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**RESEARCH ARTICLE** / ARAŞTIRMA MAKALESİ

# One Bath Dyeing of PBT/Nylon Blended Seamless Fabrics

## PBT/Naylon Karışımlı Seamless Kumaşların Bir Banyoda Boyanması

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**Abstract**

Polyesters (PES) fibers are one of the most important polymers for textile industry due to their large production amounts. Poly (butylene terephthalat) (PBT) fibers are important aromatic polyesters known as their good elasticity and easy dyeing properties. PBT is manufactured by again polycondensation reaction with BDO (1,4-butanediol) and TPA or DMT, can be easily dyed at low temperatures with disperse dyes without carrier and is known as its very good elasticity properties. Generally PBT fibers are used in intimate, ready-to-wear, active and sportswear apparels, swimwear, carpets, automotive and home upholstery applications. Seamless technology is capable to meet the needs of consumers with performance, functionality and comfort. This technology has some advantages over the cutting and sewing. Seamless technology improves the aesthetic value and comfort, fredom of body movement, gives softness to the garment and minimizes the surface friction of the seams. In seamless machines, gloves, hats, socks, sweaters, sportswear can be produced. PBT fibers can be used in seamless sport wears, tights and intimates. These fibers provide more elasticity, comfort and softness on seamless sportswear than polyester fibers due to their good elasticity properties. In seamless technology polyester fibers generally are used with other fibers such as nylon, elastane.

In this study, PBT/Nylon blend knitted seamless fabrics were dyed with disperse, acid and metal complex dyes at 98$^{o}$C in one bath. The color strength, colorimetric properties and fastness properties (rub and wash fastness) of these fabrics are investigated and compared. Moreover, the comparison of water comsumptions and costs of one and two baths dyeings are given on this study.

**Keywords:** Poly (buthylene terephthalate) fiber, PBT, elastic polyesters, easy dyeing, elasticity, seamless technology

**Öz**

Polyester (PES) elyafı, yüksek üretim miktarları nedeniyle tekstil endüstrisi için en önemli polimerlerden biridir. Poli (butilen terephthalat) (PBT) lifleri, iyi esneklikleri ve kolay boyama özellikleri olarak bilinen önemli aromatik polyesterlerdir. PBT, BDO (1,4 bütandiol) ile TPA veya DMT'nin polikondensasyon reaksiyonuyla üretilir, keriyer olmadan dispers boyarmaddelerle düşük sıcaklıklarda kolayca boyanabilir ve çok iyi esneklik özellikleri olarak bilinir. Genel olarak PBT elyafları, iç çamaşırı, hazır giyim, aktif ve spor giyim eşyalarında, mayolarda, halılarda, otomotiv ve ev döşemelerinde kullanılır. Seamless teknolojisi, performans, işlevsellik ve konfor ile tüketicilerin ihtiyaçlarını karşılayabilir. Bu teknoloji, kesim ve dikme ürünlerinde bazı avantajlara sahiptir. Kusursuz teknoloji, estetik değeri ve konforu artırır, vücudun daha özgür hareket etmesine yardımcı olur, giysiye yumuşaklık verir ve dikişlerin yüzey sürtünmesini en aza indirir. Dikişsiz makinelerde eldiven, şapka, çorap, kazak, spor giyim üretilebilir. PBT elyafları dikişsiz spor giyim, tayt ve iç çamaşırlarında kullanılabilir. Bu elyaflar, iyi esneklik özellikleri nedeniyle dikişsiz spor giyimde polyester elyaflardan daha fazla esneklik, rahatlık ve yumuşaklık sağlar. Dikişsiz teknolojide polyester elyaflar genellikle naylon, elastan gibi başka elyaflarla birlikte kullanılır.

Bu çalışmada PBT/Naylon karışımı örme seamless kumaşlar tek bir banyoda 98$^{o}$C'de dispers, asit ve metal kompleks boyarmaddelerle boyanmıştır. Bu kumaşların renk değerleri, kolorimetrik özellikleri ve haslık özellikleri (sürtme ve yıkama haslığı) araştırılmış ve karşılaştırılmıştır. Ayrıca, bu çalışmada tek banyolu ve çift banyolu boyamalarda harcanan su tüketimleri ve maliyetler karşılaştırılmıştır.

