Mühendis ve Makina / Engineer and Machinery 64, 711, 228-258, 2023

Mühendis ve Makina / Engineer and Machinery
https://dergipark.org.tr/tr/pub/muhendismakina

A REVIEW ON LABORATORY SCALE MACHINES SUPPORTING R&D STUDIES USED IN FILAMENT YARN TECHNOLOGY

Selcen ÖZKAN HACIOĞULLARI[1*], Osman BABAARSLAN[2]

[1]Çukurova Üniversitesi, Mühendislik Fakültesi, Tekstil Mühendisliği Bölümü, Adana,
ORCID No: https://orcid.org/0000-0002-9124-5593

[2]Çukurova Üniversitesi, Mühendislik Fakültesi, Tekstil Mühendisliği Bölümü, Adana,
ORCID No: https://orcid.org/0000-0002-1606-3431

Keywords

Laboratory type filament spinning machines, filament yarn, technical properties of machine, production parameters, functional filament development studies

Abstract

Lots of R&D and P&D studies are carried out in the laboratory conditions with the low-capacity types of industrial machines. Laboratory type filament yarn machines are important in Textile Sector as they form the important infrastructure/ facility for research and development studies and lots of studies are carried out in the textile sector about production of filament yarn and the development of its properties. In this study, laboratory type machines used in research studies on filament yarns have been investigated worldwide and their properties have been presented in detail. Then, the technical features and usage purposes of a laboratory type filament drawing machine developed with a new design in its field are explained. In addition, the features of this machine have been compared with another laboratory type machines.

[1] Sorumlu yazar; e-posta: selcenozkan@gmail.com
doi : muhendismakina.1319131

FİLAMENT İPLİK TEKNOLOJİSİNDE KULLANILAN VE AR-GE ÇALIŞMALARINI DESTEKLEYEN LABORATUVAR ÖLÇEKLİ MAKİNALAR ÜZERİNE BİR İNCELEME

Anahtar kelimeler

Laboratuvar tipi filament iplik makineleri, filament iplik, makine teknik özellikleri, üretim parametreleri, fonksiyonel filament geliştirme çalışmaları

Öz

Sanayi tipi makinelerin düşük kapasiteli üretim yapan türleri sayesinde, laboratuvar ortamında birçok Ar-Ge ve Ür-Ge çalışması gerçekleştirilmektedir. Bu tür makinelerden biri olan laboratuvar tipi filament iplik makineleri, araştırma çalışmalarına zemin oluşturduğu için Tekstil Sektöründe önemli bir yere sahiptir ve Tekstil sektöründe filament iplik üretimi ve özelliklerinin geliştirilmesine yönelik olarak birçok çalışma yapıldığı bilinmektedir. Bu çalışmada, filament ipliklere dair araştırma çalışmalarında kullanılan laboratuvar tipi makineler dünya genelinde araştırılmış ve özellikleri detaylı olarak incelenmiştir. Sonrasında, alanında yeni bir tasarımla geliştirilmiş olan laboratuvar tipi bir filament iplik makinesinin teknik özellikleri ve kullanım amaçları açıklanmıştır. Ayrıca, bu makinenin özellikleri diğer laboratuvar tipi makinelerin özellikleri ile kıyaslanmıştır.

Derleme Makalesi			Review Article		
Başvuru Tarihi	:	28.06.2022	Submission Date	:	28.06.2022
Kabul Tarihi	:	25.01.2023	Accepted Date	:	25.01.2023

1. Introduction

Laboratory type (lab-type) machines have many advantages. These are low-capacity production, the lab-machine covers small area and has a small working surface, trial productions can be done rapidly, changing the production parameters as desired and quickly, etc. Many R&D studies are carried out with this type of machine. Hence, various lab-type machines are manufactured by different companies in the world.

Various original studies have been carried out with lab-type filament yarn machines and at the end of these studies, new functional filaments with improved properties can be produced. Some of these studies are improvement of yarn structural properties, improvement of yarn mechanical properties and unevenness, production of functional filaments (flammability, UV resistance, antibacterial, etc.), examination of production parameters and development of new production parameters (section shape, draft ratio, winding speed, etc.) listed as. As a result, lots of original studies have been carried out on these type machines and so, these machines have a significant contribution to R&D studies. It is known that these machines are generally used in university laboratories and R&D centers of companies. In this way, different R&D studies are carried out on these machines fastly.

In this article, the technical and general properties of the lab-type filament drawing machine developed with a new design and the other lab-type filament production machines used in this field were investigated in detail. Extensive literature research has been carried out and two main results have been reached. The first is, the lab-scale filament yarn production machines have been manufactured by various companies in the world (Fiber Extrusion Research&Pilot Machines for Homo&Bicomponent Laboratory Applications, 2022; Fourné Laboratory and Pilot Melt Spintester, 2022; Hacıoğulları Özkan 2014; Hacıoğulları Özkan and Babaarslan, 2015; Laboratory Type Textile Machines Spintech, 2023; Line Types, Austrofil®, 2023; Multifilament Spin-Draw-Wind Lines Document, 2022; Spinboy Machines, 2022; Spinning Tester Equipment for Laboratory and University College, 2022; Wide Wayne Lab Sheet Roll Stack, 2022) and secondly, lots of researches and studies have been carried out by using these type machines (Bourbigot and Devaux 2002; Hacıoğulları Özkan, 2014; Hojiyev and Ulcay 2021; Kara, Erdoğan and Erdem 2012; Kebabçı, 2015).

The aim of this paper is to investigate the technical features and using areas of lab-type filament yarn machines in worldwide and explain properties of a new type of lab filament drawing machine. In this way, more detailed information of this type machines was given.

This study is a Review Article; it gives general and specific information (technical properties, figures, etc.) about lab-type filament yarn machines. In addition, information of lab-type filament drawing machine (LabFil) which was developed with university-industry cooperation was also given in this study. Technical features of all machines were compared each other and the technical properties of all these machines were given as a table (Table-1).

2. History of Man-Made Fibers and Melt Spinning Process

2.1 History of Man-Made Fibers

Man-made fibers, one of the outputs of lab-type filament drawing machines, have a long history. It has been observed that there is a continuous improvement in technology of fiber production in this history. In this section, information about the history of synthetic fiber types and these production principles were presented.

Man-made fibers have a long history. Robert Hooke first brought up the idea to create silk-like fibers in 1665, followed by René-Antoine Ferchault de Réaumur, who actually produced the first artificial filaments from different kinds of varnish in 1734. In 1883 Joseph Swan injected dissolved nitro-cellulose into a coagulation bath and thus obtained filaments for light bulbs. In 1938 DuPont de Nemours (Wilmington, DE, USA) launched the production of Nylon® (PA 6.6), the first commercial melt-spun fiber, invented by Wallace Carothers. In the same year Paul Schlack developed Perlon® (PA 6). The first polyester fiber, Terylene® (PET), was created in 1941 by Imperial Chemical Industries (ICI). The commercial production of polyolefin fibers started in 1957, based on the Ziegler-Natta catalyst recognized by a Nobel Prize in 1963. Today, chemical fibers are spun by drawing a melt or solution of a polymer or an inorganic material from a spinneret into a medium (quenching or solvent removal by air/gas, water or coagulation bath) where it solidifies. Drawing can either be applied by godets (rollers) and winders, by a high-velocity air stream, or by an electrostatic or centrifugal force (Hufenus, Yan, Dauner, and Kikutani, 2020).

2.2 Melt Spinning Process

Various synthetic filament yarns can be produced in different raw materials (PP, PE, PES, PBT, etc.) on lab-type filament drawing machine and main production methods of filament yarn are melt spinning, wet spinning and dry spinning. Lab-type filament machines mostly work according to the melt spinning principle. Information about the melt spinning process was given in this section to support the importance of lab-type filament drawing machine.

Melt spinning is an important production method of synthetic filament yarn. The origin of the melt spinning process apparently dates to the 1845 English patent of R. A. Brooman who conceived the basic concept as a method to produce filaments from gutta percha. But it was Carothers and Hill who first described the process in the modern era. The work of Carothers and his associates led to successful commercial application of melt spinning in 1939 as a process to produce polyamide 66 (“nylon”) filaments and yarn. In the last 100 years melt-spun fibers became by far the most important fibers for apparel, but even more so for technical textiles, where they spawned a myriad of novel applications (Salem, 2001).

The direct spin draw process was developed conventionally in the 1960s by coupling the spinning and drawing processes in series. As the demand for crimped yarn increased in the 1970s, the drawing and texturing processes were combined into one process, and a new spinning process was developed to produce Partially Oriented Yarn (POY) with a spinning speed of 3000-3500 m/min. to produce the fed stock for integrated draw-texturing (Salem, 2001).

