Effect of pre-treatment and dyeing parameters on Dyeing of meta-aramid Yarn

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Abstract

The meta-aramid fiber is well accepted raw material for high-performance applications. Uses of products include apparel fabrics to protect against flash fire and electric arc exposure firefighter garments, filtration applications, insulation in flame-resistant (FR) thermal protective apparel, rubber reinforcement, and transportation textiles such as aircraft carpeting. For industrial applications, there is no need to dye the fiber but for the garment, there is a need to dye the material. This is difficult to dye the fiber due to its high crystalline and compact structure. In this study, aramid yarn is pre-treated with the solvent Dimethylformamide to facilitate the dyeing process and then dyeing is done with cationic dye. Pre-treatment and dyeing were done at different temperatures and times to see how these parameters affect the process. The fastness properties of dyed fibers were found good at high dyeing time and temperature followed by high pretreatment time and temperature.

Keywords

Aramid, pretreatment, dyeing, low temperature

Citation

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1.0 Introduction:

Aramid fibers are aromatic polyamides that were developed by DuPont in the early 1960s. Meta aramid fibers are commercially available under the trade name Nomex. These fibers are being used for making high electrical and thermal protective apparel because of their high strength, high modulus and heat resistance property. These fibers can be dyed in different colours through the dope dyed process. When small batches of dyeing in different shades are required, exhaust dyeing needs to be done. But exhaust dyeing of these fibers is difficult due to its thermostable crystalline structures having a high degree of molecules orientation in the polymer chain and strong hydrogen bonding between amide groups in adjacent chains. Various attempts have been made to dyeing of aramid fibers. One feasible method of them is the treatment of fibers with polar solvents such as dimethylformamide, dimethylacetamide, and dimethyl sulfoxide which helps in structure opening and easy penetration of dyes [1]. M.T. Islam et al. [2] used N-methyl formanilide as a swelling agent in the cationic dyeing process of meta-aramid fibers and has demonstrated an increase in dyeability. S. Y. Han et al. [3] did acid dyeing of meta-aramid yarn after pre-treating it with PEO45-MeDMA diblock copolymer derived from [2-(methacryloyloxy)ethyl] trimethylammonium chloride. This pre-treatment creates dyeing sites that can bond with anionic dyes. Para-aramid fibers can be dyed with disperse dye as shown by A. A. Vassiliadis et al. [4], however, exhaustion was lower than 79%. N. Oiwa et al [5] have discussed a method of dyeing aramid fibers with sulphur or vat dye after treatment with a polar solvent. F. Azam [6] showed the dyeing behaviour of cationic dyes at different parameters. M. Morris et al [7] have shown the effect of pretreatment of the para-aramid fabric with soyabean oil and nonthermal plasma on cationic dyeing. In the present study, aramid fibers have been pre-treated with dimethylformamide and dyed with cationic dye. A systematic study on the effect of pre-treatment and dyeing temperatures and time has been done. The effect of change in such parameters in colour value, when exposed to light and washing, is also studied.

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2. Materials and Methods

2.1 Material

100% Nomex yarn of count 3/30 was procured from Arvind Limited. Dimethylformamide 99.8% purity, sodium carbonate and sodium dithionite were procured from Merck Chemicals. Coralene red cationic dye was procured from ColourTex.

2.2 Pretreatment of m-Aramid Yarn

m-Aramid yarns were pre-treated with DMF with MLR 1:15 at a definite temperature for a definite time in a water bath. To study the effect of pretreatment temperatures, the temperature was varied as 45°C, 65°C and 90°C and to study the effect of pretreatment time, it was done at 15, 60 and 120 minutes. Samples were then hot washed for 15 minutes followed by normal wash and open-air drying.

2.3 Dyeing of m-aramid yarn

Dyeing of pretreated aramid yarn was done with 3% shade, MLR 1:25, pH 3-4 at a definite temperature for a definite time. To study the effect of dyeing temperatures, the temperature was varied as 100°C, 120°C and 140°C and to study the effect of dyeing time, it was varied as 45, 90 and 150 minutes.

Dyed Samples were then treated with a 1gpl solution of sodium carbonate and sodium dithionite at a temperature of 100°C for 15 minutes followed by normal wash and open-air drying.

