# Dyeing of Cotton with Direct Dyes Using Microwave Irradiation

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***ABSTRACT***

In this research work, dyeing of cotton fabric is carried out with direct dyes in exhaustion method by microwave system. The effect of microwave power, time of dyeing, electrolyte concentration, dye concentration and L:G are outlined. The results of preliminary experiments on the effect of microwave on the dye solution and the fabric itself clearly showed that the microwave process has no effect on the cotton fabric and direct dyes. Other results indicated that an increase in the microwave power causes an increase in the dye absorption by the fabric. However, the time of dyeing process could also be very effective on the dye absorption. Therefore, extension of dyeing time up to 20 min causes a higher exhaustion but further increase in the time of dyeing leads to a decrease the absorption. Presence of electrolyte as an absorbable ionic material in dyeing process, leads to an increase in exhaustion. It can be concluded that the effect of electrolyte and dye concentration in microwave heating system is similar to the normal exhaustion dyeing. Also, the effect of liquor to good ratio in microwave irradiation was not the same as the normal exhaustion dyeing, because a higher exhaustion was obtained with increasing of L:G up to 100:1. However, the exhaustion decreased with higher L:G. Finally, the results of washing fastness showed a small improvement in the washing fastness on the fabric dyed by microwave irradiation.

***KEYWORDS:***

Microwave, Dyeing, Direct Dyes, Exhaustion, Cotton, Washing

## 1. INTRODUCTION

For many years, dielectric heating has been used commercially as a method of heating materials that are poor conductors of heat, e.g., wood and plastics. The material is exposed to a high frequency electromagnetic field and rapid internal heating is caused by molecular friction or agitation, induced by rapid reversals of the polarity of the electric field. Microwave has wavelength between about 1m and 1mm corresponding to frequency from 300 MHz up to 300 GHz. Microwave heating, a form of electric heating, is understood as the generation of heat in materials of low electrical conductivity by the action of high- frequency electric field [2]. Under the influence of an alternating field, the dipole molecules undergo oscillations in response to the high frequency field polarity changes. The intermolecular friction produces high-frequency energy which is first absorbed then transformed into thermal energy. Substances with a symmetrical molecular structure, such as benzene, cannot be heated in a high-frequency field, since they lack the necessary dipole characteristics. Apart from the dipole molecules, freely movable ions can also be influenced by an alternating electric field. They move to and from in response to the high-frequency polarity changes, and thereby collide with each other. Nevertheless, distinctions should be made between dielectric and microwave heating. Thus, what is normally referred to as dielectric heating involves a lower frequency and as high a field strength as possible, without electrical breakdown of the field, whereas microwave heating uses a much higher frequency and a comparatively low field strength. At this point, it should be stated that most textile fibers are not regarded as 'Lossy' materials. A lossy material is one in which the overall molecular structure, or a group within the structure, can be induced to resonate at frequencies similar to the frequency of the microwave radiation, resulting in a dielectric loss of the input energy which is converted into heat within the material. Since fibers are themselves comparatively non-lossy, water or another lossy substance must be present. The microwave energy heats the water, which in turns heats the fiber. Therefore moisture is required to facilitate diffusion of the dye and as a transfer medium for heat. However, it should be realized that the heating of water occurs uniformly throughout the fiber and does not involve conducting

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mechanism as in steaming where the heat is applied from outside the fibers [1].