The spinning speed increased as winder performance improved in the early 1970s, and this development encouraged the investigation of high-speed spinning. In 1983, the Association for Efficient Synthetic Fibre Technology was established in Japan with a scheme of conditional loans for research and development of innovative technologies under the Ministry of International Trade and Industry; its spinning section coordinated a project for high-speed spinning of polyester at 9000-14000 m/min. These investigations have revealed the optimum conditions for high-speed spinning and the mechanism of the fiber structure formation during the process. Today, high-speed spinning at 6000-8000 m/min is in commercial operation for the production of synthetic yarns such as nylon and polyester (Nakajima, 2000).

The melt spinning process involves melting and extrusion of the material to be processed through a multihole capillary die, called a spinneret, followed by cooling and solidification to form filaments that can be wound on a bobbin or otherwise processed (Salem, 2001).

A basic form of the melt spinning process is illustrated in Figure 1. Polymer, usually in the form of dried granules or pellets, is fed into an extruder where it is melted and conveyed to a positive displacement, metering pump. The metering pump controls and ensures a steady flow of polymer to the “spin pack” where the polymer is filtered and forced through the capillaries of a multifilament spinneret. The extruded filaments are drawn down to smaller diameters, i.e., finer deniers, by the action of a godet roll, while they are simultaneously being cooled (quenched) by air blowing across the filament bundle. The resulting filaments are either wound onto a bobbin or they are passed directly to another processing step such as “drawing” or “texturizing” (Salem, 2001).

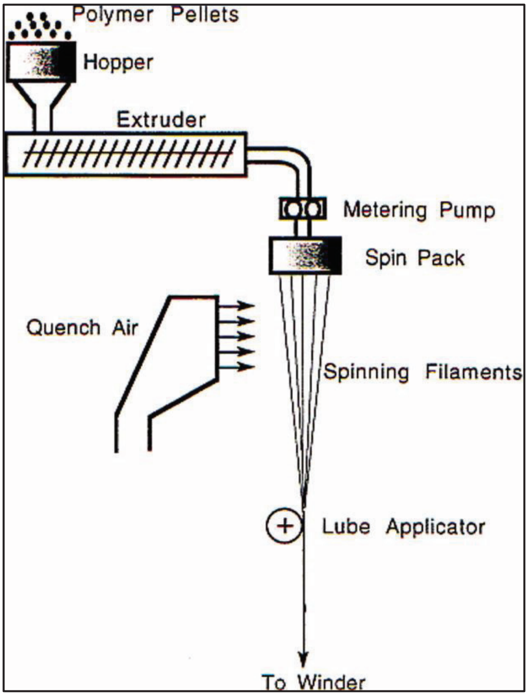


Figure 1. The Melt Spinning Process (Salem, 2001)

The major process variables for melt spinning are:

- Extrusion temperature,
- Mass flow rate of polymer through each spinneret hole,
- Take-up velocity of the wound-up or deposited filaments,
- The spinline cooling conditions,
- Spinneret orifice shape, dimensions and spacing, and
- The length of the spinline (Salem, 2001).

These variables are not entirely independent of each other. For example, the length of the spinline will generally be controlled by the efficiency of the cooling conditions along the spinline. More efficient cooling allows shorter spinlines. Spinline cooling is largely controlled by the velocity, temperature, and distribution of the cooling air, but it is also affected by factors such as spinneret configuration, mass throughput and the specific design of the cooling system.

Figure-2 shows that yarn process flow diagram from melt spinning to fabrics. The end-use areas of the filament yarns which are produced by the melt spinning method were also shown with this figure. As can be seen in Figure-2, many different types of filament yarn (LOY, POY, FDY, BCF, etc.) can be produced with the melt spinning method. In addition, these products are used in many different technical and conventional fields.

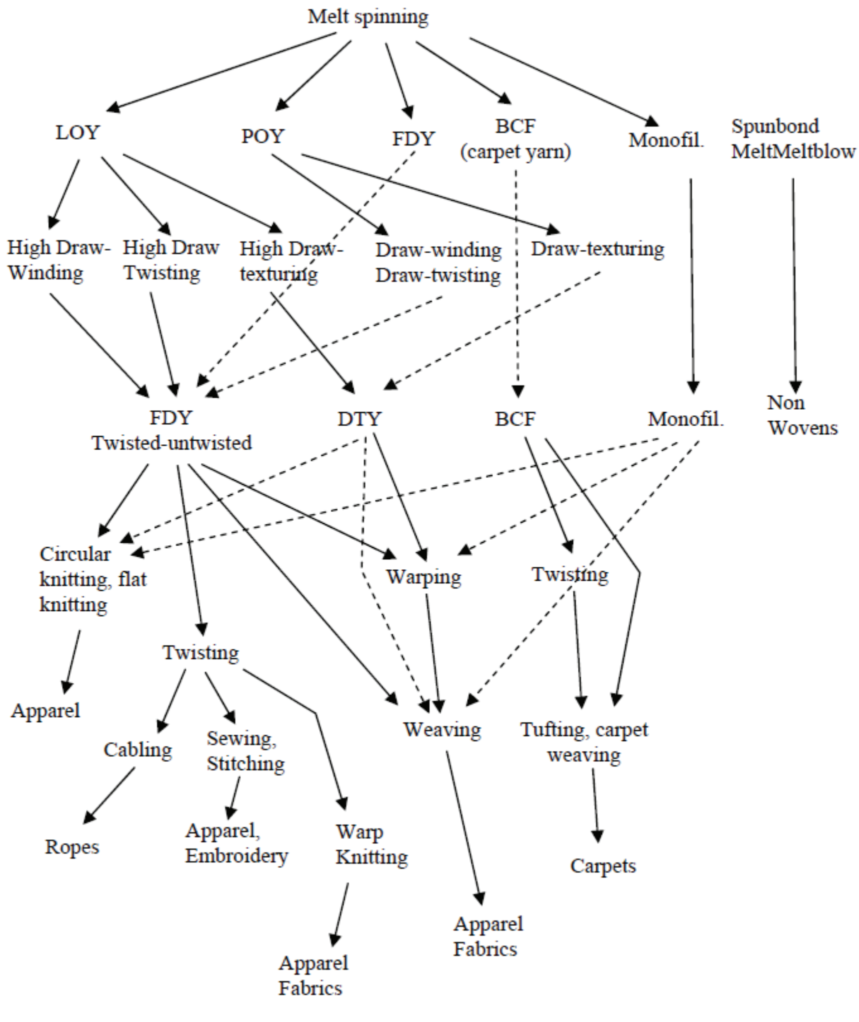


Figure 2. Yarn Process Flow Diagram from Melt Spinning to Fabrics (Mylläri, 2010)

When the filament yarn production amounts were investigated worldwide, it was seen that the filament yarn production amounts had increased. World filament yarn output in 2019 was up 6% to 55 million tonnes (Engelhardt, 2021). The filament yarns that make up this production output are divided into two technologically. These are regular filament yarns and functional filament yarns. In addition, R&D studies are carried out to improve the properties of regular filament yarns.

3. Various Laboratory Filament Drawing Machines and Theır Properties

The laboratory filament yarn machines that are important for R&D studies and which have been manufactured around the world were described below.

The figure of Spinboy lab-type filament machines in Belgium was given below (Figure 3). The company (Busschaert Engineering) has tree type machines as Spinboy I, Spinboy II and Spinboy II POY.

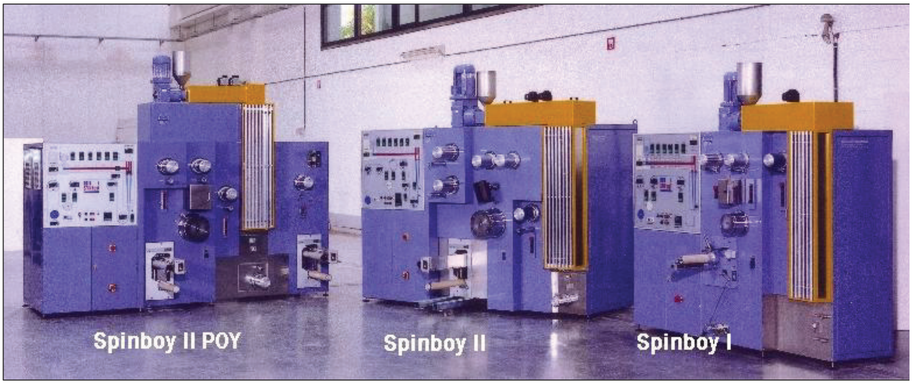


Figure 3. Spinboy Machines (Spinboy Machines, 2022)

Other lab-type filament machine was manufactured by Wayne Machine Company in the United States of America [2]. Production process of this machine is wet spinning, and this machine has horizontal operating plane (Figure 4).

