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Environmentally Sustainable Natural Dyeing of Cotton Fabrics Using Ultrasonic Technology

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ABSTRACT
Increasing demand of environmental sustainability, many processes and methods are used to designed products for industries which is obtained from nature. Natural dye extracted from Marigold flower petals is one of them. Marigold flower petals were dried and grinded to converted into powder form. This powder is further processed to obtained optimized extract at certain conditions (powder to water ratios, temperature and time). In this study, dyeing of cotton fabrics from marigold flower petal extract is done from different dyeing methods (ultrasonic and exhaust). Ultrasonic method is more feasible than conventional exhaust method because it increases the rate of reaction and saves time, energy and amount of chemicals as well as provide high colour yield at different dyeing conditions (extract to fabric ratios, temperature, time and concentration of salt). TDS (total dissolve solids) values were measured from drained effluents by digital TDS meter. Environmental sustainability can be easily seen in Ultrasonic method by TDS results. Colour yield (k/s) of dyed samples were also checked by Gretag Macbeth CE-700A Spectrophotometer. Substrates dyed by ultrasonic method were observed high colour yield (k/s) values. Furthermore, the fastness properties (Washing and light) were also assessed of dyed cotton fabrics by ISO 105 C02 and BS 1006: 1990 UK-TN respectively which is almost acceptable.

Keywords: Marigold flower, ultrasonic dyeing, environmentally sustainable, colour yield and extraction.

INTRODUCTION

Due to harmful and toxic effects of dyeing effluent, researchers are diverted towards environmental sustainable dyeing. Natural colorants are non-carcinogenic, non-toxic and biodegradable [1]. In ancient century, natural colorants not only used for textiles but also used for painting weapons, bodies and houses [2]. Researchers are also further investigating several techniques and processes [3] to reproduce natural colorants. Natural colorants are come under environmental sustainable dyes and marigold flower's petals extracted colorant is one of them. Tagetes is one of very famous specie which potentially produces brown, yellow and orange colorants for textile substrate [4-8]. The colorant component of marigold flower is lutein which contains 70-78% in its petals [9].

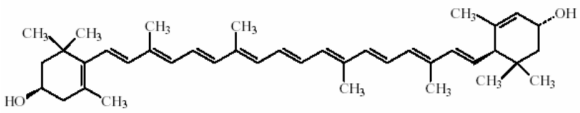

Figure 1: Chemical Structure of Lutein

Ultrasonic wave lies between 20 – 40 KHz. This energy creates bubble in liquid. The explosion of bubbles causes powerful shock which act as stirring. It swells the substrate, hence exhaustion and fixation takes in lesser time [10]. This energy accelerates the chemical reaction, hence reduction in amount of chemicals, energy, time and overall the economy of process [11]. It is one of the process of emerging technology in textile wet processing. There are several number of studies published on Ultrasonic assisted dyeing on textile substrate [12-16]. Reactive dyeing of cotton fabric was successfully done on industrial scale by using ultrasonic energy [17]. Ultrasonic dyeing of textile substrates with natural colorants have shown reduction in consumption of energy as well as reduction in waste water pollution [18-23].

Cotton is widely cultivated in asian countries. It approximately contains 60-65% crystalline and 40-35% amorphous region. It is constituted by 88-96.5 % cellulose [24].

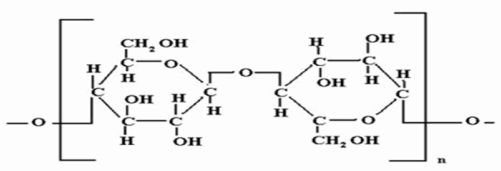

Figure 2: Chemical Structure of Cotton

Cotton is widely cultivated in Pakistan. Marigold flowers are annual planting in Pakistan. Due to easy availability, these materials are chosen for this experiments. Natural dyeing using ultrasonic energy are more environmentally sustainable. This study is used to evaluate environmental sustainability of dyeing effluents (TDS), colour yield (k/s) of dyed samples and their fastness properties (light and washing).

EXPERIMENTAL

Materials: Plain woven mercerized cotton fabric (approximately 150 g/m^2) was supplied from Gul Ahmed Textile Mills, Karachi, Pakistan. Marigold flowers were easily obtained from local market, Hyderabad, Pakistan. The flower petals were picked out and mixed homogenously to avoid colour variation. Sodium chloride (NaCl) were analytical grade of Al Beruni Scientific Store, Hyderabad, Pakistan. All experiments were using of deionized water.