The power of material for absorption of radiation depends on electrical properties and magnetic parameter of molecules [2-5]. Application of microwave as a source of thermal energy is very important and nowadays it is in favor for the textile producers. In finishing and dyeing processes of textile usually thermal energy needed and in normal heating system the transfer of heat takes place from outside of the fabric to inside of it. In this way of heating the fabric surface is warmer. This causes over drying and dye migration [6-7]. Since the microwave heating system produces heat inside the fabric, the mechanism of heat transfer differs from thermal conductance in normal heating systems. Therefore, in the microwave heating system there is no temperature differences between inside and outside of the fabric [8]. Example of application of microwave heating is a jig machine equipped with microwave's generator. The utilization of this machine in finishing showed an increase in efficiency of the process. This is along with reduction of processing time without any changes in the quality of the fabric. By application of this type of thermal energy, dyeing problems such as color differences between first and last and also differences in edges of the fabric which normally exists in conventional method can be decreased [9]. Polli and Edoardo recommended the use of a tunnel equipped with a microwave generator for drying and removing of organic waste from insects adhered to cotton. They showed that the usage of this method can improve the process ability of cotton fiber and increase the efficiency of spinning [10]. In addition, the use of microwave heating system in alkaline hydrolysis treatment of polyester (relation to normal method) can increase the hydrolysis efficiency, weight loss, wicking ability and dye uptake by polyester fabrics [11]. Also, microwave heating system used for eradication of insects from woollen textiles. In this method, 3min radiation of microwave could kill (100%) the eggs, larval and adults stages of moth with the lowest effect on the physical and chemical properties of wool fabric [12]. Badrosamaa and Amirshahi showed that no changes occurred in the absorption of reactive dyes on the cotton fabric treated with microwave radiation (600 Watt) before dyeing. They also observed that usage of the microwave heating system in dyeing of cotton with reactive dyes by exhaustion method reduces the time of dyeing without any changes in dye-uptake. They showed that the microwave heating system used for absorption and fixation steps of reactive dyes on the padded cotton fabrics increases the efficiency of dyeing in shorter time compared to the cold pad batch method [13]. There is no report on the dyeing of cotton fabric with direct dyes using microwave in exhaustion method. Thus this research work tried to use the microwave heating system for dyeing of cotton fabric with direct dyes by exhaustion method. To do this, the effects of different factor such as microwave power, time of dyeing, electrolyte concentration, dye concentration and liquor to goods ratio (L:G) were investigated.

## EXPERIMENTAL

### MATERIALS

Bleached woven cotton fabric (120 g/m²) was used in dyeing experiments. The fabric samples were dyed with direct dyes including Solophenyl Scarlet BNL 200% (C. I. Direct Red 89), Solophenyl Blue 4GL (C. I. Direct Blue 78), Solophenyl Yellow ARLE 154% (C. I. Direct Yellow 106). Analytical grade of $Na_2SO_4$ (Merck) was also used as electrolyte.

### METHODS

The dye exhaustion percentage was determined using Perkin Elmer-Lambda 25 Spectrophotometer and X-RITE Reflectance Spectrophotometer. Dyeing process carried out with LG Microwave MC-2003 TRS (900 watt-power and 2450 MHz-frequency). The fabric samples strength was measured by Instron (model 4202).

Dyeings were carried out in exhaustion method using two different heating systems. In normal heating system, cotton samples were added to the dye bath at 40°C and then the temperature was increased to boil in 20 min. The dyeing was carried out at boil for 45min and then the samples rinsed and air dried. In order to dye the samples with microwave irradiation heating system in exhaustion method, a glass container was used. Dyeing was carried out at different time intervals of 5, 10, 15, 20, 25 and 30 min and also various microwave power of 180, 360, 540, 720 and 900 watt. Effects of electrolyte, dye concentration and L:G was further investigated on selected 720 watt power and 15 min time because of optimum results obtained in this condition.

In order to determine the equation of absorbance via concentration, the absorption-concentration curve was obtained. To do this, six different concentrations of dye was prepared and the amount of absorption for each samples was measured at maximum wavelength ( $\lambda_{max}$) by absorbance spectrophotometer.

The exhaustion percent was calculated by following equation:

Exhaustion % = $(A-B/A)*100$

where A is the concentration of dye solution before dyeing and B is the concentration of dye solution after dyeing.

The K/S value were also calculated using Kubelka-Munk equation,

$$K/S = (1-R)^2/2R \quad \text{(Kubelka–Munk equation)}$$

The colour differences (ΔE D65 /10) formula was used to calculate the color differences and the fabric whiteness was reported according to Hunter equation:

$$\Delta E = [(a_1^*-a_2^*)^2 + (b_1^*-b_2^*)^2 + (L_1^*-L_2^*)^2]^{1/2}$$

$W\,(Hunter) = 100 - [(100 - L)^2 + 10b^2]^{½}$

The fabric shrinkage percentage was also measured using the following equation:

Shrinkage % = (A-B/A )*100

where A is the original distance between reference marks and B is the final (after dyeing) distance between references marks.

The washing fastness of the selected samples were measured according to ISO-R-105 and change of it was evaluated with gray scale.