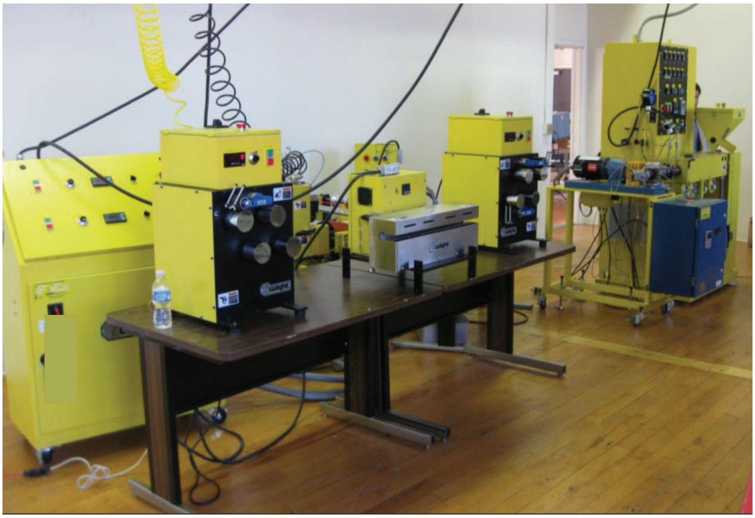


Figure 4. Wayne Machine Lab-Type Filament Machine (Wide Wayne Lab Sheet Roll Stack, 2022)

Another lab-type filament drawing machine name is the Plantex-Libe Line which is Italian company (Figure 5).

Figure 5. Plantex Libe Line Machine (Hacıoğulları Özkan, 2014)

The Hills research and pilot fiber extrusion machines provide flexible performance with reliable operations. They are currently being used for simulation of production systems, color matching trials, polymer characterization, product development, process development, and the production of specialty yarns and trial lots. Each machine has the capability to convert melt spinnable polymers into finished fibers (Fiber Extrusion Research&Pilot Machines for Homo&Bicomponent Laboratory Applications, 2022). Figures of Hills Machine were given in below.

Figure 6. Hills Lab-Type Filament Yarn Machine (Fiber Extrusion Research&Pilot Machines for Homo&Bicomponent Laboratory Applications, 2022)

Lofil group company has laboratory filament machine which name is Baby Lofil (Figure 7) and this is an Indian Company.

Figure 7. Baby Lofil HT Lab-Type Filament Yarn Machine (Multifilament Spin-Draw-Wind Lines Document, 2022)

SML's compact entry model is particularly well suited to small batch sizes of Fully Drawn Yarn (FDY) and Medium-Drawn Yarn (MDY) yarn, packing a persuasive punch with its high degree of flexibility and efficiency. This machine name is Austrofil MT/HT2x2/4E/75. This machine is bigger than other lab-type machines, nevertheless purpose of using of Austrofil MT/HT 2*2/4E/75-SML is to producing trial and R&D studies (Figure 8).

Figure 8. SML (Austrofil MT/HT 2*2/4E/75) Lab-Type Filament Yarn Machine (Line Types, Austrofil®, 2022)

Spintech lab-type machines are manufactured by Gülnar Machine company which is in Turkey. The company has three different lab-type machines as Spintech I, Spintech II and Spintech III (Laboratory Type Textile Machines Spintech, 2022). Images of machines were given in below (Figure 9).

Figure 9. Spintech Lab-Type Filament Yarn Machines (Laboratory Type Textile Machines Spintech, 2022)

Fourné Maschinenbau company has lab-type filament machine which name is Fourné Laboratory and Pilot Melt Spintester (Figure 10) and this is an German Company.

The well-known and proven technology of Fourné melt spintesters is especially suitable for:

- Testing of spinnability of polymer materials (chips or powder),
- Production of smallest amounts of filament yarns or fibers,
- Production of material samples,
- Development of new fiber materials for special applications (Fourné Laboratory and Pilot Melt Spintester, 2022).

Figure 10. Fourné Laboratory and Pilot Melt Spintester Lab-Type Filament Yarn Machine (Fourné Laboratory and Pilot Melt Spintester, 2022)

For these processes all the advantages of a Fourné melt spintester become apparent. These advantages are:

- Lowest raw material demand and minimized throughput with optimum homogeneity of the melt in Fourné spinning extruders,
- Retrofitting of side stream units for liquid or melted additives,
- Extendable for all kinds of bi-component and multi-component fiber production,
- Optional equipment available for production of hollow fibers,

- Reproduction of the production process in a small space,
- One-man operation possible.

Laboratory spintesters allow producing with material throughputs between 300 g and 5 kg per hour.

The standard spinning systems were designed for polymers with drawing temperatures up to approximately 350°C, suitable for PET, PA, PP, PE. Optionally Fourné can offer a high temperature system for spinning temperatures up to 500°C, so that drawing of polymers like PEEK or PPS become possible. Depending on the specification titers of 22-240 or 100 to 500 dtex are possible for multifilament, comprising a capillary fineness of 0.5 to 20 dtex. For monofilament diameters of approx. 0.01 to 0.15 mm are practicable (Fourné Laboratory and Pilot Melt Spintester, 2022).

Image of CF-1000 Melt Spinning lab-type machine was given in below (Figure 11). Various type thermoplastic materials which are (PP, PE, PTFE, PA, PET, PTT, PPS, PEEK, etc.) can be produced with this machine (Spinning Tester Equipment for Laboratory and University College, 2022).

Figure 11. CF-1000 Melt Spinning Lab-Type Filament Yarn Machine (Spinning Tester Equipment for Laboratory and University College, 2022)

Lab-type filament drawing machines are used for similar purposes in generally universities and research centers. R&D studies are carried out on this type machines about especially polymer science, nanotechnology, improvement of structural and functional properties of flat and textured yarns, etc. Detailed technical properties of all these machines were given in Table-1 (Section-4).

4. A New Designed and Developed Laboratory Type Machine (Labfil)

In the previous section, information about lab-type filament drawing machines in worldwide was given. When literature was considered about this subject, it was seen that various and qualified scientific studies were carried out with lab-type filament production machines. In addition, the small volume of this type machines and the low working surface are also important advantages. Also, functional filament yarns (flammable, UV resistance, etc.) are produced on these lab-type machines. An important infrastructure/facility has been created with this machine for R&D studies, undergraduate and graduate studies. A basic technical drawing of LabFil and an image of this machine were given in Figure 12 and Figure 13.

In this section, information about a lab-type machine has been developed with a new design was presented. Then the technical properties of all these lab-type machines have been compared each other (Table-1).

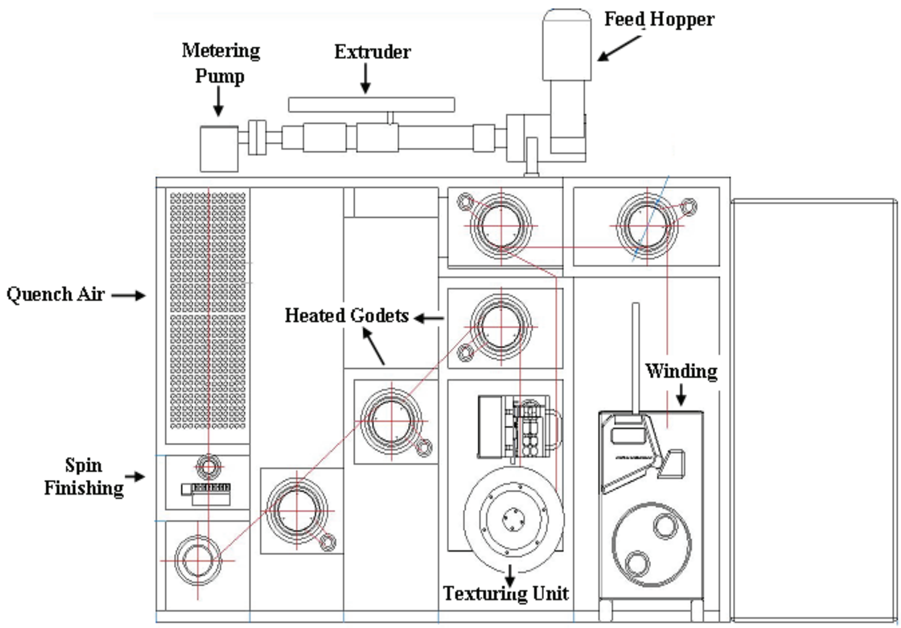


Figure 12. Technical Drawing of Developed Lab-Type Filament Drawing Machine (LabFil) (Hacıoğulları Özkan and Babaarslan, 2015)