**Anahtar Kelimeler:** Poli(bütilen tereftalat) lifi, PBT, elastik polyesterler, kolay boyama, elastikiyet, seamless technolojisi

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## I. INTRODUCTION

As the population increases natural fibers have failed to satify needs of humankind, and thus synthetic fibers were started to produce [1, 2]. Polyethylene terephthalate (PET) polyester, which was discovered by Whinfield and Dickson, was first produced commercially in 1941 [3]. The polyester is obtained by extracting the polyethylene terephthalate (PET) polymer formed by polymerization of ethylene glycol and ethylene. Polyesters (PES) are known as the most important fiber polymers for the textile industry [4, 5]. Polyester fibers are attractive for using in medicine, clothing, sports and various industrial fields due to their economic performance. When the polyester fibers are modified physically and chemically, high performance fibers are obtained [6]. Poly (butylene terephthalate) (PBT) was produced by Carothers and Hill (DuPont). PBT is a semi-crystalline polymer with similar properties to PET in both color and colorless properties and known as 4 GT or polytetramethylene terephthalate (Fig. 1). PBT is obtained by polycondensation reaction of purified terephthalic acid (PTA) or dimethyl terephthalate (DMT) with 1,4-butanediol (BDO) [4, 7].

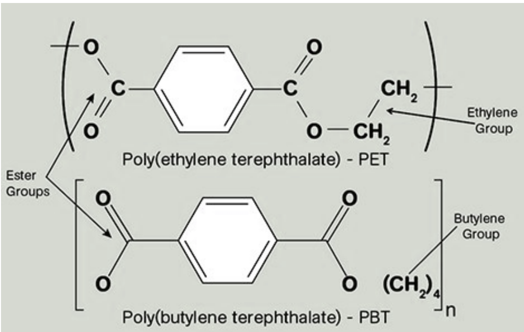



**Figure 1.** Chemical Structures for PET and PBT Repeating Units [8]

PBT fibers have very low glass transition point (Tg) values, so they can easily be dyed at atmospheric conditions without carrier. Commercial PBT fibers are produced by Zimmer and Ticona and known as Celanex® [4].

Nylon was discovered by Wallace Carothers in DuPont in 1928. Nylon (polyamide, PA) is a synthetic polymer called polyamide consisting of monomers of amides in the backbone chain and is widely used in the textile industry as PA 6.6 (nylon 6.6) and PA 6 (nylon 6). PA 6.6 is obtained by polymerizing adipic acid [$HOOC - (CH_2)_4-COOH$] with hexamethylene diamine [$H_2N - (CH_2)_6-NH_2$] (Fig. 2) [9, 10].

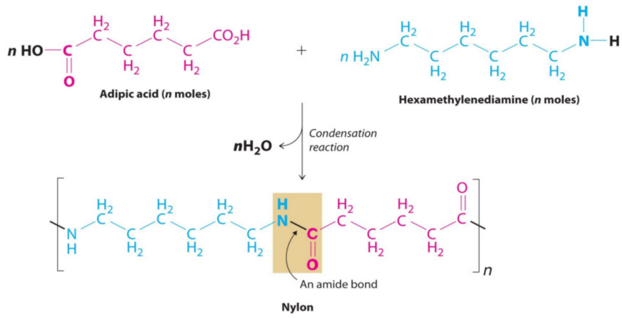



**Figure 2.** Chemical structure of nylon [11]

Nylon 6,6, is one of the most common synthetic fibers, has extensive use in many areas thanks to its excellent physical properties, good durability [12]. PBT and nylon fibers show similarities in many respects. Both polymers have fast crystallization ability, good mechanical properties, good solvent strength and similar melting temperatures (table 1) [5].

**Table 1.** Physical properties of PBT and nylon (PA 6 and PA6.6) fibers [5, 13]

| Physical Properties | PBT | PA6.6 | PA6 |
|---|---|---|---|
| Melting Point (˚C) | 224 | 265 | 220 |
| Glass Transition Temperature (Tg˚C) | 20-40 | 50-90 | 40-80 |
| Resistance | + | ++ | ++ |
| Chromaticity | +(+) | ++ | ++ |
| Dimensional Stability / Pulling | (+) | +(+) | +(+) |
| Elasticity, Dry | ++ | + | + |
| Chloride resistance | ++ | + | + |
| Resistance to hot alkalis | - | ++ | + |

