Sudan University of Science and Technology

College of Graduate Studies

Modeling and Analysis of Polypropylene Fiber Extrusion Process

نمذجة وتحليل عملية تصنيع ألياف البولي بروبيلين بالبثق

A Thesis Submitted to Postgraduate Studies at Sudan University of Science and Technology in Fulfillment for the Requirement of Doctor of Philosophy in

Polymer Engineering

By

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June 2021

قال تعالي:

﴿ وَقُلِ اعْمَلُواْ فَسَيَرَى اللّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ وَسَتُرَدُّونَ
إِلَى عَالِمِ الْغَيْبِ وَالشَّهَادَةِ فَيُنَبِّئُكُم بِمَا كُنتُمْ تَعْمَلُونَ ﴾

صدق الله العظيم   سورة التوبة الاية (104)

Dedication

To the pillars of my life: Allah, then my parents. Without them, my life would fall apart.

I might not know where life's road will take me, but walking with you, Allah, through this journey has given me strength.

My mother, you have given me so much, thanks for your faith in me, and for helping and teaching me, and giving me support to continue and I should never surrender.

My father, you are everything for me, without your love and understanding I would not be able to make it.

My Wife you always give me support and telling me to "reach the stars" I think I got my first one. Thanks for inspiring my love for success.

Acknowledgments

I wish to acknowledge the following people for their contribution to the success of this thesis and the completion of my Ph.D. degree.

First, I would like to thank my supervisor, Prof. Ahmed Ibrahim Ahmed, for tireless support, ideas, and motivation during this work. Working with you has been a privilege and a great learning experience. Thanks for his help and supervision has been my mentor.

Second, I would like to thank Dr. Muhab Salahalden Shalby To help me always advise and motivate me

Last but not least I offer my special thanks to those involved directly or indirectly in this study.

Dr .Ibrahim Yuns Ibrahim Algady
Mr. Mohammed
deen Hussein
Mr. Tajelden Musa Bakheit

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Abstract

Extrusion processes are widely used in plastic industries aiming to produce advanced solutions for increasingly sophisticated demands for plastics. Processes are not designed based on professional engineering design, but on trial and error techniques, which may complicate and/or negatively affect the extrusion processing parameters. In this study focus was concentrated on the parameters incorporated in Polypropylene Fiber extrusion process such as: screw length, screw diameter, metering zone length and flight depth. A model equations were derived based on abstracted standard equations considering the swelling occurs for the extruded fibers and the tensile drawing of fiber. Authenticated design parameters were derived and a model useful to simulate any given extrusion process successfully was resulted in a form of computer software system using C# language. The model was checked against manual calculations and gives comparable results for almost all parameters in addition to that, the model proves reliability, accuracy, high speed and integrity. Output data was useful for industrial design and operational setup and it can be further enhanced for future development and diversity conditions.

المستخلص

تستخدم عمليات البثق على نطاق واسع في الصناعات البلاستيكية التي تهدف إلى إنتاج حلول متقدمة للطلبات المتزايدة التعقيد للمواد البلاستيكية. لم يتم تصميم العمليات على أساس التصميم الهندسي المحترف ، ولكن على تقنيات التجربة والخطأ ، والتي قد تعقد و / أو تؤثر سلبًا على معلمات عملية البثق. في هذه الدراسة تم التركيز على العوامل المتضمنة في عملية بثق الياف البولي بروبلين مثل: طول البريمة ، قطر االبريمة ، طول منطقة المعايرة وعمق الريشة. تم اشتقاق معادلات نموذجية بناءً على المعادلات القياسية المستخرجة مع الأخذ في الاعتبار حدوث التورم للألياف المبثوقة ومعدل الشد للألياف. تم اشتقاق معلمات التصميم المصدق عليها ونموذج مفيد لمحاكاة أي عملية بثق معينة أدى بنجاح إلى شكل من أشكال نظام برامج الكمبيوتر باستخدام لغة C #. تم فحص النموذج مقابل الحسابات اليدوية ويعطي نتائج قابلة للمقارنة لجميع المعلمات تقريبيًا بالإضافة إلى ذلك ، يثبت النموذج الموثوقية والدقة والسرعة العالية والنزاهة. كانت بيانات المخرجات مفيدة للتصميم الصناعي والإعداد التشغيلي ويمكن تحسينها بشكل أكبر للتطوير المستقبلي وظروف التنوع.

CHAPTER ONE

Introduction

CHAPTER ONE

Introduction

1.1 Fiber Processing Background:

Fibers are fundamental unit of the ropes industry and its defined as material of axial length scale about 100 times the length scale in cross direction (width or diameter). This achieved by melt spinning which is a rapid and economic method. In melt spinning the polymer is pumped by means of and extruder through screw back in which polymer filtered, then its divided into many small streams by means of a plate containing many small holes called the spinneret (die). Swelling is resulted in the die due to the relaxation of the elastic stresses of the polymer followed cooling of the fiber by water following perpendicularly to fiber axis to achieve immediate solidification of the polymer. Then cold drawing in the region from the solidification point and take up role, cold drawing is repeated by heating the fiber followed by drawing to achieve the final thickness (diameter).(Sayyed et al., 2019).

The key aspect of modeling of fiber spinning process are:

1. Extrusion through a short die in which fluid velocity field must and design raped rearrangement
2. Swell of the melt leaving the hole.
3. Raped axis symmetric extension to along strain.
4. Raped temperature changes and hence large changes in the rheological behavior.
5. Crystallization under high conditions under high stress and raped cooling.

1.2 Statement of the Problem:

Manufacturing of Polypropylene is a known industry in Sudan as over twenty mills are operating with total capacity of about 40 tons per day. Processing method used is diverse due to high temperature of the air where in most cases it is in the range of 40 ℃ to 50℃. The Polypropylene material made in Sudan has different properties than that imported which makes the engineers hesitated about the proper operating conditions and proper parameters values. The technical knowhow in these mills is based on experience of their employees, processes are designed by just trial and error techniques and no professional engineering design was applied. These two factors affect adversely the extrusion processing parameters. The engineering design will help to analyze different parameters that prevail in the extrusion process, the fiber extrusion and the drawing of the fiber to required dimensions.

In this study focus will be concentrated on the parameters incorporated in PP rope extrusion process such as:

1. Screw length &Screw diameter
2. Compression zone length and flight depth
3. The swelling occurs for the extruded fibers
4. tensile drawing of fiber

Thus Modeling and simulation of polymer melt to produce fibers will be the core study of this work and analysis of the factors affecting the extrusion process in each step in the manufacturing sequence will formulate an effective tool to design authenticated model for the extrusion process

1.3. Objectives of the Work:

1. To determine the design parameters required for the extruder used for PP rope manufacturing.
2. To design an extrusion process based on different parameters.
3. To derive authenticated model design of the intended parameters which will be useful to simulate any given extrusion process successfully.
4. To compare resulted between manual and modeling calculations

CHAPTER TWO

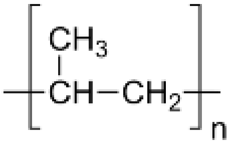
Literature Review

CHAPTER TWO

Literature Review

2.1 Polypropylene (PP)

Polypropylene (PP) is a thermoplastic material that is produced by polymerizing propylene molecules, which are the monomer units, into very long polymer molecule or chains. There are a number of different ways to link the monomers together, but PP as a commercially used material in its most widely used form is made with catalysts that produce crystallizable polymer chains. These give rise to a product that is a semi crystalline solid with good physical, mechanical, and thermal properties.(John et al., 2019). Another form of PP produced in much lower volumes as a byproduct of semi crystalline PP production and having very poor mechanical and thermal properties, is a soft, tacky material used in adhesives, sealants, and caulk products. The above two products are often referred to as isotactic (crystallizable) PP (i-PP) and Atactic (non- crystallizable) PP (a-PP), respectively.(Varnava and Patrickios, 2020).



$$-\!\left[\begin{array}{l} CH_3 \\ | \\ CH-CH_2 \end{array}\right]_n\!-$$

Figure (2.1) Polypropylene repeated unit

These properties can be varied in a relatively simple manner by altering the chain regularity (tacticity) content and distribution, the average chain lengths, the incorporation of a commoner such as ethylene into the polymer chains, and the incorporation of an impact modifier into the resin formulation. Polypropylene containing only propylene monomer in the semi crystalline solid form is referred to as homopolymer PP (HPP), and this type use to mean isotactic PP form. Polypropylene containing ethylene as a commoner in the PP chains at levels in about the 1–8% range is referred to as random copolymer (RCP). HPP containing a commixed RCP phase that has an ethylene content of 45–65% is referred to as an impact copolymer (ICP). Each of these product types is described below in more detail (Gentekos et al., 2019).

2.1.1 Polypropylene Tactility

The solid-state characteristics of PP occur because the propylene monomer is asymmetrical in shape. It differs from the ethylene monomer in that it has a methyl group attached to one of the olefinic carbons. This asymmetrical nature of the propylene monomer thus creates several possibilities for linking them together into polymer chains that are not possible with the symmetrical ethylene monomer, and gives rise to what are known as structural isomers and stereo chemical isomers in the PP chain. In structural isomerism, polymer scientists refer to the olefinic carbon with the methyl group on it as the ‘head’ (h) and the other olefinic carbon as the ‘tail’ (t) of the monomer. The most common method of polymerization uses catalysts that link the monomers together in the ‘‘head-to-tail’’ fashion. Occasionally there is a ‘‘mistake’’ made and the monomers form a ‘head-to-head’ or a ‘tail-to-tail’ linkage, but these tend to be rare. Stereo chemical isomerism is possible in PP because propylene monomers can link together such that the methyl groups can be situated in one spatial arrangement or another in the polymer. If the methyl groups are all on one side of the chain, they are referred to as being in the ‘isotactic’ arrangement, and if they are on alternate sides of the chain, they are referred to as being in the ‘syndiotactic’ arrangement.(Hunger et al., 2012)

Each chain has a regular and repeating symmetrical arrangement of methyl groups that form different unit cell crystal types in the solid state. A random arrangement of methyl groups along the chain provides little or no symmetry, and a polymer with this type of arrangement is known as Atactic polypropylene. When polymer scientists discuss the stereo chemical features of PP, they usually discuss it in terms of tactility or percent tacticity of polypropylene, and in the marketplace the term polypropylene is generally used to refer to a material that has high tacticity, meaning high isotactic content. The high-tacticity PP materials have desirable physical, mechanical and thermal properties in the solid state. Atactic material is a soft, sticky, gummy material that is mainly used in sealants, caulks, and other applications where stickiness is desirable. Syndiotactic PP, not a large-volume commercial material, is far less crystalline than isotactic PP).Tashiro et al., 2017(

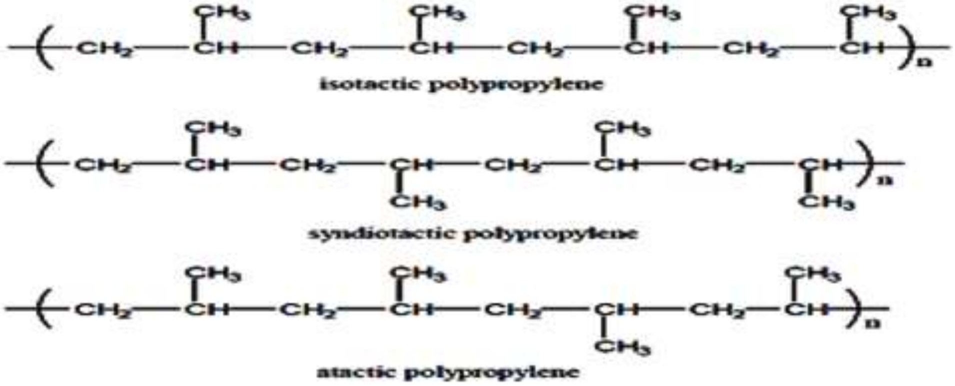


Figure (2.2) Polypropylene polymer molecule

2.1.2 Major advantages of polypropylene properties

PP is very popular as a high-volume commodity plastic. However, it is referred to as a low-cost engineering plastic. Higher stiffness at lower density and resistance to higher temperatures when not subjected to mechanical stress (particularly in comparison to high and low density PE (HDPE and LDPE)) are the key properties. In addition to this, PP offers good fatigue resistance, good chemical resistance, good environmental stress cracking resistance, good detergent resistance, good hardness and contact transparency and ease of machining, together with good processibility by injection molding and extrusion. The properties of PP are compared with other competitive thermoplastics as shown in Table .(Alsunny, 2014)

It can be seen from the table that PP offers advantages over most of its competitive materials on the basis of specific modulus (modulus to density ratio), heat deflection temperature (HDT), maximum continuous use temperature or modulus to cost ratio. Environmental and food legislation may further tip the balance in favor of PP.(Hassanien, 2015)

Table (2.1) Comparison of unmodified PP with other materials

Property	**PP**	**LDPE**	**HDPE**	**HIPS**	**PVC**	**ABS**
Flexural Modulus (GPa)	1.3	0.3	1.3	2.1	3.0	2.7
Tensile strength (MPa)	33	10	32	42	51	47
Specific density (cm^3/g)	0.905	0.92	0.96	1.08	1.4	1.05
Specific modulus (GPa)	1.66	0.33	1.35	1.94	2.14	2.57
HDT at 0.45 MPA(^oC)	105	50	75	85	70	98
Max continuous use temp (^oC)	100	50	55	50	50	70
Cost (£/ton)	660	730	660	875	905	1550
Modulus per unit cost (MPa/£)	2.27	0.41	1.97	2.4	3.31	1.47

Many available grades with different properties make polypropylene useful in applications such as fibers, films, filaments, and injection molded parts for automobiles, rigid packaging, appliances, medical equipment, food packaging, and consumer products. It is being substituted for glass, metal, and engineering plastics such as ABS, polycarbonate, polystyrene, and nylon in kitchen appliances and large appliances such as ovens, dishwashers, refrigerators, and washing machines, and high flow grades are used in molding large house wares. Super - soft grades are replacing polyvinyl chloride in medical bags and tubing and in hospital gowns.(Castro-Aguirre et al., 2016)

2.1.3 Major Disadvantages of Polypropylene Properties

The major disadvantages of PP compared with other competitive thermoplastics are evident from Table (2.1). It can be seen that PP has significantly higher mold shrinkage, higher thermal expansion and lower impact strength, particularly at sub-ambient temperatures, than HIPS, PVC and ABS. However, PP has lower mold shrinkage and thermal expansion coefficient than HDPE and LDPE. Poor UV resistance and poor oxidative resistance in the presence of certain metals such as copper are other disadvantages of PP. As any semi-crystalline material, PP also suffers from high creep under sustained load in comparison to an amorphous plastic such as ABS or PVC (Hassanien, 2015). Other disadvantages of PP are difficult solvent and adhesive bonding, poor flammability, warpage, limited transparency; poor wear properties, unsuitability for frictional applications and poor resistance to gamma radiation. However, most of these disadvantages could be overcome, either completely or to a certain degree, by proper selection of material, sensible design and good processing. The processing of PP by thermoforming and blow molding is difficult. Vacuum forming of PP is also difficult(Dunn, 2016).

Table (2.2) Comparison of unmodified PP with other materials-2

Property	**PP**	**LDPE**	**HDPE**	**HIPS**	**PVC**	**ABS**
Mold shrinkage (%)	1.9	3.0	3.0	0.5	0.4	0.6
Thermal expansion (x10^{-5})	10	20	12	7	6	8
Notched Izod impact strength (kJ/m) at 23^{o}C	0.07	>1.06	0.15	0.1	0.08	0.2

PP is not hazardous to health; however, it can release volatile organic compounds (VOCs) into the surrounding air during high-temperature processing. Workers at the processing plant can be subjected to these VOCs through inhalation or skin contact. Good ventilation using exhaust fans can minimize the exposure. Residual monomer and catalysts present in the resin can increase the toxicity.(Nandan et al., 2019)

2.1.4 Applications of Polypropylene

PP should really be considered a group of polymers, not just a single polymer. Because the properties of PPs cover a substantial range, the applications of PP are quite diverse (Gahleitner and Paulik, 2017). This, of course, belies the usual classification of PP as a commodity resin. Organizing a discussion on applications is challenging because the question arises as to whether similarity of uses or similarity of the fabricated products or similarity of the fabrication techniques should be used as the criterion for arranging information. None of the methods is perfect. (Speck and Speck, 2019). The most important applications of PP are:

2.1.4.1 Fibers

A great volume of PP finds its way into an area that may be classified as fibers. which broadly speaking include slit film or slit tape, are produced in various kinds of extrusion processes. The advantages offered by PP include low specific gravity, which means greater bulk per given weight, strength, chemical resistance, and stain resistance (Maddah, 2016).

Figure (2.3) Polypropylene Ropes

2.1.4.2 Strapping

Strapping is similar to slit film but thicker, being on the order of 20 mils. As the name implies, strapping is used to secure large packages or boxes or to hold stacks together. It takes the place of steel strapping, and its most important property is strength, although the moisture resistance of PP is also an important attribute. It is produced from either direct extrusion or from sheet that is slit. Uniaxial orientation is applied by drawing. Homopolymer resins of low MFR (between 1.0 and 1.5 g/10 min) are used for this application(Hassanien, 2015)

Figure (2.4) Polypropylene strapping

2.1.4.3 Film

By definition, film is less than 10 mils thick. There are two broad classes of film are cast film and oriented film**.** In cast film processes, polypropylene is extruded through a die into a chill roll and the resulting film is eventually taken up on winding equipment. Cast film is essentially un oriented but is still fairly clear because of the quench cooling that occurs. Film thickness usually ranges between 1 and 4 mils. An important feature of cast film is its softness and lack of cellophane-like crispness. Both homopolymer and random copolymers are used in cast film, the MFR most commonly being around 8g/10 min (Gahleitner et al., 2013). Random copolymers give slightly clearer, softer, and more impactresistant film. In case of Biaxially oriented polypropylene film. There are two methods are widely used for producing Biaxially oriented PP (BOPP) film. One is the enter process, and the other is the tubular or bubble process. In both, homo polymer of about 3g/10 min MFR is most widely used(Kock et al., 2013) .