## RESULTS AND DISCUSSION

### EFFECT OF MICROWAVE ON DYE AND COTTON FABRIC

To examine the effect of microwave irradiation on dye solution, the dye solution was exposed to the microwave irradiation and absorbance spectrum of solution before and after irradiation was investigated. The absorbance spectrum of aliquot dye bath, before and after microwave irradiation, did not show any changes and the $\lambda_{max}$ and the color of dye bath was unchanged. Also, to examine the influence of the microwave irradiation on the cotton fabric, the fabric sample was impregnated in the aqueous solution and subjected to the microwave irradiation before measuring tensile strength and fabric whiteness. The results of whiteness and tensile strength tests of cotton samples before and after microwave irradiation also showed no significant changes. This means the chemical and physical properties of the cotton fabric has not been significantly changed by the microwave irradiation (Tables 1 and 2). This makes the thermal energy produced from microwave a good source of heating for dyeing of cotton fabrics with direct dyes.

Table 1: Color indices and whiteness of samples before and after microwave heating.

| Samples | L* | a* | b* | C* | h | Whiteness |
|---|---|---|---|---|---|---|
| untreated | 91.70 | -0.09 | 3.91 | 3.91 | 91.35 | 85.11 |
| Treated fabric for 20 min. at 180w power | 88.68 | -0.17 | 3.41 | 3.41 | 93.17 | 84.94 |
| Treated fabric for 20 min. at 900w power | 90.52 | -0.07 | 4.15 | 4.15 | 90.98 | 83.81 |

Table 2: Tensile of samples before and after microwave heating.

| Samples | Untreated | Treated fabric for 20 min. at 180w power | Treated fabric for 20 min. at 900w power |
|---|---|---|---|
| Force (kgf) | 80.3 | 87.9 | 87.2 |
| Elongation (mm) | 13.7 | 23 | 24 |

Rate:125 mm/min distance between two clamp:20cm

### EFFECT OF DYEING TIME AND POWER OF MICROWAVE IRRADIATION

The results of exhaustion measurements in different dyeing time at different microwave power are shown in Figures 1-3 (for Solophenyl Scarlet BNL 200%). According to the results, extension of dyeing time to 20min at a given power of microwave (180-900 watt), leads to an increase in absorption of dye in comparison with normal exhaustion process. Increasing of dyeing time to 25-30min with irradiation of microwave at 540, 720 and 900watt also leads to decrease the dye absorption. However, the results of dye absorption showed that an increase to the time of dyeing causes the dye absorption to increase at 180 and 360 watt.

The heat transferred by conduction in normal exhaustion method during dyeing process means that the surface of the material was first heated and then transferred through the sample. Hence, heat transfer by this mechanism is time-consuming. While in the microwave irradiation the material was heated simultaneously and there is no heat gradient between the surface and inside of the material. In this manner, the dye bath reaches a specific temperature faster. The results shown in in Figures 1-3 reveals that in a given time of dyeing (20 min), increasing the microwave power can increase the dye absorption. In fact, increasing the power of microwave, absorption of energy increases by lossy materials (lossy material: absorptive electromagnetic such as water, electrolyte ...) exist in the aqueous media. Therefore, increasing the kinetic energy of the dye molecule leads to a decrease in time required for transferring dye molecules into the fiber structure. In addition, at this condition, the rate of swelling of cotton fiber was increased. Thus, the system was reached to equilibrium rapidly. With increasing the time of exposure of microwave irradiation (increasing of dyeing time to 25-30) and bringing in mind this reality that the linkage of the dye to the fabric is weak and can be broken down at high temperature. Then number of dye can be separated from the fabric and migrated to the dye-bath, as a result the exhaustion decreases (the amount of migration related to the size and structure of the dye). At low power (such as 180 watt) the energy of system was low, and longer time of dyeing leads to higher exhaustion.

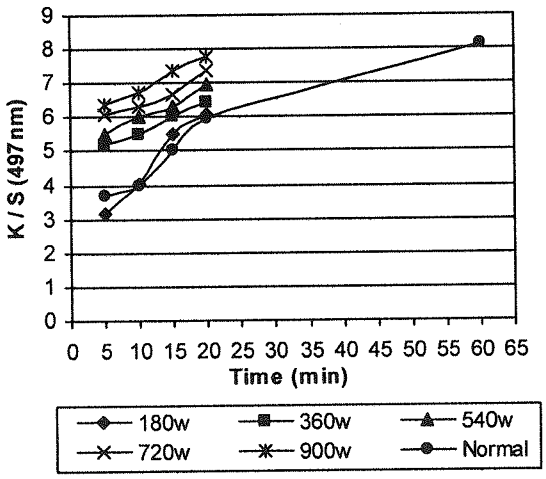


Fig. 1: Dye exhaustion on cotton fabrics dyed in normal conditions or under microwave irradiation (dyeing was done at different microwave power for 5-20min and 60 min for normal dyeing).

