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# A Design and Construction of Melt Spinning Apparatus In Laboratory Scale

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## Abstract

The melt spinning equipment in laboratory scale has been designed and constructed using the principle of Ramp Extruder. In addition, the manufacture and characterization of polypropylene fibers derived from this equipment are also investigated and described to evaluate the efficiency of the obtained equipment. Polypropylene fibers having the linear density in the range of 3-9 tex are produced by melting process in barrel at 180$^{o}$C. The viscous melt of polymer is then extruded through a spinneret at 190$^{o}$C by piston. The spinneret used contains one hole having the diameter of 0.5 mm. Afterwards, the resultant as-spun fibers are drawn and collected on take-up roll, which its speed was varied between 300 and 1200 m min$^{-1}$. The results show that the melt fracture occurs when the operation of the extrusion speed at higher 1.5 cm/min. An increase in the take-up speed leads to a reduction of fiber size, an increase of the percentage crystallinity and an enhancement of fiber strength.

**Keywords:** Melt spinning, Take-up speed, Melt fracture, Polypropylene subsequently

## 1. Introduction

Up to now, various methods for the fabrication of fiber have been reported, such as wet spinning, dry spinning, and melt spinning [1-3]. The most economical spinning is melt spinning primarily because there is no solvent to be recovered as in solution spinning. However, melt spinning is a process that needs the heat for melting the polymer. In this process, the polymer is melted and extruded through a spinneret (die) with numerous holes (one to thousands). The molten fibers are then cooled and solidified. The resulting fibers were drawn and collected on a take-up wheel. Stretching of the fibers in both the molten and solid states provides orientation of the polymer chains along the fiber axis. Nowadays, an attractive means of melting for polymer was screw extrusion. Because the rotation of screw causes the friction between polymer and screw or between polymer and barrel, the heat is generated [4-5]. Therefore, molten polymer was forced out through a nozzle and the fiber could be continuously produced. However, the continuous flow of molten polymer was also important for the manufacture of fibers. Therefore, the size of polymer pellets should be uniform and not exceed the width of the flow channel of screw. When the molten polymer emerges from the screw, it can exhibit the distortion or twisting due to the polymer memory in spiral flow like the screw movement or turning memory [1, 4]. One solution to this problem is the use of melt pump in production process to enhance the pushing of molten polymer through the spinneret resulting in the uniformity of polymer flow. Moreover, adding the screen pack to an extrusion line also helps to straighten out the spiraling melt flow which is extruded from the screw. However, these additional units lead to longer residence time. It is of particular problem for temperature-sensitive polymers or polymers with degradable components at elevated temperature are employed. Thus, the processing of these polymers need to control various process parameters, such as the speed of screw and pump, as well as temperature [3-4].

Ram extrusion is a process that compacts a compound in a heated die to form a solid profile, rod or board, etc. The advantages of this process are the allowance of various shapes of polymer pellets employed. The source of heating is generated from heating band resulting in the ease of temperature control. However, this technique is an intermittent operation. This leads to the limitation of continuous products required [5].

The goal of this work is to design and construct the melt spinning apparatus using ram extruder as a prototype. This is a process of extrusion by piston and heating at barrel by heater band to melt the polymer pellets. In this investigation, polypropylene was used to operate the obtained equipment. Polypropylene was melt-extruded through spinneret to produce fiber. It shows the uniform flow of polymer melt when piston was constantly moved. Additionally, only small amount of polymer is used for operating by this apparatus.

