National Textile Center

FY 2003 (Year 12) Continuing Project Proposal

Project No. C02-AE08
Competency: Chemical systems

Assessment of continuous, pulsed and aerated pressure-washing

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Objectives:
The objectives of this project are to: i) assess the feasibility and effectiveness of pressure washing in reducing the amount of rinse water, ii) evaluate the effect of pressure and temperature of water on colorant stability and, iii) study the impact of pressure washing on fabric structure.

Progress Statement:
Executive summary: Fundamental studies of jet impingement on flexible moving surfaces and its impact on colorant stability and fabric structure are needed to understand the physics behind pressure washing. To this end, a pressure washing system (washing box and washing nozzles) was designed and constructed using an acrylic water tank and ultra-high molecular weight PE rollers. Dyeing experiments were performed to select suitable fabrics and dyes, and initial washing experiments were conducted in the newly constructed pressure washing system. A 5Watts, continuous wave-front Argon-Ion laser was set up to explore the qualitative aspects of the jets. Fabric distortions under cross-linear load were quantified with a HeNe laser operating a 632 nm wavelength in conjunction with optical spot generator. A high-speed camera capable of 2000 digital frames per second on a circular buffer was used to record images. The images were later processed with a motion analysis system and specifically developed Matlab based image-processing routines. Ensuing sections give information on first year activities.

Pressure Washing System: The pressure washing system consists of feed roller/source spool, set of guide rollers and a take-up roller. The take-up roller connected to a variable drive universal motor by a set of pulleys and belts receives the fabric from the supply spool at desired speed. The entire system is mounted on a specially designed acrylic tank of 2ft x 2ft cross-section and 8 ft length. The tank level can be adjusted for efficient draining with two drain valves at the bottom. One of the drains is connected to a sub-tank from which samples of the used water can be drawn for analysis. A built-in sump pump drains the entire system after a test. Figure 1 shows key components and operation of the system.

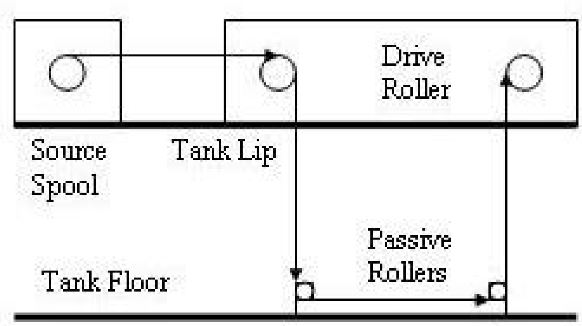

Figure 1: Schematic of test setup

Compressor and nozzles: A hot/cold variable water pressure system rated at 1000 psi was modified and used in the present experiments. A new stainless steel manifold was designed and built in the machine shop to which four fluid couplers were installed. A set of four linear spray nozzles with exit divergence angles of 20, 30, and 45 degrees was used in the experiments. Each nozzle could be easily inserted in the manifold couplers to provide a possibility of a large combination of spray patterns.

Measurements: The dynamics of impinging jets on flexible membranes is extremely complex and involves instability of thin jets, resonant modes of coupling between flexure modes of fabrics and wave numbers of fluid flows. The possibility of nonlinear interaction between amalgamated coherent structures results in sub-harmonics that can attenuate the transport properties of the water jet to carry a large quantity of dye with it. This possibility can be alleviated by higher supply pressure, use of thinner and wider jets and reduction of distance between the nozzles and the fabric. This approach also ensures the transfer of mass and momentum to the fabric but may cause fabric distortion.

A 5Watts, continuous wave-front Argon-Ion laser was used to explore the qualitative aspects of the jets. The laser beam was passed through a laser-fiber-coupler and a multi-mode fiber-optic cable to which a light sheet generator was attached to illuminate the jets during operation. Four jets were used with overlap at the edges for the reduction of impingement bias. A HeNe laser operating a 632 nm wavelength was used in conjunction with optical spot generator to quantify the fabric distortion under cross-linear loading. A high-speed camera (Redlake Imaging) capable of 2000 digital frames per second on a circular buffer was used to record images. The images were later processed with a motion analysis system and Matlab based image-processing routines. A correlation with the calibrated image and measured displacement in the sequence of frames directly yields displacement, velocity and acceleration of the target. Preliminary results are presented in Figure 3.