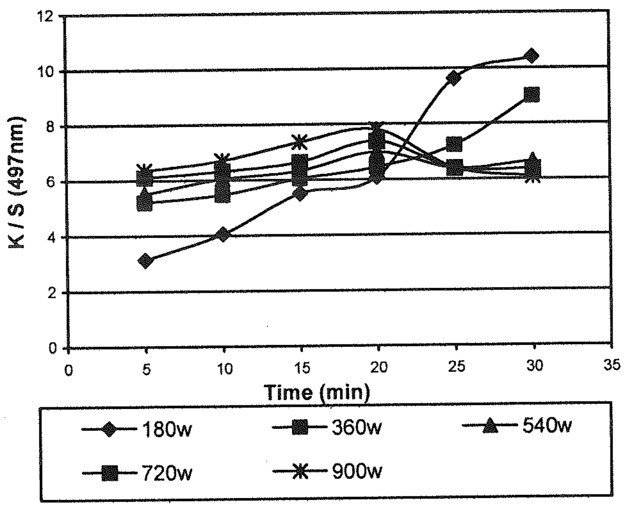


Fig. 2: Dye exhaustion on cotton fabrics dyed under microwave irradiation (dyeing was done at different microwave power for 5-30min).

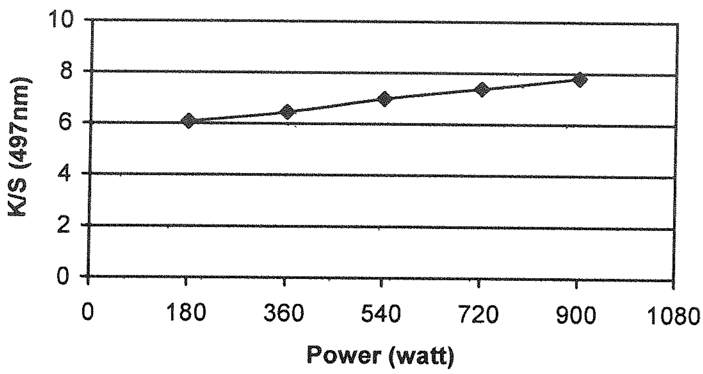


Fig. 3: Dye exhaustion on cotton fabrics dyed under microwave irradiation for 20 min.

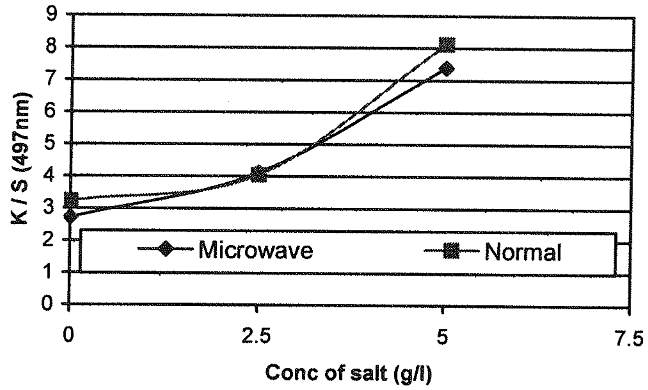


Fig.4: K/S vs. concentration of salt for dyeing of cotton fabric with direct dye by two methods exhaustion (normal and microwave).

### EFFECT OF ELECTROLYTE

Effect of electrolyte in dyeing of cotton with direct dyes in normal exhaustion method is the neutralization of fiber surface charge and decreasing of electrical repulsion between the dye and fiber. This leads to increase the absorption of dye by goods and uniformity of dyeing. The results in Figure 4 showed that changes of K/S against concentration of electrolyte in cotton dyeing with direct dyes by exhaustion method with microwave heating is similar to the normal heating as the presence and increase of concentration of electrolyte (0-5 g/l ), caused an increase to the K/S. Also, it can be observed that the dyeing by microwave irradiation is more depending upon the presence and increase of electrolyte in the dye-bath. The reason is in addition to the influence of electrolyte in the normal exhaustion dyeing, the microwave radiation can be also absorbed by ions [1, 4, 6, 7].

