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Blown Film Extrusion Process for Polybags: Technical Overview and Applications

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Abstract

The choice of extrusion process is a decisive factor that affects the finished product quality for polybag manufacturing. One important component influencing the quality of the finished product is the selection of the extrusion technique. Two popular procedures that vary in the kind of dye used and the final product's texture are cast film and blown film. In the horizontal extrusion moulding method known as "cast film", heated resin is injected into a flat dye and allowed to cool on chill rolls. The film produced is clear, lightweight, and appropriate for lamination; its thickness varies based on the winding speed and the film is slower to crystallize and has less clarity but more durability because the resin molecules have reoriented, facing limitation of high wastage generation. This study primarily focused on the preparation of polybag film using the blown film extrusion process, utilizing high-quality polymer resins such as polyester polyethylene (PP) and linear low-density polyethylene (LLDPE) to minimize waste generation. The novelty of the process was reflected in minimising the waste generation. The control parameters considered in this study are temperature, pressure, and air intake volume. We investigated the influence of these critical process control parameters on the gauge thickness, optical properties, and mechanical strength of the polybag film produced through blown film extrusion. Additionally, we replicated the blown film process using simulation software developed at Pennsylvania College of Technology. The simulation results confirmed the overall stability of the polybag film produced through the blown film extrusion process.

Keywords

LLDPE, Melt Flow Index, Blow-Up Ratio, Lay-Flat Width, Draw-Down Ratio

1. Introduction

Polybag manufacturing, crucial for the wrapping and packaging of final products, forms the cornerstone of any chemical business. This sector is deeply rooted in expertise and experience. Understanding the systemic nature of the production process and the interdependencies of its variables is key to driving innovation. The pandemic-induced rise in prices and demand has underscored the importance of this sector, setting the stage for future advancements in polythene production and addressing its environmental impact.

The process of making polybags is complex and multifaceted, utilizing many different facets of chemical engineering. The selection of the extrusion technique plays a critical role in determining the quality of the final polymeric film product. The type of extrusion process and the final product quality must be closely monitored during the manufacturing of any polybag film in the plastics sector, since they are key factors in selecting the process type. Two such methods that are frequently used in the production of polybag films are cast film and blown film [1]. The final product's texture and dye selection are different between the two techniques. In the cast film method, a horizontal extrusion process, heated resin is extruded through a flat die and then cooled on chill rolls. This process produces a film that is clear, lightweight, and well-suited for lamination, with its thickness controlled by the winding speed. The thickness of the film is adjusted based on the pace at which it is wound. The resulting film is used for laminating since it is lightweight and transparent. However, due to slower crystallization, the film has reduced clarity but increased durability with more waste generation.

The selection of the polymer resin plays a critical role in determining the alignment of the mono-film. Polymer resins are available in various forms, depending on their molecular weight and density [2]. A crucial factor influencing the operability of the blown film process is the branching and non-branching characteristics of the polymer chains. This characteristic is measured by the melt flow index, which indicates the amount of polymer that exits the die section over a ten-minute period [3]. In polymer industry, there are different types of polymer resins as follows: low-density polyethylene (LDPE), medium-density polyethylene (MDPE), high-density polyethylene (HDPE) and linear-low-density polyethylene (LLDPE). As reported in the literature, LLDPE, which has a density of 0.916 to 0.94 gm/cm^3 and an optimal melt index of 0.5 to 1.0, is the primary raw material used in the production of polybags because of its increased flexibility, high tensile strength, and resistance to wear [3] [4].

