# DIGITALLY PRINTED COTTON FABRICS WITH IMPROVED VISIBILITY FOR SAFETY APPAREL

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## Abstract

This study discusses the possibility of applying fluorescence on cotton fabrics to improve safety features. Fluorescent dyes are added to the existing ink rheology and applied through ink jet printing technology to impart high-visibility characteristics to cotton fabrics. Two types of fluorescent dyes are selected based on their compatibility with current ink set. Inks are prepared with appropriate physical and chemical properties, which are required to achieve problem-free flow through piezo-electric print heads of the ink jet printer. Fabrics are pre-treated, printed with existing and new ink sets, and steamed to fix dyes onto the fabric. Printed fabrics were tested for their spectrophotometric color measurements as well as permanence of dyes during wear such as wash, light, and crock fastness. Improvement in visibility property of fabric by applying fluorescence is discussed by defining new chromaticity coordinate system developed as per American National Standard for High-Visibility Safety Apparel (ANSI/ISEA).

## Introduction

Digital printing of textiles is a rapidly growing, commercially important printing process because of its ability to produce economical, high quality, multi-colored prints. This technique has been quickly adopted by artists and designers for their sample printing and specialty applications like soft signage, interiors. This technology is currently emerging as a solution to address the production needs for a wider variety of applications. The demand for high performance textile products has led to the development of functional textiles such as anti-bacterial fabrics, fluorescent fabrics with high-visibility properties, and a variety of nano-particle based compounds to impart specific functionality to textiles. Inkjet printing is a non-impact printing technology that has become very important in the delivery of many of these functional finishes for textiles. New developments in print-head technology such as piezo-electric heads make it easier to use various printing liquids because no heat is involved in the printing process. [King (2009) and Ujiie (2006)].

High-visibility garments worn by fire fighters, first-responders, construction/transportation/aviation workers are brighter and safer. Work zone accidents resulting from poor visibility can be reduced if not prevented by the usage of apparel made from improved high-visibility fabrics. The American National Standards Institute (ANSI) has developed a standard for high-visibility safety apparel known as ANSI 107-1999, which deals with reflective materials exhibiting the required chromaticity coordinates within the specific bounded regions [Nolan, 2003].

Ink formulation and its fixation to the substrate are the critical areas in ink jet printing. Ink jet ink formulation needs a compromise between different parameters like nozzle maintenance, drying time and print quality. Ink should have its physical properties suitable for drop formation while being capable of producing sharp, dense, and permanent images. Some of the important properties of inks for textile ink jet printing are summarized in below table (See table 1). Colorants in the ink must have proper affinity for the substrate and have good fastness properties, which include: wash, crock, and light fastness [Stefanini 1996 and Smith et al. 1987]. Ink's physical properties such as viscosity, surface tension and chemical properties like pH, solubility, and evaporation must be controlled. Variations in fluid properties affect the consistency of drops generated and result in variations in drop sizes, and nozzle exit velocities [Freire, 1994].

Table 1: Important Properties of Inks for Jet Printing of Textile Ink

| Ink formulation | Ink properties | Functional properties |
|---|---|---|
| Colorant<br>Vehicle<br>Anti-clogging fungicide<br>Viscosity control<br>Surfactant<br>pH buffer<br>$O_2$ Absorber | Surface tension<br>Viscosity<br>Conductivity<br>pH<br>Specific gravity<br>Dye purity | Machine<br>Stable drop formation<br>No particle contamination<br>No nozzle crusting<br>Low corrosion<br>No biological growth<br>Long shelf life |

## Materials & Methods

100% cotton broadcloth (bleached, mercerized, combed - style # 419 from Test Fabrics Inc.) was used for this study. Pre-treatment chemicals: Sodium Alginate – high viscosity type, Urea, and Soda ash (from Dharma Trading Co.) were used in this study. Dyes: Reactive Orange 13 (Novacron Orange P-2R from Huntsman International LLC), 1,8-naphthalimide type (water soluble type) - from Sunshine Chemlab, Keyplast Fl. Orange 2G (water insoluble type) – from Keyplast, Ethylene glycol, Glycerin, and Triton X-100 from Fisher Scientific were used in preparation of ink sets. AATCC 1993 Standard Reference Detergent WOB (without optical brightener) was used to wash the steamed fabrics.