Figure (2.5) Polypropylene film

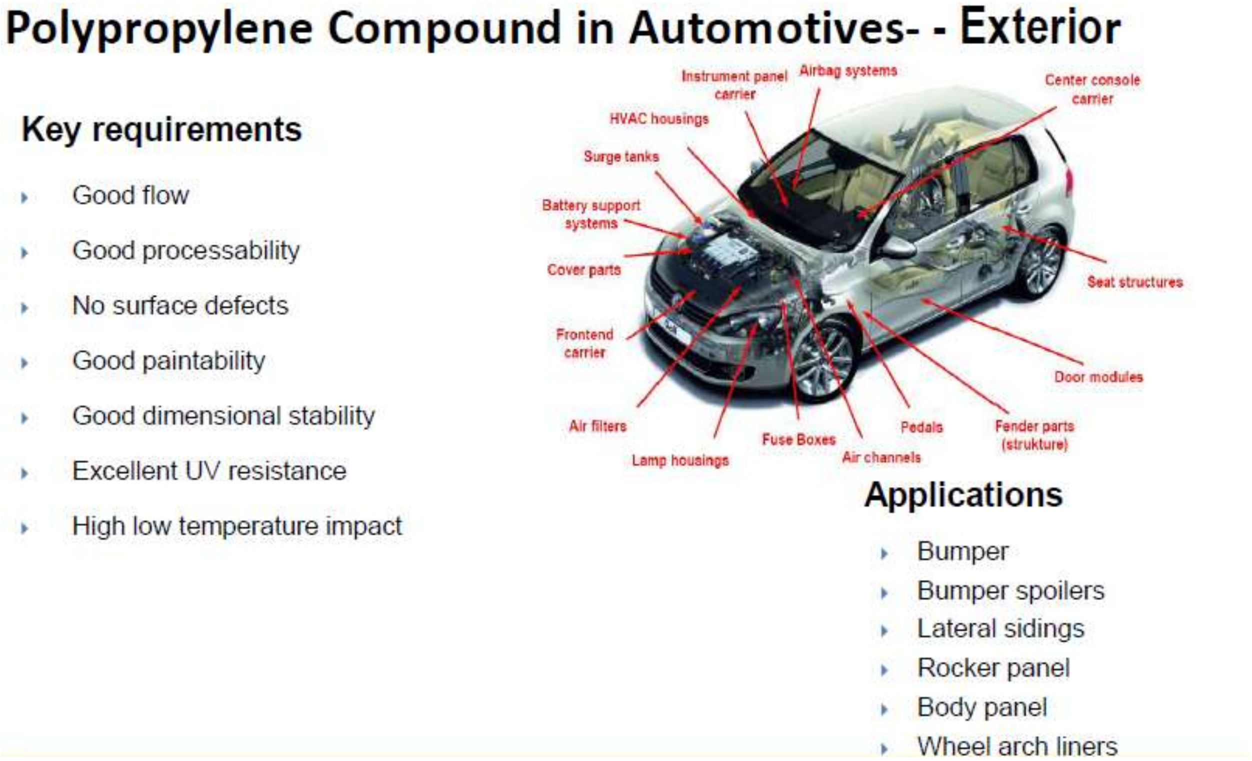
2.1.4.4 Sheet

Sheet is an extruded product that is greater than 10mm in thickness (below this the product is identified as film), 40mm being typical. Resin is extruded through a die and passes through a cooling roll stack and conveyed to nip rolls, after which sheet is wound on rolls or cut and stacked or conveyed directly to a thermoforming machine.(Rasmussen, 2011)

Figure (2.6) Polypropylene sheet

2.1.4.5 Automotive

Polypropylene has a large presence in cars and other vehicles. For the most part, impact copolymers predominate. One of the original uses was in battery cases; in this application, which goes back more than 25 years, injection-molded impact copolymer, colored black, replaced black hard rubber. Now, cases of other colors and of natural translucent material are the norm. Another long-standing use of PP in a car has been for heat and air conditioning ducts, which are mostly unseen. Fan blades of various types are produced from filled (usually with talc) PP(Pradeep et al., 2017).



Polypropylene Compound in Automotives- - Exterior

Key requirements

- Good flow
- Good processability
- No surface defects
- Good paintability
- Good dimensional stability
- Excellent UV resistance
- High low temperature impact

Applications

- Bumper
- Bumper spoilers
- Lateral sidings
- Rocker panel
- Body panel
- Wheel arch liners

Figure (2.7) Polypropylene in Automotive

2.1.4.6. Blow Molding:

The basic principle of blow molding process is to produce a hollow object by blowing a thermoplastic with hot air. A heated thermoplastic hollow tube is known as parison is placed inside a closed mould before blowing. The parison takes the shape of the mould, after blowing, and retains the shape upon leaving it. Bottles and jars are the main products of blow molding process There are three types of blow molding: extrusion blow molding in which produced PP bottles have hot-filling capability and good contact clarity, injection blow molding to produce relatively small bottles and wide-mouth jars and injection stretch blow molding to produce bi-axially oriented jars and bottles with greater clarity, strength and barrier properties (Kumar et al., 2020).Typical applications are water bottles, shampoo bottles and lubricant/pesticides containers (Maddah, 2016).

Figure (2.8) Polypropylene in shampoo bottles and lubricant

2.1.4.7.Injection Molding

In this process, granules of polymer are heated until melting. Then, the molten material is injected into a closed mould. The mould normally consists of two halves which are held together under pressure to overcome the force of the melt. After that, the injected material is allowed to cool and solidify in the mould. The two halves of the mould are then opened and the molding is become out, Figure 8. Usually, mould shapes have very complex geometries that provide designers with infinite number of design possibilities (Maddah, 2016).Thin-wall injection molding is used for rigid packaging container applications. The thickness does not usually exceed 25 mils and often less than that. Rigid packaging containers are used in consumers’ items such as food storage containers and water bottles. Water bottles have many shapes and can be round, square, flat or tall. Injection molding is the best choice for producing containers with verities of shapes easily (Maddah, 2016). Housewares applications include storage systems, toys, sports equipment, paintbrushes and garden furniture(Jin and Leng, 2015) . Screw caps for bottles and jars are some examples of closures applications produced from PP. Further, injection molding includes some appliances and hand tools applications like coffee makers, can openers, blenders and mixers as well as different medical applications such as disposable syringes (Maddah, 2016).

Figure (2.9) Polypropylene in medical applications

2.1.5. Polypropylene general properties

Polymer composition have continued to attract interest from researchers due to inherent benefits from working with polymers, which are ease of processibility and productivity, combined with the addition of filler and other additives, can significantly alter the base polymer properties resulting in a low-cost material with potentially very useful properties(Zare et al., 2019). Nevertheless, incorporation of filler and other additives in a polymer will affect the melt rheological behavior of the compound which will be critically important in defining the process ability of the polymer compound. The importance of identifying the melt rheological behavior is noted by several workers such as composition of Polypropylene (PP), ethylene propylene dyne monomer (EPDM) and zinc methacrylate(Nofar et al., 2019). Furthermore, this behavior important to study the mechanism by which addition of filler influences the original polymer and to determine those combinations in which such affect occurred(Tauste et al., 2018).

Polypropylene (PP) is a versatile thermoplastics offering a useful balance of heat (160°C) and chemical resistance, good mechanical and electrical properties and easy processing. Besides PE and PVC, PP is the third commodity polymer produced and applied in large quantities. Crystalline polymers of propylene were first described in the literature in 1954 by G.Natta and his associates at the Chemical Industrial Politechico in Milano(Bashford, 2012). Earlier efforts to initiate propylene polymerization had only resulted in non crystalline polymers of little or no importance. With the introduction of heterogeneous, stereospecific catalyst discovered by K. Ziegler for the low-pressure polymerization of ethylene, the scene suddenly changed. These reactions are products of transition metal compounds with selected organometallic compounds contained active sites for polymerization, such that each new propylene molecule was incorporated in the polymer chain in a regular, geometric manner identical to all preceding methyl groups. Three geometric forms of the PP chain can be obtained. Natta classified them as:

1. Isotactic: All methyl groups aligned on one side of the chain.
2. Syndiotactic: Methyl groups alternating.
3. Atactic: Methyl groups randomly positioned.

Both isotactic and syndiotactic forms will crystallize when there are cooled from molten states. Commercial injection molding and extrusion grade PP are generally 94 to 97% isotactic. Fabricated parts are typically 60% crystalline, with a range of polyhedral Spherulite forms and sizes, depending on the particular mode of crystallization from the melt. Atactic polypropylene is not suited to structural plastic uses, have been developed as modifiers in hot melt adhesives, roofing compounds, and communications cable-filler gels. PP can be made into a multidimensional range of products with properties and characteristics interdependent on:

- Type of polymer (homopolymer, random, or block copolymer).
- Molecular weight and molecular weight distribution.
- Morphology and crystalline structure.
- Additives.
- Fillers and reinforcing materials.
- Processing techniques.

Homopolymer have resistance to deformation at elevated temperatures, while high stiffness, tensile strength, surface hardness and good toughness can be observed at ambient temperatures. Random ethylene-propylene copolymers are characterized by higher melt strengths. They have good clarity and resistance to impact at low temperature, gained at some sacrifice in stiffness, tensile strength and hardness. Block copolymers, preferably with ethylene, are classified as having medium, high, or extra-high impact strength with particular respect to sub-zero temperatures(Posch, 2017).

2.1.5.1. Thermal properties of polypropylene

Almost all plastic have a high heat capacity (specific heat). At their normal moulding temperatures the total heat content of plastics compare with the heat content let say 20°C, can be greater than zinc or brass at their melting points. This heat content always referred as enthalpy. This heat content can be put into the plastic as well as being taken out and the former process takes places at cylinder and later in mould. Figure (2.8) plots the enthalpy of some plastics, including polypropylene, against temperature. In this figure, it is shown that crystalline materials such as polypropylene and polyethylene have heat content exceed 50cal/g(Hassanien, 2015) .

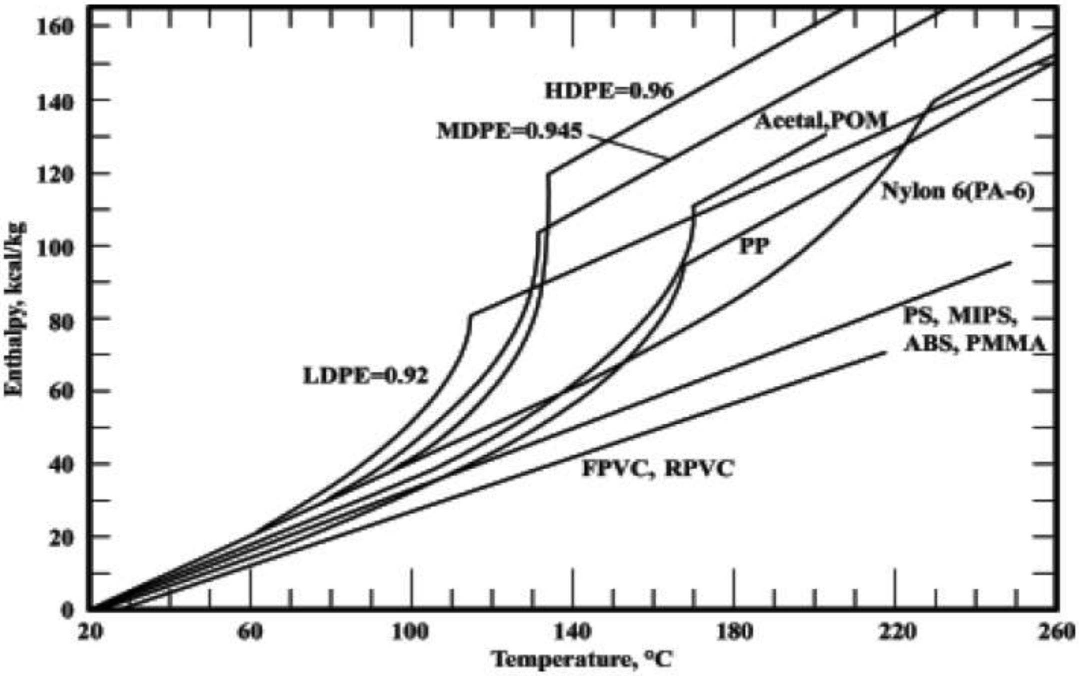


Figure (2.10) Enthalpy of some plastics against temperature

Therefore the understanding of material's thermal properties is necessary for the selection appropriate process of manufacturing. The thermal properties of polypropylene are stated as Table (2.4)(Koronis et al., 2013).

Table (2.3) Thermal properties of polypropylene

Thermal properties of Polypropylene	**Values**
Thermal conductivity (Wm-K)	0.1382
Processing temperatures (^oC)	200-250
Onset decomposition temperatures (^oC)	280
Thermal diffusion constants (m^2 sec^{-1})	0.9×10^{-7}
Specific heat	0.46
Mould temperature (^oC)	30-80
Thermal diffusivity (m^2 $^oc^{-1}$ sec^{-1})	6.5 X 10^{-9}

2.1.5.2. Mechanical properties of polypropylene

(a) Impact strength of polypropylene

Plastic products are exposed to many impact encounters during their service life. Recently a comprehensive review of the many factors that influence impact resistance and determine toughness of a fabricated or molded part subjected to an end-use application were carried. Toughness is defined as a measure of the ability of material structure or molded part to endure the application of a sudden applied load without experiencing ‘‘failure’’. The toughness of composites, based on semi crystalline resins for engineering applications, is of major concern in meeting finished product requirements necessary for good performance. High strain rates, low temperatures, and the presence of stress risers often lead to brittle failure of materials even though they behave in a ductile manner at low strain rates or higher temperatures. During early plastic product development, the commercial success of high-impact polystyrene (HIPS) and acrylonitrile-butadiene-styrene (ABS) led to the development of a whole new group of rubber toughened plastics. Since then, about 80% of blended or filled thermoplastics are compounded with some type of modifier to give products having improved impact resistance during their service lifetime. Indeed, toughness enhancement of the polymer matrix has become a major new field of polymer science and is very often the decisive characteristic used in material selection for a large variety of applications (e.g., automotive, home appliances, construction, utilities, and sporting goods). Because impact modification of PP blends and composites represents an important area of commercial interest, materials scientists seek a fundamental understanding of the mechanisms underlying fracture failure processes(Liu et al., 2012) .

Most of these mechanisms also operate in the neat polymers; however, the incorporation of a secondary phase or component alters their modus operandi or introduces impact behavior that does not occur in the neat polymer. Combinations of PP with fillers or thermoplastic blends affect the balance of stiffness and impact resistance. The challenge to product design is how to attain a favorable balance of properties that suit the particular end-use application. Rather than depending on guesswork, the development of cost-effective formulations requires guidelines based on proven hypotheses of impact fracture mechanisms.

(b) Scratch resistance of polypropylene

The use of polypropylene is expanding at an increasing rate in the fields of exterior and interior automotive trims, in electrical equipment device housing and covers as well as household and personal articles. However polypropylene is poor or inadequate in heat resistance, stiffness, scratch resistance and impact resistance. These deficiencies are obstacles in opening up new applications for polypropylene, particularly applications which have traditionally been injection molded. In order to overcome these shortcomings, especially inadequate impact and scratch resistance, polypropylene has been blended with a rubbery elastic material such as ethylene propylene copolymer rubber, ethylene propylene-diene copolymer rubber or ethylene butene copolymer rubber and other additives(Dammer et al., 2013)

2.1.5.3. Polypropylene rheology Properties:

Polypropylene is formed into articles almost exclusively by melt processes that rely on the flow of the melted material at elevated temperatures. Injection molding, blow molding, extrusion, and thermoforming are all examples of melt processing. An understanding of melt flow is essential for success with these processes. The study of the flow of materials including that of polymers is known as rheology. The rheology of a thermoplastics melt is complex, being very dependent on temperature and shear rate. This means that the melt viscosity the characteristic that makes flow easy or difficult can vary widely in the melt condition. The two key points about the flow of thermoplastics are that the behavior is non-Newtonian and that viscosities are very high(Subramanian, 2011).

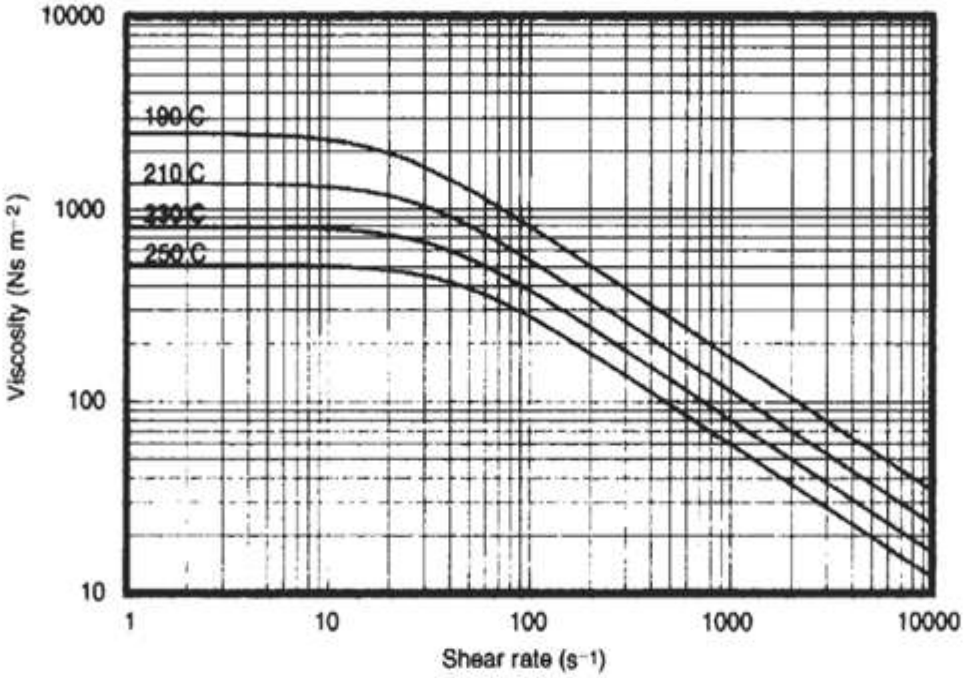


Figure (2.11) Viscosity curves for polypropylene

These characteristics are dictated by the long polymer chain molecular structure of the materials. One practical consequence is that considerable force is required to make a plastics melt flow into a mold or through a die. This explains why plastics processing machinery and molds must be so robust and are costly. To understand and control melt processes, it is necessary to define the way in which melt viscosity changes with temperature and shear rate. The shear rate is a measure of how fast the melt passes through a channel or orifice. One of the researches about flow properties of polypropylene are done by Katja et al (Aho, 2011)concluded use additives mixture containing linear polypropylene and at least one additive in a polypropylene composition comprising additive mixture and a branched polypropylene to lead to reduce the gel index of polypropylene composition(McLaren, 2019).