Table 1. The Technical Properties of Lab-Type Filament Drawing Machines in the World

Technical Properties	Machines										
	LabFil	Spinboy I	Spinboy II	Spinboy II POY	SML-Austrofil MT/HT 2*2/4E/75	Hills	Baby Lofil	CF-1000	Fourné Laboratory and Pilot Melt Spintester	Spintech I	Spintech II	Spintech III
Raw Material	PP, PE, PA, PET	PP, PES	PP, PA, PES	PP, PES, PA	PP, PA6	PP, NylonPES	PP, PE	PES, PP, PA, PBT	PET, PA, PP, PE, PEEK, PPS	PP, PA, PET, PBT	PP, PA, PET, PBT	PET, PBT
L/D or Screw Diameter (mm) and Extruder Type	27 mm Single	25-35 mm Single	45 mm Single	25-35 mm Single	28 L/D 75 mm Single	30 L/D Single	28 L/D Single	Extruder diameter:20 mm	25 L/D Single	25 mm 32 L/D Single	25 mm, 32 L/D Single	25 mm 32 L/D Single
Number of Spinneret	2	2	2	2	8	1	2	2	2	2	2	2
Texturizing Unit	Hot Air and Texturizing Drum	3D-Hot AirJet	Hot Air Open Jet	Hot Air Open Jet	Interm. Jet	There is not tex. unit	Interm. Jets	AirJet Interm. Unit	There is a texturing unit	Hot Air	Hot Air	Hot Air
Filament Yarn Type	Flat and Textured Yarn	Flat and Textured Yarn	Flat and Textured Yarn	Flat and Textured Yarn	FDY and MDY	Flat Yarn	Flat Yarn	Flat Yarn	Flat and Textured Yarn	Flat and Textured Yarn	Flat and Textured Yarn	Flat and Textured Yarn
Number of Filament Yarn	CF: 200-1500 denier BCF: 500-2500 denier				165-4400 dtex		600-2400 denier	20-80 denier	100-500 dtex	CF: 300-1200 dtex BCF: 400-3800 dtex	CF: 300-1200 dtex BCF: 400-3800 dtex	FDY: 200-500 dtex POY: 200-600 dtex
Capacity (max.)	72 kg/day	GH: 10 kg	GH: 20 kg	GH: 20 kg	110 kg/hour	MPC: 1,20 cc/rev	MC: 20 kg/hour	120 kg/day	4 kg to 50 kg per hour	4,5-5 kg/hour	4,5-5 kg/hour	4,5-5 kg/hour
Winding Speed (m/min-max.)	2050	1500	2500	2500-3500	1000-3500		1200	1000	3000	1000	1000	4500
Dimensions [meter for Height (H), Length (L), Width (W)]	H: 3 L: 3,5 W: 1,6	H: 2,6 L: 2,6 W: 1,2	H: 2,8 L: 2,6 W: 1,4	H: 3,6 L: 3 W: 1,7	H: 6 L: 8,1 W: 7,2	H: 1,3 L: 1,1 W:0,6	H: 4,5 L: 2 W: 3,4	H: 2,5-3 L: 2 W: 1,5		H: 2,65 L: 3,4 W: 2,05	H: 2,95 L: 3,7 W: 2,37	H: 4,75 L: 5,1 W: 2,65
Installed Power of Machine	78,8 kW	IPM: 4 kW	40 kW	IPM: 25-30 kW	247 kW		45 kW			55 kW	60 kW	60 kW

*: Detailed research has been carried out about all lab-type machines. All technical properties of these machines are given in the Table-1. The technical specifications that could not be found were not given (Interm: Intermingling, MPC: Metering Pump Capacity, MC: Melt Capacity, GH: Granulate Hopper, IPM: Installed Motor Power).

Figure 13. Image of Developed Lab-Type Filament Drawing Machine (LabFil) (Hacıoğulları Özkan and Babaarslan, 2015)

LabFil and other machines have melt spinning principle (only Wayne machine is working on wet spinning principle). The detailed technical properties of these machines were presented in Table 1.

"Wayne Machine" works according to the wet spinning principle and has 24 L/D ratio. The other machine, Plantex Libe Line, works according to the melt spinning principle and has 30 L/D ratio. Information of Wayne Machine and Plantex Libe Line machine is not in Table-1 because sufficient technical properties about these machines could not be reached.

Also, scientific studies were carried out on this type machines such as development of the structural, mechanical, and functional properties of filament and textured yarns. One of the aims of this paper is to shed light on the scientific works that can be done in such machines. Also, it is an original table was prepared by researching the technical features of this type of machines in detail.

Table-1 shows that these machine features are generally similar to each other, and these technical properties effect the quality of filament yarn directly. Also, the structural and mechanical properties of the yarns produced on these machines should be similar to the first quality yarns produced in the industry. In this way, acceptable scientific study results will be obtained. In addition, the filament yarns produced on these machines should have sufficient structural and mechanical properties (especially yarn tenacity, breaking elongation and unevenness).

As mentioned before, a wide variety of scientific studies can be carried out on these machines. Some of these study topics were listed below:

- Effects of production parameters on the structural, mechanical, and specific properties of flat filament or textured yarns,
- Development of production conditions/parameters of a lab-type machine,
- Filament yarns can be produced with different/various additive materials such as flame retardant, UV resistance, antimicrobial, etc. and then properties of these yarns can be examined,
- Functionalized filament yarns can be produced with different sized additive materials (micro and nano scale). Then, properties of these products can be examined,
- Studies can be performed for development of texturizing properties of filament yarns (Changing production parameters; spinneret configuration, drawing ratio, etc. Texturizing conditions; air pressure, air temperature, nozzle configuration, etc.),
- Filament yarns (CF and BCF) can be produced with newly features (by using new additive material),
- Properties of filament yarns (CF and BCF) can be developed (Hacıoğulları Özkan and Babaarslan, 2015).

5. Production Parameters of Lab-Type Filament Drawing Machine

Lab-type filament drawing machines provide the facility for trials of yarn production. This type machines have easily changeable production parameters and production types. In this way, lots of trial productions can be done quickly on these machines. PP, PE (Polyethylene), PLA (Polylactic Acid), PES (Polyester), PA (Polyamide) and PBT (Polybutylene Terephthalate) polymers are used mostly in these type machines (especially PP and PLA). PP polymer has easily productivity, widely end-used areas, large productive capacity, low cost, etc. Therefore, this polymeric material is mostly preferred.

There are many studies in the literature on filament yarns produced by the melt spinning process. Some of these studies are the effects of production parameters on filament properties (structural, mechanical and functional), productions of functional filament yarn, etc. (Ahmed, Shamey, Christie and Mather, 2006; Babaarslan and Özkan Hacıoğulları, 2013; Bagheri, Tavanai, Ghiaci, Morshed and Shamsabadi, 2019; Bhattacharya and Chaudhari, 2015; Chiu, Lin and Hong, 2011; Çelen and Koçer, 2022; Erdem, Cireli and Erdogan, 2009; Kalantari, Rahbar, Mojtahedi, Shoushtari and Khosroshahi, 2007; Kara, Üreyen, and Erdogan, 2016; Kılıç, Jones, Shim and Pourdeyhimi, 2016; Kim, Lin and Bhattacharyya, 2017; Maqsood, Langensiepen and Seide, 2020; Misra, Spruiell, Lu and Richeson, 1995; Ni, Li, and Chen, 2020; Özkan, 2008; Rangasamy, Shim and Pourdeyhimi, 2011; Subasinghe, Somashekar and Bhattacharyya, 2018). It is known that these process parameters of extruder should be determined correctly for quality production of filament yarns.

Technical properties of lab-type filament drawing machines (L/D ratio, texturizing unit, etc.) are so important for quality of products. The basic technical parameters that determining of the characteristics of laboratory type filament machines and the units of these machines were given in this section.

I. Screw Extruder:

In majority of commercial processes melting is done by continuous screw extruders. While the screw rotates, it heats, homogenizes, and transports the material forward. Screw extruders have three zones: Feeding, compression and metering. The goal is to make the material as homogenous as possible in a right temperature. Material is fed through a hopper and generally it flows by gravity to the extruder barrel which is annular space between the barrel and the screw. Polymer is heated with frictional and conduction heat. When polymer is moving forward friction between it and the metal barrel generates substantial amount of heat. The rest of the heat needed comes from barrel heaters by conduction. At the end of the screw, in the metering zone, polymer should be totally melted and homogenous (Mylläri, 2010).