Ostwald's viscometers, Capillary tubes, gas picnometer were used to determine ink's viscosity, surface tension, and specific gravity respectively. Branson Sonifier 450 was used for ultrasonic treatment for inks. Lab Pad 36" wide (Poterala Mfg. Co.) was used to pad the pre-treatment chemicals onto the fabric. Mimaki TX2- 1600 was used to print the fabrics. Jacquard bullet type steamer with atmospheric pressure set-up steamer was used to steam the printed fabrics. Kenmore 80 series washing machine and Kenmore Elite model dryer were used to wash and dry the samples respectively.

### Ink Preparation

Three sets of ink: control ink (with no fluorescent compounds), ink with water-soluble fluorescent compounds, and ink with water-insoluble fluorescent compounds were prepared. Dye or mixture of dyes was added to surfactant solution and DI water. The mixture was heated, and stirred using a magnetic stirrer to dissolve the dye. Further, ethylene glycol and glycerin were added to the dye solution and the mixture was stirred for 10 minutes using a magnetic stirrer to prepare ink. In case of water insoluble fluorescent dye, the dye was dissolved using ethylene glycol and small amounts of glycerin and then this mixture was added to the reactive dye solution. Their recipes are tabulated below (See Table 2). All the quantities are weight/weight based (w/w).

Table 2. Ink formulations

| **Ingredient** | **Control ink** | **Ink with water-soluble fluorescent dye** | **Ink with water-insoluble fluorescent dye** |
|---|---|---|---|
| Dye | 15 wt% | 15% | 20g |
| Fluorescent dye | N/A | 7.5% | 0.5% |
| Triton X-100 (10% solution) | 7 grams of 10% w/w | 7 grams of 10% w/w | 7 grams of 10% w/w |
| Ethylene Glycol | 25% | 25% | 25% |
| Glycerin | 7% | 7% | 7% |
| | Water balance | Water balance | Water balance |

**Evaluation of ink performance**

Viscosity - The viscosity of all ink samples was determined by Ostwald viscometers (Number 50, and 100 sizes). The viscometers were soaked in diluted nitric acid (5% w/v) for a day and cleaned thoroughly with distilled water. A 25º C thermostat was immersed in a water bath to equilibrate. A small flask filled with ink was placed for approximately 10 minutes in a 25º C bath to equilibrate. The viscometer was mounted vertically in the bath so that both fiducial marks were visible below the water level. Ink was poured into a pipette (viscometer) and drawn up to a point well above the upper fiducial mark using a rubber tube activated by suction. The suction was then released and the flow time between the upper and lower marks was measured with a stopwatch. Two more additional runs with the same filling of the viscometer were obtained and the average time was calculated. The density of the ink was measured using a picnometer (the procedure is given in the surface tension measurement procedure, next paragraph). The viscosity was calculated using the following equation/formula [Shoemaker et al. 1974]: $\boldsymbol{\eta / \rho = Bt}$

where 'η' is the viscosity of the fluid (ink) in cPs (centipoises or mPa.sec)

'ρ' is the density of the solution (ink) in gms/cc

'B' is the apparatus constant that must be determined through calibration with a liquid of known viscosity (the preliminary study was conducted to calculate B).

't' is the time required for the upper meniscus to fall from the upper to the lower fiducial mark of the viscometer in seconds.

Surface tension - A set up based on the capillary rise principle was used to determine the surface tension of all ink samples. The capillary tube was soaked in hot nitric acid for several hours and rinsed before the experiment. A test tube with ink and the capillary tube was then dipped into it. To reduce the surface tension of the ink, the meniscus was raised in the tube until the force of gravity on the ink in the capillary tube exactly counter balanced the tension at the circumference. The capillary tube was adjusted upward and downward until the outside ink level was at or slightly above the zero position on the scale. Next, the height of the capillary rise was determined and this procedure was repeated two times to get the average value of the capillary rise height. The surface tension was calculated by the following equation/formula [Shoemaker et al. 1974]: $\boldsymbol{\gamma = \frac{1}{2} (h + r/3)\, r\rho g}$

where 'γ' is surface tension of the liquid (ink) in dynes /cm or mN /meter

'h' is the height of the liquid above the outside surface in cms

'r' is the radius of the cylindrical capillary in cms

'ρ' is the density of the liquid (ink) in gms /cc

'g' is the acceleration of gravity in cms /sec$^2$

In both Viscosity and Surface tension measurements, the density of the ink was measured by picnometer. The volume of the picnometer was measured first, and for this the weight of the picnometer (including the stopper) was measured ($w_1$) using a balance. Then the picnometer was filled with distilled water (with no air bubbles) and measured for its weight ($w_2$ - with stopper and water). The volume of the picnometer was obtained by

$\boldsymbol{V = (w_2 - w_1) / \rho}$ where 'ρ' is the density of the water 0.9970 gms /cc (at 25˚ C)

With the known volume ($V$), and weight of the empty picnometer ($w_1$), the density of ink was measured, where '$w_2$' would be the weight of the picnometer with ink (instead of distilled water). The quantities of surfactant and the solvents - ethylene glycol, glycerin, and water were adjusted based on the fluorescent dye's concentration in order to obtain the required range of viscosities, that is around 3 cPs (Centi Poises), and the surface tensions at around 40 dynes/cm or mN/m.