2.1.5.4. Polypropylene morphology Properties:

By using Ziegler-Natta catalysts, polypropylene (PP) has been produced from monomer of propylene. When cooled to temperatures below the melting point (the crystallization temperature), polypropylene molecules associate to form supra molecular structures. Polypropylene is a semi crystalline polymer; varying degrees of crystallinity and different types of crystal structures are possible, depending on the stereo chemical structure, the processing or crystallization conditions, and the presence of additives. Crystallinity arises from the stereo regularity in the molecular structure; occasional irregularities such as branching or tail-to-tail addition during polymerization or the presence of copolymers limit the extent of crystallization. Atactic polypropylene, with its random, irregular molecular structure, is predominantly amorphous. Semi crystalline polymers have high strength, stiffness, and density and sharp melting points. Amorphous polymers are tough and ductile, with higher impact strength, lower density, and lower haze. Properties of a polypropylene resin can be adjusted, depending on processing conditions and catalysts, by varying the level of crystallinity in the polymer(Sangroniz et al., 2017) .

The usefulness properties of polypropylene and its copolymers make this polymer become an excellent choice for many applications such as house ware, automobile parts, packaging products, laboratory ware, hospital ware, toys, sports and others (Stevens, 2020).

2.2 Extrusion Process:

Plastic extrusion process is a manufacturing process in which raw plastic is melted and formed into a continuous profile producing items such as pipe/tubing, fencing, deck, railings, window frames, plastic films, fibers. and wire insulation. The general process starts by feeding plastic materials, like pellets, granules, flakes, or powders from a hopper into the barrel of the extruder. The material is gradually melted by mechanical energy generated by turning screws, and by heaters arranged along the barrel. The molten polymers are then forced into a shape that hardens during cooling(Rauwendaal, 2014b) .

2.2.1 Extrusion Machine Components:

The single screw extruder consists of different mechanical and electrical components. Mechanical components include Hopper, Screw, Barrel, Die, Drive system meanwhile electrical components are PID controllers, Electrical heaters, Solid state relay, Thermocouple. The brief descriptions of individual some components are discussed below. the figure below shows extrusion machine component(Neupane et al., 2019) .

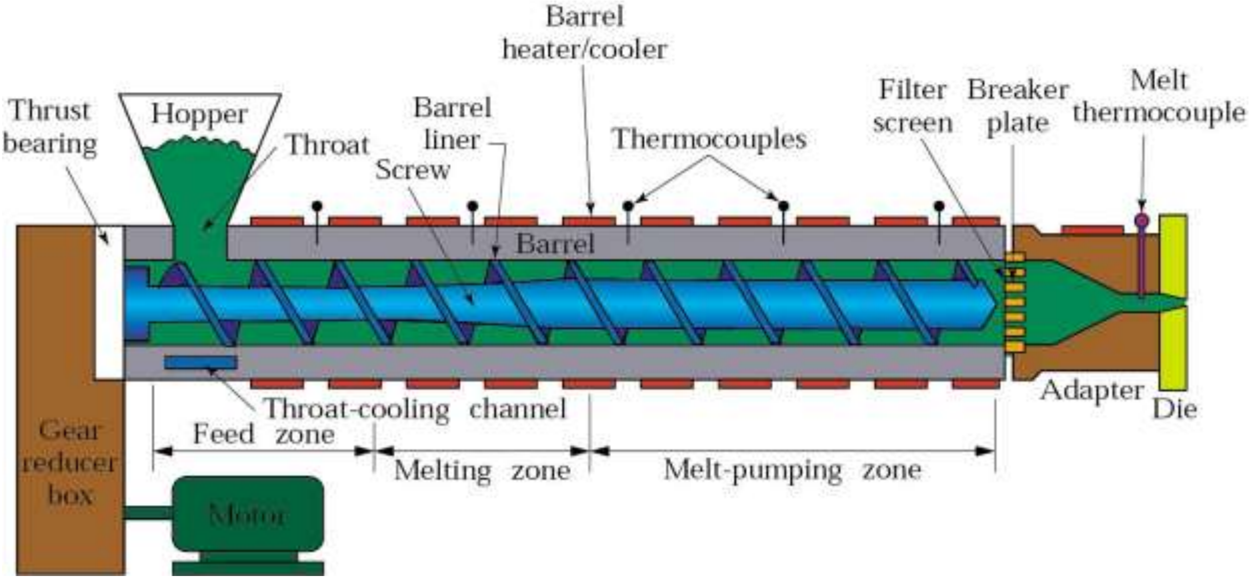


Figure (2.12) Extrusion Machine Component

2.2.2 Single Screw Extruders:

The extruder screw is one of the most important component of the machine, it’s design is crucial in the mixing and process ability of the polymer in question, with respect to the type of polymer to be process. The screw is designed into five different sections known as zones. Different types of polymer may have different screw design; some design may not have the entire zone(Rauwendaal, 2014a).

Three zones are usually identified in most screw which are shown in Figure 1

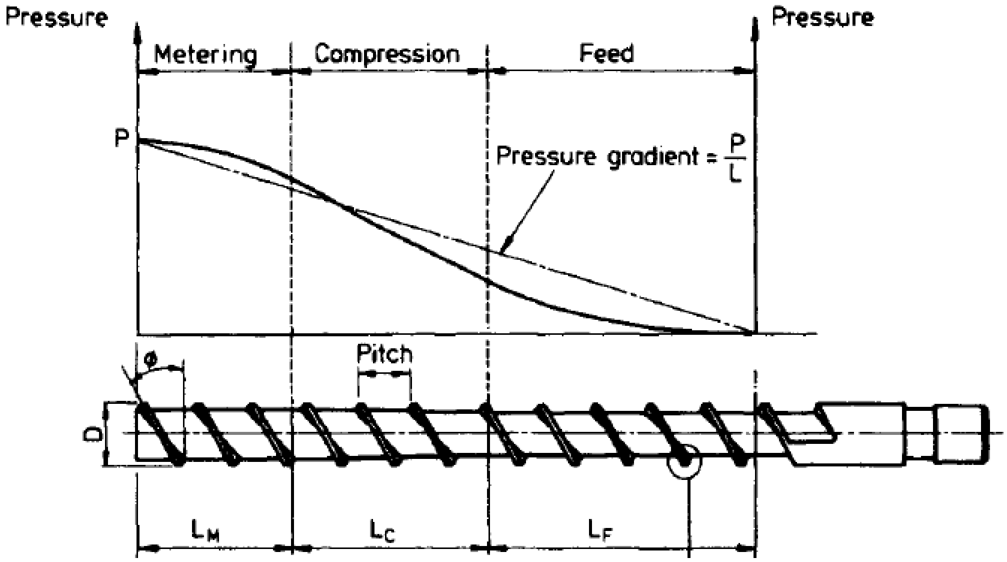


Figure (2.13) Screw Zones

a. **Feed zone**:

The feed zone is the point where the resin enters the extruder. In this zone, the width of the flight is the same, and the channel distance is usually the same all over the zone. (Nana, 2012).

.

b. **Melting zone:**

This is where the melting begins, as the screw rotate, more and more resins are being melted and the channel depth gets more and more reduced. (Park and Lyu, 2018)

c. **Metering zone:**

In this zone, the channel depth is again the same throughout the zone, melting of the last particles and mixing of the polymer to a uniform temperature and composition occurs in this zone, here, barrel heaters may contribute some energy needed to complete the melting.(Nana, 2012)

2.2.3 The Die:

The extruder contains breaker plate placed at the head of the extruder barrel which connects with the die. Gear pumps are also often placed in between die and the extruder for producing very uniform pressure, which produce uniform cross section dimensions. It provides a seal between the extruder and the die. It contains many holes due to which the plastic is forced to pass in straight line after rotating movement during process. It also filters other impurities to enter die. Dies are all replaceable and according to product requirement. The opening area of die is usually larger than the area to the finished side. Die is a key unit of the extruder throughout the extrusion process .(Neupane et al., 2019)

2.2.4 The Spinneret

Spinneret is the starting position where the spinning dope begins to form tow, which is the key part for forming tow, and the initial spinning conditions will greatly affect fiber geometrically and mechanically. To optimize a spinneret, the spinning process for fabrication of chemical fibers should be considered. There are different types of spinning such as: dry spinning, wet spinning, melting spinning, composite spinning, and others. The spinneret should be specially designed to match the requirement of different fibers such as long and staple fibers of polyester, nylon, acrylic, PP, and cellulose acetate. Recently much attention was paid on spinneret design due to rapid development of industrial fabrics, however, there is, so far, no report on optimal spinneret distribution and its effect on fiber's tensile properties. He & Khan first studied theoretically the effect of spinning speed on the diameter and mechanical properties of dragline during the spider-spinning procedure .(Yang et al., 2013)

Figure:(2.14) The Spinneret

2.3. Extrusion Process Parameters:

Designing of the Single Screw Extruder have amejor influence on the process parameters such as the Length-Over-Diameter (L/D) ratio , filight depth , metering zone length ,The swelling occurs for the extruded fibers and tensile drawing of fiber (Fiscus et al., 2017).

2.3.1 Length-Over-Diameter (L/D) Ratio

The length over diameter (L/D) is also one of the important measures in screw design. The ratio generally is found ranging from 20:1 to 34:1 of any typical screw. The ultimate application of the screw is responsible to determine its length. So, length of the screw is depending on, each turn while designing the screw. For typical extrusion there are three zones, feeding, compression and metering zones. Therefore, conventional screw generally has L/D ratio of 24:1. Besides conventional screws application, there are other fields of application where high pressure, heat and constant temperature is required in order to process the material. After knowing the Length-over diameter, it is possible to find out how long is the barrel.(Neupane et al., 2019)

2.3.2 Analysis of Flow in Extruder

to consider the output from the extruder as consisting of three components - drag flow, pressure flow and leakage put in most designs the leakage flow it considered zero so it is neglected. The derivation of the equation for output assumes that in the metering zone the melt has a constant viscosity and its flow is isothermal in a wide shallow channel. These conditions are most likely to be approached in the metering zone.(Zitzenbacher et al., 2007)

2.3.3 Drag Flow

Consider the flow of the melt between parallel plates

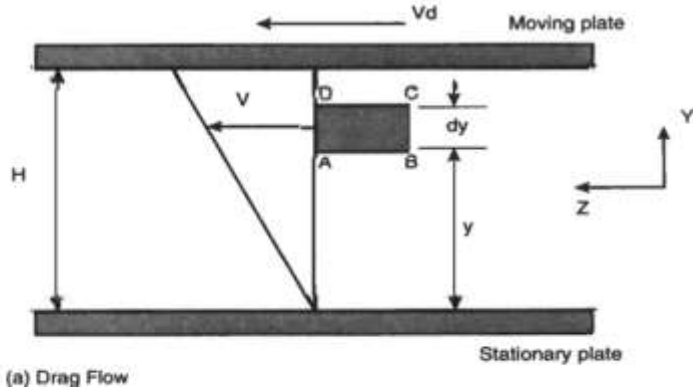


Figure (2.15) Flow between parallel plates

Volumetric Flow Rate (dQ):

$$dQ = Vdydx$$

Assuming the velocity gradient is linear, then

$$V = V\mathrm{d}(\frac{y}{H})$$

$$dQ \;=\; V\text{d}\;\left(\frac{y}{H}\right) dydx$$

Integrating above equation:

$$Q_d = \int_0^T \int_0^H V\text{d}\frac{y}{H}\, dydx$$

$$Q_d = \frac{V\text{d}}{H}\int_0^T \int_0^H y\,dy\,dx$$

$$Q_d = \int_0^T \frac{V\text{d}y^2}{H\;\;2}\, dx$$

$$Q_d = \int_0^T \text{Vd}\frac{H}{2}\, dx$$

$$Q_d = \frac{V\text{d}TH}{2} = \frac{1}{2}THV\text{d}\;\; {-}{-}{\rightarrow}(2.1)$$

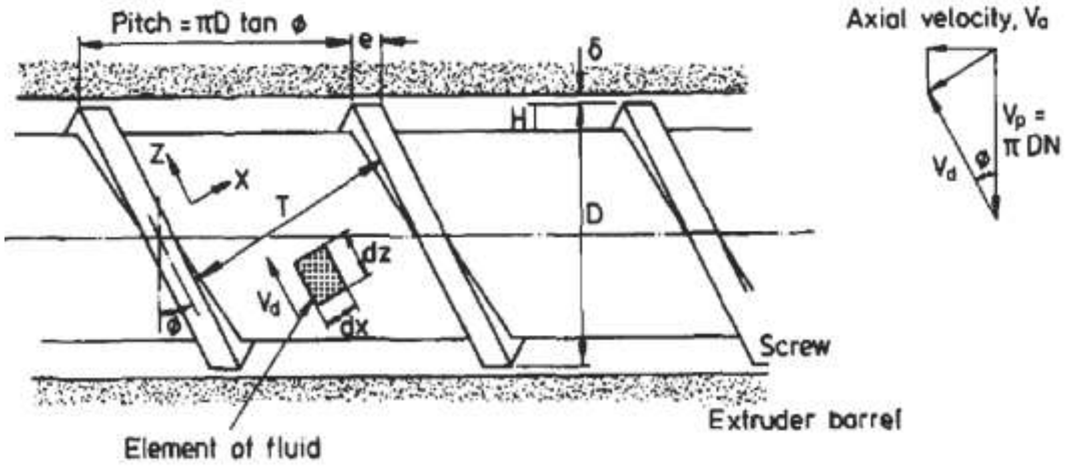


Figure (2.16) Screw analysis

$$\frac{T}{\pi D\tan(\phi) - e} = \;cos(\phi)$$

$$T \;= (\pi Dtan(\phi) – e)cos(\phi) {-}{\rightarrow}\; (2.2)$$

$$V\text{d} \;=\; \pi DNcos(\phi) {-}{\rightarrow}\; (2.3)$$

$$Q_d \;=\; \left[\frac{1}{2}THV\text{d}\right]$$

$$Q_d \;=\; \frac{1}{2}\,(\pi Dtan(\phi) - e)\;cos(\phi)\;.\pi DNHcos(\phi)$$

In most cases the term, e, is small in comparison with $(\pi Dtan(\phi))$ so this expression is reduced to

$$Q_d = \frac{1}{2}\pi^2 D^2 \frac{sin(\phi)}{cos(\phi)} cos^2(\phi)\ NH$$

$$Q_d = \frac{1}{2}\pi^2 D^2 NH\ sin(\phi)cos(\phi) \dashrightarrow (2.4)$$

Note that the shear rate in the metering zone will be given by:

$$\dot{\gamma} = \frac{Vd}{H}$$

$$\dot{\gamma} = \frac{\pi DN cos(\phi)}{H} \dashrightarrow (2.5)$$

2.3.4 Pressure Flow:

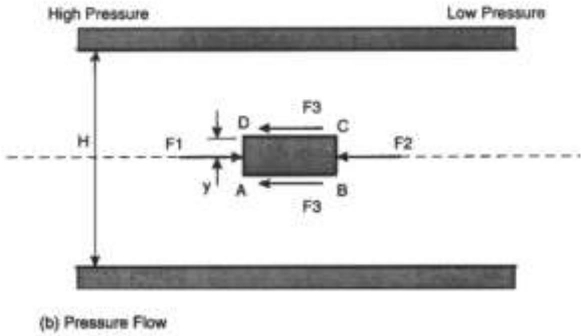


Figure (2.17) Pressure Flow

Consider an element of fluid between parallel plates, **T** wide and spaced a distance **H** apart. For unit width of element, the forces acting on it are:

Since the flow is steady

$$\sum F = 0$$

$$P_1(2y)(x) - P_2(2y)(x) - 2\,\tau\,\Delta Z\ = 0$$

$$\tau\ = \frac{\Delta P}{\Delta z}\ y = \frac{dP}{dz}\ y \dashrightarrow (2.6)$$

In many cases the pressure gradient is uniform, so that for a pressure drop, P, over a length, L

$$\frac{\Delta P}{\Delta z} = \frac{dP}{dz} = \frac{P}{L} = \text{Constant}$$

The maximum shear stress will be at the wall $\mathrm{y} = \frac{\mathrm{H}}{2}$

$$\tau_w = \frac{P\ H}{2\ L} \dashrightarrow (2.7)$$

at center line between tow surface:

$$\tau_w = 0 \longleftarrow \qquad y = 0$$

Newtonian Fluid

$$\tau = \mu\,\dot{\gamma} = \mu\frac{dv}{dy}$$

Substitute in equation (1)

$$\mu\frac{dv}{dy} = \frac{dP}{dz}\ y$$

Integrating:

$$\int_0^v dv = \frac{1}{\mu}\frac{dP}{dz}\int_{\frac{H}{2}}^{y} y\ dy$$

$$v = \frac{1}{2\mu}\frac{dP}{dz}\left[y^2 - \left(\frac{H}{2}\right)^2\right] - -\rightarrow (2.8)$$

At center line y=0 reach the maximum velocity V :

$$V = -\frac{1}{2\mu}\left(\frac{dP}{dz}\right)\left(\frac{H}{2}\right)^2 - -\rightarrow (2.9)$$

are divided equation [2.8]/[2.9]

$$\frac{\mathrm{v}}{\mathrm{V}} = \left[1 - \left(\frac{2y}{H}\right)^2\right] - - \rightarrow (2.10)$$