Extruder parameters are ratio of L/D, temperature, pressure, etc. and there are various studies carried out in the literature about parameters of extruder (Arslan, 2016; Dulmalik, Chafidz, Fernandi and Ardianto, 2019; Kotek, Afshari, Avci and Najafi, 2017; Lewandowski and Wilczynski, 2022; Şahin, 2018; Şen, 2015; Vahabi, Laoutid, Formela, Saeb, and Dubois, 2022). These parameters were explained in below.

a. L/D Ratio of Extruder:

L/D ratio is one of the basic construction parameters of the extruder and this parameter determines as the characteristic of the extruder. L is the screw length and D is the screw diameter (Figure 14). L/D ratio must be chosen high value for the better mixing process and quality product; an increased L/D ratio creates the better mixing process and a more even distribution. For this purpose, value of the L/D ratio must be 27 or more.

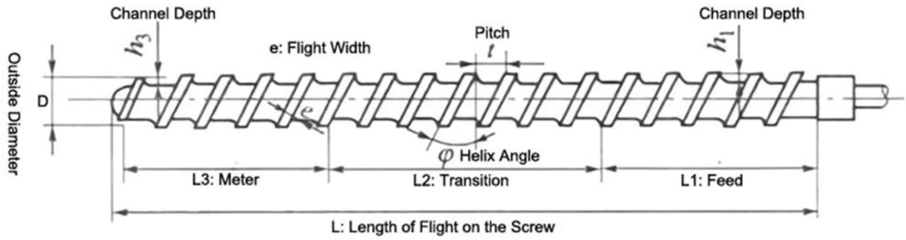


Figure 14. Single-Screw Extruder and The Main Parameters of Extruder (What Is L/D ratio in injection moulding machine, 2022)

b. Temperature:

The value of extrusion temperature must be chosen according to melting point of polymer type and homogeneity of melt flow temperature is a major factor which influences product quality. Otherwise, the material may not melt completely or may burn.

c. Pressure:

The pressure of the inside the extruder is set according to the screw rotation speed and this parameter is selected according to characteristic of polymeric material; as the screw rotation speed increases, the pressure also increases.

II. Metering Pump:

Capacity of metering pump unit is measured accurately the molten polymer and pumps to spinnerets. In this way, the desired filament fineness, filament unevenness and yarn quality can be obtained.

Metering pump capacity is important parameter, and this parameter is the amount of flowing melted polymer in one revolution of the metering pump. There are various studies in the literature about the importance of the metering pump and its effect on product properties (Chung, 2020; Shumpert, Padsalgikar, Ellison, Hosangadi and Henshaw, 1996; Turukmane, Shinde, Gulhane and Gupta, 2021; Vogel, Hatzikiriakos, Brünig, Tändler and Golzar, 2003; Younes, Fotheringham, El-Dessouky and Haddad, 2011).

III. Quenching:

Filament starts to cool down, after the spinneret, take-up rolls are horizontally below the spinneret and before the filament touches them the material should be totally solidified. The spinning operation is characterized by the extrusion of molten polymer through small spinneret capillaries into an air quench cabinet where the individual streams attenuate and solidify to form filaments. There are lots of studies in the literature about the importance of quenching and effect of the quenching parameters on product properties (especially fineness, unevenness, tenacity, etc.) (Arslan, 2016; Kim, 1986; Kothari, 2000 and Yıldırım, 2007; Kretzschmar and Furter, 2009; Mylläri, 2010; Ruckdashel and Shim, 2020).

IV. Fiber Cross-Sectional Shape

The fiber cross-sectional shape is an important structural/production parameter that effects directly the mechanical and functional properties of filament yarns (Babaarslan and Özkan Hacıoğulları, 2013; Çelen and Koçer, 2022; Kara, Erdoğan and Erdem, 2012; Hufenus, 2011; Kara, Üreyen and Erdogan, 2016; Karaca and Özçelik, 2007; Kebabçı, Babaarslan, Hacıoğulları Özkan and Telli, 2015; Özkan, 2008; Özkan Hacıoğulları and Babaarslan, 2018; Shin, Kim and Kim, 2005; Turukmane, Shinde, Gulhane and Gupta, 2021; Varshney, Kothari and Dhamija, 2011; Varshney, Kothari and Dhamija, 2014). Fiber cross-sectional shape is determined with shape of spinneret orifices. Mostly preferred filament cross-sectional shapes (round, trilobal, hexsa, etc.) were given in below (Figure 15).

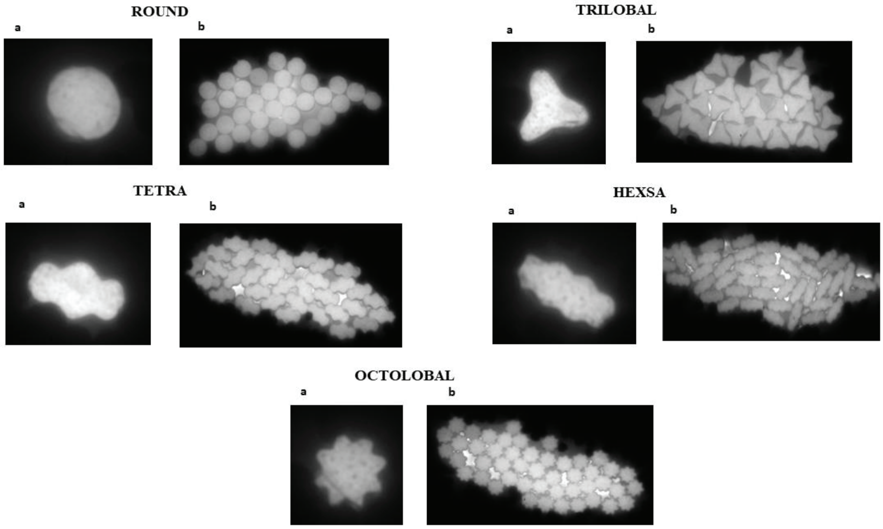
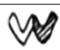
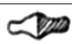


Figure 15. Some of Fiber/Filament Cross-Sectional Shapes (a: Monofilament, b: Multifilament) (Özkan, 2008).

Functional properties of filament yarns can be obtained by using different cross-sectional shapes. For instance, trilobal shape helps in altering hand and increasing the luster. The hexsa cross-sectional shape is an unique shaped construction with six channels that transport the moisture away from the skin and thus keep the wearer dry (Figure 15). Also, more specific cross-section shapes have been developed. Specialized cross-sectional shapes are used for giving various and delicate luster, handle, and texture to the fabrics. In addition, specialized cross-sections are produced with special orifices, such as a slit, L-shape, T-shape, H, W, X or similar shape modified slits, combinations of circle and slit, and arranged plural circles (Nakajima, 2000). These specialized cross-sections were given in Table-2.

Table 2. Examples of Specialized Cross-Section (Nakajima, 2000)

Trade mark	Producer	Cross-section	Basic technology	Specialities of the product
Solo Sowaie®	Asahi Chemical Industries Ltd.		Hollow, triangular, thick and thin	Higher bending stiffness, mild color
Fontana µ®	Asahi Chemical Industries Ltd.		W-shaped, self crimping	Bulky, crispy, dry and cool hand
Soielise N®	Kanebo Ltd.		Pentagonal cross section	Mild luster, dry hand and water-absorbent
Vivan®	Kanebo Ltd.		U-shaped cross-section, thick and thin.	Mild luster, dry, spun-yarn like and bending stiffness
Deforl®	Kuraray Ltd.		Flat cross-section, self-crimping	Deep color, bulky and higher bending stiffness
MSC®	Unitika Ltd.		Arrow-like cross-section.	Dry and cool hand
Mixy®	Unitika Ltd.		Random and multi-shaped cross-section	Dry hand, natural appearance, higher bending stiffness

V. Drawing Unit:

Complicated molecular chains are occurred because of transition suddenly of polymer from liquid to solid. Filament yarns are drawn for arrange this structure and increase of ratio of crystallin region. This process is carried out with the difference of speed of the godets in the drawing unit. With this process, the tenacity values of the filament yarns reach the required level. Parameters of drawing unit directly affect the mechanical properties (tenacity, breaking elongation) of filament (Castiglioni, 2008; Dabrowska, Fambri, Pegoretti, Slouf, Vackova and Kolarik, 2015; Gajjar, Stallrich, Pasquinelli and King, 2021; Gupta, Mondal and Bhuvanesh, 1997; Heuvel and Huisman, 1978; Kim, 1986; Salem,1992; Varma and Cameotra, 1973; Viková, Periyasamy, Vik and Ujhelyiová, 2017; Viková, Sakurai, Periyasamy, Yasunaga, Pechočiaková, and Ujhelyiová, 2021; Yuan, Mak, Kwok, Yung and Yao, 2001).