### EFFECT OF CONCENTRATION OF DYE

The results of changes of K/S of cotton fabric dyed with direct dyes (normal and microwave exhaustion method) against concentration of dye showed in Figure 5. It can be seen that, in normal heating dyeing with increasing of dye concentration, the exhaustion increases. This process was also done for dyeing of cotton with some dyes (at 0.25-1% concentration) by microwave irradiation. The results indicated that a little sensitivity to dye concentration exist which is based on the structure of dye, specially with electrical charged dyes. These could absorbed electromagnetic wave directly, same as water and electrolyte and vibrated with frequency equal to the frequency of microwave. In this way, the dye molecules in addition to losing absorbed energy to form heating energy they could produce electrical layer around them which may increase the chance of effective contact between the dye and fiber (i.e., increasing exhaustion).

### EFFECT OF L:G

In dyeing of cotton fabric with direct dyes by normal exhaustion method, depending on the kind of machine, different L:G may used. However, it is desirable to use a low L:G process also at low L:G seems to have a lower electrical repulsion between dye and fiber and can be obtain an increased exhaustion. The results showed that with increase of L: G from 40:1 to 100:1 the K/S increases, higher increase to 150:1 decreases the K/S of the samples dyed with microwave irradiation (Figure 6). It can be concluded that the energy of microwave irradiation can cover certain volume of an aqueous solution. It can be also resulted that at L:G of 40:1 with microwave irradiation the complete energy cannot be discharged. With increasing of volume of aqueous solution the energy of irradiation produced can be discharged and then it increase the number of dye molecules with higher energy. This could arise the chance of contact between dye molecules and fiber which increases the exhaustion. There was no free microwave radiation with increase of volume of solution and therefore distribution of microwave energy between high numbers of particle was encountered. Therefore, in this condition each particle has a lower energy and at a given time of dyeing causes a reduction in exhaustion. **EVALUATION OF WASHING FASTNESS**

The results of washing fastness showed in Table 3. The results indicated that the washing fastness of samples dyed with microwave irradiation a little improved and staining on the white cotton and wool fabrics was reduced.

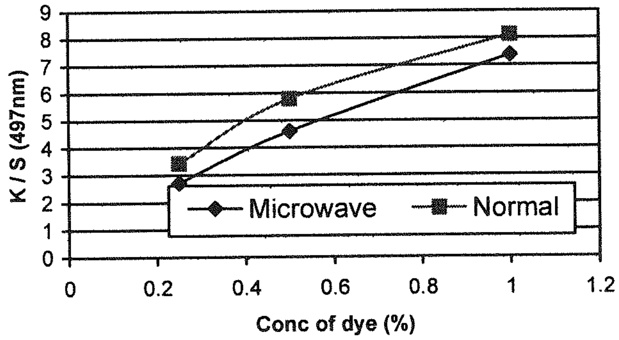


Fig. 5: K/S vs. concentration of dye for dyeing of cotton fabric with direct dye by two methods exhaustion (normal and microwave).

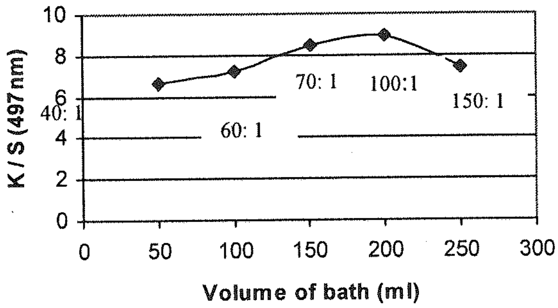


Fig. 6. Influence of L:G on K/S for the cotton samples dyed with direct dye through microwave irradiation.

## 2. CONCLUSIONS:

The results of this research showed that microwave irradiation with the conditions used in this experiment has no influence on the structure of direct dyes and also cotton fabrics. Therefore, the thermal energy produced by the microwave irradiation can be used for dyeing process. In comparison of cotton dyeing with direct dyes by normal condition and microwave irradiation, it was observed that the microwave irradiation, reduces the time of dyeing with increasing in the rate of dyeing. This may increase the efficiency. Meanwhile with the microwave irradiation the limitation of selection of L:G is not the same as normal heating, and also the microwave irradiation causes a relative improvement (0.5-1 gray scale unit) in the washing fastness.

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