## 2. Design and construction method

The basic structures of this melt spinning apparatus were 0.5 m wide, 0.6 m long and 2.5 m high. Its height was designed to have the distance between spinneret and take-up unit more than 2 m. This led to polymer melts cooled down at ambient temperature although high take-up speed was operated [6]. This instrument consisted of three major parts, as illustrated in Figure 1

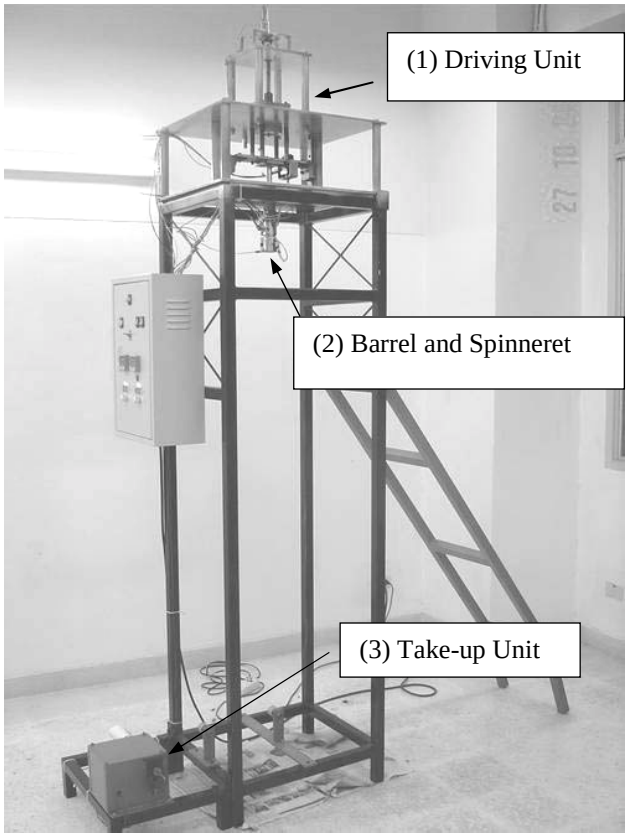



Figure 1 Melt spinning apparatus in ram extrusion type

**2.1 Driving unit**

Driving or extrusion unit could move up and down linearly. In this work, DC motor was used to drive ball screw moving in the vertical direction. Ball screw was connected to steel cantilever attaching to piston. Therefore, when ball screw was moved in vertical direction, it caused cantilever and piston moved in the same direction as ball screw movement. Microswitch was used to cut off the supply voltage in order to protect the crash between piston and barrel, as well as the cantilever and driving unit. The diameter and the length of piston were 19.75 and 120 mm, respectively.

**2.2 Barrel and spinneret**

Barrel and spinneret were set up closely to driving unit. The distance between the beginning of barrel and the tip of piston is approximately 4 cm when the piston moved to the maximum position leading to the feed of polymer chips. A schematic of the design of barrel and spinneret was demonstrated in Figure 2. The diameter of barrel decreased in the first stage and a decrease occurred again in the spinneret zone. This led to the better heat transfer causing the acquirement of enough heat to melt the polymer pellets, which has low thermal conductivity.

In this work, the spinneret has the L/D ratio of 30 in order to avoid die swell (due to the relaxation of the elastic stresses of the polymer) [7]. The diameter of barrel is 20 mm. To distribute the heat uniformly to polymer, the heater bands were set up at barrel and spinneret, respectively (Figure 3).

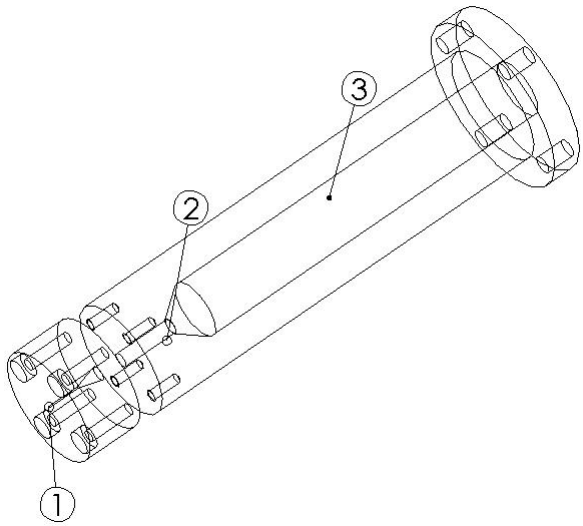



Figure 2 The design of barrel and spinneret. The diameter of barrel decreased from zone (3) to (1)

**2.3 Take-up unit**

When the fiber was extruded through the spinneret, it passed two wheels before the traverse guide and take-up unit. The first wheel supported the fibers. The other changed the fibers from vertical to horizontal direction. Take-up unit, the device to take-up, to handle and to wind the fibers emerging from traverse guide, consisted of two rolls. The first roll handled the fibers, whereas the second one winded and collected the obtained fibers. Figure 4 presents the design of fiber collection.

