SCHOOL OF MATERIAL AND MINERAL RESOURCES ENGINEERING

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INVESTIGATION ON PROCESSING PARAMETER OF SINGLE SCREW EXTRUSION USING EXPERIMENTAL AND NUMERICAL APPROACH

By

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled “INVESTIGATION ON PROCESSING PARAMETER OF SINGLE SCREW EXTRUSION USING EXPERIMENTAL AND NUMERICAL APPROACH”. I also declare that is has not been previously submitted for the award of any degree or diploma or the similar title of this for any other examining body or university.

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LIST OF ABREVATIONS

LDPE	Low Density polyethylene
PE	Polyethylene
PP	Polypropylene
PVC	Polyvinyl Chloride
PS	Polystyrene
PC	Polycarbonate
PA	Polyamide
PSO	Polysulfone
PEI	Polyetherimide
PEEK	Polyetherether Ketone
ABS/PC	Acrylonitrile Butadiene Styrene/Polycarbonate Blend
POM	Polyoxymethylene
PPS	Polyphenylene Sulfide
PBT	Polybutyl Terephatalate
PTA	Polyphthalamide
PET	Polyethyl Terephatalate
T_m	Melting Temperature
T_g	Transition Temperature
FVM	Finite Volume Method
3D	Three Dimension
CFD	Computational Fluid Dynamics
VOF	Volume Of Fluid

NOMENCLATURES

η_o	Zero shear viscosity
η_∞	Infinite shear viscosity
η	Viscosity
γ	Rate-of-strain tensor
$\dot{\gamma}$	Apparent viscosity
λ	Lambda
λ_c	Time constant
τ	Torque
$\tau *$	Power low region
K	Thermal conductivity
n	Power- law index
ρ	Density
Q_o	Total flow rate
W	Diameter of screw
H	Height of flight
Φ	Helix angle
γ	Solid conveying angle

ABSTRAK

KAJIAN TERHADAP PARAMETER PEMPROSESAN EKSTRUDER SKRU TUNGGAL SECARA KAEDAH EKSPERIMENTAL DAN PENDEKATAN BERANGKA

Pengekstrudan adalah proses yang merupakan salah satu pemprosesan plastik yang biasa digunakan dalam industri. Tetapi proses ini memerlukan banyak pertimbangan dari aspek parameter pemprosesan untuk mengatasi masalah seperti bengkak acuan dan ketidakstabilan aliran. Kajian ini dijalankan untuk menyiasat persamaan suhu yang berbeza dan mengubah kelajuan skru pada polietilina berketumpatan rendah (LDPE) dengan menggambarkan kelakuan aliran leburan polimer dalam proses pengekstudan dengan menggunakan analisis isipadu terhingga. Simulasi tiga dimensi (3D) reologi polimer dalam pengkstrudan skru tunggal telah digunakan. Dalam simulasi ini, perisian ANSYS FLUENT 15.0 digunakan untuk mengesahkan model kelikatan (model Cross). Kajian ini telah menentukan kesan parameter proses pada kelakuan nisbah bengkak acuan. Simulasi dijalankan pada suhu dan kelajuan skru yang berbeza. Setelah itu, pendekatan eksperimen telah dijalankan untuk mengesahkan hasil dari simulasi. Pengunaan pelbagai kelajuan skru dan suhu didapati telah mempengaruhi nisbah bengkak acuan sebanyak 1.4 sehingga 1.8. Kesan peningkatan suhu menunjukkan kenaikan dalam nisbah bengkak acuan. Selain itu, kesan kelajuan skru menunjukkan bahawa peningkatan kelajuan skru akan meningkatkan nisbah bengkak acuan. Pengaruh dalam parameter proses seperti suhu dan kelajuan skru didapati mempunyai pengaruh yang ketara pada kelikatan leburan LDPE. Selain itu, profil suhu ekstrudat yang diperhatikan dalam kedua-dua eksperimen dan simulasi, menunjukkan hasil yang ketara. Kajian dalam simulasi aliran polimer perlu mempertimbangkan pelbagai paramater.

Kekuatan ANSYS FLUENT 15.0 dalam mengendalikan proses simulasi pengekstruadan yang diperlukan untuk dikaji secara terperinci untuk menghasilkan keputusan yang tepat dan jitu.