Dye Extraction: Marigold flowers' petals were dried in oven (laboratory scale). Dried petals were crushed in grinder to convert dried petals into powder form. Powder of marigold flowers' petals were heated at various temperatures (60-120 ^{o}C) for varying time (30-90 mins) with different powder to water ratios (0.5:20 – 1.5:20). To optimized extraction conditions, cotton fabrics were dyed by these extractions with certain rapid dyeing conditions: extract to fabric ratio is 15:1, concentration of sodium chloride is 50 g/l at 70 ^{o}C for 30 mins. Homogenous extracted solution and rapid dyeing were carried out at exhaust dyeing equipment (Rapid Laboratory CO, ltd, Taiwan). The treated substrates were subjected to note maximum colour yield (k/s) values by Gretag Macbeth CE-700A spectrophotometer for optimum extraction condition.

Dyeing: The exhaust dyeing of cotton fabrics was carried out by HT Rapid dyeing equipment (Taiwan). The ultrasonic dyeing of cotton substrates was achieved by Ultrasonic equipment (Japan). Dyeing of cotton fabrics were done by optimum extract solution with different extract to fabric ratios (10:1 – 30: 1) and salt concentrations (45-105 g/l) at various temperatures (40-80 ^{o}C) for varying time (30-70 mins). Dyed cotton samples further rinsed by hot water and dried at 100^{o}C in oven (SDL Atlas textile testing solutions).

Testing: TDS (total dissolve solids) in before and after dyeing effluents were assessed by digital TDS meter. Colour yield (*K/S* value at maximum absorption) of all dyed samples were observed by Gretag Macbeth CE-700A Spectrophotometer. Furthermore, the fastness properties of treated samples were also analyzed. Washing fastness and light fastness were determined by roaches washtec (ISO 105 C02) and mercury light fading lamp (BS 1006: 1990 UK-TN) respectively.

RESULTS AND DISCUSSION

Optimization of Extraction Conditions: The k/s values extraction of powder to water ratios, temperatures and time as shown in figure 3, 4 and 5 respectively. As the quantity of powder of marigold flowers' petals is increased, so k/s values also increases. This increment shows direct relation in figure 3. As shown in figure 4 and figure 5, as the temperature increases so, k/s values are decrease and as the time increases so, k/s values increases up to 60 mins then k/s values were decreased. This may be due to over-cooked the extracted colour which causes colour decomposition.

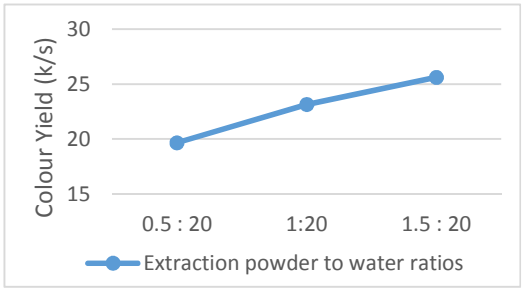

Figure 3: Effect of powder to water ratios of dyed samples on it Colour yield

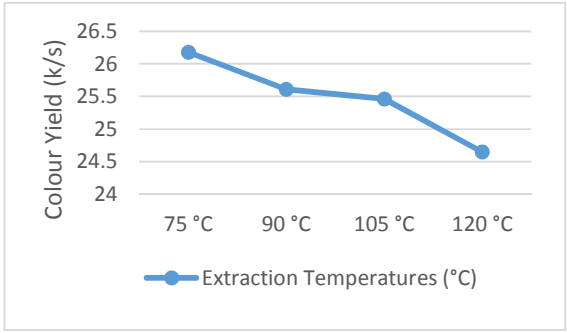

Figure 4: Effect of Extraction Temperature of dyed samples on its colour yield

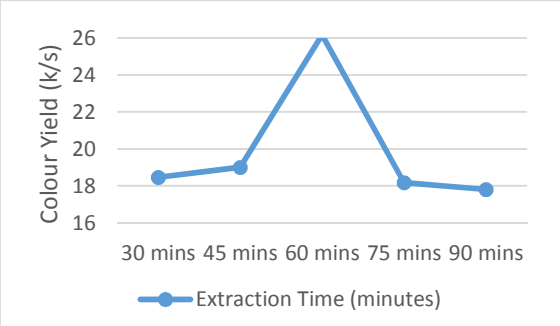

Figure 5: Effect of Extraction Time of dyed samples on its Colour Yield

Optimization of Exhaust and Ultrasonic Dyeing Conditions: Results of the effects of extract to fabric ratios, temperatures, time and salt concentrations are shown in figure 6, 7, 8 and 9 respectively. It is observed that every optimum value of dyeing condition has high colour yield (k/s) in ultrasonic dyeing in comparison with exhaust dyeing. Optimum dyeing conditions of ultrasonic dyeing save energy and amount of salt, hence process is economical.