- **The volume flow rate(Q) :**

$$Q = \ v \, dA \quad , \ dA = T \ 2y$$

$$= v \int_0^y 2 \ T \ dy$$

From equation (4)

$$\mathrm{v} = \mathrm{V}\left[1 - \left(\frac{2y}{H}\right)^2\right]$$

Substitute *v* :

$$Q = 2 \ V \ T \ \int_0^{\frac{H}{2}} \left[1 - \left(\frac{2y}{H}\right)^2\right] dy$$

$$Q = \ 2 \ V \ T \ \left[y - \frac{4}{H^2}\frac{1}{3}y^3\right]_0^{\frac{H}{2}}$$

$$Q = \ 2 \ V \ T \ \left[\frac{H}{2} - \frac{4}{H^2}\frac{1}{3}\frac{H^3}{8}\right] = 2 \ V \ T \left[\frac{H}{2} - \frac{H}{6}\right] = \ 2 \ V \ T \left[\frac{3H - H}{6}\right]$$

$$Q = \ 2 \ V \ T \ \left(\frac{H}{3}\right) \ \leftrightarrow \ \ V = \frac{3Q}{2TH} - - \rightarrow (2.11)$$

Sub. maximum velocity V in eq. (3)

$$Q = - \ \frac{1}{12\mu} \ T \ H^3 \left(\frac{dP}{dz}\right) - - \rightarrow (2.12)$$

$$T \ = \ \pi D tan \ (\phi) \ \ cos(\phi)$$

$\frac{dL}{dz} = \ sin(\phi)$Then$\frac{dP}{dz} = \frac{dPdL}{dLdz} = \frac{dP}{dL} sin(\phi)$

$$Q_p = -\frac{\pi\, D\, H^3\, sin^2(\phi)}{12\,\mu} \cdot \frac{dP}{dL} \dashrightarrow (2.13)$$

2.4 Analysis of Flow in Extruder

The analysis of melt spinning:

a. Swell of the melt leaving the hole
b. Extrusion through short die
c. Extrusion along fiber axis
d. Rapid cooling

2.4.1. Swelling in extruded fiber:

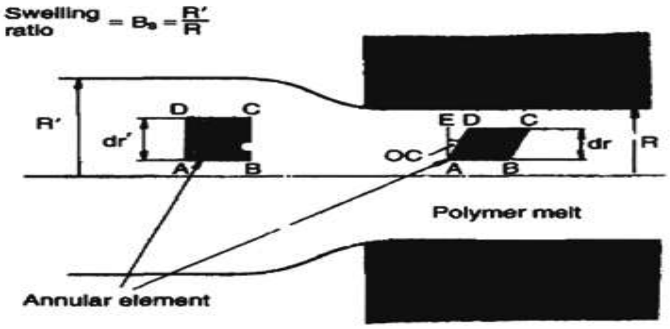
polymer melts can also exhibit elasticity. During flow they have the ability to store strain energy and when the stresses are removed, this strain is recoverable example of elastic recovery is post extrusion swelling. After extrusion the dimensions of the extrudate are larger than those of the die .In these circumstances some knowledge of the amount of swelling likely to occur is essential for die design. If the die is of a non-uniform section (tapered) then there will be recoverable tensile and shear strains. If the die has a uniform cross-section and is long in relation to its transverse dimensions then any tensile stresses which were set up at the die entry for example, normally relax out so that only the shear component contributes to the swelling at the die exit. If the die is very short (ideally of zero length) then no shear stresses will be set up and the swelling at the die exit will be the result of recoverable tensile strains only(Stevens and Covas, 2012)

To analyze the phenomenon of post extrusion swelling it is usual to define the swelling ratio, B, as :

$$\mathrm{B} = \frac{\text{Dimension of extrudate}}{\text{Dimension of die}}$$

2.4.2 Swelling Ratios Due to Shear Stresses:

I. Long Capillary Channel :



—

— Figure (2.18) Capillary Channel

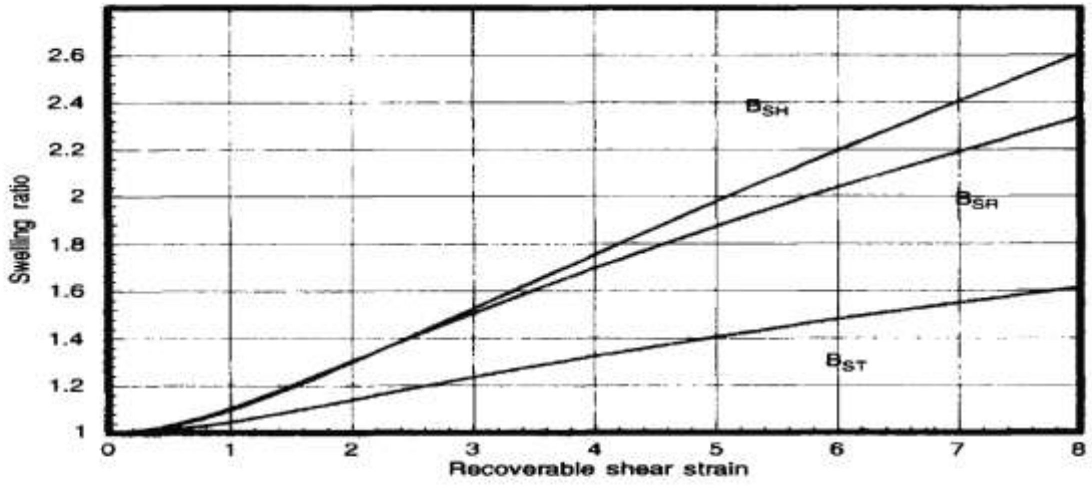
—

— $$B_{SR} = \left[\frac{2}{3}\gamma_R\{1+\gamma_R{}^{-2}\}^{\frac{3}{2}} - \gamma_R{}^{-3}\right]^{\frac{1}{2}} \longrightarrow \qquad (2.14)$$

Where:

— $\gamma_R =$ is the shear strain at the wall

— B_{SR} = Shear swelling in the Radial direction



Variation of Swelling Ratio for Capillary and Slit Dies

Figure (2.19) Variation of Swelling Ratio for Capillary and Slit Dies

Refer to the sketch

Take the origin of coordinates at the point of max^{m} swell

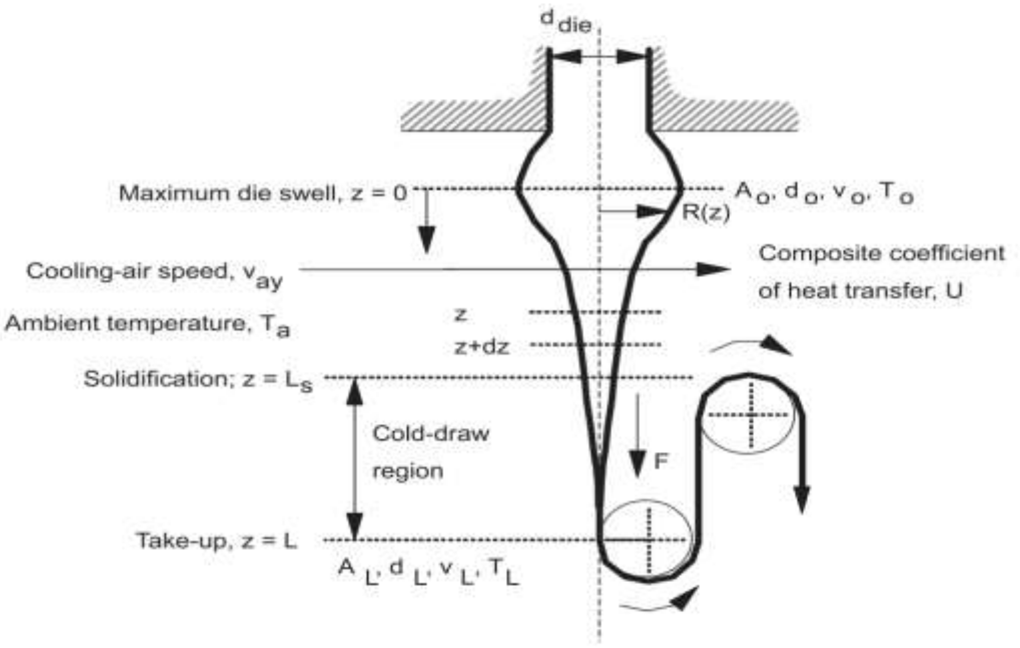


Figure (2.20) Analysis of melt spinning

For balance: Inertia force = Tensile force

For a differential element of height dz :

$$A\frac{d}{dz}\,(e\,v_z^2) = \frac{d}{dz}\,(\sigma.A)$$

But $\sigma = \lambda\dot{\varepsilon} \quad = \lambda\frac{dv_z}{dz} \qquad (\lambda - \ tensile\,viscosity)$

$$\sigma.A = \pi R^2\lambda\,\frac{dv_z}{dz}$$

$$\frac{d}{dz}(e\,v_z^2) = \frac{1}{\pi R^2}\frac{d}{dz}(\pi R^2\lambda\frac{dv_z}{dz})$$

$$2e\,v_z^2\,v_z' = \frac{\lambda}{R^2}\,[R^2 v_z'' + 2RR'v_z']$$

$$2e\,v_z^2\,v_z' = \lambda\,\left[v_z'' + 2(\frac{R'}{R})v_z'\right] \dashrightarrow (2.15)$$

The mass balance:

$$\dot{m} = e\,A\,v_z = e\,\pi R^2 v_z = \text{constant}$$

$$\therefore R^2 v_z = \text{constant}$$

Differentiate:

$$2RR'v_z + R^2 v_z' = 0$$

$$2RR'v_z = -R^2 v_z'$$

$$2\left(\frac{R'}{R}\right) = -\left(\frac{v_z'}{v_z}\right)$$

Substitute into equation (1)

$$2\text{e}\ v_z v_z' = \lambda \left[v_z'' + \frac{(v_z')^2}{v_z}\right]$$

$$v_z' = \frac{\lambda}{2\ e}\left[\frac{v_z v_z'' - (v_z')^2}{{v_z}^2}\right]$$

The left hand side is too small and can be neglected:

$$\left(\frac{v_z'}{v_z}\right) = 0$$

$$\frac{v_z'}{v_z} = c_1$$

$$\ln v_z = c_1 z + c_2$$

$$v_z = c_2 e^{c_1 z}$$

Boundary conditions:

@ z = 0 $v_z = v_0$

Z = L $v_z = v_L$

$\therefore c_2 = v_0$ => $v_z = v_0 e^{c_1 z}$

$v_L = v_0 e^{c_1 L}$ => $\frac{v_L}{v_0} = e^{c_1 z}$

$$\frac{v_L}{v_0} = \text{draw ratio } (\text{D}_\text{R})$$

$$\ln D_R = \text{c}_1\text{L} \quad => \text{c}_1 = \ln D_R$$

$$v_z = v_0\ e^{\frac{z}{l}\ln D_R} = v_0(e^{\ln D_R})^{\frac{z}{l}}$$

$$v_z = v_0 {D_R}^{\frac{z}{l}} \quad \longrightarrow (2.16)$$

The radius of filament is a function of axial distance z:

$$R^2 v_z = R_0^2\, v_0$$

$$R = R_0 (\frac{v_0}{v_z})^{\frac{1}{2}} \qquad \longrightarrow (2.17)$$

$$R = R_0 (\frac{v_0}{v_0 D_R^{\frac{z}{l}}})^{\frac{1}{2}}$$

$$R = \; R_0 D_R^{\frac{-z}{2l}}$$

Stretching rate $\dot{\varepsilon}$:

$$\dot{\varepsilon} = \frac{dv_z}{dz} = \frac{d}{dz}\left[v_0 e^{(\ln D_R)^{\frac{z}{l}}} \right]$$

$$= v_0 (\frac{\ln D_R}{L}) e^{(\ln D_R)^{\frac{z}{l}}}$$

The maximum stretching rate @ Z = L

$$\dot{\varepsilon}_{max} = v_0 \left(\frac{\ln D_R}{L}\right) e^{(\ln D_R)}$$

$$= v_0 \left(\frac{\ln D_R}{L}\right) D_R$$

$$= v_0 \frac{v_l}{v_0} \left(\frac{\ln D_R}{L}\right)$$

$$\dot{\varepsilon}_{max} = v_l \left(\frac{\ln D_R}{L}\right) - - \longrightarrow (2.18)$$

Tensile stress $\sigma = \lambda\, \dot{\varepsilon}_{max}$ λ- tensile viscosity

Usually $\lambda = 3\mu$ μ- shear viscosity

$$\sigma_{max} = \; \lambda\, \dot{\varepsilon}_{max}$$

$$= \lambda v_l \left(\frac{\ln D_R}{L}\right)$$

$$D_R = (\frac{R_0}{R_L})^2 \;\; - - \longrightarrow (2.19)$$

2.4.3 Cooling System:

To increase the productivity of the extrusion procses , it must be supplied with a cooling system so as to remove the heat transferred to it by the melted plastic . Generally water is used to cool the moulds ,but in some special cases air is used , in which a cooling system can not be applied, or when the plastic material is affected by quick water cooling. Cooling time is the time required for the part to be sufficiently cooled so that it can be leave cooling bath. In most polymer flow studies it is preferable to consider the efect of heat transfer between the melt and its surroundings. Some simple methods may be used for heat flow calculations ,one of them is fourier equation for non-steady heat flow.(Rosato, 2013)

$$\frac{\partial^2 T}{\partial r^2} = \frac{1}{\propto} \frac{\partial T}{\partial t} \longrightarrow \quad (2.20)$$

Where T is temperature and $\propto$ is thermal diffusivity defined as the thermal conductivity K to the heat capacity per unit volume

$$\propto = \frac{\mathrm{k}}{\rho C_p} \text{ ---------------------- } (2.21)$$

- Anumber of empirical relationships have also been proposed [10].Tow of the moreuseful equations take the form:

For cylndrical shape :

$$\text{Time, } t = \frac{4r^2}{\pi^2 \alpha} \ln\left(\frac{1.7}{.\Delta T}\right) \text{ ------------------------} \rightarrow (2.22)$$

Where:

t =is Cooling time

r = is the radius of the fiber .

2. temperature gradient**:**

$$\Delta T = \frac{T_t - T_m}{T_i - T_m} \text{ ----------------------------------} (2.23)$$

2.5 Modeling Tools and Software

Computer and its applications have entered various fields of applied sciences and engineering, for instance, Computer Aided Design (CAD) is being efficiently used for devices and equipment design, reducing the design calculations complexity in reliable manner. Regarding to plastic engineering, which deals with devices, equipment and plastic materials together, it uses in order to facilitate and accelerate the process of conducting engineering calculations. In This study used computer program namely MatLab and C# to write the code to develop a software system capable of performing complex design calculations of the single screw extruder. beside analysis of extrusion and spinning.(Lowther and Silvester, 2012)

2.5.1 C# Language:

Programming Language C# is a modern object-oriented, general-purpose programming language, created and developed by Microsoft together with the .NET platform. There is highly diverse software developed with C# and on the .NET platform: office applications, web applications, websites, desktop applications, mobile applications, games and many others. C# is a high-level language that is similar to Java and C++ and, to some extent, languages like Delphi, VB.NET and C. All C# programs are object-oriented. They consist of a set of definitions in classes that contain methods and the methods contain the program logic – the instructions which the computer executes. You will find out more details on what a class, a method and C# programs are in the next chapter. Nowadays C# is one of the most popular programming languages. It is used by millions of developers worldwide.(Odeh, 2019)

2.6 Previous Studies:

Funaki and other conducted a research on screw zones and geometry. Experimental analysis for extrusion screw geometry to produce highly transparent polypropylene sheets was investigated The observation was experimentally conducted by using many screws with various geometries to obtain a highly transparent polypropylene melt resin sheet. The pressure distribution in the extruder, melt temperature profile across melt flow, the extruder throughput and the specific energy consumption were monitored. The work obtained screw geometry optimization was conducted using the analysis of melting performance by the cooling experiment and the pressure pattern. As a result, the screw geometry to satisfy a low external haze and an extrusion stability under higher throughput conditions was designed.(Funaki et al., 2010)

[Farhoumand and Ebrahimi] was used finite element method to investigate the effect of process parameters of plastic deformation behavior in Forward-Backward-Radial Extrusion (FBRE) process. The result of an symmetric model shows that the friction between die components and the sample has a substantial effect on the material flow behavior. Although strain heterogeneity index (SHI) slightly decreases with an increase in friction, large portion of the sample experiences significant strain heterogeneity. Increasing the friction factor also localizes the strain heterogeneity effect in the backward section, and spread the effect in the forward section. The numerical simulation has a good agreement with the experimental results which confirms the accuracy of the proposed finite element.(Farhoumand and Ebrahimi, 2016).