ABSTRACT

INVESTIGATION ON PROCESSING PARAMETER OF SINGLE SCREW EXTRUSION USING EXPERIMENTAL AND NUMERICAL APPROACH

Extrusion is one of the common process used in plastic processing that has been used in the industry. But this process needs a lot of consideration from the processing parameter to overcome the problem such as die swell and flow instability. This study were carried out to investigate the effect different temperatures setup and varies screw speed on the Low Density Polyethylene (LDPE) extrudate. Also in this research aimed to visualise the flow behaviour of the polymer melt in the extrusion process by using finite volume analysis. Three dimensional (3D) simulation of polymer rheology in a single screw extrusion was used. In this simulation, the ANSYS FLUENT 15.0 software was used to verify the viscosity model (Cross model). This study determined the effect of process parameter on die swell behavior. Simulation was carried out at different temperatures and screw speeds. Then, an experimental approach were carried out to verify the result from the simulation. The temperature and screw speed was found to be affecting the die swell ratio. The effect of increasing the temperature showed the increment in the die swell ratio. Besides, the effect of screw speed showed that the increasing screw speed increase the die swell ratio up to 1.4 to 1.8. The effect of process parameter such as temperature and screw speed were found to have prominent influences on the viscosity of the LDPE melts. Other than that, the temperature profile of the extrudate were observed both from experimental and simulation and revealed significant results. Simulation study of flow of polymer had to consider various parameters. The strength of ANSYS FLUENT 15.0 in handling simulation of extrusion process needs to be studied in detail in order to produce an accurate and precise result.

CHAPTER 1

INTRODUCTION

1.1 Overview

Plastic is very versatile material in the world. The presence of the plastic cannot be ignored and its importance is such as for another material like metal and ceramic. Plastic can be shaped into many shapes and being used in many applications from common household, specialized high engineering application to the outer space. For fulfilling the requirement of the application, there are several manufacturing methods to form the plastic into desired shape such as injection moulding, blow moulding, rotational moulding, thermoforming and extrusion.

One of the most common plastic manufacturing processes is injection molding lends itself to mass production of products ranging from common household application to very high- end precision product. The injection molding process melts resin pellets inside the injection machine with a heated barrel. Another processing method is blow molding process for the production of a hollow, pre-shaped length of melted thermoplastic, known as a parison. Air pressure forces the hollow plastic to expand into the mold shape, leaving the interior of the object hollow. Thermoforming is one of the oldest methods of processing plastic materials. The process involves heating a plastic sheet until soft and then draping it over a mould. And the last is extrusion process that been used to produced continuous or semi- continuous product with simple shape and excellent surface finish.

Numerical simulation is used to enhance the productivity, quality, turnaround times and resources utilization in polymer processing. With aid of simulation, it enable to study important flow modelling such as rheological properties of polymer melt. Not only benefit on quality of product but also effectively cut cost for the whole process. Such as for the extrusion process, numerical simulation is achieving an increasingly important role in the part and die design process, as well as in adjusting the right processing parameters for the actual production (Aho, 2011).

1.1.1 Extrusion Process

Extrusion is a continuous process carried out in extruder, to form a long and continuous extrudate such as pipe, sheet, tube and other complicated shape (Rauwendaal, 2010). Extruder is a machine to force out a material through an opening called the die. As the materials flow through the die, it acquires the shape of the die flow channel. The main function of extruder is to develop sufficient pressure in the material to force the material through the die. The pressure necessary to push a material depends on the geometry of the die, the flow properties of the material, and the flow rate. There are two main classes of extruder machine, which is plasticating extruder (plasticates or melts the material) and melt-fed extruder (extrude material without melting it). Based on Jing et al. (2014), polymer extrusion is a process in which a polymer is melted and conveyed to a die, forms the basis of most polymer processing techniques.

An extruder is made of a barrel containing one or two Archimedean screws rotating inside the barrel. In single screw extruders, a screw mixer melts the entering plastic materials, pushes the material through the extruder, and forms the plastic into the desired shape. Twin screw extruders have two intermeshing screws and operate in the same manner as a single screw extruder. Besides, there is another process in extrusion called co- extrusion that being used in extruding two or more material together through the same die.

1.1.2 Single Screw Extruder

The extruder are made up from a few set- up like hopper, barrel, screw and die. The extrusion process are performed with a number of event such as solid conveying, melting, mixing, melt conveying, degassing and shaping or forming the product. The raw material, in the form of small plastic pellets, is placed in the hopper. The hopper rests on top of the barrel. The barrel is a heated hollow steel cylinder, sort of like a really thick pipe. An auger-type screw rotates inside of the barrel. The screw's rotation takes the plastic pellets and pushes them forward, into the barrel. As the pellets move towards the front of the barrel, frictional and electrical heat from the barrel melt the plastic. After the plastic is melted, the rotating screw continues to act as a pump and forces the molten plastic through a die. The die is usually a piece of metal with the shape of the desired part machined into it. Once the melted plastic exits the die, it is shaped like the finished product. Next, it is pulled through some sort of cooling apparatus, which usually cools with air or water. Once cool, the product can be rolled up, cut into sections, packaged, or can go on to secondary operations.