Hence, a well-known and challenging method of extrusion-blown film moulding is utilized in our present study when higher tensile strength and superior cling qualities are needed for wrapping. In addition, blown film is a simple technique to blast into extrusion films, where we can tune the diameter to suit our specific requirements. A blown film extrusion process line consists of several key components, including a blowing cooling device mechanism, a collapsing frame, nip rollers, a winder, an extruder-hopper system that feeds polymer resin pellets, and an extruder die set [1]. In this method, a heated resin film is blasted out of a vertical die until it eventually collapses between the nip rolls. The resulting film is less clear due to the gradual crystallization and reorientation of resin molecules, but it is pre-stretched, increasing the final polythene wrap's endurance. A consistent temperature must be maintained throughout the extruder screw's rotational length to facilitate the intense shearing and mixing that occurs in the extruder section of the blown film line. We used LLDPE resin that has an ideal melt flow index required for the film to be pre-stretched in the radial direction. LLDPE can be blown and elongated in the machine direction, thus making sense to use it for blown film moulding. The entire schematic process of blown film extrusion is carried out depending on the choice of raw material in the present study [4]. Additionally, the blown film extrusion technique uses higher-quality polymer resins, such as LLDPE and PP, of which LLDPE will be the main emphasis of this article and produces less waste from scrap. This truly encapsulates the novelty of our work. Herewith, we investigated the influence of these critical process control parameters on the gauge thickness, optical properties, and mechanical strength of the polybag film produced through blown film extrusion. Certain quantitative ratios, such as the blow-up ratio, draw-down ratio, and lay-flat breadth, can be tuned differently depending on the blower's volumetric air flow, temperature, and pressure. To get experimental results and summarize the data more effectively, these process control variables were also simulated using a blown-film simulator. The obtained data were replicated and simulated to provide optimum output using simulation software developed by Dr. Kirk Cantor, a professor of plastics and polymer engineering technology at the Pennsylvania College of Technology. The simulation of the blown film process yields results that showed similarities with the real process and the general stability of polybag film made by blown film extrusion moulding, which is the main crux of the process used in the production of polythene in the plastics industry.

2. Theory

2.1. Linear Low-Density Polyethylene: Structure and Properties

It is a linear polymer, having short, branched structure (**Figure 1**) formed by the co-polymerization of ethylene molecules with olefins by Zeigler-Natta catalysis reaction [5]. It has shorter chain branching and less shear sensitivity, therefore when it is subjected to film processing during extrusion operation, it easily allows for a faster relaxation of polymer chains and does not get stiff or harden during elongation. This characteristic is important for film formation as in case of blow film extrusion moulding and LLDPE molecules maintain high strength and toughness simultaneously without undergoing degradation [6]. This is the reason that it finds extensive application for packaging and wraps polybag production. In the blown film extrusion process, it becomes extremely viable to get a monolayer polyform of uniform thickness. As this film bubble rises up, it is stretched further and so for such purposes, the elasticity and melt flow index properties play an important role [7]. The shorter chains with a little branching ensure the proper flow of heated resin, avoiding any breakage of bubbles under high pressure. Therefore, LLDPE structure is excellent when it comes to overall maintenance of structure and adequate blow-up ratio, which will be discussed in the further sections.

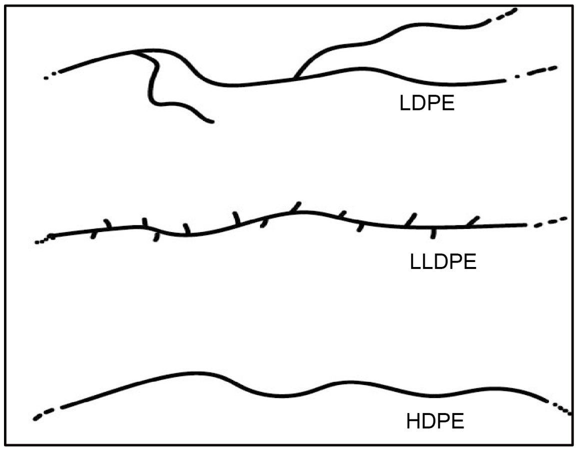

Figure 1. The short branching structure of LLDPE as compared to other variants.