2.4 Testing of prepared samples

Samples were exposed to Xenon arc light of energy 500W/m^2 and the change in colour value after 1, 2, 5 and 8 hours of light exposure is evaluated. For analysis of change in colour value after washing, Soap solution is prepared with standard soap of 5 gpl and sodium carbonate 2 gpl. Samples were then subjected to washing with MLR 1:50 at a temperature of 95°C for 4 hours in a laundometer followed by normal wash and open-air drying.

2.5 Colour value measurement

Prepared samples were then analysed for colour value using Macbeth color-Eye 7000 A spectrophotometer.

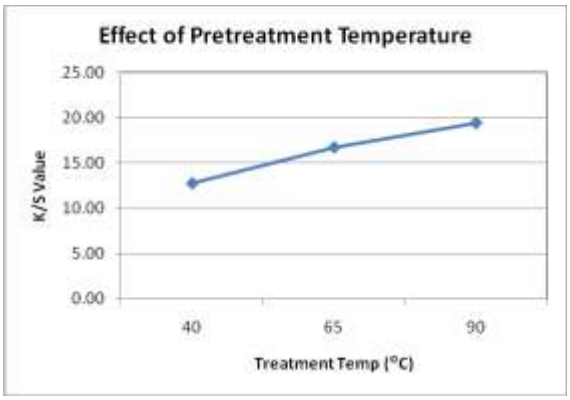
3. Results and Discussion

3.1 Effect of change in parameters on a colour value

Table 1 shows the colour value of the samples prepared with different parameters and a graph showing the change in colour value with the change in parameters is shown in figure 1. The results show that with the increase in pretreatment temperature, pretreatment time, dyeing temperature and dyeing time colour value of the sample increases. However, the percentage increase in colour value in case of an increase in dyeing temperature is higher compared to the dyeing time. This shows that dyeing temperature plays important role in the dyeing of aramid fibers. Similarly, the effect of pretreatment temperature is more compared to the pretreatment time.

Table 1: Colour Value of samples at different parameters

Parameters	K/S Value	% Increase in colour value
Pretreatment Temp (^{0}C)		
40	12.77	
65	16.73	31.0
90	19.41	52.1
Pretreatment Time (min)		
15	14.73	
60	17.25	17.2
120	19.64	33.4
Dyeing Temp (^{0}C)		
100	4.10	
120	9.31	123.0
140	14.33	264.0
Dyeing Time (min)		
45	13.62	
90	14.61	7.3
150	17.39	30.3



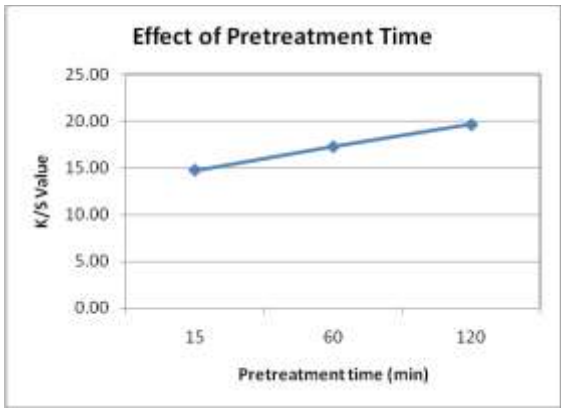
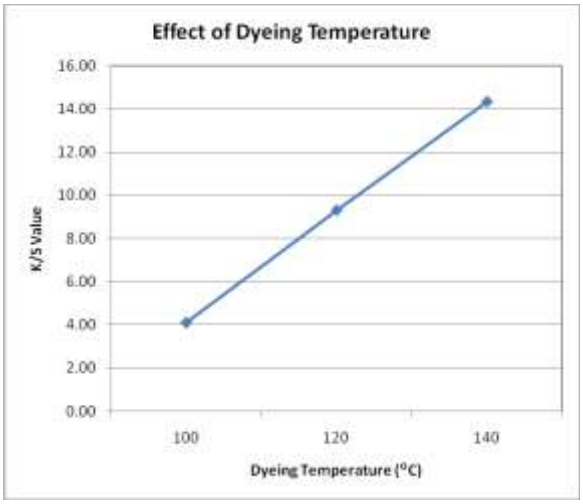