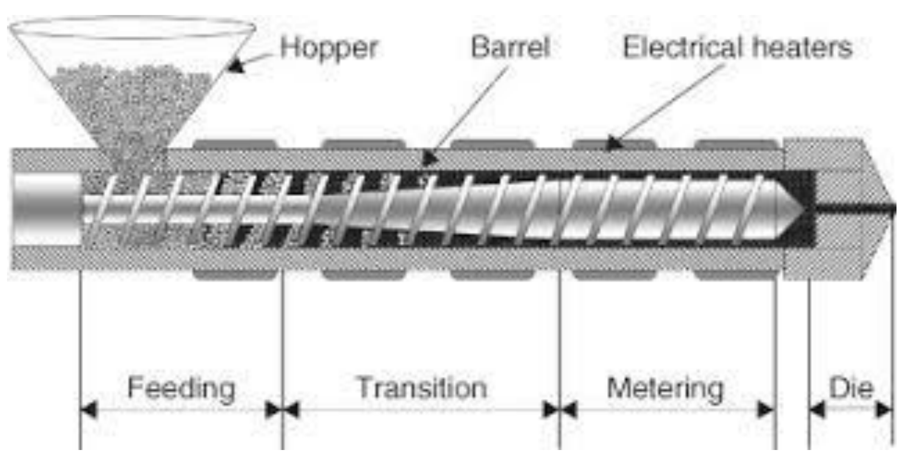

Figure 1.1: Schematic drawing of a single-screw extruder for plastic. (Incarnato and Di Maio, 2012)

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1.1.3 Twin Screw Extruder

Twin screw extruders depend minimally on the friction of the material against the barrel to move forward. They rely instead on the properties of the extruder and the screws. Compared to single screw extruder, double screw extruder has several features that becomes advantages, such as material flow is stable, uneasy happen cut off or billow, productive process is reliable. After that, most heat of twin screw extruder mainly come from mechanical transformation during operation, small amount of heat comes from the heating jacket. The single screw extruder often require additional equipment preheat quenched materials. Time distribution is relatively narrow range of material retained in the machine, which is easier to control the temperature of the material, sufficient energy utilization, yield and quality are very stable. Then, twin screw extruder has a screw surface self-cleaning effect, so that the transportation of materials is stable, little residual material in cavity when finish working, and no need stop to cleaning if change the production material. Lastly, twin screw extruder has large productivity, is appropriate for processing of materials containing high oil (> 17%) and high humidity of materials (more than 30% moisture content).

The two most important features are the meshing characteristics and the type of rotation. At the output, the extruder is equipped with a die from which the material is extruded from the process. The process is controlled by the barrel temperature and the screw speed to ensure the desired properties such as moisture, density and mechanical properties at the die in presence of perturbations (Saeren, 2013). These parameters relate just to the extruder. However, there are many more process parameters for the entire extrusion line depending on the design of the extrusion line such as motor load, cooling rate, melt pressure and melt temperature.

1.2 Problem Statement

Extrusion is a process that need a lot of consideration from the processing parameter setting, die design and also type of material. Although it been used in the industry for a long time, this processing method need to be consider to control the defect in the process such as die swell and flow instability. Besides that, there are also problems like poor mixing, limited ability to transport viscous material and high material waste. Extrusion process includes complicated rheological parameter which increase the difficulty in measurement of real life condition (Zhou et al, 2014). According to Wang (2012) die swell is a common phenomenon in polymer extrusion. When a viscoelastic fluid flows out of a die, the extrudate diameter is usually greater than the channel size. This is called die-swell, extrudate swell or the Barus effect. The degree of die swell is usually expressed by the die-swell ratio of extrudate diameter versus die diameter. A better understanding of such flow behavior will be beneficial for the optimization of processing parameters and the design of extrusion equipment, both of which affect product quality and production cost.

Therefore, the aforementioned issues were investigated through experimental and numerical simulation analysis. During the processing, the real situation of interaction or interplay on the polymeric material and the component of the extruder such as screw and barrel cannot be visualized experimentally. Therefore, with the current problem that usually encountered in the extrusion process, this research will be revealed the factors that may affected the quality of the extrudate. Hence Finite Volume method (FVM) offered by ANSYS FLUENT 15.0 analysis have been carried out.

1.3 Objectives

This research was conducted to find the factor of processing parameter to produce a good quality of the extrudate that can be improved with taking the consideration of several processing parameter.

1. To evaluate the effect different temperatures profile on the die swell ratio of the extrudate.
2. To analyse the effect of varies screw speed on the die swell ratio extrudate.
3. To visualise the flow behaviour of the polymer melt in the extrusion process by using finite volume analysis.

1.4 Scopes and outline project

This project mainly focused on the effect of the using different parameter on the extrusion process to the die swell and feed rate of the extrudate. The processing parameters that are being conducted are temperature and different screw speed which wiil affect the extrudate quality such as die swell. The result of die swell due to feed rate differences will be correlated to one another and been discussed. The research also involved the uses of the finite volume analysis, ANSYS Fluent. The simulation of the extrusion process are simulated through the numerical modelling and the result of the simulation are verified with the experimental result.