2.2. Rheological Properties

The rheological property of raw material (LLDPE) is important as the melt flow index is defined as the weight of polymer flowing through a die section per 10 minutes. Higher the melt flow index, lower the viscosity [8]. It is needed that in case of film blow extrusion process, the melt flow remains between the value of 10 to 5 gm/10min. This is necessary for the film tube to rise up the blower and then get relaxed and rolled between sheets during cool down. The linear low-density polyethylene comes in the form of pellets that are melted in the extruder machine. It is very essential to ensure that there is proper, homogenous melting of pellets in the extruder lest there will be chances of collapse of film bubble from the die itself. The quality is checked so that there is no defect in the pellets of these raw materials. The pellets serve as the starting point of which inspection and quality check become crucial to ensure the product quality at the end stream. The pellet size, shape and texture influence the uniform mixing in the extruder section in which the shearing takes place between particles [9]. The LLDPE melting point is sharply at 122˚C [10], however for preventing the degradation of resins at high temperature as the operation is performed in a continuous manner, it is necessary to set the temperature, an hour earlier at 100˚C of internal heaters inside the extruder and finally, at a uniform temperature of 20˚C - 25˚C when the operation is successfully occurring as now, the cumulative temperature reaches enough to allow the softened heating of resin pellets without degradation or improper mixing.

3. Experimental: Blown Film Extrusion Process

It is a specialized extrusion process typically used to manufacture plastic film for packaging and converting into polybag (Figure 2). It comprises of extrusion of molten thermoplastic tube and its constant inflation through the air blower, which is cooled and rolled to form a double flat layer film. In this, the upward-blown film process is used for LLDPE-type polymer pellet melt. The plastic melt is extruded via an annular slit die, through which the air is constantly blown to form an inflated bubble tube. The introduction of air takes place through a hole present in the die's centre for blowing up the tube just like a balloon. The hot film is cooled as it rises upwards by the high-speed air ring set-up that blows into it. This air ring occupies the upper position of die, upon which it is mounted. The feed of LLDPE is fed into the hopper as pellets, which are melted and controlled by temperature-controlled unit. The temperature is set between 40˚C - 50˚C as medium temperature for the formation of plastic film. Air pressure is maintained with the help of compressor based on the thickness and the length of tube required, which can go up to heights of 70 inches, if required. The tube of plastic melt is extruded out of die while the cool air is blown from the sideways to maintain the temperature and cool the hot melt just in case the bubble might burst in presence of extreme temperatures. The bubble is subjected to air pressure or IBC (internal bubble cooling) between the die and the frame beneath the nip rollers [11] [12]. The bubble tube is flattened by pair of collapsible frames before it is passed through the nip rollers [13]. It is then winded over the rolls to produce a 2-layer flat film, which is rolled over the cones with the help of idler rollers. The flat film can be cut into two or four parts depending on the sizing requirements and the thickness of the film is maintained by the speed of the rollers in gauges.

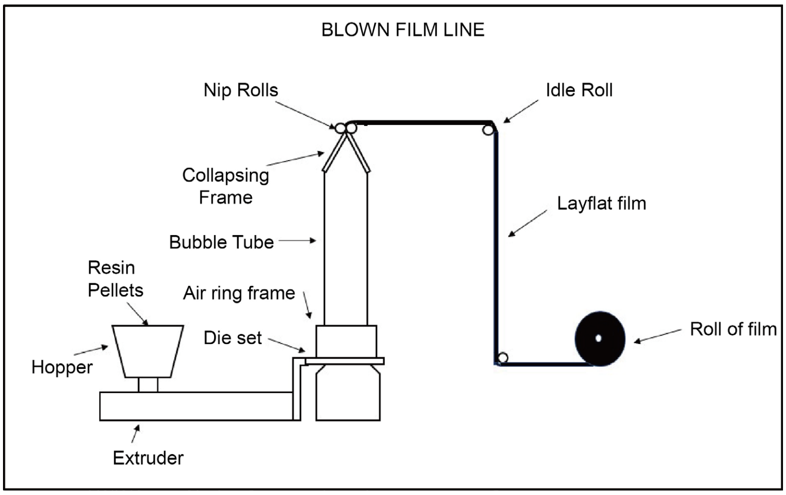

Figure 2. Blown film extrusion line flowsheet.

3.1. Elements of Blown Film

The blown film extrusion line consists of certain parameters like blow-up ratio, lay-flat width, draw-down ratio and frost line height. These elements along with die size, die gap, film thickness, and speed of nip rollers control the dimensions and sizing of a blown film tube, which must undergo pressing and winding in further stages.