++ good / strong; + moderate; – bad / weak

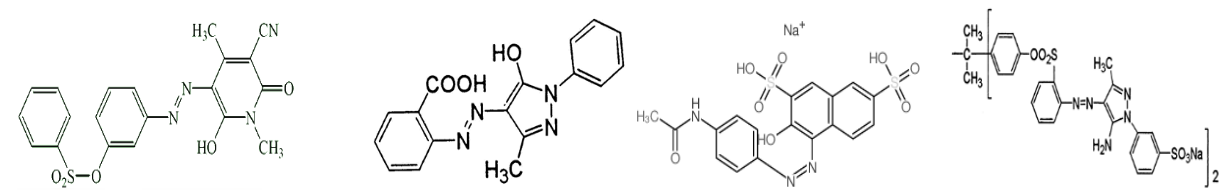
In recent years, many researchers have studied dyeing conditions for PBT and blended yarns with PBT [14-25]. In this study, PBT/Nylon (PBT/PA) blended seamless fabrics were dyed with disperse, acid and metal complex dyes at 98˚C. The color strength, colorimetric properties and fastness properties (rub and wash fastness) and differences of these fabrics were examined and compared.

## II. EXPERIMENTAL SET-UP AND PROCEDURE

75% Naylon-25%PBT seamless knitted farbics were used in this study. All fabric samples were dyed in one bath and rinsed after dyeing. Dyeing processes were carried out using commercially available low, medium and high energy disperse dyes (table 1), acid and metal complex dyes. Four different color shades are used for this study such as yellow, green, red and salmon. Disperse dyes and acid dyes used in one bath dyeing were given in table 2 and figure 3.

**Table 2:** Structures and C.I. numbers of disperse and acid and metal complex dyes

| **Disperse dyes** | **Molecular weight of disperse dyes** | **Acid and metal complex dyes** |
|---|---|---|
| Yellow P-6G (C.I. Dispers Yellow 114) | High energy | Red SRL (C.I. Acid Red 414) |
| Orange S2PR | High energy | Yellow KGLN (C.I. Acid Yellow 59) |
| Yellow SE-2GR | Medium energy | Yellow M4GL (C.I. Acid Yellow 79) |
| Blue SE-5R | Medium energy | |
| Blue ENF | Low energy | |
| Yellow ENF | Low energy | |
| Red ENF | Low energy | |



C.I. Dispers Yellow 114 [26] C.I. Acid yellow 59 [27] C.I. Acid Red 414 [28] C.I. Acid Yellow 79 [29]

**Figure 3**: Chemical structures of disperse, acid and metal komplex dyes used in dyeing

Dyeing processes of PBT and Nylon blended fabrics were carried out in Laboratory Eco Dyer at 1:10 liquid ratio at 98 ºC. The fabrics rinsed with warm water and tumbler dried.

## III. ANALYSIS

The *K/S* values were measured with using Spectrophotometer under illuminant D65, using 10º Standard observer for each dyed samples. The colour strength value K/S is calculated by using the Kubelka-Munk equation. The equation of *K/S, Equation (1)* is given at below:

$K/S = (1-R^2)/2R$ (1)

The wash and rub fastness properties of dyed fabrics were investigated. The wash fastness test was performed according to ISO 105:C06 B2S test. Both dry and wet rub fastness tests were performed according to ISO 105: X12 protocol. Overall fastness properties were evaluated by using ISO grey scales in the light box. The energy and water savings obtained by dyeing the fabrics in one bath instead of two baths were also calculated.