1.5 Outlines report

In this thesis it consists of five chapters and it will be explained accordingly. Chapter 1 is the introduction of the research to the extrusion process, problem statement, objectives and scope of the research

Chapter 2 is about literature review which is discussed about the previous studies and research related to the experiment and numerical analysis on extrusion process.

In Chapter 3, it will explain the research methodology such as procedure in the simulation, experiment and calculations on how they are conducted and needed to be included in the research.

Chapter 4 will be discussed about the result and the related discussion that obtained from those effect, screw speed and different temperature setup on the die swell and surface appearance of the extrudate.

Lastly, Chapter 5 is the conclusion of the research. The recommendation for future research is also included for improvement and better understanding of the extrusion process.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

The advance development of polymer processing such as extrusion process in industrial and commercial applications has motivated a lot of work in studying about polymeric fluids and its flow behavior. This field have confronted with several difficulties about fluid flow which is modified in the presence long chain macromolecules. Flow properties of molten polymers are important since processing of thermoplastic involves flow of polymer melts. In polymer processing such as extrusion process, the flow and stability of the liquids as they pass through the extruder need to be concerned. Rheology is the study of flow of material. In extrusion, fluid measurement must be related to fluid properties such as viscosity of non-Newtonian fluid. In this chapter, the polymer flow concept and the theory on the extrusion process will be discussed. It also concern on the parameter and properties that influence the polymer melt behavior.

2.2 Plastic Extrusion Process

The extrusion process is widely used in the polymer industry. Most polymers used in commercial processing have sufficiently high molecular weight so that the polymer chains are highly entangled in the melt, resulting in a flow field that differs significantly from that of a Newtonian fluid, for instance a viscoelastic fluid experiences significant swelling as compared to the case of a Newtonian fluid. (Wang, 2012)

kl2.3 Extruder Temperature Profiles

Temperature is the first factor that need to be took in to account in the extrusion process. The polymer need to be processed above the melting temperature. The possible barrel temperature combinations available for operating the extruder are almost limitless. However, only a few temperature profiles will produce an acceptable product while providing optimum process conditions. Possible temperature profiles include progressive or increasing temperature, with the set- points increasing continually from the feed throat to the die, an inverted or decreasing temperature profile, with the set points decreasing from the first heated barrel to the die, straight temperature profile, where all barrels are set at exactly the same temperature set point, a humped profile, where the temperature is lowest in the first heated barrel, gradually increases toward the middle of the extruder, and then decreases progressively toward the die. Polymer melt temperature is a critical property in controlling the extrusion process and optimizing the throughput while minimizing resin degradation.

From Chevanan et al. (2007) stated that increased temperature profile shows decrement in die pressure, slightly decrease of apparent viscosity and reduced the mass flow rate.

2.4. Screw Speed Effects

Screw speed in a starve-fed extruder is a critical process parameter in controlling mixing, melting, pressure generation, and melt temperature. Screw speed determines the percent fill of the various screw flights, the residence time in the extruder and the torque level. Processing is always a balance of processing conditions where throughput, screw speed, melt temperature, residence time, mixing, and screw design are optimized to produce the highest quality product. Higher screw speed may generate so much shear heat that the melt temperature cannot be controlled. In this event the throughput is reduced, allowing the screw speed to be reduced, lowering the melt temperature. Hence, the limitation of the screw speed is the maximum shear rate that the heat sensitive product can experience without degradation. Increasing screw speed elevates the friction between the product and screw and thus more mechanical energy is produced. On the other hand increased screw speed results to the shorter residence time (Singh, 2016). This statement also supported by the Deng et al. (2014) reported that if the screw speed is high, the screw rotation becomes the main heating sources and provides shear heating.

According to Abecassis et al (1994), the screw speed affecting the pressure along the screw length and residence time. The pressure increases regularly from the beginning to the end of the screw. Then it decreased at the die head. Pressure will result in reduced free volume of the melt and accordingly, it increase in viscosity near to polymer Tg. In addition, the reduction of free volume caused the limited molecular mobility in the polymer melt. Different screw speed caused the differences in residence times. Increasing in speed will reduce the residence times.

In single screw process, screw rotation functioning for mixing, plasticizing, and extruding as accordingly divided at each zones. Varies speed screw have a significant influence such as for rheological parameters of materials. Also it also affect the economic efficiency of production. Zhou et al. (2014) reported that the increase of the screw speed will cause the changes of viscosity. This is also give the effect on pressure increment and heat accumulation and then temperature rise.

A previous study by the Vera- Sorroche et al. (2014), noted that conduction is the dominant form of heat generation at low screw speeds in contrast to viscous shearing at higher speeds. These result suggest that melting predominantly by conduction is less efficient and indicates that the extruder should run at medium to high screw speed to improve specific energy consumption.