Ultrasonification - During the suction phase of the piezo crystal in the piezo printing technique, the pressure on the ink decreases. The presence of dissolved gases in the ink forms bubbles, which interrupt ink flow in the tubes and block the nozzles. It is therefore necessary to de-aerate the inks using ultrasonic treatment before filling the ink reservoirs/cartridges [8].The output (micro tip limit) of the sonifier was set at 5, which is equivalent to 50% output power. The sonifier was operated for 30 seconds and switched off for 30 seconds to avoid ink heat-up. This cycle (30 seconds on and 30 seconds off) was repeated 10 times to get a homogeneous mixture.

**Pre-treatment, Printing, and Post-treatment**

The concentrations of the pre-treatment chemicals were: alginate (0.8%), urea (10%), soda ash (4%) and water (85.2%). The quantity of the pre-treatment liquor needed for 1 yard of fabric was 500 grams and all the ingredients were blended thoroughly to produce lump-free solution, which was then padded onto the fabric. The optimum padding process parameters (roller pressure and roller speed) used in this study were 20 psi and 40 rpm respectively. [Namwamba 2005]

A custom engineered print was designed using U4ia software. The goal was to develop a print that would allow for custom fluorescence on targeted areas of the fabric. A custom palette was created to coordinate with the inks on the printer. The fluorescent ink was assigned a special value on the palette to ensure that is was delivered to specific locations of the print design. The methodology developed can be used to apply the fluorescent ink or other functional finishes to any specified location on the fabric and in any desired pattern.

The custom engineered print was printed using prepared inks replacing yellow ink cartridge on the Mimaki printer. The print options set were bi-directional with 4 passes and 720 x 720 dpi resolution. The yellow portions in the camouflage palette were printed with all the three sets of prepared inks. The printed samples were steamed at 212F for 30 minutes. Steamed samples were then washed through two 6-minute cold wash/drain cycles followed by two 6-minute hot wash/drain cycles. Then the samples were dried in a commercial dryer.

## Results and Discussion

Table 3. Ink property evaluations (average of 3 readings)

| **Property** | **Control ink** | **Ink with water-soluble fluorescent dye** | **Ink with water-insoluble fluorescent dye** |
|---|---|---|---|
| Specific gravity (gms / cc) | 1.24 | 1.29 | 1.25 |
| Viscosity (centi poise) | 2.01 | 2.84 | 2.05 |
| Surface Tension (dynes/cm or mN/m) | 37.99 | 41.69 | 38.60 |

Printed fabrics were examined visually under UV light and the fabrics printed with water-soluble fluorescent inks had an extra glow (See below images).

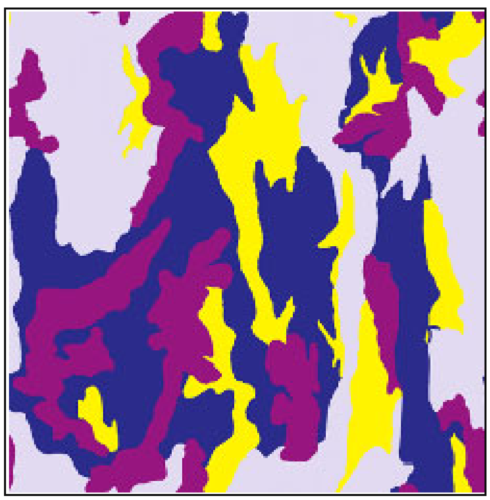

Figure 1. Camouflage palette

Figure 2. Printed fabric with water-soluble fluorescent inks

## Summary

Fluorescent dyes were successfully added to the ink rheology without disturbing the ink's physical and flow properties. Then the inks were degassed by subjecting to Ultrasonification treatment to avoid the air bubbles in the printer nozzles. The fabrics printed with water-soluble fluorescent dyes exhibited extra glow producing high visibility properties of the cotton fabrics. The study resulted in a new procedure of using inkjet technology to deliver functional finishes to specific locations on fabric prints.

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