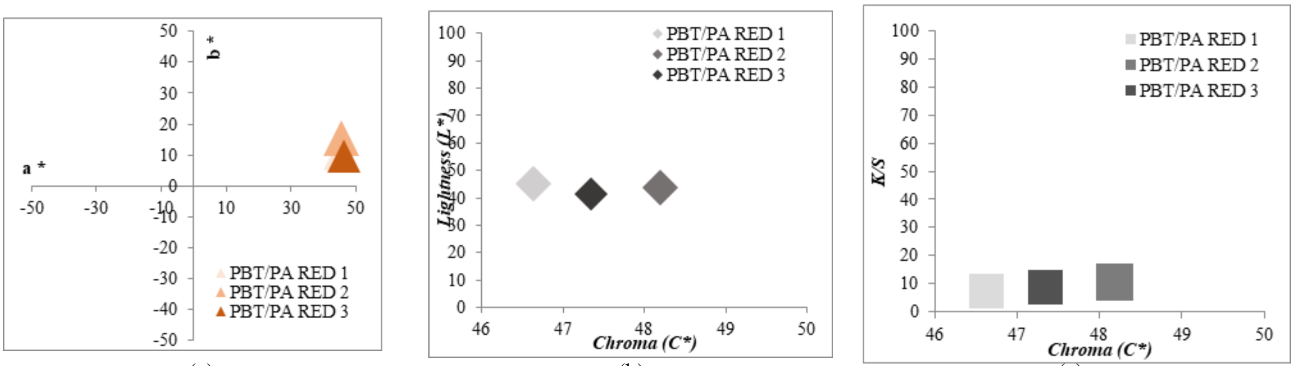
## IV. RESULTS AND DISCUSSIONS

The colorimetric properties of red dyed PBT/Nylon (PBT/PA) blended fabrics are given on Table 3 and Figure 4 (a)-(c). With these experiments, color diffrerences between dyed fabrics with only metal complex dyes and both metal complex and disperse dyes were investigated.

**Table 3:** Colorimetric properties of PBT/PA blended fabrics dyed with only metal complex dyes and both metal complex and disperse dyes.

| *Samples* | Dyes | | Molecular weight of disperse dyes | Color | *K/S* | *L** | *a** | *b** | *C** | *h*º | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***PBT/PA RED 1*** | **Metal complex** | | - | Red | 7,15 | 45,2 | 45,3 | 10,9 | 46,6 | 13,5 |  |
| | Red SRL | | | | | | | | | | |
| ***PBT/PA RED 2*** | **Metal complex** | **Disperse dyes** | Low energy | Red | 10,3 | 43,7 | 45,6 | 15,5 | 48,1 | 18,7 |  |
| | Red SRL | Red ENF | | | | | | | | | |
| ***PBT/PA RED 3*** | **Metal complex** | **Disperse dyes** | Low energy | Red | 8,45 | 41,6 | 46,4 | 9,4 | 47,3 | 11,4 |  |
| | Red SRL | YellowENF | | | | | | | | | |

Color strength values of red dyed PBT/PA blended fabrics change range from 7,15 to 10,3. The highest color strength value is observed on PBT/PA RED 2 sample. This fabric was dyed with metal complex dye and low energy red disperse dye. PBT/PA fabric dyed with only metal complex red dyed showed lowest color strength value. PBT/PA blended fabrics dyed with metal complex and disperse dyes in one bath exhibited better color strength values than those of fabrics dyed with only metal complex dyes. Therefore, dyeing with metal complex and disperse dyes in one bath could be recommended.




(a) (b) (c)

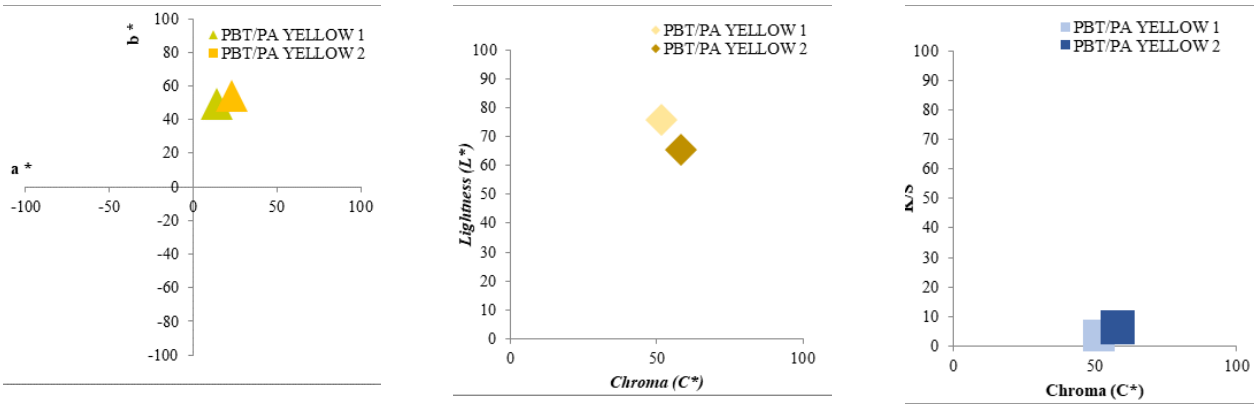
**Figure 4:** graphics of dyed PBT/PA blended fabrics; (a) redness (*a**) – yellowness (*b**) plots, (b) Lightness (*L**)-Chroma *(*C*) plots, (c) color strength (*K/S*) – Chroma *(*C*) plots

As seen on Figure 4, PBT/PA fabric dyed with only metal complex dyes exhibited similar redness-yellowness values. But its chroma values are lower than that of PBT/PA blended fabrics dyed with both metal complex and disperse dyes. The colorimetric properties of yellow dyed PBT/Nylon blended fabrics are given on Table 4 and Figure 5 (a)-(c).