Figure 2: Laser flow visualization of planar spray

Initial Dyeing Experiments: Bench-top dyeing experiments were developed to select the most suitable dye. Since the initial dyeing and washing procedures will be performed on cotton fabric, fiber-reactive, direct, azoic, vat and sulfur dyes can be used. Direct dyes are the easiest to apply, show the highest variation in performance, especially washfastness, and require the highest amount of neutral salts for fixation. In order to amplify washing effects with the conventional and the pressure system, direct dyes were chosen for the initial experiments. A selection of five different direct dyes was made which, according to the Color Index, rank medium to good in washfastness. A dyeing procedure was set-up at 0.5% dye concentration. Cotton fabric was cut to samples of size 7 x 5 inches and was wetted out in cold distilled water. Each sample was immersed in 400 mL dyebath which was heated to 85ºC and the samples dyed for 20 min. 5% of sodium chloride was added in four equal portions after every 20 min of dyeing. After a final dyeing period of 20 min, the samples were rinsed three times in cold distilled water, and

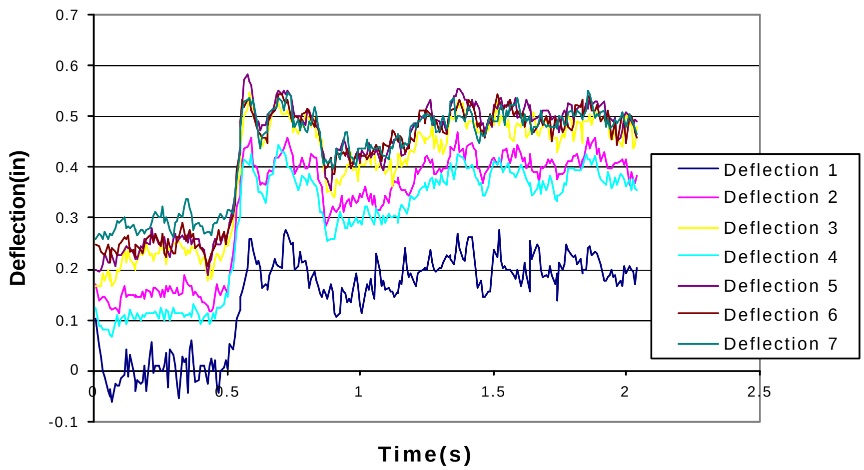

Figure 3: Relative displacement of laser dots at fabric distortion points

a sample of the rinse water collected. The CIEL*a*b* color coordinates of the dyed fabrics and the rinse water were determined with the color spectrophotometer.

From the five test dyes, C.I. Direct Yellow 4 was selected and cotton fabric in rope form was dyed using C.I. Direct Yellow 4 in a Werner Mathis Jumbo Jet Dyeing Machine, and the washing water was analyzed for dye content and quantity. The water volume used is 40:1 liquor ratio – based on weight of fabric. Salt concentration is 20% – based on water amount added in 4 separate steps of only 5% at a time. Each salt addition is mixed with 200mL of water. The temperature of the water used is 85C. After dyeing the fabric rope was cut into two portions, one half washed in the Mathis Jet and one half in the pressure washer. Rinse water was collected at four stages of each process and the color coordinates compared.

Next Year's Goals:

Next year activities will: i) optimize fabric handling and transport in wash box, ii) examine the integral quantities of the jets using particle image velocimeter, a dual-pulsed YAG laser, a high-resolution (1k x 1k pixels) cross-correlation camera, and a dynamics flow map system, iii) characterize the break-up features of the jet prior to its impingement on the fabric using high speed pulsed IR laser, iv) study fabric dynamics under jet impingement from both sides, v) determine the effectiveness of linear suction at entry roller for dye removal, vi) construct a semi-empirical model to develop an understanding of the impact of various process element on the fabric, and v) compare color coordinate from both washing techniques.

Approach:

In order to achieve the project goals for the first year, a pressure washing system was designed and constructed and an experimental setup was devised to evaluate the qualitative aspects of the jets and quantify possible fabric distortions. Experiments were carried out to select suitable fabrics and dyes and initial washing experiments were conducted in the newly constructed washing system.

Lessons learned from initial washing experiments included: i) the need for placing pressure jets on both sides of the fabric to enhance wash efficiency and allow better control of fabric motion, ii) changing the angle of the pressure nozzles, iii) adding a squeeze/vacuum roller at the fabric entry into the washing box to remove excess dyes and water, and iv) improve the rinse water collection procedure. This information focused our effort on optimizing the wash box setup and comparing the rinse water from the conventional jet washing to that of the pressure washing system. Rinse water from both washing techniques will be evaluated and used as one of the measures of washing efficiency for pressure washing.

Data acquired from fabric distortion experiments, as shown in Figure 3, will be used to construct a semi-empirical mechanical model to correlate nozzle parameters to the removal rate of residual dyes and auxiliaries. The total removal will be considered as the convolution integral of the removal rate with respect to time which will include the frequency of pulsation for pulsed-jets, the air content for aerated jets, the rate of flow of fluid from nozzles, the inclination of the jet impingement with respect to fabric, the flow velocity, the fabric cover factor, and the water temperature.

Outreach to Industry:

The textile industry is interested in saving costs and improving environmental practices through reducing the amount of rinse water. Pressure washing technology can reduce the amount of water and address the environmental concerns. After completion and optimization of the wash box and data acquisition systems, members of the dyeing and finishing industries will be invited to witness its operation, and provide input to guarantee necessary feedback and success of the project. Furthermore, the process will be video taped and shared with the dyeing industry.

New Resources Required:

Aerated and pulsed jets will be purchased.