Figure 1: Effect of change in parameters on a colour value



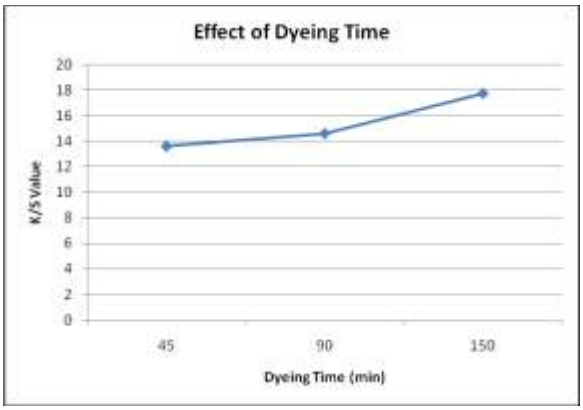


Figure 1: Effect of change in parameters on a colour value

3.2 Effect of change in parameters on colour value with light exposure

3.2.1 Effect of pretreatment temperature:

Effect of change in pretreatment temperature on colour value and percentage change in colour value with exposure to light is shown in table 2, figure 2 and figure 3. With the increase in exposure to the light colour value of all samples decreases. With the increase in pretreatment temperature, the percentage change in colour value after light exposure decreases, which shows that a higher pre-treatment temperature helps to improve the fastness to light.

Table 2: Effect of pretreatment temperature in colour value and percentage change in colour value with light exposur

Time of Exposure (Hr)	Colour Value			% Change in colour value		
Pretreatment Temp	**45^0 C**	**60^0 C**	**90^0 C**	**45^0 C**	**60^0 C**	**90^0 C**
0	12.77	16.73	19.41			
1	8.64	11.76	14.99	32.3	29.7	22.8
2	7.98	11.71	15.83	37.5	30.0	18.5
5	6.67	9.70	12.43	47.7	42.0	36.0
8	5.31	7.75	10.24	58.4	53.7	47.3

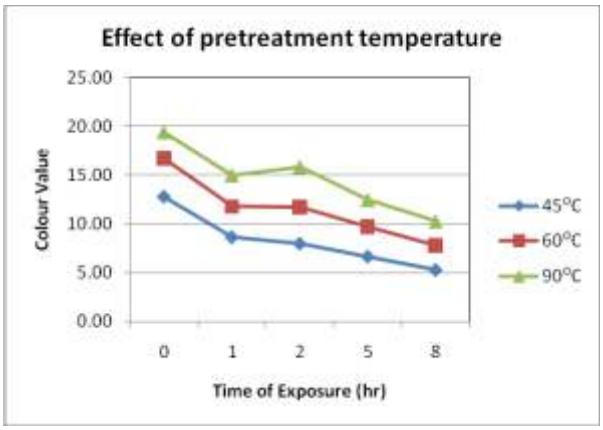


Figure 2: Effect of pretreatment temperature on colour value after light exposure

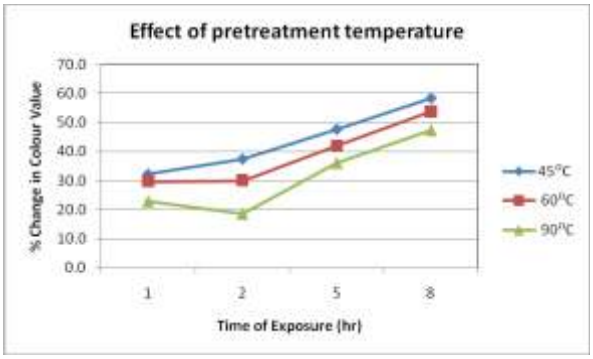


Figure 3: Effect of pretreatment temperature in percentage change in colour value after light exposure

3.2.2 Effect of change in pre-treatment time:

The effect of change in pre-treatment time in colour value and percentage change in colour value with exposure to light is shown in table 3, figure 4 and figure 5. With the increase in exposure to light, the colour value of all samples decreases. However, with 60 minutes of pretreatment time, the percentage change in colour value is less at 15 minutes and 120 minutes of pretreatment time which shows that pretreatment of fibers for a longer duration does not help in fixing the dye. From the observed values, the standardised time for treatment of fiber was kept for 60 minutes.