[Abdel-Ghany and others] investigated the characteristics of single screw extruders and evaluate the performance of various types of screw under different working conditions using finite element analysis. Finite element analysis is used to master a technique to evaluate the radial displacement of the used screw, while analytical solution is used to clearly describe the polymer behavior affecting the proposed screw. The results show that the minimum displacement occurred at the metering zone, while the maximum displacement occurred at the feed zone moving to the compression zone for traditional screw.(Abdel-Ghany et al., 2015)

[Futal and other] used a statistical, design of experiments (DoE) approach. For a conventional screw design, barrel temperature, screw speed and two vastly different melt viscosity PP mixtures were selected as the independent factors, whilst melt pressure, mass output, screw torque and temperature rise at the die due to shear heating, were the dependent responses. A central composite design (CCD) in the framework of response surface methodology (RSM) was constructed, and an analysis of variance (ANOVA) was carried out to determine the significance of the response surface models. The resulting statistical and response surface predictions have demonstrated that the low viscosity component concentration in the blend is a dominating factor on melt pressure and screw torque. The data confirms that statistical tools make quantitative predictions for the effects of experimental process variables. (Fu et al., 2017)

[Zhou and other] Used POLYFLOW simulation plat form to model and analyzed the single screw extrusion process of propellant through the application of Finite Element Analysis on extrusion of plastic. The simulation shows that the risk at the screw edge is higher because of severe mixing and plasticizing process, and the viscous heating . Parameters under different speed conditions were studied as well, which provide guidance for the coordination of security and economy in production.(Zhou et al., 2014)

[Stimm and Dong] investigated the influence of process parameters to the melt spinning process a fiber model is used and coupled with CFD calculations of the quench air flow. In the fiber model energy, momentum and mass balance are solved for the polymer mass flow. To calculate the quench air the Lattice Boltzmann method is used. Simulations and experiments for different process parameters and whole configurations are compared and show a good agreement.(Stimm and Dong, 2001)

[Jia] analyzed the dynamics of melt spinning by establishing a set of simultaneous partial differential equations over a wide range of spinning conditions (Jia, 2010)

(Doufas and McHugh) Studied the temperature field subjected to an exponential stretching rate. The numerical analysis of melt spinning were also extended from isothermal Newtonian flow to viscoelastic fluid, non-isothermal Newtonian flow, non-isothermal viscoelastic flow and recently flow with crystallization(Doufas and McHugh, 2001)

CHAPTER THREE

Process Design and modeling Materials

CHAPTER THREE

Process Design and modeling Materials

3.1 Modeling Material:

Polypropylene (PP) is one of the most important thermoplastic materials, is used in all plastic processing methods such as injection molding, blow molding and extrusion molding, in PP fiber used materials are include specification(Jubinville et al., 2020). The table (3.1) shows the specifications of Polypropylene product supplied by Khartoum Petrochemical Company (KPC, Sudan), in powder with the following particulars:

Table (3.1) Specifications of Polypropylene KPC 113

Trade name	**KPC Polypropylene (PP 113)**
Density	910kg/m^3
Melting point	210°C
Heat diffusion	23.4J/kg
Medium temperature	30°C
Eject temperature	60°C
Thermal conductivity	0.172J/m.k
Thermal diffusely	10^{-7}
Critical Draw Ratio (D_R)	3 – 5
Mass Flow Rat	65kg/h
Temperature of heating bath	80°C
Shear modulus (G)	5x10^4 N/m^2
Glass transition temperature	-80°C
Elastic modulus at room temp.	1.5 GN/m^2
Materials constant C_1	17.4
Materials constant C_2	51.6

3.2 Modeling Methods:

Most of the lines that produce fibers for rope manufacturing has the capacity of 65kg/h. Used this as the basis of the design to analyze the flow of the PP melt in order to specify the design features of the extruder the extruder diameter and its length. Used different design equations of the extruder specify the three zones feeding. Melting and metering zone for each zone fight high is determined in addition to the required heating at melting zone the length of each zone is determined. Used different design equations of the spinneret to analyze the swelling that occurs for the extruded fibers and cooling process and then analyzed the following processes of heating and tensile drawing of fiber to obtain the required diameter for the use of ropes. Designing a model to solve the parameters for any given process.

3.2.1. Manual Calculations Methods.

Analytical calculations for single screw and spinneret was made as folows:

3.2.1.1 High flight in Compression zone (H):

High flight of Compression zone was determine using equation (3.1) as shown below:

$$H = 0.6\, d \sqrt[3]{n} \quad ------(3.1)$$

Where:

H = High flight of metering zone

n = number of holes

d = die diameter

3.2.1.2 Screw Diameter(D):

screw diameter is determined using equation (3.2) as shown below :

$$D = \sqrt{\frac{3\dot{m}}{\pi^2\ \rho_s NHSin(\emptyset)Cos(\emptyset)}} \quad \text{-------------}\ \ (3.2).$$

Where:

D = Screw diameter.

$\dot{m}$ = mass flow rate.

H = High flight of metering zone.

$\emptyset$ = flight angle.

N = Screw speed rotating.

ρ_s = Solid Density.

3.2.1.3 Length of Compression zone:

The length of compression zone is determined using equation (3.3) as show below:

$$\mathrm{L}_{\boldsymbol{C}} = \frac{0.9\ \dot{m}\ \Delta h_f\ \delta\ Ln\left[\frac{T - T_r}{T - T_t}\right]}{\pi DK[T_t - T_m]} \dashrightarrow (\mathbf{3.3})$$

3.2.1.4 Number flight of compression zone:

Number flight of compression zone is determined using equation (3.4) as show below

$$\mathrm{n}_{\boldsymbol{C}} = \frac{0.9\ \dot{m}\ \Delta h_f\ \delta\ Ln\left[\frac{T - T_m}{T - T_t}\right]}{\pi K\ D^2\ [T_t - T_m]} - -\!\!\rightarrow (\mathbf{3.4})$$

3.2.1.5 Number flight of Feed zone:

Number flight of feed zone is determined using equation (3.5) as show below:

$$\mathrm{n}_{\boldsymbol{f}} = \frac{0.45\,\dot{m}\,\Delta h_f\,\delta\,Ln\left[\frac{T-T_m}{T-T_t}\right]}{\pi K\,D^2\,[T_t-T_m]} --(\mathbf{3.5})$$

3.2.1.6 Number flight of metering zone ($\mathrm{n}_{\boldsymbol{m}}$) :

Number flight of metering zone is determined using equation (3.6) as show below:

$$\mathrm{n}_{\boldsymbol{m}} = \frac{0.45\,\dot{m}\,\Delta h_f\,\delta\,Ln\left[\frac{T-T_m}{T-T_t}\right]}{\pi K\,D^2\,[T_t-T_m]} -\!\!\rightarrow (\mathbf{3.6})$$

3.2.1.7 Swelling ratio in extruded fiber (B_{SR}):

Swelling in ratio of extruded fiber is determined using equation (3.7) as shown below:

$$B_{SR} = \sqrt{\left[\frac{16\dot{m}\mu}{5\pi\rho_s GR^3}\right]\left(1+\left[\frac{0.83\pi\rho_s GR^3}{4\dot{m}\mu}\right]^2\right)^{\frac{3}{2}} - \left[\frac{0.83\pi GR^3}{4\dot{m}\mu}\right]^3} -\!\!\rightarrow (3.7)$$

Where

B_{SR} = Swelling Ratio

Q = Volume flow rate

R = hole radius

G = Shear Modulus

μ = shear viscosity

3.2.1.8 Draw Ratio (DR):

Draw ratio of the fiber is determined using equation (3.8) as shown below:

$$D_R = \left[\frac{R \times B_{SR}}{R_L}\right] \dashrightarrow (3.8)$$

Where:

D_R = draw ratio

R = hole of die radius

R_f = fiber radius

3.2.1.9. Radius of fiber before drawing (RFBD)(R_L):

Radius of fiber before drawing is determined using equation (3.9) as shown below:

$$\boldsymbol{R_L} = \frac{R \times B_{SR}}{\mathbf{2}} \dashrightarrow (3.9)$$

3.21.10 Drawing velocity of the fiber (V_L):

Drawing velocity is determined using equation (3.10) as shown below:

$$V_L = \frac{4.8\dot{m}D_m}{\pi n d^2 \rho_s} \dashrightarrow (3.10)$$

Where:

$\dot{m}$ = mass flow rate

D_m = drawing of the melt

ρ_s = PP Solid density

d = hole of the die diameter

V_L = drawing velocity

3.2.1.11 Cooling Bath length(CBL):

Cooling bath length is determined using equation (3.11) as shown below:

$$L_c = \frac{1.7V_L{R_L}^2Ln\left[\frac{[1.7(T_i - T_{mc})]}{T_f - T_m}\right]}{\pi^2\alpha} - -\rightarrow (3.11)$$

Where:

T_i = melt temperature.

T_{mc} = medium cooling temperature.

T_f = temperature of fiber at leaving cooling bath.

α = thermal diffusely of Polymer

3.2.1.12. Force required to draw the melt (FRTDM) F:

Force required to draw the melt is determined using equation (3.12) as shown below:

$$F = \frac{3\pi\bar{n}\,\mu{R_L}^2V_LLn\,D_m}{L_c} - -\rightarrow (3.12)$$

Where:

F = force required to draw the melt

L_{cbl} = cooling bathe length

$\bar{n}$ = number of hole in the die

3.2.1.13 Heating Bath Length (HBL) L_h :

Cooling bath length is determined using equation (3.13) as shown below:

$$L_h = \frac{1.7 V_L {R_L}^2 Ln\left[\frac{[1.7(T_i - T_{mh})]}{T_f - T_m}\right]}{\pi^2 \alpha} --\rightarrow (3.13)$$

Where:

T_i = initial temperature

T_{mh} = medium of heating temperature

T_f = final temperature of the solid fiber

3.2.1.14 Force required to draw the Solid fiber (FRDSF) F_s:

Force required to draw the solid fiber is determined using equation (3.14) as shown below:

$$F_s = \frac{\pi n(R_L - R_f\ )E_r {R_f}^2}{v R_L} \times 10^{\left[\frac{17.4(T_r - T_g)}{51.6 + (T_r - T_g)} - \frac{17.4(T_h - T_g)}{51.6 + (T_h + T_g)}\right]}$$

Where:

F_s = Force required to draw the Solid fiber

T_r = polymer at room temperature

T_g = polymer glass temperature

C_1 , C_2 = Carriu constant

E_r = elastic modulus of polymer at room temperature

v = poison’s ratio

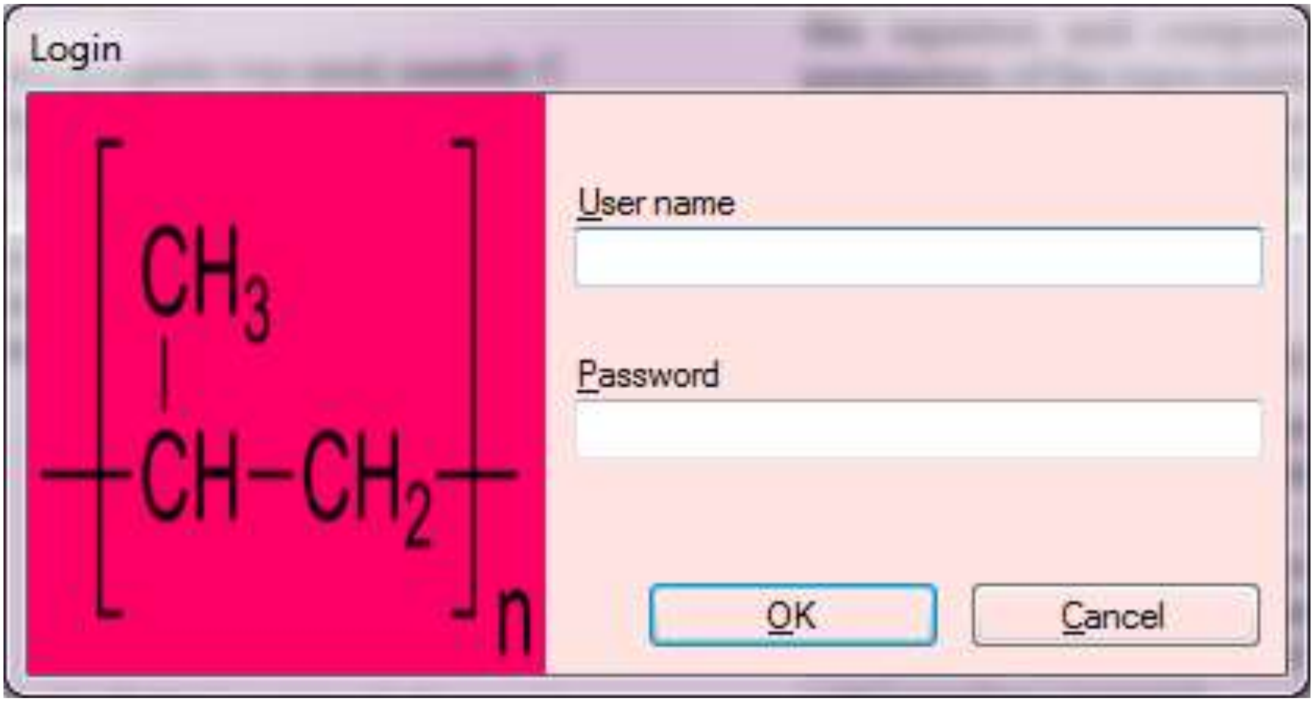
3.2.2 Modeling Calculations methods:

A computer program is prepared to accomplish all the task that need to specify the design of the line to produce the polypropylene fibers. The user of the program is requested to specify the dimension of the fibers and production capacity of the line.

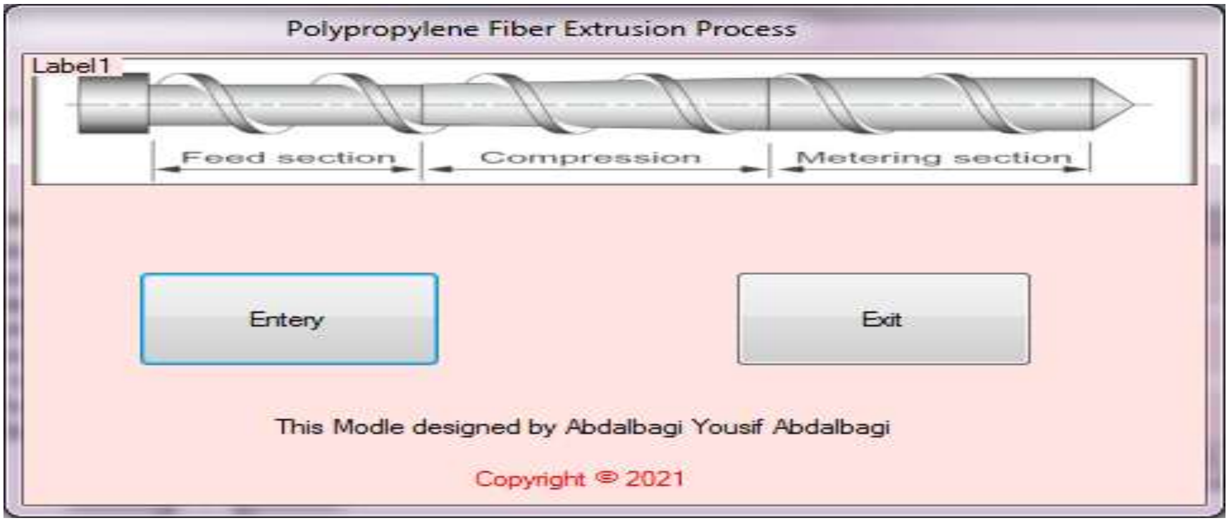
The user should input the plastic materials basic properties or to select from the materials already listed in the program. The result of this study is used in the program to find the design parameters of the extrusion and process condition in each stage the processing line.

A system model is designed to simulate a polypropylene fiber extrusion process; the system consists of screens as shown in the following figures:

1. The login screen contains the user name and password



2. Main screen contains allows for entry data input and output tasks



This Modle designed by Abdalbagi Yousif Abdalbagi

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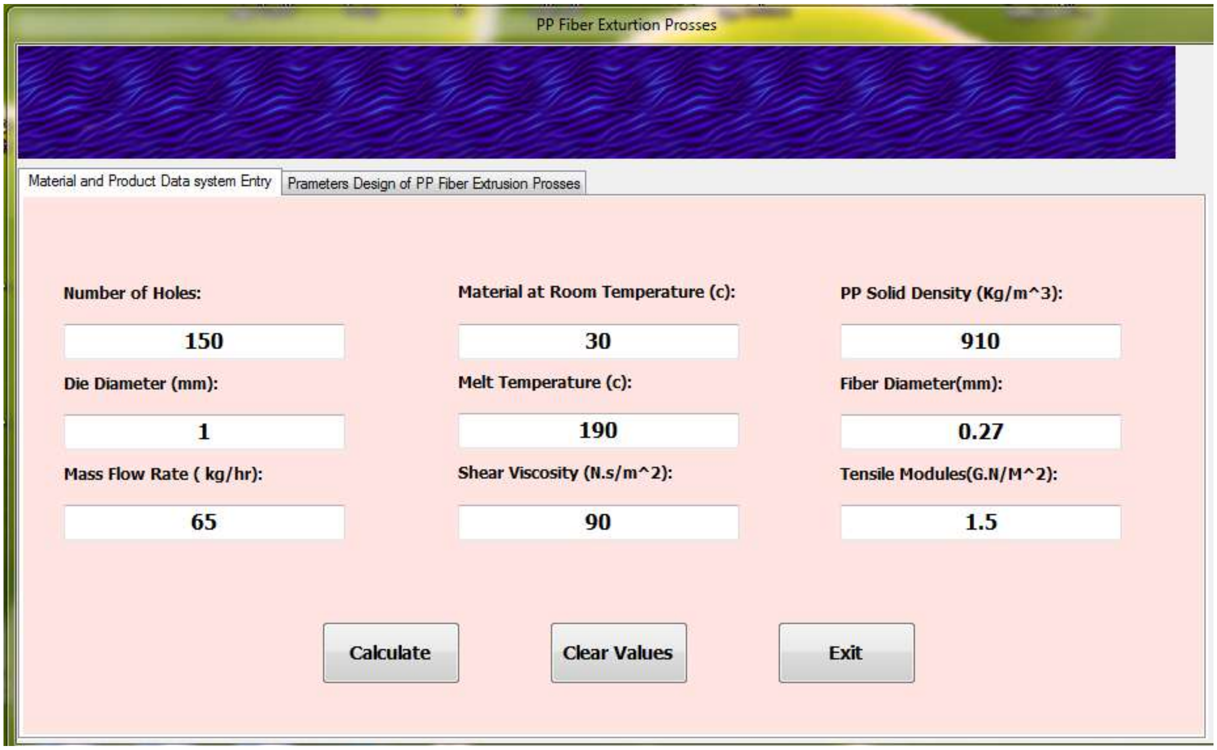
3. Input task contains the materials properties and product demission required