3.1.1. Blow-Up Ratio (BUR)

The BUR indicates the maximum amount of stretching for a particular material in the crosswise or perpendicular direction to the length [14].

$$\text{Mathematically, BUR} = D_b/D \tag{1}$$

where D_b is the diameter of the bubble and D is the diameter of the die. For a normal reference, BUR = 2:1. A blow-up ratio greater than 1 means that the bubble has been blown to a diameter greater than the diameter of the die orifice. It also shows that the poly wrap film has been thinned and it acquires the orientation towards the transverse direction.

3.1.2. Draw-Down Ratio

It is the measure of the extent by which a tube can be stretched or drawn without getting ruptured [15]. It is also represented as the ratio of the die hole gap to the film thickness at blow-up ratio BUR = 1.

$$\text{Draw-Down Ratio} = \text{Die Gap/Film Thickness} \times \text{Blow-up ratio} \tag{2}$$

If a draw-down ratio is greater than 1, it shows that the melt has been pulled away from the die orifice at a much faster rate than it is being issued from the die orifice. In that case, the film has been thinned and acquires orientation towards the machine direction.

3.1.3. Lay-Flat Width

It is the width of the film flattened up between the nip rolls [16].

$$\text{Mathematically, lay-flat width} = (\pi\, D/2) \times \text{BUR} \tag{3}$$

3.1.4. Frost Line Height

It is the height from the face of the die at which the bubble tube melt freezes. The freeze line height influences the optical property of the film due to reorientation and relaxation of molecules at the point of freeze line [17]. If the freeze line height is higher, poorer optical properties will be there and brittleness increases as freeze line height shifts down. Also, the below-given formulas become essential in quality analysis of blown film produced by varying the parameters.

$$\text{Film lay-flat width} = 1.57 \times D_b \times \text{BUR} \tag{4}$$

$$\text{BUR} = 0.637 \times (\text{film width}/D_b) \tag{5}$$

One must note that the die diameter (D_b) used is of the standard value of 50 mm and the die gap is between 0.5 to 3 mm.

3.1.5. Sizing

The sizing is decisive in maintaining the overall product quality owing to the requirements of the customers. The speed of the nip rollers and idlers determine the size of the flat film in terms of its thickness and width. The units to measure the length and width of a plastic film employed in the polybag industry are generally in inches and the thickness is measured in gauge. One gauge is equal to 10^{-5} inches and that is equal to 0.254 microns. The plastic film is always measured in the gauge system. Thus, with the help of a micrometre, we can easily measure the thickness of plastic film in microns and convert them into gauge. There are different range of gauge of plastic films that are used of packaging and wrapping purposes. The desired value of gauge is either probed by a micrometre from one plastic bag as in the extruder process it is automatically set according to the pre-defined system values. The recycle size of plastic also is in the range of 2 × 70 inches (width by length) and the gunny bags that are used are in the size range of 20 × 30 inches or 22 × 24 inches. The 3 × 7 inches is the common dimensional size for a small packaging polybag to be supplied in the consumers across the market.

4. Blown Film Extrusion Process: Components and Operations

The components of the polybag manufacturing along with the major process variables are listed as follows.

4.1. Main Control Unit

It is the heart of the polybag manufacturing plant as it controls the temperature, AC current, DC motor, speed of nip rollers, idlers as well as connected to the air blower and compressor for ON/OFF and emergency shut off. It has six temperature knobs each of four regulates the temperature of the extruder section where pellets are melted and two of which control the temperature of the die set. It also has a speed control unit which regulates the speed of nip rollers to adjust the thickness of the plastic film and its width.

4.2. Air Compressor

The compressed air output from the air compressor and the storage tank enters the centre hole of the spiral core rod of the die head through the outlet valve of the tank. The gas enters the centre of the bubble tube through the centre hole of the mandrel and blows out the plastic to form the bubble-shaped tube that rises upwards and gets stabilized, elongated and cooled before collapsing and pressed through the nip rollers. The pressure is set between 0 - 140 psi.