Table 3: Effect of pretreatment time in colour value and percentage change in colour value with light exposure

Time of Exposure (Hr)	Colour Value			% Change in colour value		
Pretreatment Time	**15 min**	**60 min**	**120 min**	**15 min**	**60 min**	**120 min**
0	14.73	17.25	19.64			
1	10.54	13.36	13.54	28.5	22.6	31.0
2	10.11	12.89	12.97	31.3	25.3	34.0
5	8.09	10.45	10.10	45.1	39.4	48.6
8	6.73	8.90	8.60	54.3	48.4	56.2

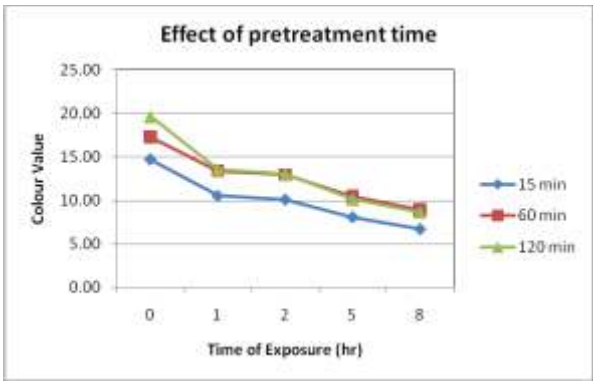


Figure 4: Effect of pretreatment time in colour value with light exposure

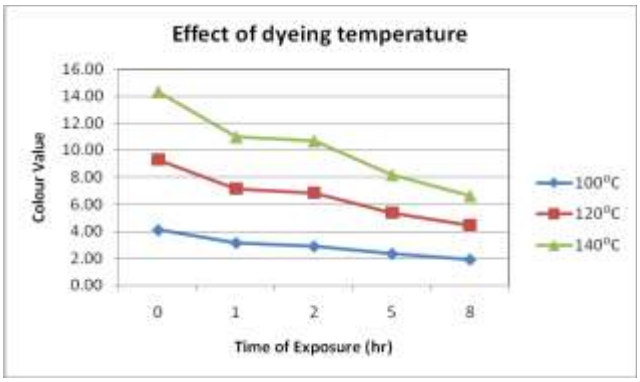


Figure 6: Effect of dyeing temperature in colour value with light exposure

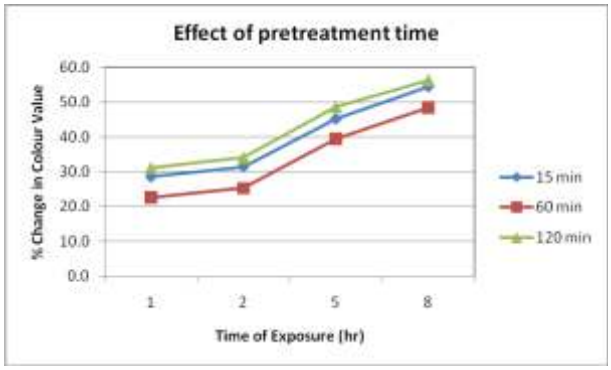


Figure 5: Effect of pretreatment time in percentage change in colour value with light exposure

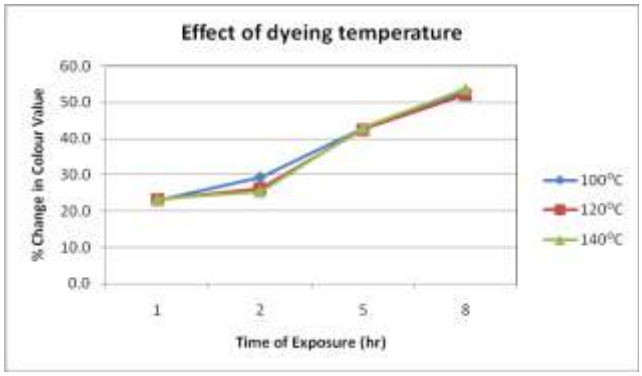


Figure 7: Effect of dyeing temperature in percentage change in colour value with light exposure

3.2.3 Effect of change in dyeing temp:

The effect of change in dyeing temperature on colour value and percentage change in colour value with exposure to light is shown in table 4, figure 6 and figure 7. With the increase in exposure to light, the change in colour value and percentage of the colour value of all samples shows a similar decreasing trend.

Table 4: Effect of dyeing temperature on colour value and percentage change in colour value with light exposure

Time of Exposure (Hr)	Colour Value			% Change in colour value		
Dyeing Temperature	**100° C**	**120° C**	**140° C**	**100° C**	**120° C**	**140° C**
0	4.10	9.31	14.33			
1	3.16	7.15	10.98	22.99	23.15	23.35
2	2.89	6.86	10.69	29.43	26.29	25.39
5	2.35	5.35	8.17	42.80	42.49	42.98
8	1.92	4.45	6.63	53.20	52.17	53.71

3.2.4 Effect of change in dyeing time:

The effect of change in dyeing time on colour value and percentage change of colour value with exposure to light is shown in table 4, figure 6 and figure 7. With the increase in exposure to the light colour value of all samples dyed at different temperatures decreases. Above the 90 minutes f dyeing, There is no significant improvement in fastness to light.