Number of Holes: 150

Die Diameter (mm): 1

Mass Flow Rate (kg/hr): 65

Material at Room Temperature (c): 30

Melt Temperature (c): 190

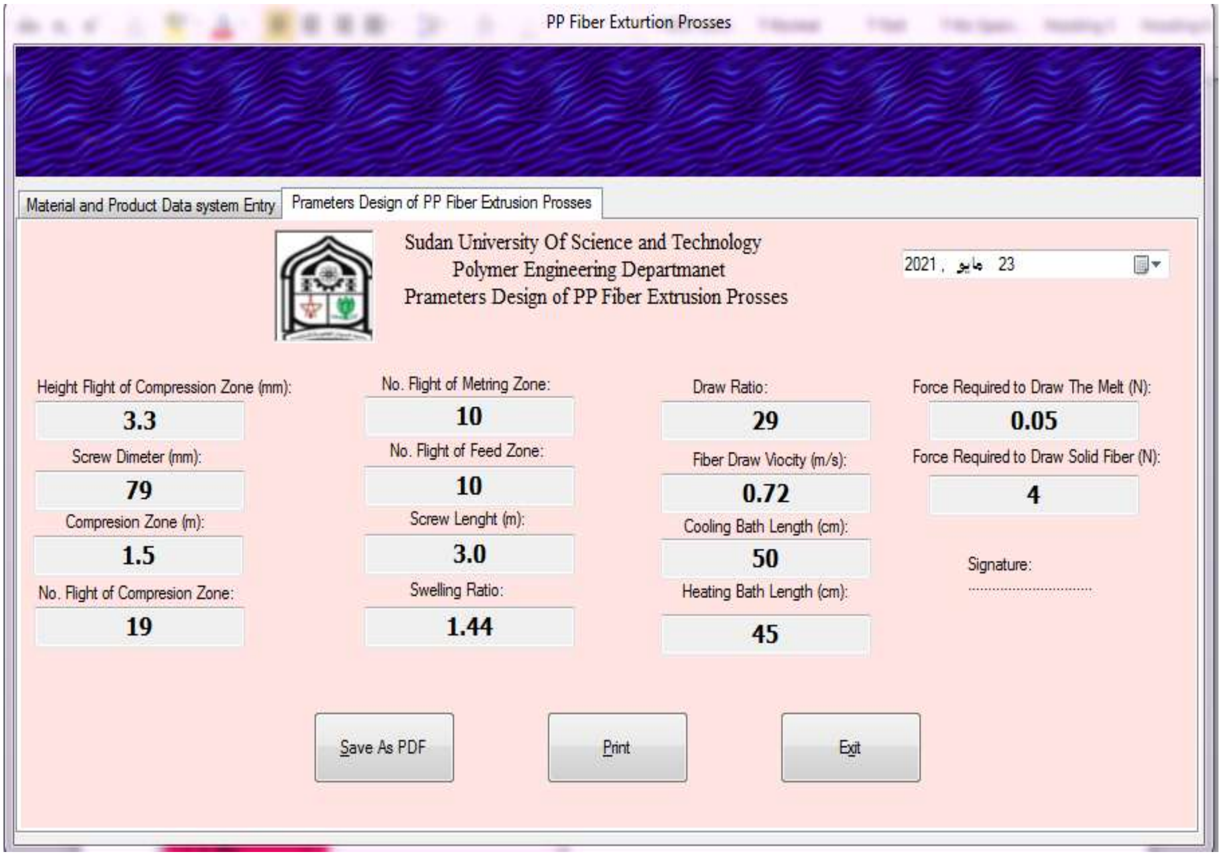
Shear Viscosity (N.s/m^2): 90

PP Solid Density (Kg/m^3): 910

Fiber Diameter(mm): 0.27

Tensile Modules(G.N/M^2): 1.5

4. output task contains design parameters of the extrusion and process condition



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Polymer Engineering Departmanet
Prameters Design of PP Fiber Extrusion Prosses

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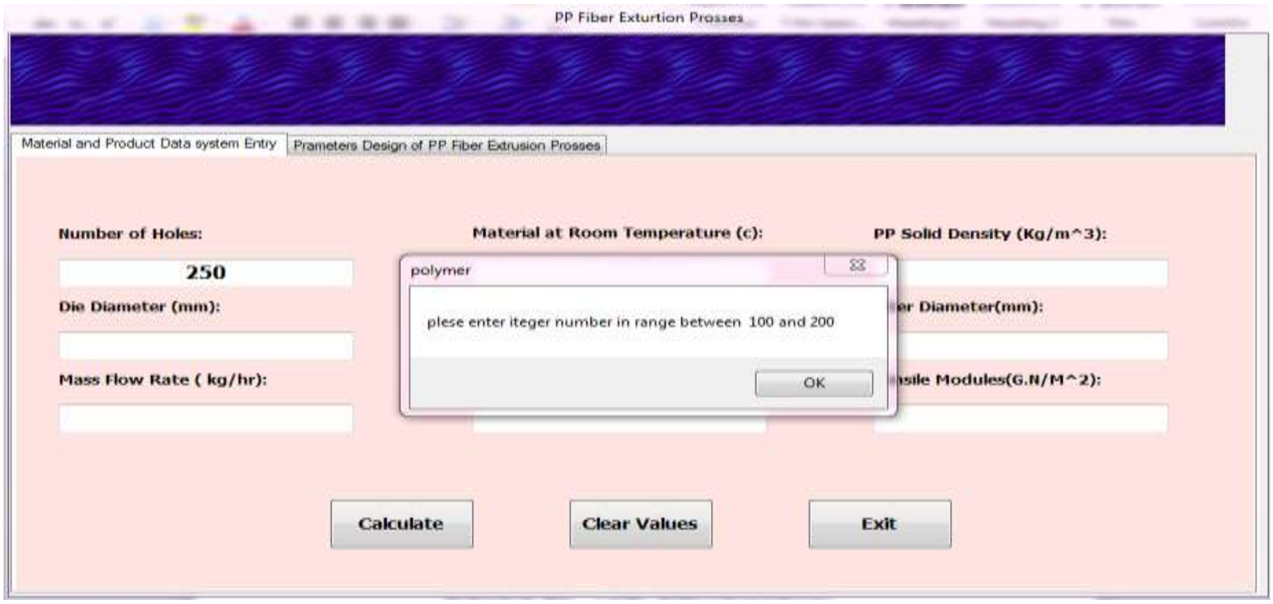
Height Flight of Compression Zone (mm): 3.3
Screw Dimeter (mm): 79
Compresion Zone (m): 1.5
No. Flight of Compresion Zone: 19
No. Flight of Metring Zone: 10
No. Flight of Feed Zone: 10
Screw Lenght (m): 3.0
Swelling Ratio: 1.44
Draw Ratio: 29
Fiber Draw Viocity (m/s): 0.72
Cooling Bath Length (cm): 50
Heating Bath Length (cm): 45
Force Required to Draw The Melt (N): 0.05
Force Required to Draw Solid Fiber (N): 4
Signature: ....

3.2.3 .Model design:

The design of the code was based on validating the design equations for the design of the process of manufacturing the polypropylene fibers used in the manufacture of ropes, so that all inputs have specified a certain range for the value of each input so that they are suitable for the manufacturing process.

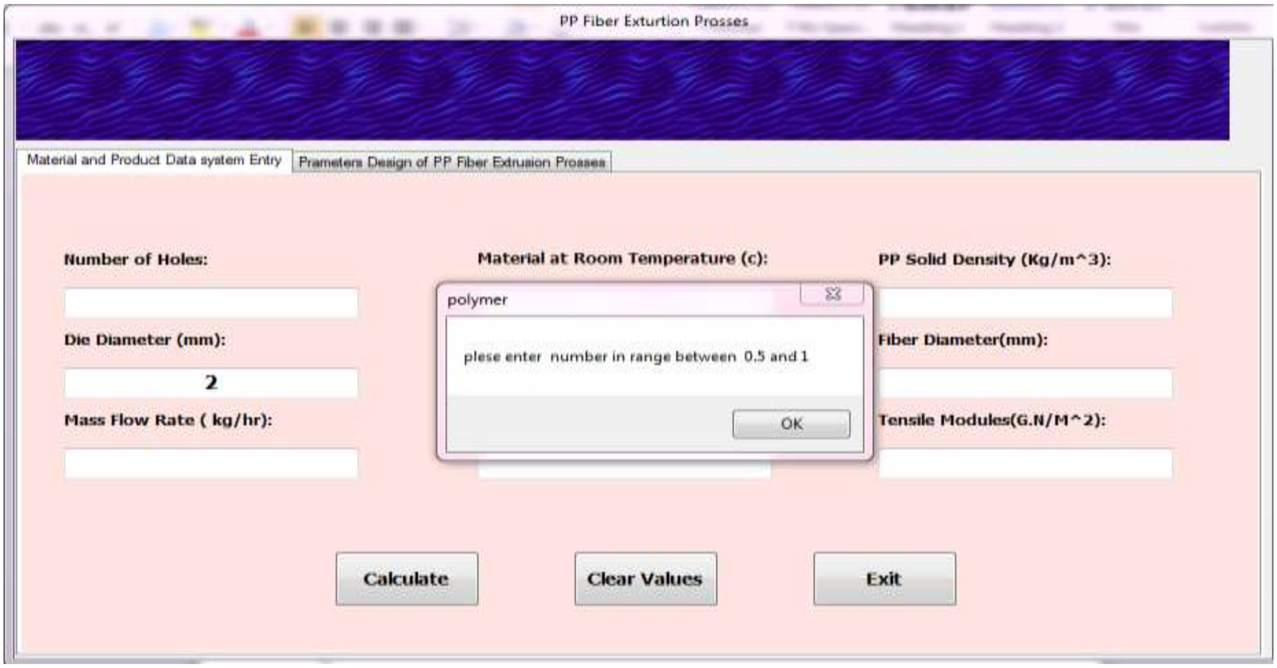
1. Number of holes between 100 and 200 holes Any value outside this range, a message appears as shown in the following figure:



Number of Holes: 250

plese enter iteger number in range between 100 and 200

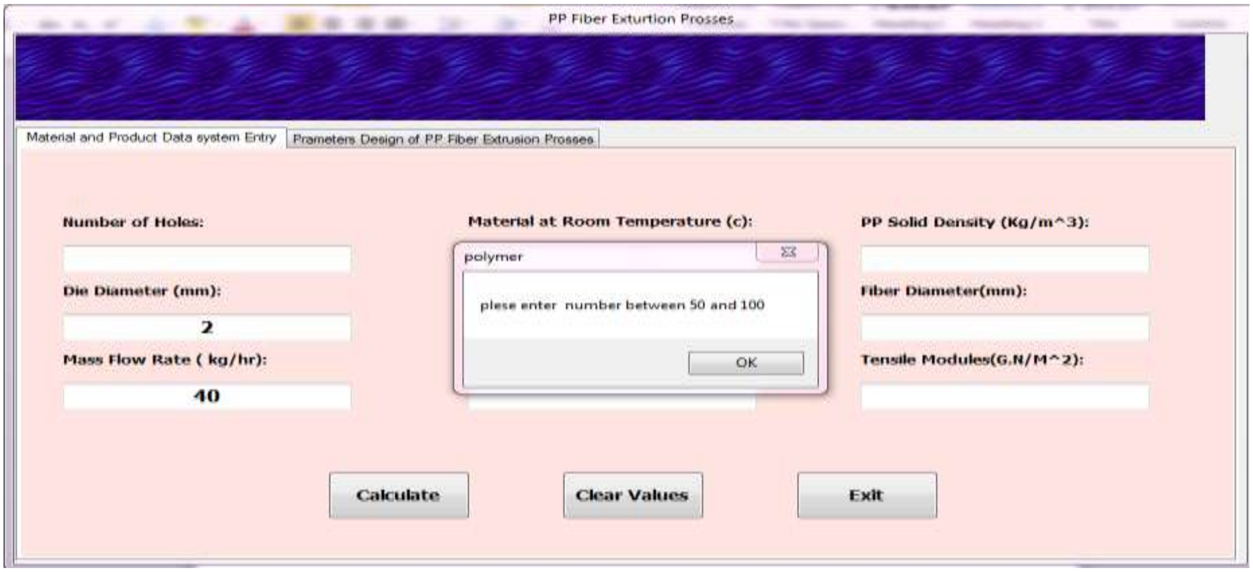
2. Specific range of Die Diameter between 0.5 and 1mm Any value outside this range, a message appears as shown in the following figure:



Die Diameter (mm): 2

plese enter number in range between 0.5 and 1

3. Specific range of Mass flow rate between 50 to 100kg/h Any value outside this range, a message appears as shown in the following figure:

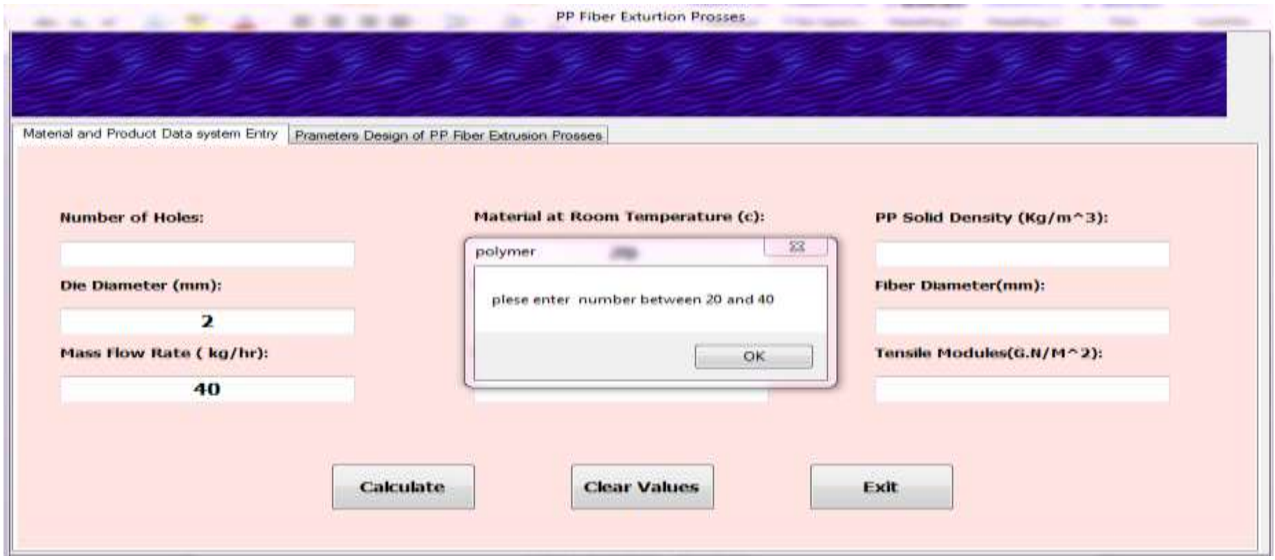


Die Diameter (mm): 2

Mass Flow Rate (kg/hr): 40

plese enter number between 50 and 100

4. Specific range of material room temperature between 20 ^{o}C to 40 ^{o}C, Any value outside this range, a message appears as shown in the following figure:

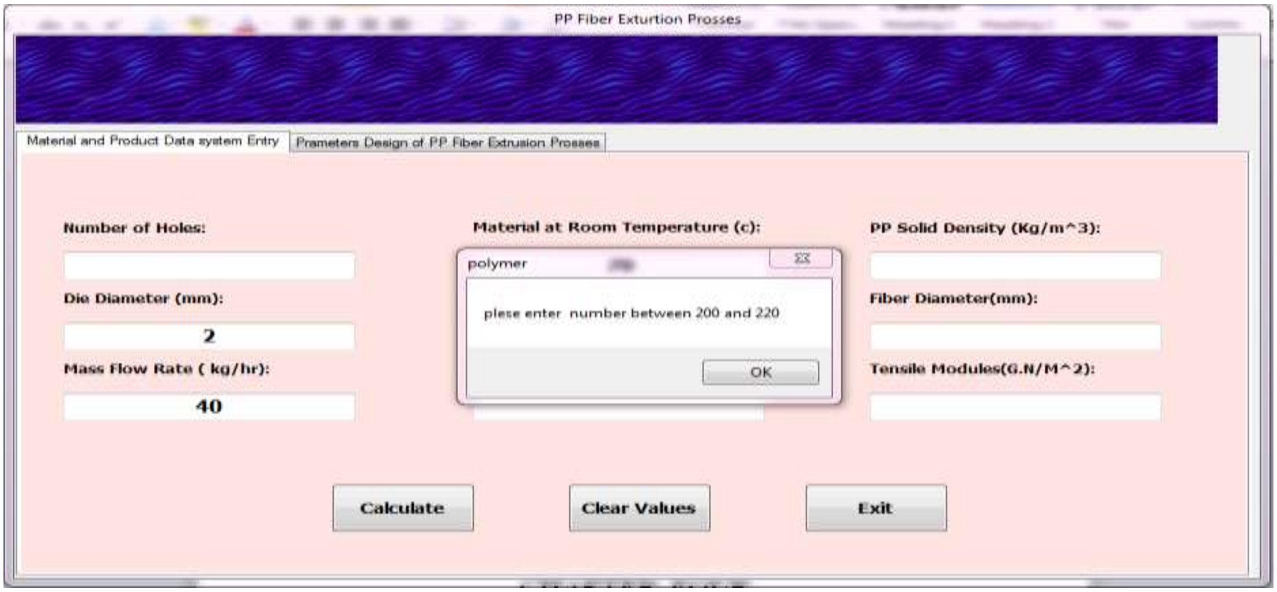


Die Diameter (mm): 2

Mass Flow Rate (kg/hr): 40

plese enter number between 20 and 40

5. Specific range of Melt temperature   between 200 ^{o}C to 220 ^{o}C, Any value outside this range, a message appears as shown in the following figure:



Number of Holes:

Die Diameter (mm): 2

Mass Flow Rate (kg/hr): 40

Material at Room Temperature (c):