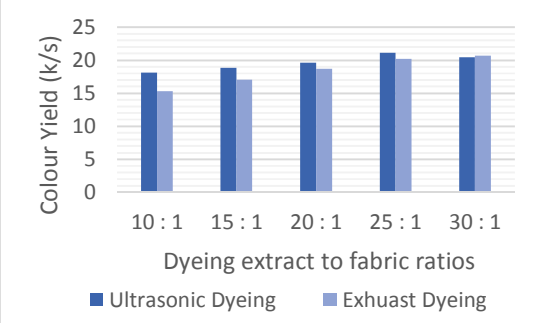

Figure 6: Effects of Extract to Fabric Ratios in Dyeing of Dyed Samples on its Colour Yield

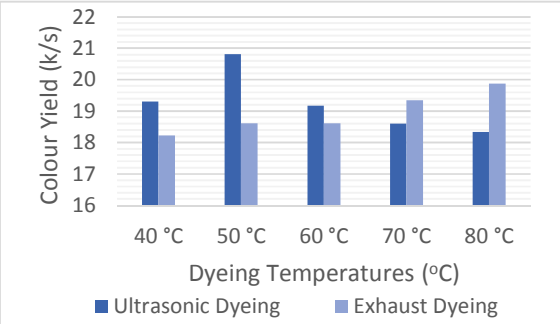

Figure 7: Effects of Dyeing Temperature of Dyed Samples on its Colour Yield

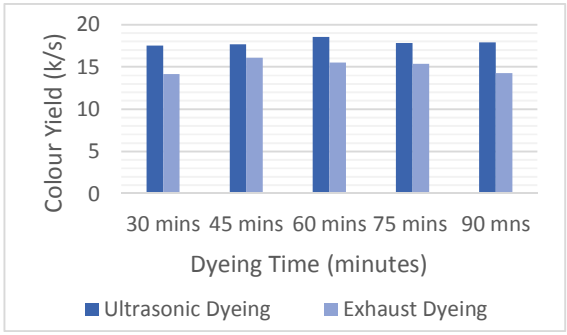

Figure 8: Effects of Dyeing Time of Dyed Samples on its Colour Yield

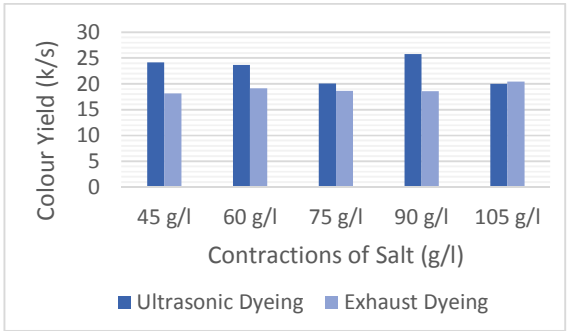

Figure 9: Effects of Salt Concentration of Dyed Samples on its Colour Yield

Assessment of Effluents: TDS testing of 50 times diluted effluents of marigold flowers extract dyeing of cotton fabrics were carried out by digital TDS meter. TABLE I shows assessment of effluents TDS (ppm) of both dyeing methods (Ultrasonic and Exhaust). According to results, Ultrasonic assisted dyeing effluents are containing low TDS than conventional exhaust dyeing effluents. The cavitation effect of ultrasonic energy reduces amount of chemicals and energy. Hence waste water pollution also reduces, that is why ultrasonic assisted dyeing has low TDS.

TABLE I: Assessment of Effluents TDS (ppm)

	Before Dyeing	After Dyeing
Ultrasonic Dyeing	1850	1730
Exhaust Dyeing	2030	1900

Assessment of Fastness Properties of Dyed Fabrics: The fastness properties of dyed fabrics are acceptable for light fastness and staining of fabrics but not acceptable for washing fastness as shown in Table II.

Ultrasonic Dyeing were given better results than exhaust dyeing. Thus this process also improves dye fixation.

Table II: Assessment of Fastness Properties of Dyed

	Staining on multi fiber strip						Change in Shade	Light Fastness
	Wool	Nylon	Polyester	Acrylate	Cotton	Acetate		
Ultrasonic Dyeing	4/5	5	5	5	4/5	5	2	4
Exhaust Dyeing	4	5	5	5	4	5	2/1	3

CONCLUSION: Dyeing of cotton fabric was successfully done by marigold flower petals extracted dye using ultrasonic energy. TDS results of effluents of ultrasonic dyeing were shown environmental sustainability in comparison with exhaust dyeing. Colour yield of ultrasonic dyed fabrics is higher than exhaust dyed fabrics. Fastness properties (washing and light) of dyed cotton fabrics are almost acceptable.

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