VI. Texturizing Unit:

Lab-type filament drawing machines generally have texturizing unit and textured yarns can also be produced on the machine with this unit and so, also can done lots of R&D studies can done about texturizing subject.

Several processing techniques have been developed to production of textured yarns such as mechanical/thermal (torsional crimping), chemical/ thermal or mechanical alone. Textured yarns are more stretchable and have a higher capacity for moisture absorption and moisture transport, better tenacity and lower breaking elongation. Generally, hot air texturizing unit is used on lab-type filament drawing machines. Lots of studies have been done about this subject (Bagheri, Tavanai, Ghiaci, Morshed and Shamsabadi, 2019; Çirkin, 2006; Pal, Gandhi and Kothari, 1996; Tavanai, Morshed and Hosseini, 2003).

VII. Take-Up

Melt spinning is a process where melt polymer passes through a spinneret, solidifies rapidly and forms a fiber structure. The polymer has to be melted and preferably mixed which is normally done with a screw extruder. Extruder is normally used in commercial applications because it ensures sufficient throughput. After melting granulates, the mass goes through a hole or multiple holes. The number of holes can vary from one to many hundreds (Mylläri, 2010). The final process of the filament yarn production machine is the winding process. The aim of winding unit is to create a well bobbin without changing the properties of filament yarn. The important parameters of the winding unit are winding speed, winding tension and winding shape (straight or cross winding), etc (Abbasi, Mojtahedi and Khosroshahi, 2007; Bansal and Raichurkar, 2016; Feldman, 2008; Gajjar, Stallrich, Pasquinelli and King, 2021; Ho, Kim, Jin and Park, 2010; Morgan, 2006; Nakajima, 2000; Pelzer, Vad, Becker, Gries, Markova and Teplyakov, 2021; Raichurkar and Ramachandran, 2015; Ramirez, Bashir, Luo and Liu, 2009; Turukmane, Gulhane and Kakde, 2020). In this type of machines, fully automatic or semi-automatic winders can be used. The winding speed is generally 1000-3500 m/min. Modern take-up machines include not only a winding unit but also yarn guiding, yarn cutting, aspirators, godets (rotating rolls that transport, stretch or thermally treat yarns), heating system and different kind of sensors, etc. In addition, friction drives are the most common type but also tension-controlled and surface speed-controlled machines have been manufactured.

6. Advantageous and Superior Properties of Labfil Machine

In the previous sections, information about the basic technical features and units of lab-type machines were given. In addition, the technical properties of all lab-type machines were presented in Table-1 (Section-4).

Studies of design and developing LabFil machine (Optimal selection of machine sizes, determination of machine units, etc.) has been carried out in detail. The superior features of the LabFil machine compared to other lab-type machines were given below.

- Many different raw materials can be used in LabFil machine. In this way, R&D

studies can be carried out with various raw materials on LabFil machine.

- If the L/D ratio is high, a good and homogeneity polymer mixing can be done. Hence, L/D value must be 27 or more. L/D ratio of LabFil is 27.
- Textured yarn is an important type of synthetic yarn imitating natural fibers. LabFil machine has hot air texturizing unit and high-quality textured yarns can be produced on this machine. Hence, R&D studies about these yarns can be done successfully.
- The LabFil machine has many godets. In this way, various types of filament yarns (MOY, POY, FOY, HOY, Textured yarns, etc.) can be produced on Lab-Fil machine.
- LabFil machine has lots of advantages about machine sizing such as low volume and optimum working surface.
- LabFil machine has been developed and manufactured with university-industry cooperation. This project has been provided a significant contribution to science and technology. In addition, lots of R&D studies are still carried out on this machine.

LabFil machine has advantageous features. Thus, various R&D and P&D studies can be done on this machine.

Another important issue is that the basic structural and mechanical properties of these filament yarns produced by using these machines should be similar to the first quality yarns produced in the industry because the results of scientific studies should be acceptable.

Research and publication ethics were complied with in this study.

7. Conclusions

Lab-type filament yarn production machines have lots of advantages such as low volume and optimum working surface, easily changeable production parameters, etc. In this way, many scientific studies can be carried out by using these type machines. These scientific studies are generally carried out about polymer science, filament yarn production and properties, and nanotechnology. Thus, the using of lab-type machines is important for the developing innovative products and production processes.

The doctoral thesis is named "Design and Manufacture of Laboratory Type Filament Yarn Machine and Development of Original Product" has been the source of this paper. In this doctorate thesis, a lab-type filament production machine (LabFil) was developed a newly design and then various functional yarns (flat filament and textured yarn) were produced by using LabFil. Information about this machine is also given in this paper. In addition, such lab-type machines have been researched around the world and the technical properties and production parameters of all these machines were given in this paper. In this study, information about the important units of lab-type filament drawing machines was also presented and an extensive literature was given. The aim of this study is contributed to the researchers in this field.

Acknowledge

This work was financial supported by the "Turkey Ministry of Science, Industry and Technology" within the research program called SAN-TEZ, Project Number: 00428.STZ.2009-2.

References

Abbasi, M., Mojtahedi, M. R. M., & Khosroshahi, A. (2007). Effect of spinning speed on the structure and physical properties of filament yarns produced from used PET bottles, *Journal of Applied Polymer Science,* 103, Issue 6, pp. 3972-3975. Doi: https://doi.org/10.1002/app.25369.

Ahmed, S. I., Shamey, R., Christie, R. M., & Mather, R. R. (2006). Comparison of the performance of selected powder and masterbatch pigments on mechanical properties of mass coloured polypropylene filaments, C*oloration Technology,* 122(5), 282–288. Doi: https://doi.org/10.1111/j.1478-4408.2006.00042.x

Arslan, Z. (2016). *Investigation of process parameters affecting quality of polyamide 6 POY and textured yarn production,* (MSc. Thesis), Namık Kemal University Institute of Natural and Applied Sciences, Tekirdağ/Turkey.

Babaarslan, O., & Özkan Hacıoğulları, S. (2013). Effect of fibre cross-sectional shape on the properties of POY continuous filaments yarns, *Fibers and Polymers,* 14(1), 146-151. Doi: https://doi.org/10.1007/s12221-013-0146-z.

Bagheri, G., Tavanai, H., Ghiaci, M., Morshed, M., & Shamsabadi, A.S. (2019). An investigation on the effect of pigments on the texture-ability and mechanical properties of polypropylene BCF yarns, *Journal of the Textile Institute,* 111(9), 1308-1317. Doi:10.1080/00405000.2019.1694824.

Bansal, S., & Raichurkar, P. (2016). Review on the manufacturing processes of polyester-PET and nylon-6 filament yarn, *International Journal on Textile Engineering and Processes,* 2(3), 23-28.

Bhattacharya, S. S., & Chaudhari, S. B. (2015). Study on structural and thermal properties of polypropylene silica nanocomposite filaments, *International Journal of Textile and Fashion Technology (IJTFT),* 5(1), 15-22.

Bourbigot, S., & Devaux, E. (2002). Flammability of polyamide-6/clay hybrid nanocomposite textiles, *Polymer Degradation and Stability,* 75(2), 397-402. Doi: https://doi.org/10.1016/S0141-3910(01)00245-2.

Busschaert Engineering. (2022). Spinboy Machines. Retrieved from: http://www.busschaert-eng.be/English/HomeEnglish.htm.

Castiglioni, M. (2008). Control and stability in velocity of individually driven drawing godets for thermoplastic filament yarns (PhD Thesis), ETH Zurich, Switzerland.

ChinaFiber XinLun Co., Ltd. (2022). Spinning Tester Equipment for Laboratory and University College, Melt Spinning Machine Trial Production Line, Pilot Plant for Melt Spinning. Retrieved from: http://www.chinafiber.com/tester/.

Chiu, C-W., Lin, C-A., & Hong, P-D. (2011). Melt-Spinning and thermal stability behavior of TiO2 nanoparticle/polypropylene nanocomposite fibers, *Journal of Polymer Research,* 18(3), 367–372. Doi: https://doi.org/10.1007/s10965-010-9426-0.

Chung, C. I. (2020). Extrusion of Polymers Theory & Practice 3nd Edition, Munich: Hanser Gardner.

Çelen, O., & Koçer, H. B. (2022). The effect of cross section on poly (L -Lactic Acid) filament yarn properties, U*ludağ University Journal of The Faculty of Engineering,* 27(1), 375-388. Doi: https://doi.org/10.17482/uumfd.1017015.

Çirkin, S. (2006). Effect of the texturing variables on the yarn properties during false-twist texturing process (MSc Thesis), Çukurova University Institute of Natural and Applied Sciences, Adana.