2.5 Die Swell of Extrudate

Die swell is a typical defect in polymer extrusion. The die swell can be observed when a polymer melts exits from a die, the diameter of the product is usually greater than the diameter of the die. This phenomenon is obviously observed when the extrudate is pulled from the extruder or droll on the floor very slowly. Besides called as die swell, this defect also known as extrudate swell or Barus effect.

Die swell effect due to the characteristic of the elastic behaviour of elastic fluid. Polymer molecules in the die land area are oriented in the flow direction. One of the factor that affecting die swell is velocity profile. The extrudate velocity profile is higher at the centre of the flow front and lower near the die walls. Immediately after exiting the die, the extrudate velocity profile is identical across the entire cross section. Consequently, the velocity at the extrudate surface outside the die is identical to the velocity in the centre of the extrudate. This change in the flow velocity profile gives rise to molecular relaxation outside the die and the resultant extrudate swell. The increased swelling is due to the relaxation of the polymeric chains, which, from being oriented primarily in the flow direction inside the die, can relax to any configuration outside it, where the flow field is completely rearranged. From the viewpoint of macro-rheology, the extrusion process produced considerable elongation and shear deformation to the polymer melt. If the elastic part in the deformation does not completely recover before the melt leaves the die, hence the polymer melt will recovered the elasticity and leading to die swell.

Wang (2012) has reported that, due to the action of the shear, compression and extension of polymer melt caused molecular chain of the polymer to disentangle and realign. The realignment of the polymer chain happened in convergent region have increased the entry effect and increase the internal stress and strain. So the polymer melt being under stress with addition of shear and elongation action during the extrusion. When the polymer melt exit the die, the molecular chain being relaxed due to the re-entanglement and recoiling. This action will caused the extrudate tend to contract in the flow direction and to grow in the normal direction, so die swell happen.

During melt extrusion, chain orientation and extension of the polymer melt is often restricted due to fast relaxation process. The entropic forces cause chains to return back to their random coil conformation. However, it is well known that polymer chains can be efficiently oriented below, which relaxation times in solid state are infinite. (Zhang et al. 2017)

2.6 Factor That Affecting Die Swell

According to Wang (2012), the extent of the swelling will depend on both external factors as well as the intrinsic characteristic of the polymer. The former include the geometry of the extrusion system (reservoir, entry and die) and the capillary operating conditions (the applied shear rate, stress and temperature) and the external environment medium. Die swell can be used to assess the polymer viscoelasticity upon melt extrusion. Through rheological characterization, die swell can be also be correlated with the molecular structure of the polymer (molecular weight, and extent of crosslinking and long branching).

Also Jing et al. (2013) have stated a statement about the factors that affect the extrusion process. The homogeneity and melt flow stability are dependent on the melt temperature and screw speed.

2.7 Material Uses for Extrusion Process

Extrusion is a very versatile process that can be used for many thermoplastic polymer. Thermoplastic polymer is polymer that can be reshaped or reprocessed with temperature. In extrusion process, the polymer resin will be heated up to melting temperature. Thermoplastic materials are generally categorized as either commodity resins or engineering resins. Commodity resins are lower price with lower property performance and higher sales volume. Thermoplastics falling into this group include polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC) and polystyrene (PS). Engineering resins generally have higher tensile, flexural, and impact properties combined with higher temperature performance. Thermoplastics falling into this group include, polycarbonate (PC), nylon (PA), polysulfone (PSO or PSF), polyetherimide (PEI), polyetherether ketone (PEEK), polyphenylene sulfide (PPS), acrylonitrile butadiene styrene/polycarbonate blend (ABS/PC), polyoxymethylene (POM), thermoplastic polyesters (PET and PBT) and polyphthalamide (PTA). In between these two classes are resins that have very good properties and slightly lower temperature resistance. They are not as cheap as the commodity resins and not as expensive as the engineering thermoplastics.

2.8 Low Density Polyethylene (LDPE)

Low Density Polyethylene (LDPE) is one of the derivative polymer from ethylene monomers are manufactured using free radical polymerisation at high pressure process to producers long chain branching. LDPE usually used for commercial and industrial application. It has good properties such as good insulation, ductile and rigid, made a suitable material used for container and plastic film application. The LPDE are used in various application.