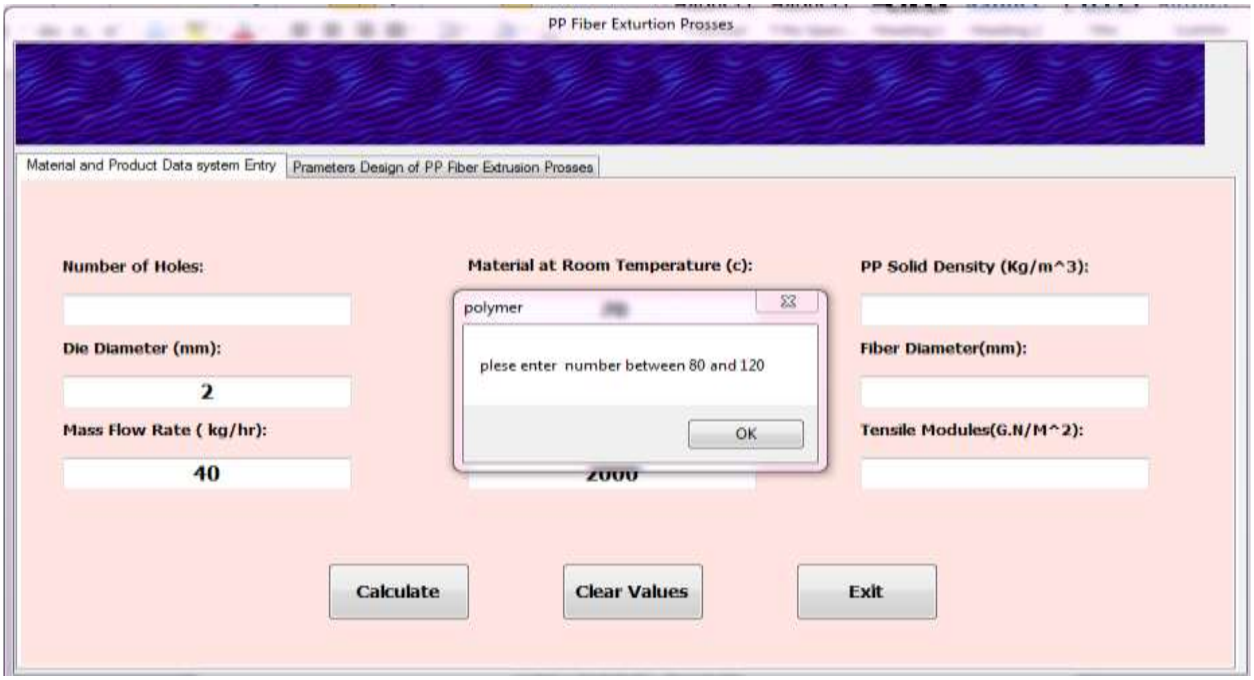
PP Solid Density (Kg/m^3):

Fiber Diameter(mm):

Tensile Modules(G.N/M^2):

plese enter number between 200 and 220

6. Specific range of Shear viscosity between 80 to 120 pa.s, any value outside this range, a message appears as shown in the following figure:



Number of Holes:

Die Diameter (mm): 2

Mass Flow Rate (kg/hr): 40

Material at Room Temperature (c): 2000

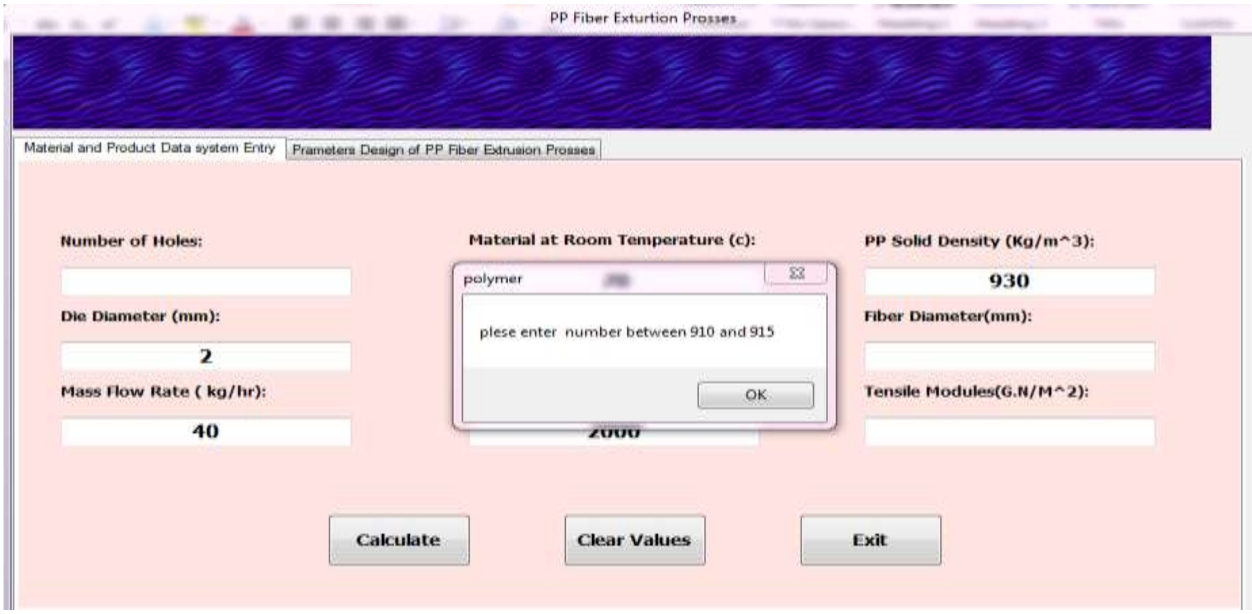
PP Solid Density (Kg/m^3):

Fiber Diameter(mm):

Tensile Modules(G.N/M^2):

plese enter number between 80 and 120

7. Specific range of PP Solid density between 910 to 915 kg/m^3 Any value outside this range, a message appears as shown in the following figure:



Number of Holes:

Die Diameter (mm): 2

Mass Flow Rate (kg/hr): 40

Material at Room Temperature (c): 2000

PP Solid Density (Kg/m^3): 930

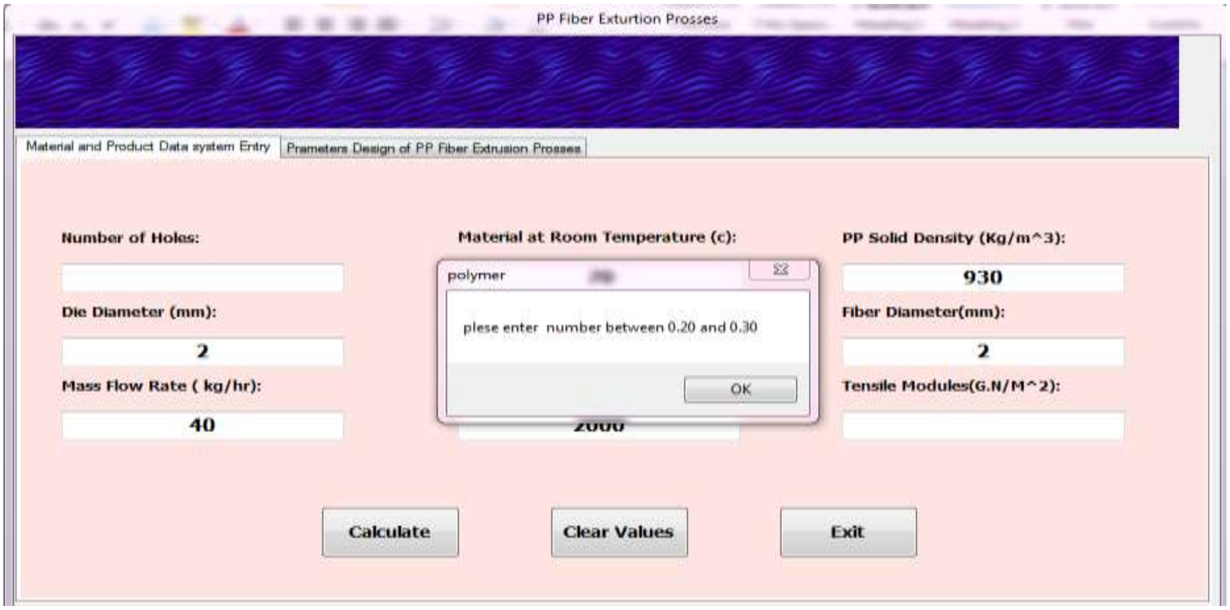
Fiber Diameter(mm):

Tensile Modules(G.N/M^2):

polymer

plese enter number between 910 and 915

8. Specific range of Fiber diameter between 0.2 - 0.3 mm Any value outside this range, a message appears as shown in the following figure:



Number of Holes:

Die Diameter (mm): 2

Mass Flow Rate (kg/hr): 40

Material at Room Temperature (c): 2000

PP Solid Density (Kg/m^3): 930

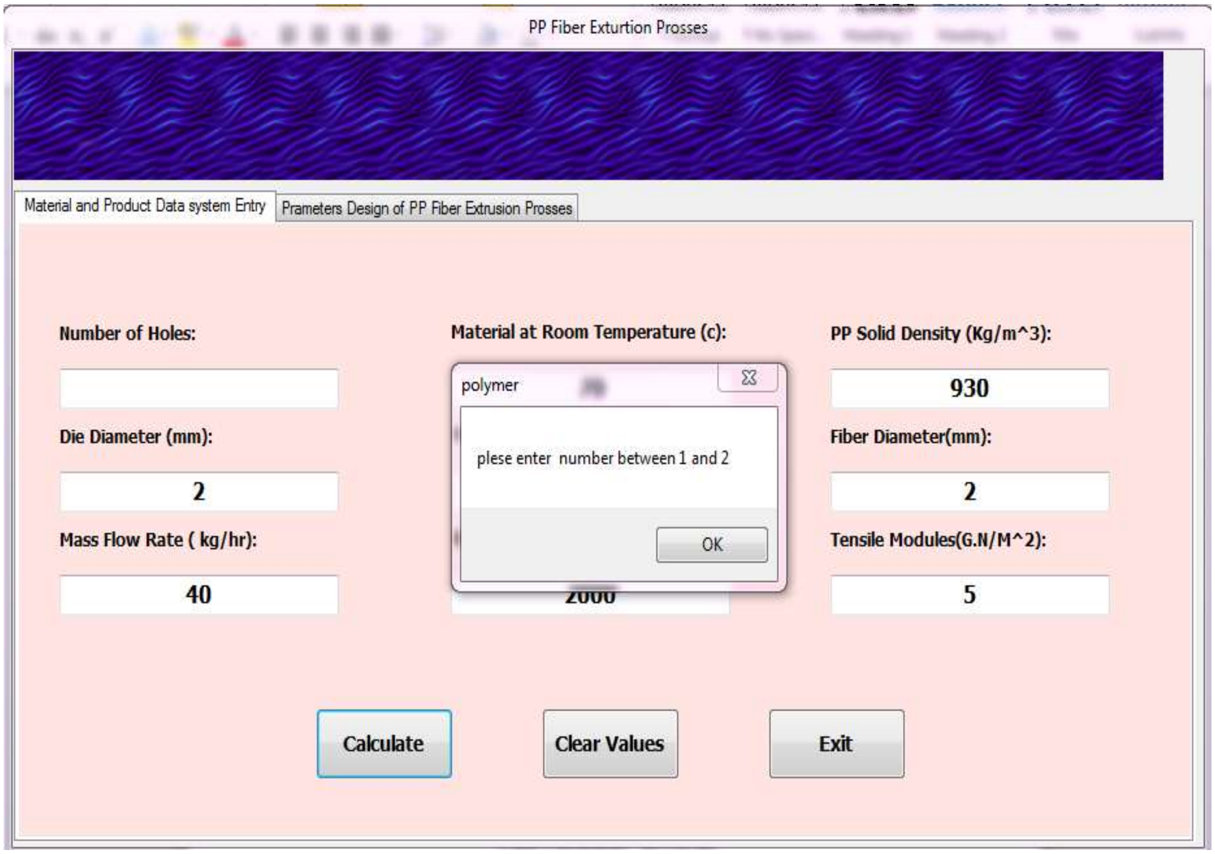
Fiber Diameter(mm): 2

Tensile Modules(G.N/M^2):

polymer

plese enter number between 0.20 and 0.30

9. Specific range of Tensile modulus between 1.5 to2 N/m^2 Any value outside this range, a message appears as shown in the following figure:



Number of Holes:

Die Diameter (mm): 2

Mass Flow Rate (kg/hr): 40

Material at Room Temperature (c):

2000

PP Solid Density (Kg/m^3): 930

Fiber Diameter(mm): 2

Tensile Modules(G.N/M^2): 5

polymer

plese enter number between 1 and 2

OK

CHAPTER FOUR

RESULTS AND DISCUSSION

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Results

4.1.1. The high flight of compression zone was calculated using equation (3.1), the results of the inputs parameters, manual and modeling calculations are as shown in table (4.1) below:

Table (4.1): high flight of compression zone

Parameters Inputs	Unit	Value
Die diameter(d)	mm	1
Number of holes(n)	-	168
Manual calculations	**mm**	**3.2**
Modeling calculations	**mm**	**3.3**

4.1.2 The Screw Diameter was calculated using equation (3.2)), the results of the inputs parameters, manual and modeling calculations are as shown in table (4.2) below:

Table (4.2): Screw Diameter

Parameters	Unit	Value
Mass flow rate $(\dot{m})$	kg/h	65
Solid density (ρ_S)	kg/m^3	910
Screw speed (N)	rev/s	1
Flight angle $(\emptyset)$	°	17.7
High Flight (H)	mm	3.2
Manual calculations	**mm**	**80**
Modeling calculations	**mm**	**79**

4.1.3 Compression zone length was calculated using equation using equation (3.3), the results of the inputs parameters, manual and modeling calculations are as shown in table (4.3) below:

Table (4.3): Compression zone length

Parameters	Unit	Value
Mass flow rate ($\dot{m}$)	kg/h	65
heat of fusion	J/kg	23.4×10^4
Thermal Conductivity.	J/ms^2k	0.172
Melt Temperature.	C^0	210
Medium Temperature.	C^0	30
Temperature of melt leaves melting zone	C^0	190
Screw Diameter	mm	80
Melt adjacent film	mm	1
Manual calculations	**m**	**1.2**
Modeling calculations	**m**	**1.2**

4.1.4 Number of compression zone was calculated using equation (3.4)), the results of the inputs parameters, manual and modeling calculations are as shown in table (4.4) below:

Table (4.4): Number of compression zone

Parameters	Unit	Value
Mass flow rate	kg/h	65
heat of fusion	J/kg	23.4×10^4
Thermal Conductivity.	J/ms^2k	0.172
Melt Temperature.	C^0	210
Medium Temperature.	C^0	30
Temperature of melt leaves melting zone	C^0	190
Screw Diameter	mm	80
Melt adjacent film	mm	1
Manual calculations	**-**	**7**
Modeling calculations	**-**	**8**

4.1.5 Number flight of feed zone was calculate d using equation (3.5), the results of the inputs parameters, manual and modeling calculations are as shown in table (4.5) below:

Table (4.5): Number flight of feed zone

Parameters	Unit	Value
Mass flow rate	kg/h	65
heat of fusion	J/kg	23.4×10^4
Thermal Conductivity.	J/ms^2k	0.172
Melt Temperature.	℃	210
Medium Temperature.	℃	30
Temperature of melt leaves melting zone	℃	190
Screw Diameter	mm	80
Melt adjacent film	mm	1
Manual calculations	**-**	**7**
Modeling calculations	**-**	**8**

4.1.6 Number flight of metering zone was calculated using equation (3.6) the results of the inputs parameters, manual and modeling calculations are as shown in table (4.6) below:

Table (4.6): Number flight of metering zone

Parameters	Unit	Value
Mass flow rate	kg/h	65
heat of fusion(Δh_f)	J/kg	23.4×10^4
Thermal Conductivity(K).	J/ms^2k	0.172
Melt Temperature.	℃	210
Medium Temperature.	℃	30
Temperature of melt leaves melting zone	℃	190
Screw Diameter	mm	80
Melt adjacent film	mm	1
Manual calculations	**-**	**15**
Modeling calculations	**-**	**16**

4.1.7 Swelling ratio in extruded fiber was Calculated using equation (3.7) the results of the inputs parameters, manual and modeling calculations are as shown in table (4.6) below:

Table (4.7): Swelling ratio in extruded fiber

Parameters input	Unit	Value
Mass flow rate ($\dot{m}$)	Kg/h	65
PP Solid density (ρ_s)	Kg/m^3	910
Shear Viscosity (μ)	$N.s/m^2$	90
Shear modulus (G)	N/m^2	$5x10^4$
Number of holes (n)	-	168
Die radius (R_0)	mm	0.5
Manual calculations	**-**	**1.7**
Modeling calculations	**-**	**1.44**

4.1.8 Draw ratio was Calculated using equation (3.8) the results of the inputs parameters, manual and modeling calculations are as shown in table (4.8) below:

Table (4.8): Draw ratio

Parameters input	Unit	Value
Die radius (R_0)	mm	0.5
Swelling ratio B_{SR}	-	1.7
Fiber radius (R)	mm	0.135
Manual calculations		**39.6**
Modeling calculations		**29**

4.1.9 Drawing fiber velocity was Calculated using equation (3.9) the results of the inputs parameters, manual and modeling calculations are as shown in table (4.9) below:

Table (4.9): Drawing fiber velocity

Parameters input	Unit	Value
Mass flow rate ($\dot{m}$)	Kg/h	65
PP Solid density (ρ_s)	Kg/m^3	910
drawing of the melt (D_{D_m})	-	40
Die diameter (d)	mm	1
Number of holes (n)	-	168
Manual calculations	**m/s**	**0.73**
Modeling calculations	**m/s**	**0.72**

4.1.10 Cooling bath length was Calculated using equation (3.10) the results of the inputs parameters, manual and modeling calculations are as shown in table (4.10) below:

Table (4.10):(C.B.L) manual and modeling results

Parameters input	Unit	Value
medium cooling temperature	℃	30.0
temperature of fiber at leaving cooling bath	℃	60.0
melt temperature	℃	210
thermal diffusely of PP	-	10^{-7}
Radius fiber before drawing(R_L)	mm	0.425
Manual calculations	**cm**	**52**
Modeling calculations	**cm**	**50**