**Table 4:** Colorimetric properties of PBT/PA blended fabrics dyed wit only disperse dyes and both metal complex and disperse dyes.

| *Samples* | Dyes | | Molecular weight of disperse dyes | Color | *K/S* | *L** | *a** | *b** | *C** | *h*° | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *PBT/PA YELLOW 1* | Disperse dyes | | High energy | Yellow | 3,30 | 75,8 | 13,9 | 49, 5 | 51,4 | 74,2 |  |
| | Yellow P6G | Oranj S2PR | | | | | | | | | |
| *PBT/PA YELLOW 2* | Metal complex | Disperse dyes | Low energy | Yellow | 6,20 | 65,5 | 23,1 | 53,5 | 58,34 | 66,5 |  |
| | Yell. KGLN | Red ENF | | | | | | | | | |

Dyed samples displayed orange-yellow color shades. Samples dyed with both metal complex and disperse dyes displayed darker than that of samples dyed with only disperse dyes. Color strength values of yellow dyed PBT/PA blended fabrics change range from 3,3 to 6,2. The highest color strength value is observed on PBT/PA YELLOW 2 sample which was dyed with metal complex dye and low energy class red disperse dye. Only dipserse dyed PBT/PA fabric showed lowest color strength value. Dyed PBT/PA blended fabrics with metal complex and disperse dyes in one bath exhibited better color strength values than those of fabrics dyed with only disperse dyes. Therefore, dyeing with metal complex and disperse dyes in one bath could be recommended.

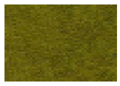
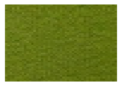



(a) (b) (c)

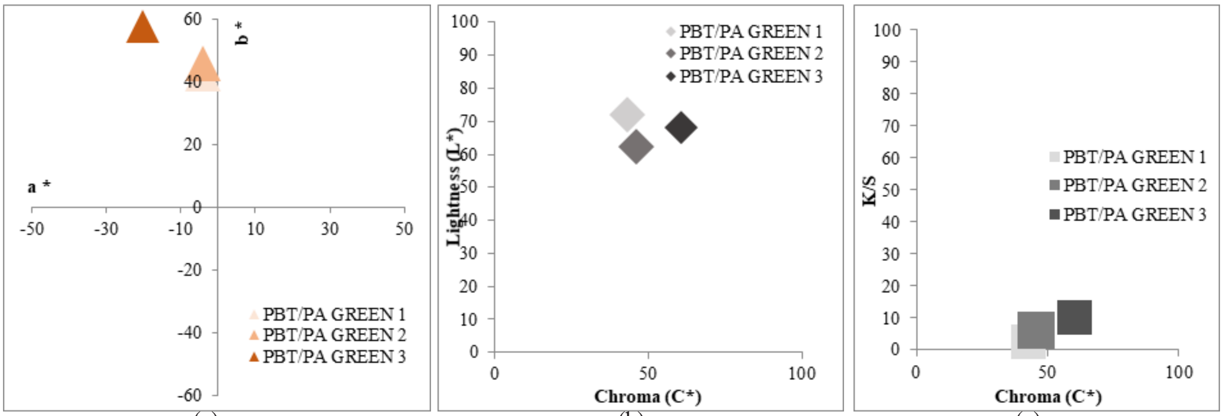
**Figure 5:** graphics of dyed PBT/PA blended fabrics; (a) redness (*a**) – yellowness (*b**) plots, (b) Lightness (*L**)-Chroma (**C*) plots, (c) color strength (*K/S*) – Chroma (**C*) plots

As seen on figure 5, PBT/PA fabric dyed with only disperse dyes exhibited similar redness-yellowness values. But its chroma values are lower than that of PBT/PA blended fabrics dyed with both metal complex and disperse dyes. The colorimetric properties of green dyed PBT/Nylon blended fabrics are given on table 6 and Figure 6 (a)-(c).