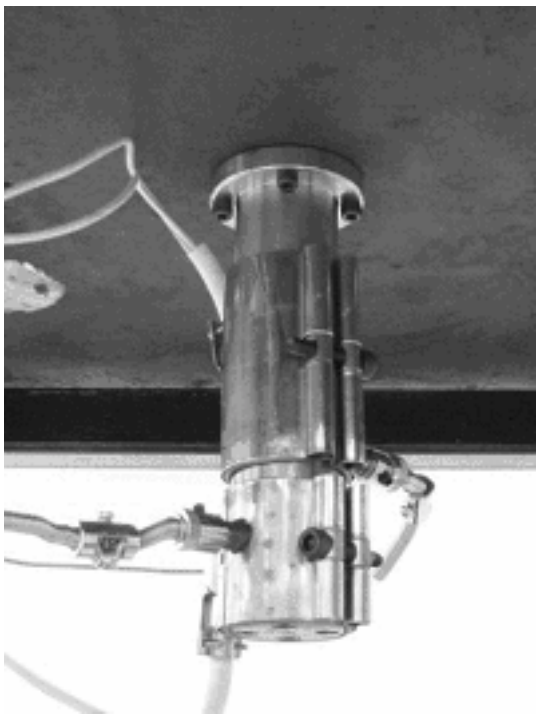
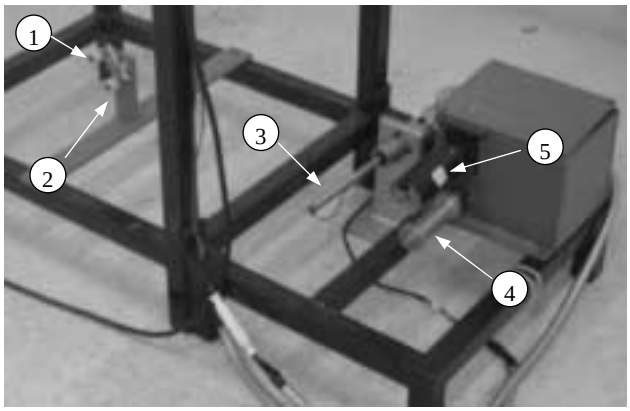


Figure 3 The setup of heater band at barrel and spinneret.



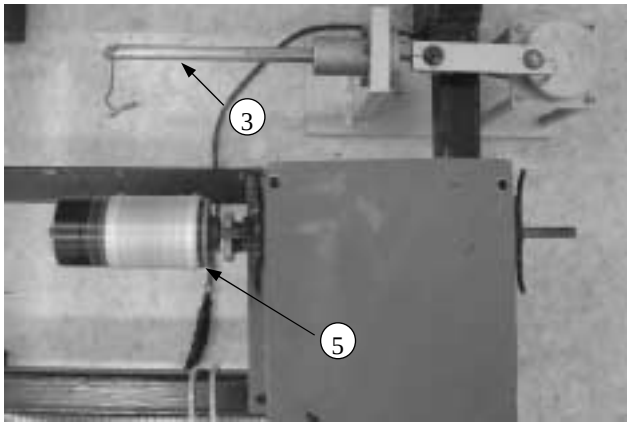




Figure 4. The operation during collecting the fibers. 1) The first wheel, 2) The second wheel, 3) Traverse guide, 4) The first roll in take-up unit, 5) The second roll in take-up unit.