Dabrowska, I., Fambri, L., Pegoretti, A., Slouf, M., Vackova, T., & Kolarik, J. (2015). Spinning, drawing and physical properties of polypropylene nanocomposite fibers with fumed nanosilica, *eXPRESS Polymer Letters,* 9(3), 277-290. Doi: 10.3144/expresspolymlett.2015.25.

Dulmalik, A Chafidz, R Fernandi, & Ardianto. (2019). Partially Oriented Yarn (POY) produced from semi-dull via melting spun using an extruder: Effect of die extruder temperature on elongation of the POY, *Journal of Physics: Conference Series,* 1295, The 3rd International Conference of Chemical and Materials Engineering, Semarang, Indonesia.

Engelhardt, A. W. (2021). Global development of spun and filament yarns, The Fiber Year 2021 Report.

Erdem, N., A. Cireli, A., & Erdogan, U. H. (2009). Flame retardancy behaviors and structural properties of polypropylene/nano-$SİO_2$ composite textile filaments, *Journal of Applied Polymer Science,* 111(4), 2085-2091. Doi: https://doi.org/10.1002/app.29052.

Feldman, D. (2008). Polymer History, *Designed Monomers and Polymers,* 11(1), 1-15. Doi: https://doi.org/10.1163/156855508X292383.

Fiber Extrusion Research&Pilot Machines for Homo&Bicomponent Laboratory Applications. (2022). Retrieved from: http://www.hillsinc.net/assets/pdfs/pilot-equipment.pdf.

Fourné Maschinenbau. (2022). Fourné Laboratory and Pilot Melt Spintester. Retrieved from: https://fourne-maschinenbau.de/en/pilot-schmelzspinntester-2/.

Gajjar, C. R., Stallrich, J. W., Pasquinelli, M. A., & King, M. W. (2021). Process-property relationships for melt-spun poly(lactic acid) yarn, ACS Omega, 6, 15920-15928. Doi: 10.1021/acsomega.1c01557.

GM Gülnar. (2023). Laboratory Type Textile Machines Spintech. Retrieved from: https://www.gulnarmakina.com/eng/urunler.aspx?kat=1.

Guangzhou Guanxin Machinery Limited. (2022). What Is L/D ratio in injection moulding machine. Retrieved from: https://guanxin-machinery.com/what-is-l-d-ratio-in-injection-moulding-machine.

Gupta, V.B., Mondal, S.A., & Bhuvanesh, Y.C. (1997). Spinning speed-throughput rate relationships for polyester, nylon, and polypropylene fibers, Journal of Applied Polymer Science, 65(9), 1773-1788. Doi: https://doi.org/10.1002/(SICI)1097-4628(19970829)65:9<1773::AID-APP14>3.0.CO;2-O.

Hacıoğulları Özkan. S. (2014). *Design and manufacture of laboratory type filament yarn machine and development of original product* (PhD Thesis). Çukurova University Institute of Natural and Applied Sciences, Adana, Turkey. Retrieved from: http://libra.cu.edu.tr/libra.aspx?IS=DETAY&KN=9994.

Hacıoğulları Özkan S. & Babaarslan, O. (2014). Structural analysis and mechanical properties of polypropylene filament yarns containing flame retardant additive, *15th Romanian Textiles and Leather Conference-CORTEP-2014,* 25-30, Poiana Braşov, Romanya.

Hacıoğulları Özkan S. & Babaarslan, O. (2015). Design, manufacturing of a new laboratory type filament yarn drawing machine and featured yarn development studies, *Marmara Journal of Pure and Applied Sciences, Special Issue-1,* 27(5), 53-57. Doi: https://doi.org/10.46399/muhendismakina.1136513

Hacıoğulları Özkan, S. & Babaarslan, O. (2018). An investigation on the properties of polyester textured yarns produced with different fiber cross-sectional shapes, *Industria Textila,* 69(4), 270-276. Doi: http://doi.org/10.35530/IT.069.04.1281.

Heuvel, H. M. and Huisman, R. J. (1978). Effect of winding speed on the physical structure of as-spun poly(ethylene terephthalate) fibers, *Including Orientational-Induced Crystallization,* 22(8), 2229-2243. Doi: https://doi.org/10.1002/app.1978.070220815.

Ho, Y. S., Kim, H. Y., Jin, F. L., & Park, S. J. (2010). Effects of spinning conditions on properties of polyester yarn prepared using an ultra-high-speed melt spinning technique equipped with a steam chamber", *Bulletin of the Korean Chemical Society,* 31(11), 3252-3258. Doi: https://doi.org/10.5012/bkcs.2010.31.11.3252.

Hojiyev, R., & Ulcay, Y. (2021). Polyester yarns reinforced by nanoclays, *Polymer Science Series A,* 63(3), 318-333. Doi:10.1134/S0965545X21030068

Hufenus, R. (2011). Fiber Development by Multicomponent Melt-Spinning, 11th World Textile Conference AUTEX, 8-10 June 2011h, Mulhouse/France.

Hufenus, R., Yan, Y., Dauner, M., and Kikutani, T. (2020). Melt-Spun fibers for textile applications, *Materials,* 13(4298), 2-32. Doi: 10.3390/ma13194298.

Kalantari, B., Rahbar, R. S., Mojtahedi, M. R. M., Shoushtari, S. A. M., & Khosroshahi, A. (2007). Production and characterization of polypropylene fiber upon addition of selective peroxide during melt spinning and comparison with conventional polypropylene fibers, *Journal of Applied Polymer Science,* 105(4), 2287-2293. Doi: 10.1002/app.26255.

Kara, Ş., Erdoğan, Ü. H., & Erdem, N. (2012). Effect of polypropylene fiber cross sectional shapes on some structural/mechanical fiber properties and compressibility behaviour of plain knitted fabrics, *Fibers and Polymers,* 13(6), 790-794. Doi: https://doi.org/10.1007/s12221-012-0790-8.

Kara, Ş., Üreyen, M. E., & Erdogan, U. H. (2016). Structural and antibacterial properties of PP/CuO composite filaments having different cross sectional shapes, *International Polymer Processing XXXI,* 31(4), 398-409. Doi: https://doi.org/10.3139/217.3159.

Karaca, E., & Özçelik, F. (2007). Influence of the cross-sectional shape on the structure and properties of polyester fibers, J*ournal of Applied Polymer Science,* 103(4), 2615-2621. Doi: https://doi.org/10.1002/app.25350.

Kebabçı, M., Babaarslan, O., Hacıoğulları Özkan, S., & Telli, A. (2015). The effect of drawing ratio and cross-sectional shapes on the properties of polypropylene CF and BCF yarns, *Journal of Textiles and Engineer,* 22(100), 47-53. Doi: http://dx.doi.org/10.7216/1300759920152210006

Kılıç, A., Jones, K., Shim, E., & Pourdeyhimi, B. (2016). Surface crystallinity of meltspun isotactic polypropylene filaments, *Macromolecular Research,* 24(1), 25-30. Doi: https://doi.org/10.1007/s13233-016-4011-y.

Kim, S. L. (1986). Effects of spinning speed and quench air temperature on the characteristics of melt spun poly(ethylene terephthalate) yarn, *Textile Research Journal,* 56(11), 697-704. Doi: https://doi.org/10.1177/004051758605601108.

Kim, N. K., Lin, R. J. T., & Bhattacharyya, D. (2017). Flammability and mechanical behaviour of polypropylene composites filled with cellulose and protein based fibres: A comparative study, *Composites Part A: Applied Science and Manufacturing,* 100, 215-226. Doi: https://doi.org/10.1016/j.compositesa.2017.05.017.

Kotek R., Afshari M., Avci H., & Najafi M. (2017). Production of Polyolefins, United States: Woodhead Publishing, Elsevier.

Kothari, V.K. (2000). *Progress in Textiles: Science and Technology,* New Delhi/India: Hardbound, IAFL Publications.

Kretzschmar, S. D., & Furter, R. (2009). *Process Optimization in a Filament Yarn Plant, Pakistan Textile Journal,* Uster Technologies AG., Uster, Switzerland.

Lewandowski, A., & Wilczynski, K. (2022). Modeling of Twin Screw Extrusion of Polymeric Materials, *Polymers,* 14(274), 2-28.

Lohia Corp Limited. (2022). Multifilament Spin-Draw-Wind Lines Document. Retrieved from: https://www.lohiagroup.com/baby-lofil.

Maqsood, M., Langensiepen, F., & Seide, G. (2020). Investigation of melt spinnability of plasticized polylactic acid biocomposites-containing intumescent flame retardant, *Journal of Thermal Analysis and Calorimetry,* 139(1), 305–318. Doi: https://doi.org/10.1007/s10973-019-08405-3.