**Table 6:** Colorimetric properties of PBT/PA blended fabrics dyed with only disperse dyes, both metal complex and disperse dyes and both acid and disperse dyes.

| *Samples* | Dyes | | Molecular weight of disperse dyes | Color | *K/S* | *L** | *a** | *b** | *C** | *h*° | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***PBT/PA GREEN 1*** | **Disperse dyes** | | Medium energy | Green | 2,5 | 71,9 | -4,04 | 42,84 | 43,1 | 95,4 |  |
| | Yellow SE-2GR | Blue SE-5R | | | | | | | | | |
| ***PBT/PA GREEN 2*** | **Metal complex** | **Disperse dyes** | Low energy | Green | 5,8 | 62,3 | -4,2 | 45,8 | 45,9 | 95,2 |  |
| | Yell. KGLN | Blue ENF | | | | | | | | | |
| ***PBT/PA GREEN 3*** | **Acid Dyes** | **Disperse dyes** | Low energy | Green | 10,1 | 68,2 | -19,8 | 57,4 | 60,7 | 109,1 |  |
| | Yell M4GL | Blue ENF | | | | | | | | | |

Dyed samples displayed green color shades. Color strength values of green dyed PBT/PA blended fabrics change range from 2,5 to 10,1. The highest color strength value is observed on PBT/PA YELLOW 2 sample which was dyed with Acid dye and low energy class red disperse dye. PBT/PA fabrics dyed with only disperse dyes showed lowest color strength value. PBT/PA blended fabrics dyed with metal complex, acid and disperse dyes in one bath exhibited better color strength values than those of fabrics dyed with only disperse dyes. Therefore, dyeing with acid and disperse dyes in one bath could be recommended.



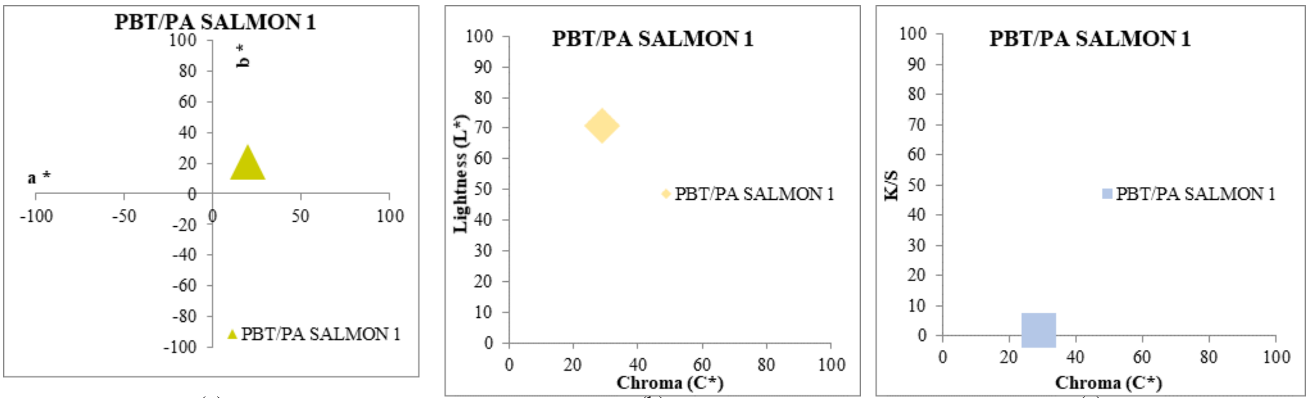

(a) (b) (c)

**Figure 6:** graphics of dyed PBT/PA blended fabrics; (a) redness (*a**) – yellowness (*b**) plots, (b) Lightness (*L**)-Chroma *(*C)* plots, (c) color strength (*K/S*) – Chroma *(*C)* plots

As seen on figure 6, PBT/PA fabric dyed with only disperse dyes exhibited similar redness-yellowness values as PBT/PA fabric dyed with metal complex and disperse dyes. PBT/PA fabrics dyed with acid and disperse dyes displayed highest color strength and redness-yellowness values. The colorimetric properties of salmon dyed PBT/Nylon blended fabrics are given on table 7 and Figure 7 (a)-(c).