2.9 Finite Volume Method (FVM)

According to Moukalled et. al. (2016), Finite Volume Method (FVM) is a numerical technique that transforms the partial differential equations representing conservation laws over differential volumes into discrete algebraic equations over finite volumes (or elements or cells). In a similar fashion to the finite difference or finite element method, the first step in the solution process is the discretization of the geometric domain, which, in the FVM, is discretized into non-overlapping elements or finite volumes. The partial differential equations are then discretized/transformed into algebraic equations by integrating them over each discrete element. The system of algebraic equations is then solved to compute the values of the dependent variable for each of the elements. In the finite volume method, some of the terms in the conservation equation are turned into face fluxes and evaluated at the finite volume faces. Because the flux entering a given volume is identical to that leaving the adjacent volume, the FVM is strictly conservative. This inherent conservation property of the FVM makes it the preferred method in CFD. Another important attribute of the FVM is that it can be formulated in the physical space on unstructured polygonal meshes. Finally in the FVM it is quite easy to implement a variety of boundary conditions in a noninvasive manner, since the unknown variables are evaluated at the centroids of the volume elements, not at their boundary faces. These characteristics have made the Finite Volume Method quite suitable for the numerical simulation of a variety of applications involving fluid flow and heat and mass transfer, and developments in the method have been closely entwined with advances in CFD. Computational Fluid Dynamics is just one of the later Computer Aided Engineering tools that has gone mainstream that amazingly enough models accurately a whole set of flow phenomena from turbulent or laminar single phase incompressible flows, to compressible all-speed flows, and all the way to multiphase flows. From a limited potential at inception confined to solving simple physics and geometry over structured grids, the FVM is now capable of dealing with all kinds of complex physics and applications.

2.10 Research Scope

Rheology is a study of the changes in form and flow of matter, viscosity and plasticity. Plastic extrusion has been used widely in industries. In my study, an attempt is made to simulate the model of extrusion process to study the polymer rheology of LDPE plastic in an extrusion process. The Volume of Fluid (VOF) technique is used and numerical simulation is performed by ANSYS FLUENT 15.0. Cross model are used to describe the rheological properties of LDPE plastic.

The main objectives in this project is to investigate the effect of processing parameter such as barrel temperature and screw speed on the die swell and surface appearance of the extrudate. Second is to study the effect of processing parameter on the feed rate of the extrudate. And lastly, to study the behaviour of the polymer melt in the extrusion process by using finite volume analysis.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Overview

Finite volume simulations give results on material flow and die deflection. A method for simulation of viscoelastic flows using an ANSYS FLUENT simulation based finite volume formulation was presented. This ANSYS FLUENT simulations are used to implement and can accurately simulate the thermoplastics behaviour of transient polymer flow through complex geometries. In the present study, steady flow through abrupt contractions of planar and asymmetric geometries were studied by performing transient flow simulations. The strength of the proposed method lies in its ability to simulate die swell phenomena in an extrusion die. The idea is to simulate the flow of thermoplastics fluid in a single screw when subjected to temperature and screw speed.

3.2 Experimental Procedure on Extrusion Process

The material used is low density Polyethylene (LDPE) provided from Lotte Chemical. A virgin polymer grade used to prevent the influence of the additive or chemical composition to the rheological properties and quality of end product. 800 g were heated overnight in an oven at temperature of 50 °C to remove the moisture.

(a)

(b)

Figure 3.1: (a) LDPE package in 25kg (b) LDPE solid state

3.2.1 Machine Preparation

The extruder machine used was manufactured by Brabender® GmbH & Co. KG. The extruder is multipurpose stand-alone single screw extruder KE19. This extruder machine have multi-master system, extremely flexible, self-identification and self-validation, real-time data communication powerful software for control and evaluation for all actual Windows® versions.

The extruder preparation stated with setting the temperature of feed zone, transition zone, metering zone, and die zones. The heater of extrusion machine was started earlier to preheat the barrel and die, until stable temperature was achieved. After temperature stabilization, LDPE resins were poured into the hopper in sufficient amount for purging purpose. Purging process are important to make sure the barrel of extruder is free from impurities and contaminated with another polymer resin or additive from the previous usage.

Figure 3.2: KE 19 Brabender stand-alone extruder

3.2.2 Experimental Procedure

The experiment played with two processing parameter which are temperature profile and screw speed. For the first temperature profile that is temperature A, all zone are set with 120 °C. After all temperature zone temperature were stabilised, the extruder screw speed were set at 20 rpm. The extudate will be let to be extrude with constant time about 90 seconds. After extrudate are getting about 10 cm long, it will be cut and label. The process were repeated to collect three sample of extrudate from same screw speed 20 rpm. The same procedure also repeated for screw speed of 40 rpm, 60 rpm, 80 rpm and 100 rpm. Then the same procedure were repeated for temperature setup B, C and D.

The extruder heating element was set according to each zone as shown in the Table 3.1 below.

Table 3.1: Extruder temperature setup

Zone	Feeding	Transition	Metering	Die
A	120	120	120	120
B	120	120	130	140
C	120	130	140	150
D	130	140	150	160

3.2.3 Geometry designing

Currently, in the present of world designing industry, Solidworks takes the biggest share for visual designing creation. Based on the model simulation, the element that assumed to be incompressible are molten LDPE and air. The extruder model dimensions are mentioned in Figure 3.3 shows that the extruder that was drawn in three dimensional shape.