Misra,F.-M., S., Spruiell, Lu, J., & Richeson, E. G. C. (1995). Influence of molecular weight distribution on the structure and properties of melt-spun polypropylene filaments, *Journal of Applied Polymer Science,* 56(13), 1761-1779. Doi: https://doi.org/10.1002/app.1995.070561307.

Morgan, P. W. (2006). Brief history of fibers from synthetic polymers, *Journal of Macromolecular Science: Part A-Chemistry,* 15(6), 1113-1131. Doi: https://doi.org/10.1080/00222338108066456.

Mylläri, V. (2010). *Production of filament yarns made of PEEK* (Master of Science Thesis). Tampere University of Technology, Finland.

Nakajima, T. (2000). Advanced fiber spinning technology. Wiltshire, England: Woodhead Publishing.

Ni, H., Li, Y., and Chen, Z. (2020). Study on preparation and properties of luminescent polyamide fiber doped with graphene, *6th Annual International Work-*

shop on Materials Science and Engineering: Journal of Physics Conference Series, 1-7, Jinan, Shandong, China. Doi: 10.1088/1742-6596/1622/1/012038.

Özkan, S. (2008). *The effect of filament cross sectional shape, number and linear density on POY and textured yarn properties,* (Msc. Thesis), Çukurova University Institute of Natural and Applied Sciences, Adana/Turkey.

Pal, S.K., Gandhi, R.S., & Kothari, V.K. (1996). Draw-Texturing of microfiber polyester yarn, *Textile Research Journal,* 66(12), 770-776. Doi: https://doi.org/10.1177/004051759606601205

Pelzer, M., Vad, T., Becker, A., Gries, T., Markova, S., & Teplyakov, V. (2021). Melt spinning and characterization of hollow fibers from poly(4-methyl-1-pentene), *Journal of Applied Polymer Science,* 138(1), 1-12. Doi: https://doi.org/10.1002/app.49630

Raichurkar, P., & Ramachandran, M. (2015). Recent trends and developments in textile industry in India, *International Journal on Textile Engineering & Processes,* 1(4), 47-49.

Ramirez, M. I., Bashir, S., Luo, Z., & Liu, J.L. (2009). Green synthesis and characterization of polymer-stabilized silver nanoparticles, *Colloids and Surfaces B: Biointerfaces,* 73(2), 185-191. Doi: https://doi.org/10.1016/j.colsurfb.2009.05.015.

Rangasamy, L., Shim, E., & Pourdeyhimi, B. (2011). Structure and tensile properties of nanoclay-polypropylene fibers produced by melt spinning, J*ournal of Applied Polymer Science,* 121(1), 410-419. Doi: 10.1002/app.33619.

Ruckdashel, R., & Shim, E. (2020). Effects of melt spinning parameters on polypropylene hollow fiber formation, *Journal of Engineered Fibers and Fabrics,* 15, 1-11. Doi: https://doi.org/10.1177/1558925019899680.

Salem, D. R. (1992). Development of crystalline order during hot-drawing of poly(Ethylene Terephthalate) film: Influence of strain rate, *Polymer,* 33(15), 3182-3188. Doi: https://doi.org/10.1016/0032-3861(92)90232-L.

Salem, D. R. (2001). Structure formation in polymeric fibers: Structure formation during melt spinning. *Princeton,* USA: Hanser Gardner Publication.

Shin, K.I., Kim, S.H., & Kim, I-J. (2005). Image analysis of the luster of fabrics with modified cross-section fibers, *Fibers and Polymers,* 6(1), 82-88. Doi: https://doi.org/10.1007/BF02875578.

Shumpert, B. B., Padsalgikar, A. D., Ellison, M. S., Hosangadi, G. S., & Henshaw, I. (1996). Gear pump performance in polypropylene filament yarn uniformity, *International Polymer Processing,* 11(4), 347-351. Doi: https://doi.org/10.3139/217.960347.

SML Maschinengesellschaft mbH. (2022). Line Types, Austrofil®. Retrieved from: https://www.sml.at/multifilament-lines/austrofil-fdy-mdy-poy#austrofil-ht-2x2-4-e-75.

Subasinghe, A., Somashekar, A. A., & Bhattacharyya, D. (2018). Effects of wool fibre and other additives on the flammability and mechanical performance of polypropylene/kenaf composites, *Composites Part B: Engineering,* 136(1), 168-176. Doi: https://doi.org/10.1016/j.compositesb.2017.10.034.

Şahin, R. (2018). Investigation of the dyeability properties of polypropylene nonwoven surfaces with amorf silic", (MSc. Thesis), *Erciyes University Graduate School of Natural and Applied Sciences,* Kayseri/Turkey.

Şen, S. C. (2015). *Synthesis of polymer films at different ratios by using twin screw extruder and investigation of their biodegradability under controlled composting conditions,* (MSc. Thesis). Hacettepe University Graduate School of Science and Engineering, Ankara/Turkey.

Tavanai, H., Morshed, M., & Hosseini, S. M. (2003). Effects of On-line melt blending of polypropylene with polyamide 6 on the bulk and strength of the resulting BCF yarn, *Iranian Polymer Journal,* 12(5), 421-430.

Turukmane, R., Gulhane, S. S., & Kakde, M. V. (2020). Effect of take-up speed on the final performance of fully drawn yarn (FDY), *Man-Made Textiles in India,* 48(1), 12-14.

Turukmane, R., Shinde, S., Gulhane, S., & Gupta, K. K. (2021). Effect of spinneret shapes on the properties of polyester filament, *Chemical Fibers International,* 71(3), 130-131.

Vahabi, H., Laoutid, F., Formela, K., Saeb, M. R., & Dubois, P. (2022). Flame-Retardant polymer materials developed by reactive extrusion: Present status and future perspectives, *Polymer Reviews,* 62, 919-949. Doi: https://doi.org/10.1080/15583724.2022.2052897.

Varma, D. S., & Cameotra, S. S. (1973). Effect of draw ratio on moisture sorption, dyeability, and mechanical properties of cold-drawn nylon 6 filament, *Textile Research Journal,* 43(12), 745-747. Doi: https://doi.org/10.1177/004051757304301210.

Varshney, R. K., Kothari, V. K., & Dhamija, S. (2011). Influence of polyester fibre fineness and cross-sectional shape on low-stress characteristics of fabrics, *Journal of the Textile Institute,* 102(1), 31-40. Doi: https://doi.org/10.1080/00405000903453661.

Varshney, R. K., Kothari, V. K., & Dhamija, S. (2014). Influence of polyester fibre shape and size on the hairiness and some mechanical properties of yarns, Indian Journal of Fibre & Textile Research, 39, 24-32.

Viková, M., Periyasamy, A. P., Vik, M. and Ujhelyiová, A. (2017). Effect of drawing ratio on difference in optical density and mechanical properties of mass colored photochromic polypropylene filaments, Th*e Journal of The Textile Institute,* 108(8), 1365-1370. Doi: https://doi.org/10.1080/00405000.2016.1251290.

Viková, M., Sakurai, S., Periyasamy, A. P., Yasunaga, H., Pechočiaková, M., & Ujhelyiová, A. (2021). Differential scanning calorimetry/small-angle X-ray scattering analysis of ultraviolet sensible polypropylene filaments, *Textile Research Journal,* 92(17-18), 3142-3153. Doi: https://doi.org/10.1177/00405175211053394.

Vogel, R., Hatzikiriakos, S. G., Brünig, H., Tändler, B., & Golzar, M. (2003). Improved spinnability of metallocene polyethylenes by using processing aids, *International Polymer Processing XVIII,* 18(1), 67-74. Doi: https://doi.org/10.3139/217.1722.

Yıldırım, K. (2007). Determination of Degree of Production Parameters Influences to the Cristallinity Ratio on the PET Yarn (PhD Thesis), *Uludağ University Graduate School of Natural and Applied Science,* Bursa/Turkey.

Younes, B., Fotheringham, A., El-Dessouky, H., & Haddad, G. (2011). Factorial optimization of the effects of melt-spinning conditions on as-spun aliphatic-aromatic copolyester fibers I. spin draw ratio, overall orientation and drawability, *International Journal of Polymeric Materials,* 60(5), 316-339. Doi: https://doi.org/10.1080/00914037.2010.531804.

Yuan, X., Mak, A. F. T., Kwok, K. W., Yung, B. K. O., & Yao, K. (2001). Characterization of poly(L-lactic acid) fibers produced by melt spinning, *Journal of Applied Polymer Science,* 81, 251-260. Doi: https://doi.org/10.1002/app.1436.

8.5" Wide Wayne Lab Sheet Roll Stack. (2022). Retrieved from: https://www.arlingtonmachinery.com/product-detail/18478/85quot-wide-wayne-lab-sheet-roll-stack/.