4.3. Extruder Feed System

The extruder is mainly composed of screw, barrel, hopper, reducer and drive motor; through the belt drive reducer, the reducer drives the screw to rotate in the barrel. The screw facilitates the uniform mixing of melted resin throughout the various sections of the extruder. When working, it depends on the surrounding plastic to support centring. The gear reducer motor drives the screws at a rpm of 30 - 70.

4.4. Nip Roll System

The bubble is slowly compressed from a round shape to a flat double layer, between the gap of the nip rolls, and further the static current is applied for smoothening the stretch film as it enters the traction idler system [18]. The collapsing frame guides the mono-layer bubble and folds it into double flat film between the nip roller whose speed of rotation determines its thickness and width.

4.5. Winding, Cutting and Stitching

The lay-flat film is further rolled upon idler rollers and the cuts are made according to the sizing requirements and it is passed through the slitting cage, and it is now rolled over the reels that are rotating in the bender portion. The reels are then sent into the decker machine for stitching and cutting purposes to prepare the final polybag product. The constant gap winding is employed for the rolling-over operation onto different sizes of cones. The cutting operation is performed in two segments. Initially, the sizing of product is determined and how many roles we require further for putting into the decker press for stitching and edge-cutting purposes. Maximum of four rolls is employed in the bender housing system so that it does not affect the productivity, and should not be time-consuming, as in the case of long plastic film. For instance, if there is a bubble air tube of 24 inches and after laying flat into double paper film its width becomes 12 inches. Now, if three cutters are used to slit the flat film, there will be four different flat films each of size 3 inches and the length is determined further in the decker press. This is how cutting helps in setting the required size standards. In the decker machine, the pulley belt system train is used to convey the four to five wraps of plastic film over the ledge of decker for size cutting and pressing and finally stitching. The cutting is done according to the size set in the decker machine and the speed is varied of the pulley system if the film starts to lose grip or fall of. Before sealing, it must be carefully noted the edge margin or else the seal might be made at wrong axis. The air is blown with mouth to open the film to take it off the belt and the static electric current is used for the polybag to press properly while stitching and sealing. Once all these factors are considered, the final polybag product is filled into storage bags where it is transported to printing and colouring.

5. Process Control Variables

The thickness of the flat film, lay-flat width and optical shine is controlled by variables like temperature of the extruder heater, air pressure, volumetric air flow, and speed of nip rollers.

5.1. Temperature

The temperature of the extruder as well as the die set is controlled to ensure that the bubble does not collapse and there is uniform distribution of polymer content over the entire film after elongation.

5.2. Pressure/Back Pressure

The air pressure is important for deciding the width and thickness of bubble tube and the back pressure facilitates the emission of molten material of polymer from the die orifice.

5.3. Speed of Rollers

The speed of rollers controlled by DC influences the thickness as well as the lay-flat film width [18]. Lower speed will give thick film, and higher speed will give thinner overall films.

6. Results and Discussion

Blown Film Extrusion Process Simulation

The data given below is based on the results produced by the simulator software, blown film extrusion simulator developed by Dr. Kirk Cantor, Professor of Plastics and Polymer Engineering Technology at the Pennsylvania College of Technology. The co-relationship between the volume of air and nip roller speed with that of other four dependent variables such as film thickness, bubble diameter, lay-flat width and frost line height has been established through this simulation. The figures and plots help us to deduce the results to get a better insight into the actual blown film extrusion process.

It can be inferred from the above plots that the film thickness and bubble diameter are a function of both air flow volume and nip roller speed. As shown in Figure 3, if air flow volume is increased, the film thickness decreases and the bubble diameter increases, which in turn increases the blow-up ratio.