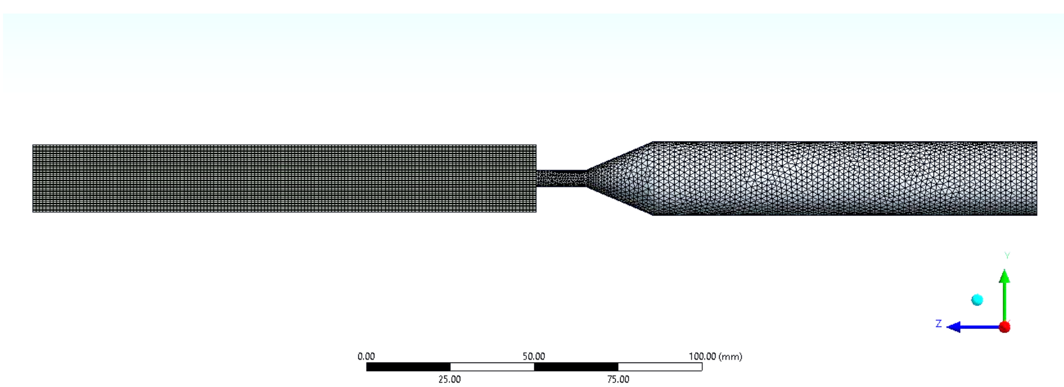


Figure 3.3: Geometry of the extruder model

Extrusion machine part were drawn approximately to the real extrusion machine of KE 19 Brabender Extruder machine. The dimension of each parts of extrusion machine were measured approximately same with the actual extrusion machine. The diameter of the screw which is 19 mm was used.

3.3 Mathematical Model

According to the characteristic of the polymer melts flow in a die, the following assumptions are made in the numerical simulations: the LDPE melt is an incompressible fluid, the flow in the barrel of extruder and die head are laminar and isothermal, lastly the extruder system is always full of the polymer melt.

Polymer under stress exhibit unusual, unexpected behaviour or that the wrong constitutive equation may give stresses totally inappropriate for a polymer undergoing deformation and flow.

For purely viscous fluids, the rheological constitutive equation that relates the stresses $\tau$to the velocity gradients is generalized Newtonian model and is written as

$$\tau = \eta(\gamma)(\dot{\gamma}) \tag{3.1}$$

Where γ= Δv+ Δv^T is the rate- of- strain tensor and ($\dot{\gamma}$) is the apparent viscosity given in its simplest form by the Power Law model,

$$\eta(\dot{\gamma}) = K\gamma^{n-1} \tag{3.2}$$

Where K is the consistency index and *n* is the power- law index (usually 0< *n* < 1, representing a degree of shear thinning). Another popular model for viscosity, among other, is Cross model given by

$$\eta(\dot{\gamma}) = \eta_{\infty} + \frac{\eta_o}{1 + (\lambda_c \gamma)^{1-n}} \tag{3.3}$$

In the above equations, η_o is the zero shear rate viscosity, η_{∞} is the infinite shear viscosity, λ_c is a time constant and *n* is again the power law index.

With:

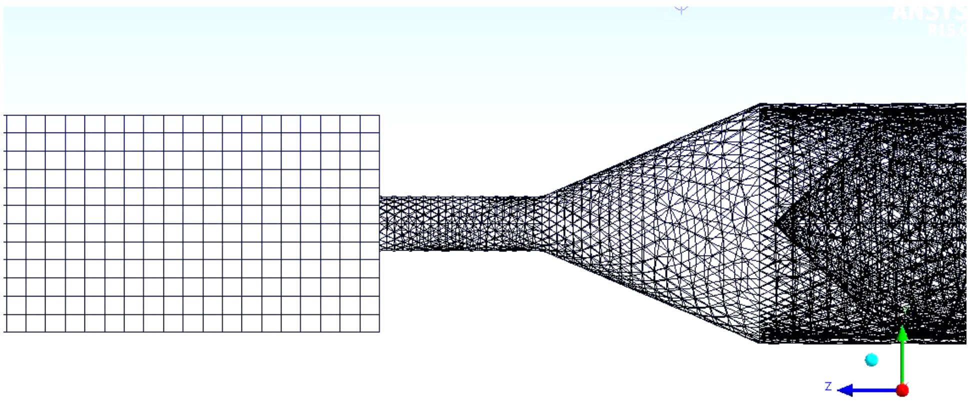
$$\lambda = \frac{\eta_o}{\tau^*} \tag{3.4}$$

Where $\tau^*$is the parameter that describes the transition region between zero shear rate and power law region of viscosity curve.

