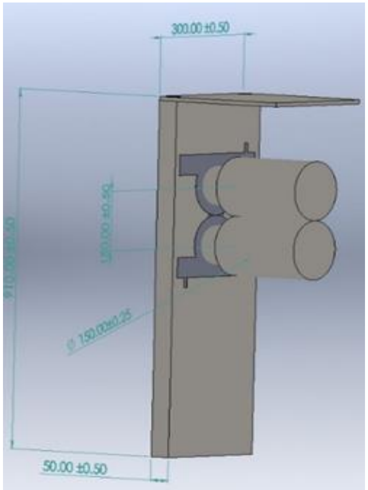
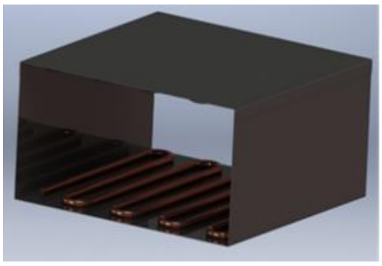


Figure 8: Padder Design. **Figure 10:** Padder Section. **Figure 11:** Padder.

Stage 3: Shock After textile have been squeezed by rolling shafts, it enters shock which is manufactured by four welded sheet metal with a heating coil fixed on the top to apply heat on textile as shown in figure 12 so, that it enters the furnace dry not damped. Made from Galvanized St-37.



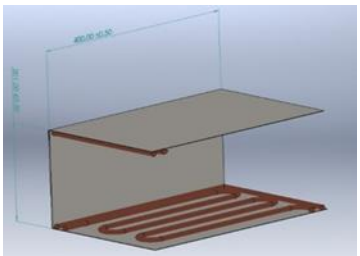


Figure 12: Shock Design. **Figure 13:** Shock Section View. **Figure 14:** Shock

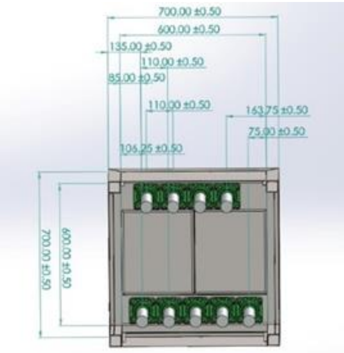


Figure 15: Furnace Design. **Figure 16:** Furnace Section. **Figure 17:** Furnace.

Stage 4: Furnace After textile took a high temperature in a shock, it enters furnace which have Five shafts at the top and Four shafts at the bottom as shown in figures 13 - 15 below with a temperature of 135ºc through nine paths to complete the last operation for dyeing our sample. Furnace is assembled by its chassis and Housing where each of them has a separate material as St-37 is the material of Furnace chassis and Galvanized iron is the material of Furnace housing.

Stage 5: Transmission Shafts its function is to transmit power between the motor and the machine absorbing power to be able to transfer the textile from one stage to the stage following it. There is shaft between the sink and shock, between the shock and furnace and at last after the furnace to move the textile after the dyeing process is completed to the trolley. Made from St-37.

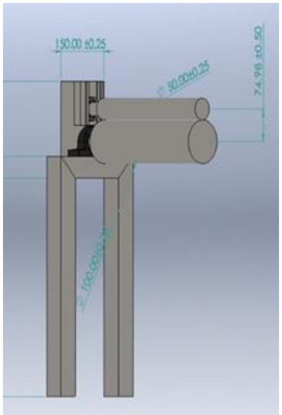


Figure 18: Padder Design. **Figure 19:** Padder Section. **Figure 20:** Padder Design.

3.1 Control system on machine

Classic control is the type used in the control system where the control is done stage by stage according to the previous defined in the design.

Stage 1: Motor 1 (1.5 Kw) with gear box located on the padder found in stage 2 in design stages where the speed of motor is given to first shaft through belt and given to the second shaft takes its movement through a belt from the first shaft and double pulley.

Stage 2: Coils (2 KW) in shock which when the machine is on gives the heat.

Stage 3: Coil (2 KW) and blower in furnace coils produces the heat and the blower duty is to distribute the air evenly through the furnace.

Stage 4: Motor 2 (1.5 KW) located on the transmission shaft 1 as well taking its movement through v- belts and double pulley

Stage 5: Motor 3 (1.5 KW) located on the last transmission shaft 2 taking its movement through belts and single pulley

All the previous mentioned stages are controlled through the control panel shown in the following figures:

Figure 21: Control Panel.

Figure 22: Control Panel Components.

3.2 Control panel components

3.2.1 Push Buttons

Push button start with green led; Push button stop with red led and emergency stop.

3.2.2 Inverters

An inverter provides an ac voltage from dc power sources and is useful in powering electronics and electrical equipment rated at the ac mains voltage. Which controls over the speed of the three motors found in stages 1, 4 and 5.

3.2.3 Circuit breaker

which interrupts the faulty current and performs the function of a switch thus protecting the electrical system from damage. There are 3 circuits breaker controlling over each inverter and one main circuit breaker controlling over the whole machine.

3.2.4 RTD Sensor

Sensors used to sense the temperature of coils in stages 2 and 3 to be sure not to exceed the required temperature

3.2.5 Contractor

Contactors are electrically controlled switching devices which are used for switching electrically. There are two contactors controlling over the two RTDs

3.2.6 Temperature control

Controlling over the temperature of the two coils found in stages 2 and 3 which when the shock and furnace reaches the required temperature the sensor gives signal to the contactor and it switches off automatically.

4. Conclusion

The dyeing process is a pivotal technique for imparting desired colors to fabrics while ensuring color fastness. This research project introduces an innovative approach to dyeing, aiming to reduce the time required for dyeing, consolidate multiple processes into a single machine, optimize space utilization, and produce ready-to-use textiles without the need for further steps. The study focuses specifically on dyeing polyester fabric, which has emerged as one of the most widely used materials in the global market. Unlike natural fabrics, polyester is a synthetic material that requires dyeing at high and precise temperatures using various chemicals.

The proposed technique involves the use of a Continuous Dyeing Machine, comprising three main components. Initially, the fabric is immersed in chemicals within a chemical sink, followed by the removal of excess chemicals through a padder. Finally, the fabric undergoes a shock and furnace treatment at elevated temperatures to ensure dye stability. The integration of these processes into a single machine allows for space efficiency and facilitates a streamlined dyeing process.

The control system employed in this research project is based on the principles of classic control theory, which deals with the behavior of dynamical systems with inputs. Consequently, the selection of control system components aligns with this classic control system framework.

This innovative technique holds significant promise for the dyeing industry, as it addresses the critical need to reduce dyeing time, optimize resource utilization, and enhance overall productivity. we aim to contribute to the advancement of textile dyeing technologies and their implications for the global textile industry.

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