4.1.11 Force require to draw the melt was Calculated using equation (3.11) the results of the inputs parameters, manual and modeling calculations are as shown in table :(4.11) below:

Table (4.11): Force require to draw the melt

Input Parameters	Unit	Value
Radius fiber before drawing(R_L)	Mm	0.425
drawing of the melt (D_m)	-	4.00
Number of holes (n)	-	168
Shear viscosity (μ)	$N.s/m^2$	90.0
Draw velocity (V_L)	m/s	0.73
Manual calculations	**N**	**0.05**
Modeling calculations	**N**	**0.05**

4.1.12 Heating bath length was Calculated using equation (3.12) the results of the inputs parameters, manual and modeling calculations are as shown in table (4.12) below:

Table (4.12**)**: Heating Bath Length

Input Parameters	Unit	Value
medium heating temperature	℃	80
final temperature of the solid fiber	℃	70
initial fiber temperature	℃	40
thermal diffusely of PP	**-**	10^{-7}
Manual calculations	**cm**	**44**
Modeling calculations	**cm**	**45**

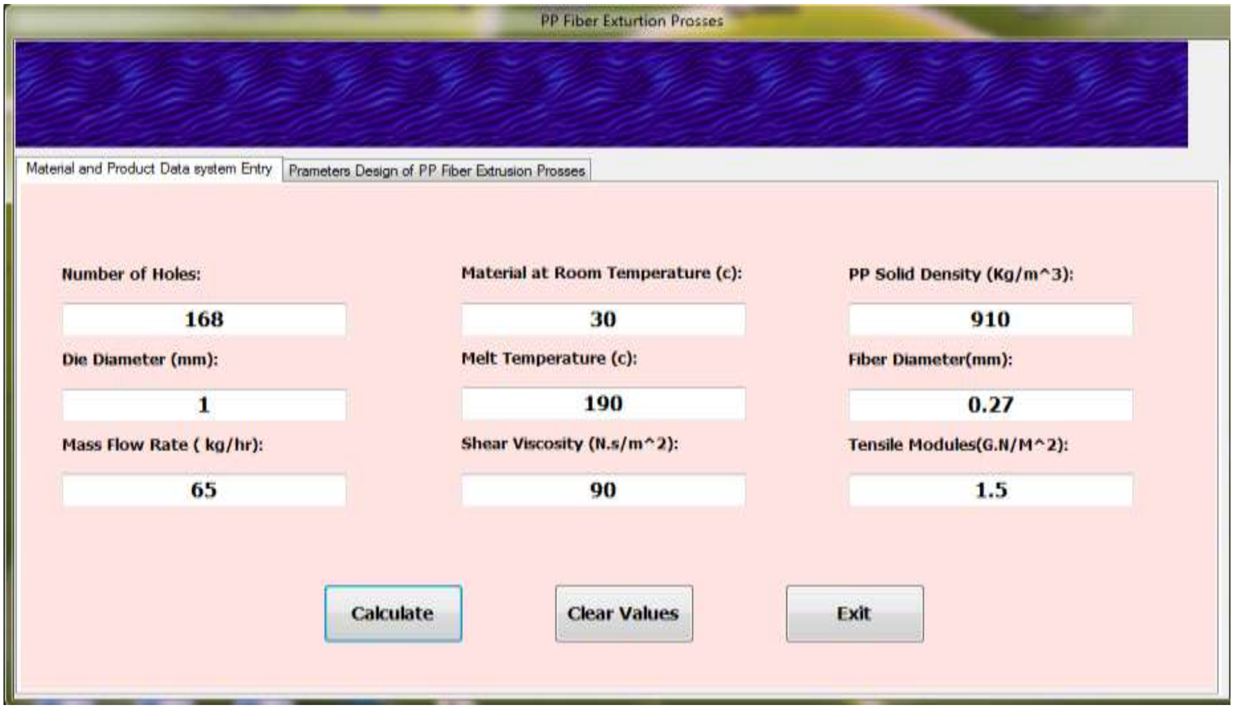
4.1.13 Force required to draw the solid fiber was Calculated using equation (3.13) the results of the inputs parameters, manual and modeling calculations are as shown in table(4.13)

Table (4.13): Force required to draw the solid fiber

Input Parameters	Unit	Value
Radius of solid fiber (R_f)	mm	0.135
Radius fiber before drawing(R_L)	mm	0.425
Poison’s ratio (v)	-	0.4.00
Glass transition temperature (T_g)	C^0	-10
PP at room temperature (T_r)	C^0	20
Temperature of Solid fiber ((T_s)	C^0	70
Manual calculations	**N**	**4**
Modeling calculations	**N**	**4**

4.2 Analytical calculations using the application:

The figures below show that values have been entered on the input screen to obtain different results.



Number of Holes: 168

Die Diameter (mm): 1

Mass Flow Rate (kg/hr): 65

Material at Room Temperature (c): 30

Melt Temperature (c): 190

Shear Viscosity (N.s/m^2): 90

PP Solid Density (Kg/m^3): 910

Fiber Diameter(mm): 0.27

Tensile Modules(G.N/M^2): 1.5

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Height Flight of Compression Zone (mm): 3.3
Screw Dimeter (mm): 79
Compresion Zone (m): 1.2
No. Flight of Compresion Zone: 15
No. Flight of Metring Zone: 8
No. Flight of Feed Zone: 8
Screw Lenght (m): 2.4
Swelling Ratio: 1.44
Draw Ratio: 29
Fiber Draw Viocity (m/s): 0.72
Cooling Bath Length (cm): 50
Heating Bath Length (cm): 45
Force Required to Draw The Melt (N): 0.05
Force Required to Draw Solid Fiber (N): 4

Signature: ....

4.3 Discussion

From the above tables (4.1 – 4.13) it is quite obvious that there are no significant differences between the manual and system calculations except in the case of the Draw ratio in the table (4.8) in which the manual calculation gives higher draw ratio compared to the system results. This proves the reliability of the designed system which can be relied on to safely calculate the needed parameters for any given extrusion process for pp ropes processing.

On the other hand, the speed of calculations after entering data is negligible compared to the long time needed to complete the calculations manually to get the process parameters.

Extruder and spinneret design most important in polypropylene fiber process for the determination of appropriate parameters for the process. The extruder analysis was depended on flow mechanism, considering the circular section most of the flow produced from extruder is drag flow and pressure flow. Some considerations to inherent melting and flow of the molten process were taken into account, such as the amount of heat required from the heaters and the resulting shear, the area to be heated, the heat transfer coefficient. This beside the use of the data on the physical, thermal, and rheological properties of polypropylene to determine the parameters: screw diameter, screw length, feed zone length, metering zone length, compression zone length, high flight of compression zone length, number flight of compression zone, number flight of feed zone and number flight of metering zone. For the determination of the final dimension of the fibers, some considerations such as Swelling ratio, heat transfer process at cooling and heating bath and tensile force. Therefore, the analysis made for the fibers extrusion process with the above mentioned considerations and relevant standard equations, assist in developing an authenticated application that gave real results. The application allows documenting the result as a pdf or printing it and compared with the real value of parameters of the ropes making manufacturing that was manufactured by trial, error and experience, and the same result was obtained. Mechanism of the modeling software included all these design equations.

CHAPTER FIVE

Conclusion and Recommendations

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Conclusion and Recommendations

5.1 Conclusion

Based on the problem of this study and the solutions proposed the following conclusions were derived:

- Equations were derived that helps designing any extrusion machine parameters.
- Software was developed to be used as a generic tool for obtaining the extrusion process parameters based on different conditions and designs.
- The produced system addressed directly the problems of machine designers and helped to reduce the cost, time and effort exerted in designing through monotonous trial and error techniques.
- The deigned software is suitable as a model was to assist the designer of polypropylene fiber manufacturing machines used in the manufacture of ropes, as it helps in solving the problems facing maintenance and operator’s engineers by determining the appropriate parameters according to the product dimensions and the specifications of the polypropylene material.
- Reliability and accuracy of the system were validated.

5.2 Recommendations

- Other forms of display of the results of the different design parameters, such as charts are to be added to the design of the system.
- Extending the application scope so that it can include other extrusion processes products such as pipes and sheets. Plus allow the user to choose freely from a list of products.
- Introducing the properties of polymeric materials within the application to facilitate the search for them.
- compare the resulted analytical data with prevailing data in the mill.

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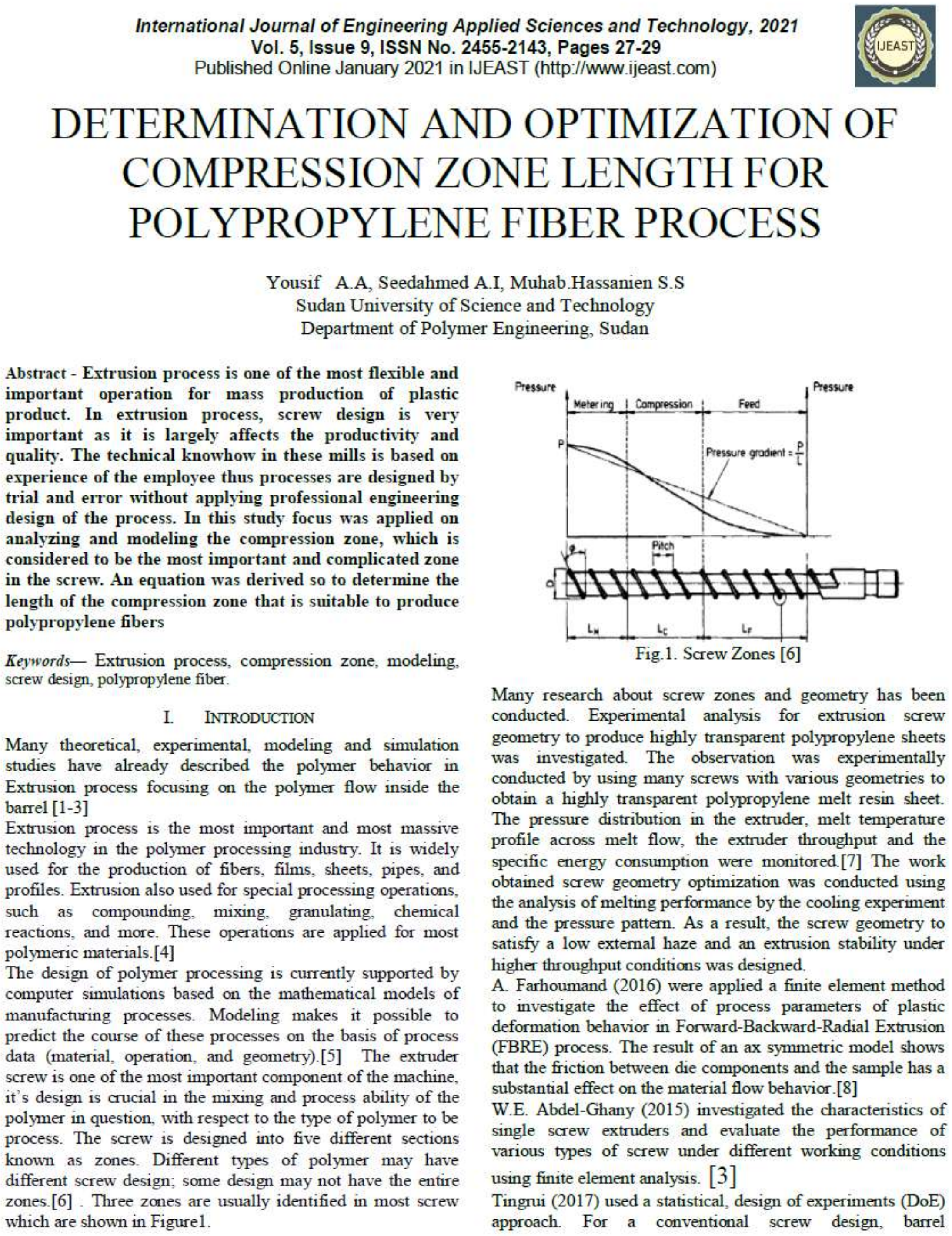
Appendix

Abstract of Publish Paper



International Journal of Engineering Applied Sciences and Technology, 2021
Vol. 5, Issue 9, ISSN No. 2455-2143, Pages 27-29

DETERMINATION AND OPTIMIZATION OF COMPRESSION ZONE LENGTH FOR POLYPROPYLENE FIBER PROCESS

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Abstract - **Extrusion process is one of the most flexible and important operation for mass production of plastic product. In extrusion process, screw design is very important as it is largely affects the productivity and quality. The technical knowhow in these mills is based on experience of the employee thus processes are designed by trial and error without applying professional engineering design of the process. In this study focus was applied on analyzing and modeling the compression zone, which is considered to be the most important and complicated zone in the screw. An equation was derived so to determine the length of the compression zone that is suitable to produce polypropylene fibers**

Keywords— Extrusion process, compression zone, modeling, screw design, polypropylene fiber.

I. INTRODUCTION

Many theoretical, experimental, modeling and simulation studies have already described the polymer behavior in Extrusion process focusing on the polymer flow inside the barrel [1-3]

Extrusion process is the most important and most massive technology in the polymer processing industry. It is widely used for the production of fibers, films, sheets, pipes, and profiles. Extrusion also used for special processing operations, such as compounding, mixing, granulating, chemical reactions, and more. These operations are applied for most polymeric materials.[4]

The design of polymer processing is currently supported by computer simulations based on the mathematical models of manufacturing processes. Modeling makes it possible to predict the course of these processes on the basis of process data (material, operation, and geometry).[5] The extruder screw is one of the most important component of the machine, it's design is crucial in the mixing and process ability of the polymer in question, with respect to the type of polymer to be process. The screw is designed into five different sections known as zones. Different types of polymer may have different screw design; some design may not have the entire zones.[6] . Three zones are usually identified in most screw which are shown in Figure1.

Fig.1. Screw Zones [6]

Many research about screw zones and geometry has been conducted. Experimental analysis for extrusion screw geometry to produce highly transparent polypropylene sheets was investigated. The observation was experimentally conducted by using many screws with various geometries to obtain a highly transparent polypropylene melt resin sheet. The pressure distribution in the extruder, melt temperature profile across melt flow, the extruder throughput and the specific energy consumption were monitored.[7] The work obtained screw geometry optimization was conducted using the analysis of melting performance by the cooling experiment and the pressure pattern. As a result, the screw geometry to satisfy a low external haze and an extrusion stability under higher throughput conditions was designed.

A. Farhoumand (2016) were applied a finite element method to investigate the effect of process parameters of plastic deformation behavior in Forward-Backward-Radial Extrusion (FBRE) process. The result of an ax symmetric model shows that the friction between die components and the sample has a substantial effect on the material flow behavior.[8]

W.E. Abdel-Ghany (2015) investigated the characteristics of single screw extruders and evaluate the performance of various types of screw under different working conditions using finite element analysis. [3]

Tingrui (2017) used a statistical, design of experiments (DoE) approach. For a conventional screw design, barrel

International Journal of Engineering Applied Sciences and Technology, 2021
Vol. 5, Issue 12, ISSN No. 2455-2143, Pages 317-321

MODELING AND ANALYSIS OF POLYPROPYLENE FIBER EXTRUSION PROCESS

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Abstract - **Extrusion processes are widely used in plastic industries that aim to produce advanced solutions for increasingly sophisticated demands for plastics. Processes are not designed based on professional engineering design process, but on trial and error techniques. These two factors affect the extrusion processing parameters. In this study focus will be concentrated on the parameters incorporated in Polypropylene rope extrusion process such as: screw length, screw diameter, metering zone length and flight depth. A model equations were derived considering the swelling occurs for the extruded fibers and the tensile drawing of fiber. The authenticated design parameters was derived and a model useful to simulate any given process successfully was resulted in a form of computer software system.**

Keywords— **extrusion, polypropylene fiber, Swelling Ratio, Modeling and Analysis.**

I. INTRODUCTION

For many years, polypropylene (PP) has been very successfully used for film blown, injection molded, and extrusion applications. [1] The interest in polypropylene(PP) is specifically due to the fact that the polymer is widely used as important engineering materials in the automotive, electrical appliances and packaging industries due to their excellent properties such as rigidity and stiffness, oil resistance and their thermal stability. [2]

Extruders are common devices in the plastic, metal, and food processing industries, and the utilization of extrusion processes is particularly widespread in product manufacturing that uses polymers as a raw material. Typical products made from extruded polymers includes, for example, pipes, hoses, insulated wires, cables, sheets, films, and tiles. [3-4]

Many theoretical, experimental, modeling and simulation studies have already described the polymer behavior in Extrusion process focusing on the polymer flow inside the barrel. [5]

Computer and its applications have entered various fields of applied sciences and engineering, for instance, Computer Aided Design (CAD) is being efficiently used for devices and equipment design, reducing the design calculations complexity in reliable manner. Regarding to polymers engineering, which deals with devices, equipment and polymer materials together, it uses in order to facilitate and accelerate the process of conducting engineering calculations. [6]

The design of polymer processing is currently supported by computer simulations based on the mathematical models of manufacturing processes. Modeling makes it possible to predict the course of these processes on the basis of process data (material, operation, and geometry). Modeling and simulation of polymer melt to produce fibers which are then used in ropes is a subject of this dissertation. The objective of this work to analyze the factors that affect the process in each step in the manufacturing sequence. [3]

Many research about screw design has been conducted. Experimental analysis for extrusion screw design to produce polypropylene fibers was investigated. The observation was experimentally conducted by using many screws with various geometries to obtain a highly transparent polypropylene melt resin sheet. The pressure distribution in the extruder, melt temperature profile across melt flow, the extruder throughput and the specific energy consumption were monitored. The work obtained screw geometry optimization was conducted using the analysis of melting performance by the cooling experiment and the pressure pattern. As a result, the screw geometry to satisfy a low external haze and extrusion stability under higher throughput conditions was designed. [7]

[Kaiserslautern (2001) simulated the influence of process parameters to the melt spinning process a fiber model is used and coupled with CFD calculations of the quench air flow. In the fiber model energy, momentum and mass balance are solved for the polymer mass flow. [8]