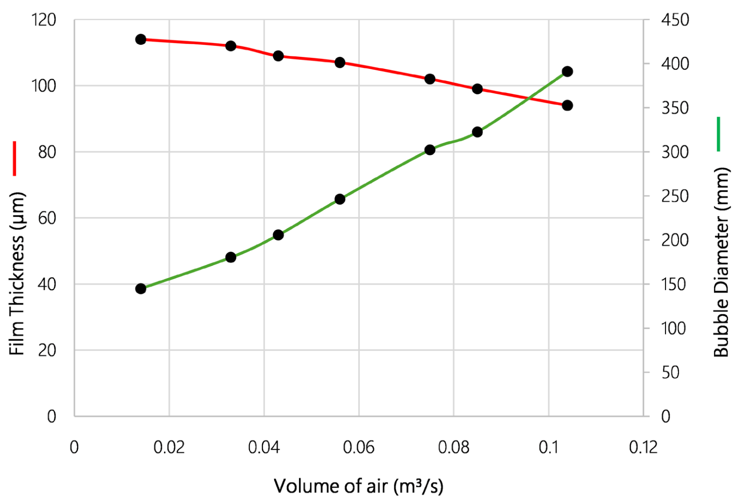

Figure 3. Volume of air versus film thickness (red) and bubble diameter (green) plot.

In **Figure 4**, it can be inferred that both the lay-flat width and the frost line height of the plastic film are dependent on-air flow volume. To manufacture a plastic film of lower thickness, we need to increase the nip roller speed at a constant air flow volume as observed in **Figure 5**. Frost line height controls the optical properties of the film. Thus, increasing the air flow volume will decrease the frost line height and this will eventually increase the brittleness of the film. In **Figure 6**, however the reverse trend is noticed as we can observe that increasing the nip roller speed increases both the lay-flat width and frost line height. It can be concluded that both nip roller speed and air flow volume are the major process control parameters to significantly affect the properties of a plastic film as found in the actual blown film process.

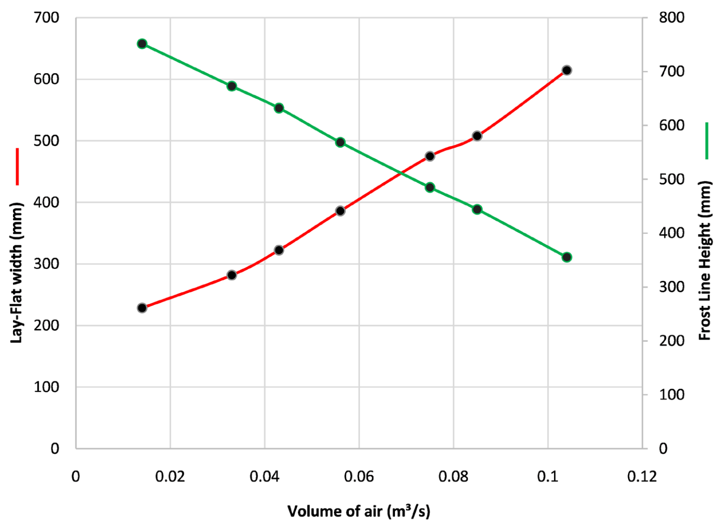

Figure 4. Volume of air versus lay-flat width (red) and frost line height (green) plot.

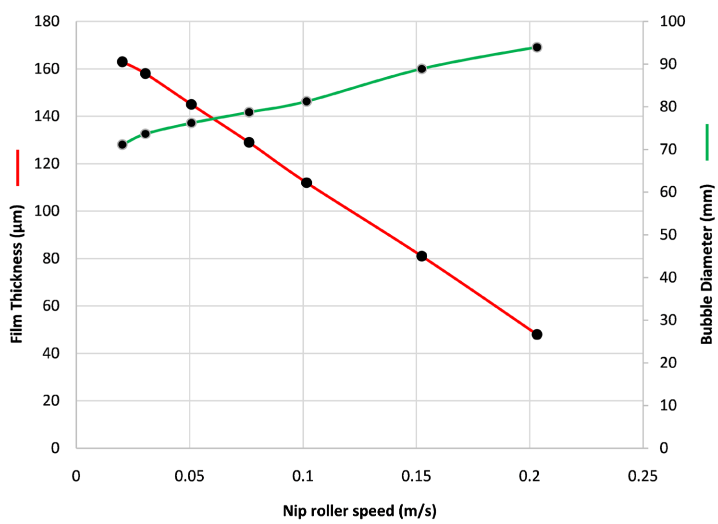

Figure 5. Nip roller speed versus film thickness (red) and bubble diameter (green) plot.