Table 5: Effect of dyeing time in colour value and percentage change in colour value with light exposure

Time of Exposure (Hr)	Colour Value			% Change in colour value		
Dyeing Time	**45 min**	**90 min**	**150 min**	**45 min**	**90 min**	**150 min**
0	13.62	15.22	17.39			
1	10.05	11.68	13.06	26.17	23.22	24.87
2	9.74	11.33	13.40	28.45	25.57	22.94
5	7.74	9.13	10.45	43.18	39.98	39.90
8	6.30	7.66	8.70	53.72	49.66	49.96

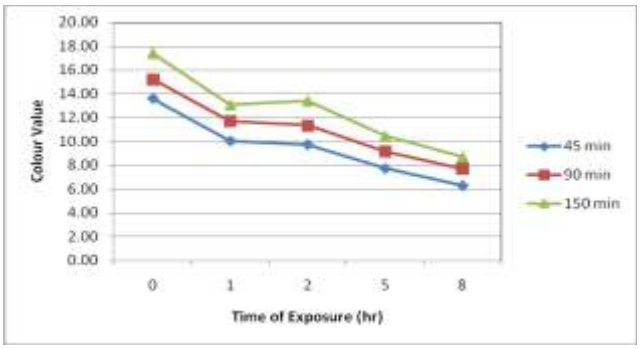


Figure 8: Effect of dyeing time in colour value with light exposure

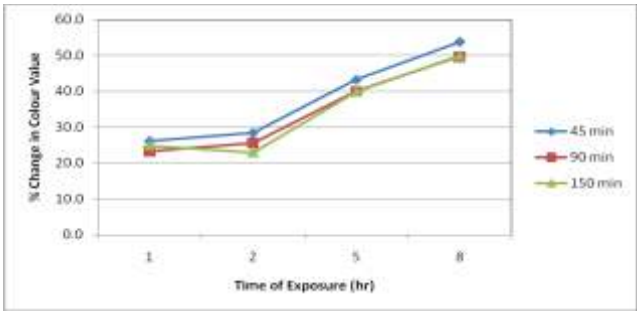


Figure 9: Effect of dyeing time in percentage change in colour value with light exposure

3.3 Effect of change in parameters on colour value with washing

3.3.1 Effect of pretreatment temperature:

The effect of change in pretreatment temperature on the colour value of samples after washing is shown in table 6 and figure 10. At higher temperatures of 65°C and 90°C, the percentage change in colour value is similar.

Table 6: Effect of change in pretreatment temperature in colour value after washing

Pretreatment Temp	Colour Value before wash	Colour Value after wash	% Change in colour value
40° C	12.77	8.61	32.56
65° C	16.73	12.99	22.35
90° C	19.41	15.07	22.38

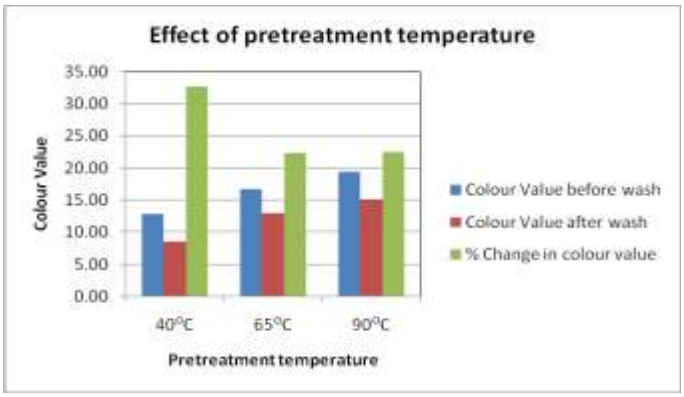


Figure 10: Effect of change in pretreatment temperature in colour value after washing

3.3.2 Effect of pretreatment time:

The effect of change in pretreatment time on the colour value of samples after washing is shown in table 7 and figure 11. At 60 minutes of pretreatment, the percentage reduction in colour value is less as compared to 15 minutes and 120 minutes of pretreatment, which shows that 60 minutes pretreatment is an optimum pretreatment time. This result is an agreement to change in colour value to light exposure.