**Table 7**: Colorimetric properties of PBT/PA blended fabrics dyed with only low energy disperse dyes

| *Samples* | Dyes | | | Molecular weight of disperse dyes | Color | *K/S* | *L** | *a** | *b** | *C** | *h°* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Disperse dyes | | | | | | | | | | | |
| *PBT/PA SALMON 1* | Red ENF | Yellow ENF | Blue ENF | Low energy | Salmon | 1,5 | 70,7 | 19,8 | 21,2 | 29,1 | 47 |  |




(a) (b) (c)

**Figure 7:** graphics of dyed PBT/PA blended fabrics; (a) redness (*a**) – yellowness (*b**) plots, (b) Lightness (*L**)-Chroma *(*C)* plots, (c) color strength (*K/S*) – Chroma *(*C)* plots

Dyed sample displayed salmon color shade. Color strength value of salmon color dyed PBT/PA blended fabric is 1,5. Wash and rub fastness properties of dyed samples were analyzed. Rub and wash fastness levels of the PBT/PA blended fabrics were given on table 8.

**Table 8:** Rub and wash fastness properties of all dyed samples

| *Samples* | Dyes | | Molecular weight of disperse dyes | K/S | Rub fastness | | Wash Fastness | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Wet | Dry | WO | PC | PES | N6,6 | CO | AC |
| *PBT/PA RED 1* | **Metal complex**<br>Red SRL – 1 | | - | 7,15 | 5 | 5 | 4/5 | 4/5 | 4/5 | 4 | 4/5 | 4/5 |
| *PBT/PA RED 2* | **Metal complex**<br>Red SRL – 1 | **Disperse dyes**<br>Red ENF | Low energy | 10,3 | 5 | 5 | 4/5 | 5 | 4/5 | 3/4 | 4/5 | 4 |
| *PBT/PA RED 3* | **Metal complex**<br>Red SRL – 1 | **Disperse dyes**<br>YellowENF | Low energy | 8,45 | 5 | 5 | 4/5 | 5 | 5 | 4 | 4/5 | 5 |
| *PBT/PA YELLOW 1* | **Disperse dyes**<br>Yellow P6G | Oranj S2PR | High energy | 3,30 | 5 | 5 | 4/5 | 5 | 4/5 | 4 | 4/5 | 4 |
| *PBT/PA YELLOW 2* | **Metal complex**<br>Yell. KGLN | **Disperse dyes**<br>Red ENF | Low energy | 6,20 | 5 | 5 | 4/5 | 5 | 4/5 | 3/4 | 4/5 | 4 |
| *PBT/PA GREEN 1* | **Disperse dyes**<br>Yellow SE-2GR | Blue SE-5R | Medium energy | 2,5 | 5 | 5 | 5 | 5 | 5 | 4/5 | 5 | 4/5 |
| *PBT/PA GREEN 2* | **Metal complex**<br>Yell. KGLN | **Disperse dyes**<br>Blue ENF | Low energy | 5,8 | 5 | 5 | 5 | 5 | 5 | 3/4 | 4/5 | 4/5 |
| *PBT/PA GREEN 3* | **Acid Dyes**<br>Yell M4GL | **Disperse dyes**<br>Blue ENF | Low energy | 10,1 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 4/5 |
| *PBT/PA SALMON 1* | **Disperse dyes**<br>Red ENF<br>Blue ENF | Yellow ENF | Low energy | 1,5 | 5 | 5 | 5 | 5 | 4/5 | 3/4 | 5 | 4 |

All dyed samples exhibited excellent wet and dry rub fastness properties. Wash fastness values are generally exhibited good to excellent wash fastness by 5 grey scale rating for staining except nylon 6.6 and acetate fabrics. As known, metal complex and acid dyes have an interest in nylon fibers. Therefore, nylon fabrics in adjacent fabrics exhibited 3/4 – 4/5 staining values. PBT/nylon fabrics dyed by high energy disperse dyes exhibited better wash fastness values than those of fabrics dyed by low energy disperse dyes. Because high energy class disperse dyes have higher molecular weight and show better wash fastness.

In this study, one bath dyeing of PBT/Nylon 6.6 fabrics was investigated. Therefore, only disperse dyes and their combinations such as disperse dyes – acidic dyes, disperse dyes – metal complex dyes were compared to obtain the best one bath dyeing process. Moreover, some dye combinations were recommended. It is seen that, one bath dyeing can be made for PBT/Nylon seamless products. In this section a comparison is made of how much water and energy would be consumed in two dyeing baths instead of these one bath dyeings. The calculations were made for 25 kg capacity machine. Comparison of water and time consumptions of the one and two bath dyeings are given on the Figure 8.