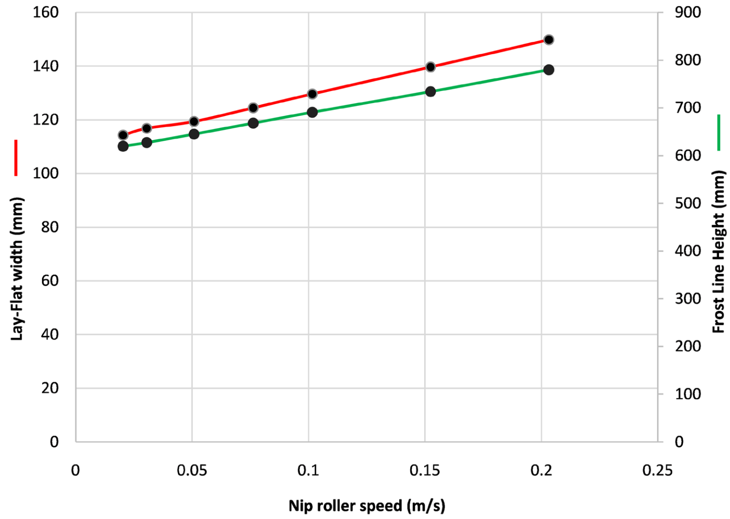

Figure 6. Nip roller speed versus lay-flat width (red) and frost line height (green) plot.

7. Cost Consideration and Challenges

In any industry, the commercial aspect of the raw material, transport, labour cost, recycle margin, capacity consideration is of utmost importance [19]. The fluctuations in the prices or the market trends highly influence the production output and product value keeping in mind that the quality must not be compromised in any scenario. The LLDPE pellet raw material bag of 25 kg is purchased for Rs. 130 - 140/kg. The capacity of the extruder hopper is 40 kg and the total production per day is 300 kg. The processed polybag is sold into the market at Rs. 140 - 150/kg.

If we consider these factors and try to evaluate the cost and profit margin, then we find out that; Total running capital cost = Rs. 42,000.

Total selling margin window = Rs. 45,000.

Thus, the profit margin per day run of the plant is = Rs. 3000.

However, it is not the perfectly exact estimate as the labour, transport charges which keep fluctuating, and the recycled plastic film also adds to final profit which is sold at Rs. 22/kg.

Challenges

The variety of challenges emerge during the entire blown-film operation ranging from the correction of gauge and cutting dimensions [20]-[23]. The rheological properties of the polymer also influence the freeze line height [24], and it must be carefully analysed. Sometimes, due to high cling, the stitching becomes difficult, and it results in wastage of material. The similarity in the processing conditions produce the same mechanical properties of the film [22] [25]. Generally, it becomes difficult in maintaining such conditions during scale-up. The mandrel die set may clog with incompletely melted pellets. The challenge in the working of the die is to maintain the uniform velocity distribution of polymer melt exiting through the die hole [23] [26]. The bubble may collapse or may not even rise due to inconsistent or poor flow due to leakage in the annular section of die [24] [27]-[30]. The pressure can sometimes cause problems and lead to premature rupture of bubble tube and the geometry of the collapsing frame also causes problems resulting in production of the wrinkled film [25] [31]-[35]. Therefore, this continuous process must be strictly monitored to ensure that the product of desired quality is being manufactured and cleared of all defects.

8. Conclusion

The blown film process is a complex extrusion technique, and it is observed that the quality of the LLDPE pellets is of utmost importance in the case of high-grade polybag products. The temperature, air flow volume and nip roller speed affect the process. Strictly, it can be inferred that increasing the nip roller speed at constant air flow volume through die orifice decreases the film thickness but increases the lay-flat width, bubble diameter and frost line height. However, if the nip roller speed is kept constant, and the air volume is increased at a higher pressure, the lay-flat width increases as well along with bubble diameter, but the film thickness and the frost line height decrease, which results in the brittle film formation. All the parameters are strictly dependent on each other, and careful examination becomes necessary for obtaining the desired film quality of polybag.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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