**3. Experimental**

The material employed in this investigation was injection-molding-grade polypropylene (PP 1100 PK) provided by TPI Co. Ltd. (Bangkok, Thailand). 20 g of polypropylene in each batch was used as received. The temperature of barrel and spinneret were controlled at 180$^{o}$ and 190$^{o}$C, respectively. To study the effect of the extrusion speed, polymer pellets were fed into barrel and then kept for 15 min. The molten polymer was extruded using the extrusion speed of piston at 0.5, 1.0 and 1.5 cm/min. To investigate the influence of melting time, polymer pellets were fed into barrel and then kept for 5, 10, and 15 min with take-up speed of 300 m/min, as well as the extrusion speed of piston of 1.0 cm/min. In addition, the take-up speed was varied in the range of 300-1200 m/min.

The obtained fibers were examined the strength using Tensile Universal Testing Machine (LLOYD Instrument, Model LR 50K). A Perkin-Elmer DSC Pyris 1 was used for the crystallinity analysis. The crystallinity of polymers is commonly represented by the following equation [8]

$$\%X_C = \frac{\Delta H}{\Delta H_C} x100 \qquad (1)$$

where $X_C$ is the % crystallinity, $\Delta H$ is the enthalpy change of unknown samples, $\Delta H_C$ is the enthalpy change of pure crystalline standard (100% crystallinity), $\Delta H_C$ for 100 % crystalline polypropylene is 138 J/g [9].

**4. Results and discussion**

When the extrusion speed of piston was operated at 1.5 cm/min, it was found that melt fracture occurred as illustrated in Figure 5. However, this phenomenon didn't exhibit when PP fibers were fabricated with extrusion speed of 0.5 and 1.0 cm/min. It could be implied that the optimum extrusion speed of piston is in the range of 0.5 to 1.0 cm/min. leading to the absence of melt fracture in fiber products.

Figure 5 The formation of melt fracture of the resulting PP fibers at speed of 1.5 cm/min.

When polymer pellets were fed and hold in barrel ranging from 5 to 15 min. at take-up speed of 300 m/min and extrusion speed of piston at 1.0 cm/min, it was found that fibers obtained have no occurrence of distortion and breakage. It indicates that this apparatus could be operated even though short melting time of polymer (5 min.) was employed. Hence, it can be applied for the fabrication of fibers easily degraded by heating. Figure 5 shows the PP fibers derived from this apparatus. There have no yellow fibers obtained for all the operation. It could be implied the thermal degradation didn't occur in this system.

Table 1 presents the mechanical property, the size of fibers, and the % crystallinity of PP fiber obtained using melting time of 5 min, extrusion speed of 1 cm/min, and the distance between spinneret and take-up unit of 280 cm. An increase in take-up speed led to a decrease in size of fibers. This clearly indicated that with increasing take-up speed, more force was transferred to the fiber, which resulted in the deterioration of size of the obtained fiber. In addition, it caused more alignment and orientation of fiber structure leading to the enhancement of crystallinity.

Consequently, an increment of crystallinity also led to an enhancement of fiber strength.

Figure 6. Polypropylene fibers obtained.

Table 1 The tensile strength, fiber size and % crystallinity of the PP fibers prepared using melting time of 5 min, extrusion speed of 1 cm/min, and the distance between spinneret and take-up unit of 280 cm.

| Velocity (m/min) | Tensile Strength ($N/mm^2$) | Tex (g/km) | %Crystallinity |
|---|---|---|---|
| 300 | 77.62 | 8.81 | 61.28 |
| 800 | 310.34 | 7.32 | 62.31 |
| 900 | 326.13 | 5.03 | 66.20 |
| 1200 | 499.79 | 2.81 | 68.27 |

**5. Conclusions**

Melt spinning apparatus in the type of ram extrusion was successfully constructed. It can be used to produce polypropylene fiber using only small amount of polymer pellets in each experimental batch. In addition, the short melting time of approximately 5 min. before extrusion through spinneret can be operated. This leads to a decrease of the residence time used in this process. Hence, it can be applied for the fiber fabrication of temperature-sensitive polymers.

**Acknowledgments**

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