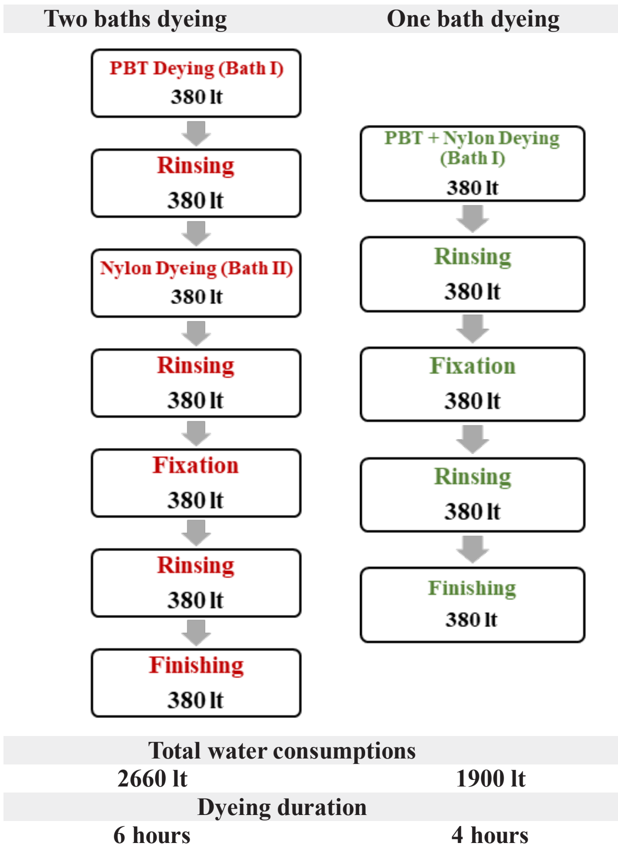



**Figure 8:** comparison of total water consumption and dyeing durations of one and two bath dyeings

As seen on Figure 8, two baths dyeing consumes more water and time than one bath dyeing. And also one bath dyeing's fastness values are moderate to good and commercially acceptable. It is noticed that, considering the difference between two dyeing one bath dyeing appears to be advantageous. In recent days when water consumption is becoming more important, the one bath dyeing technique becomes even more important. Additionally, the cost of the 1 kg of fabric dyed both one and two baths is given in the Table 9.

**Table 9:** the costs and cost reduction of the 1 kg of fabric dyed in one and two baths

| Costs | Two baths dyeing | One bath dyeing | Reduction % |
|---|---|---|---|
| **Labour costs** | 0.50 € | 0.45 € | 10 |
| **Maintance costs** | 0.09 € | 0.08 € | 11 |
| **Mechanical +illumination costs** | 0.19 € | 0.16 € | 15 |
| **Dye+Chemical costs** | 0.60 € | 0.48 € | 20 |

One bath dyeing is more advantegous than two baths dyeing. As shown on table 9, there is a decrease in the costs per 1 kg fabric. When all the results are examined, it is much more advantaneous to dye PBT/Nylon blended seamless fabrics in one bath instead of two baths.

## V. CONCLUSIONS

Poly (butylene terephthalat) (PBT) fibers are important aromatic polyesters known as their good elasticity and easy dyeing properties. Nylon 6,6, fibers are the another common synthetic fibers, has extensive use in many areas thanks to its excellent physical properties. Generally PBT and nylon fibers are used in intimate, ready-to-wear, active and sportswear apparels, swimwear. Seamless technology is capable to meet the needs of consumers with performance, functionality and comfort and improves the aesthetic value and comfort, fredom of body movement, gives softness to the garment and minimizes the surface friction of the seams. PBT and nylon fibers can be used in seamless sport wears, tights and intimates. In this study, PBT/Nylon blended knitted seamless fabrics were dyed with disperse, acid and metal complex dyes at 98ºC in one bath. The color strength, colorimetric properties and fastness properties (rub and wash fastness) of these fabrics were investigated. All samples dyed with disperse and metal complex dyes exhibited better colorimetric properties than that of fabrics dyed with only disperse dyes or metal complex dyes. These dyed fabrics showed highest color strength values. The highest color strength value is 10,3 and has been observed on dyeing PBT/PA fabrics by metal complex and low energy disperse dyes with red color shades. All dyed samples exhibited excellent wet and dry rub fastness properties. Wash fastness values are generally exhibited good to excellent wash fastness by 5 grey scale rating for staining except nylon 6.6 and acetate. In terms of costs, water consumptions and all the results, it is much more advantaneous to dye PBT/Nylon blended seamless fabrics in one bath instead of two baths.

**Acknowledgements**

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