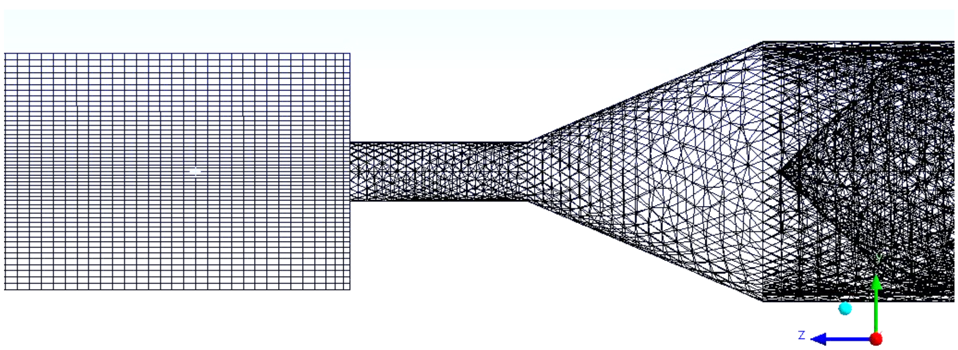
3.4 Procedure for Numerical Simulation at Different temperature

The numerical simulation process was started with creating the geometry. This was done using SOLIDWORKS. The file was imported in .sat file to DesignModeler ANSYS Workbench. The next step is to mesh the geometry. ANSYS FLUENT being an unstructured solver uses internal data structures to assign an order to the cells, faces and grid points in a mesh and to maintain contact between adjacent cells. This gave the flexibility to use the best grid topology for all the problems, as the solver did not force an overall structure or topology on the grid. For this study, the mesh of the geometry model was selected from four different methods. The geometry being meshed using the original, biased mesh, two different number of divisions; 150 and 300.

Figure 3.4 below shows that the mesh of extruder with the screw, die head and outlet plate. There are two zone, first zone is the mesh used for the barrel at metering zone and die-head zone. For the second zone is the mesh used for outlet. So the model chosen is the model with number of division 150 like be shows in Figure 3.4 (c). There are three zones in total; first and second zone, the mesh used was tetrahendral. While the third zone, the mesh used was quadrilateral elements with 150 number of divisions on the z direction and 50 number of division for x and y direction.

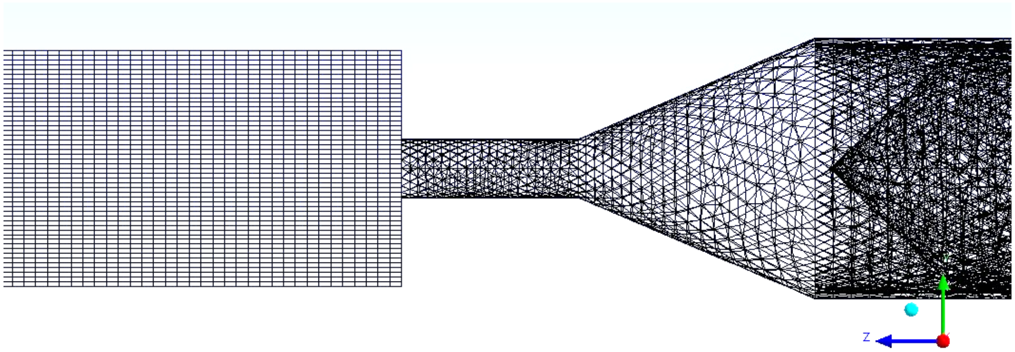


(a)

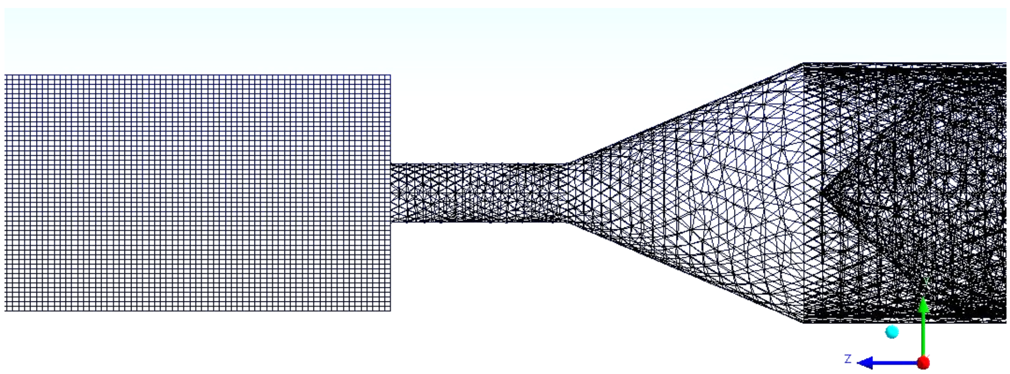


(b)

Figure 3.4: Geometry of extruder model: (a) original mesh (b) biased mesh



(c)



(d)

Figure 3.4(cont.): Geometry of extruder model: (c) 150 number division (d) 300 number of division

The purpose to used type and number of division in meshing is to find out the best model to be used to run the simulation and give accurate result. But there are a few consideration need to be aware such as total number of element and the skewness value. The higher number of element will took longer time to complete one simulation.

3.5 Setup Solution ANSYS FLUENT in Steady State.

Following the designation of the zone types, the meshed geometry then exported as file and then imported into FLUENT. The following procedures was followed while using