Table 7: Effect of change in pretreatment time in colour value after washing

Pretreatment Time	Colour Value before wash	Colour Value after wash	% Change in colour value
15 min	14.73	10.779	26.81
60 min	17.25	13.918	19.33
120 min	19.64	14.466	26.34

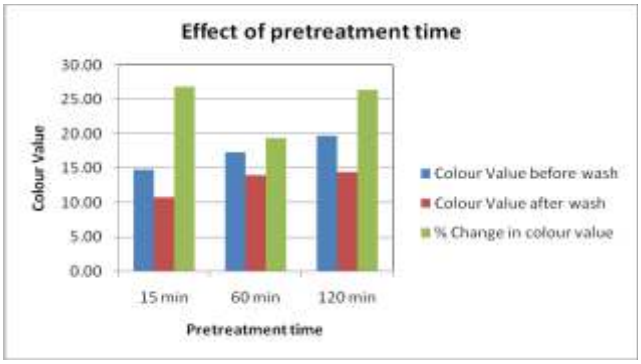


Figure 11: Effect of change in pretreatment time in colour value after washing

3.3.3 Effect of dyeing temperature:

The effect of change in dyeing temperature time on the colour value of samples after washing is shown in table 8 and figure 12. At temperature 140°C percentage reduction in colour after washing was observed compared to low-temperature values.

Table 8: Effect of change in dyeing temperature in colour value after washing

Dyeing Temp	Colour Value before wash	Colour Value after wash	% Change in colour value
100° C	4.10	3.10	24.34
120° C	9.31	6.50	30.17
140° C	14.33	11.56	19.36

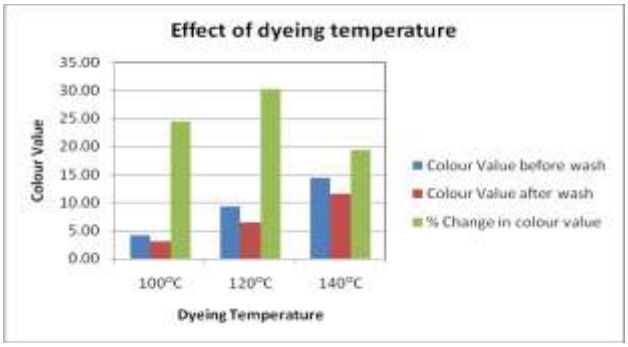


Figure 12: Effect of change in dyeing temperature on colour value after washing

3.3.3 Effect of dyeing time:

The effect of change in dyeing time on the colour value of samples after washing is shown in table 9 and figure 13. At 150 minutes of dyeing time, the percentage reduction in colour was found less after washing.

Table 9: Effect of change in dyeing time in colour value after washing

Dyeing Time	Colour Value before wash	Colour Value after wash	% Change in colour value
45 min	13.62	10.51	22.85
90 min	14.61	11.14	23.77
150 min	17.39	15.503	10.85

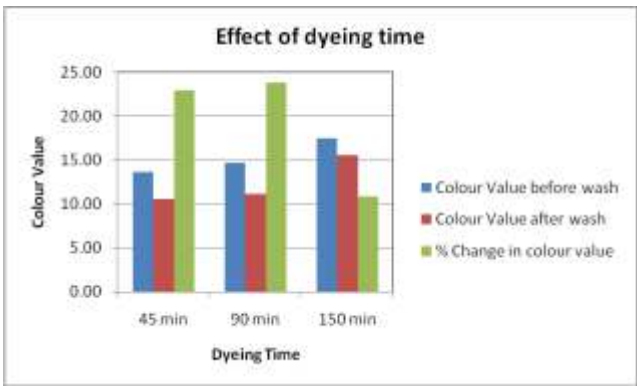


Figure 13: Effect of change in dyeing time in colour value after washing

4. Conclusion

In this study, the effect of pretreatment temperature, pretreatment time, dyeing temperature and dyeing time on the dyeing of aramid fibers was studied. It was found that the effect of dyeing temperature is prominent among others. Higher pretreatment temperature with standard pretreatment time and higher dyeing time leads to a darker shade. In this study, standard parameters were pretreatment at 90°C temperature for 60 minutes with dyeing at 140°C for 2.5 hours. These results were supported by the percentage of colour change after light exposure and washing. High dyeing temperature and time help to improve the fastness of washing. At the pretreatment temperature of 90°C and time of 60 min there is comparatively less fading of samples to light and wash fastness.

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