INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & MANAGEMENT

Design and simulate the flow of polymers in the die by using Comsol & calculate the output mass flow rate and the operating point of the die

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Abstract

The point of this building postulation was to plan and mimic a kick the bucket for a rectangular master document. The venture comprised of considering melt stream attributes of plastics and how amazing ought to be set with a specific end goal to get the wanted shape. After the kick the bucket has been de-marked on 3D Solid edge outline programming it was reproduced on COMSL stream reproduction programming. On the reproduction programming it was simple to study how the dissolve streams and in which segment of the bite the dust is the shear anxiety lively and barren. The drag stream and weight stream were then separated from the screw parameters which lead into the estimation of the operation point and the working weight for the kick the bucket.

Keywords- 3D –Solid edge, Comsol, Extrusion Die,Die Design, Viscosity, LDPE Plastic Material .

Introduction

Extrusion is a high volume creating process. The plastic material is mellowed with the utilization of warmth and ousted through pass on into a needed shape. A round and empty turning screw is put inside the barrel which drives out fluid plastic material through a pass on. The removed material happens as intended as showed by the cross-section of bite the dust. Working Principle In this system, plastic material as pellets or granules is gravity victualed from a top mounted compartment into the barrel. Included substances, for instance, colorants and splendid inhibitors (liquid or pellet edge) can be commixed in the holder. The plastic material enters through the sustenance throat and comes into contact with the turning screw. The turning screw pushes the plastic spots forward into the barrel. The barrel is warmed utilizing the warming parts up to the softening temperature of the plastic. The warming parts are utilized as a part of such ways that constantly augment the temperature of the barrel from the back to the front. There are three possible zones in a turning screw i.e. sustenance zone melting zone, and metering zone. In the victual zone, the plastic touches disintegrate a little bit at a time as they appear to be, pushed through the barrel. The plastic material is totally broken up in the softening zone. An indoor controller is utilized to keep up inside temperature of the barrel. The overheating of plastics should be constrained which may realize debasement in the material properties. A cooling fan or dihydrogen monoxide cooling structure is utilized to keep up the temperature of the barrel in the midst of the strategy. At the front of the barrel, the fluid plastic leaves the screw and peregrinates through a screen pack to process any contaminants in the fluid plastic. The screens are reinforced by a breaker plate. The breaker plate get together besides suits to affect back weight in the barrel. The back weight gives uniform softening and perfect commixing of the fluid plastic material into the barrel. In the wake of experiencing the breaker plate, fluid plastic goes into fail horrendously. The fail miserably gives the looked for condition of plastic thing. An uneven stream of fluid plastic would bring about undesirable stresses in the plastic thing. These nerves can realize bending in the wake of solidifying of fluid plastic. Plastics are incredible warm defenders and consequently it is outstandingly difficult to cool rapidly. The plastic thing is cooled by pulling through a plan of cooling rolls.

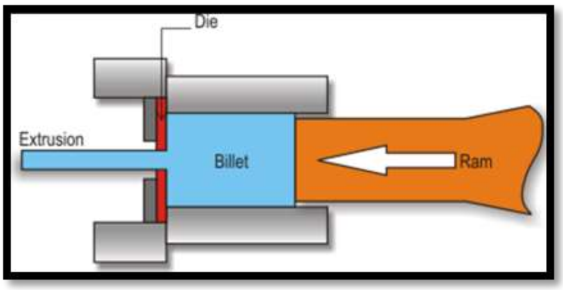

Figure 1.1 Extrusion process

Aim of the report

The main aims of this thesis are

1. To calculate the output mass flow rate and the operating point of the die.
2. To simulate the flow of polymers in the die using Comsol.
3. To design a die using a Solid Edge modeling software for a rectangular profile.

Outright Viscosity – a term utilized conversely with thickness to recognize it frame either kinematic consistency or business consistency. Supreme thickness is the proportion of shear worry to shear rate. IT is a liquid's inward imperviousness to stream. The regular unit of outright thickness is the balance. Outright consistency separated by liquid thickness rises to kinematic consistency. It is every so often alluded to as dynamic thickness. Supreme consistency and kinematic thickness are communicated in central units.

ISSN 2277–5528
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Clear Viscosity – The proportion of shear worry to rate of shear of a non-Newtonian liquid, for example, greasing up oil, or multi-review oil, computed from Poiseuille's condition and measured in balances. The clear thickness changed with changing rates of shear and temperature and must, along these lines, be accounted for as the incentive at a given shear rate promotion tem-perature
Back Pressure – The resistivity of liquid plastic material to forward stream.
Barrel – The piece of the extruder encasing the screw or plunger.
Barrel Liner – The sleeve framing the inward surface of the barrel.
Calendaring – The way toward squeezing or smoothing material between rollers.
Cladding - otherwise called "sidings" is the extruder PVC-U sheets that are utilized as out-entryway climate safe façade boards
Compound – Any plastic material arranged for resulting fabricating forms, particularly expulsion, shaping or calendaring.
Pressure Section – The move segment of tighten divert which a decrease in the screw channels volume happens.
Die– The segment on a plastics extruder joined to the extruder head through which the dissolve is pushed to frame the coveted profile.
Die Plate– In molds, the primary support for the punch or shape cavity.
Dry Blend – A free streaming mix of compound or gum and different fixings are pre-pared for an extra assembling operation particularly for expulsion or embellishment.
Extrudate – The item or aftereffect of an expulsion procedure. An extrudate is an item or material constrained however a molding hole as nonstop body.
Extruder Size - The insignificant internal width of the extruder barrel
Extrusion Coating – A covering method in which liquid plastic bolsters straightforwardly from an extruder bite the dust into a pinch move gathering consolidated with the substrate.
Warm Aging – The extraordinary procedure of maturing a thermoplastic or thermoset item and inspecting the rate of held physical and compound properties after introduction to warm for delayed timeframe.
Soften – Any expulsion material warmed to plastics condition.
Soften quality – A term that alludes to the quality of liquid plastic.
External Die Ring – The component of tubing tie that shapers the external surface of a tube.
Pellets – Resins or blends for tars with exacerbating added substances in the state of simi-lar estimated tables and granules that have been expelled or slashed into short fragments to set them up for embellishment operations.
Ram Extruder– A barrel with temperature control, where in a plunger pushes material in a liquefied state to the Die.

Literature Review

A standout amongst the most extraordinary elements of plastics is the simplicity with which they can be prepared. Now and again semi-completed articles, for example, sheets or poles are delivered and in this way created into shape utilizing ordinary techniques, for example, welding or machining. In the larger part of cases, be that as it may, the completed article, which might be very perplexing fit as a fiddle, is delivered in a solitary operation. The handling phases of warming, forming and cooling might be consistent (e.g. creation of pipe by expulsion) or a re-peated cycle of occasions (e.g. generation of a phone lodging by infusion shaping) yet much of the time the procedures might be robotized as are especially reasonable for large scale manufacturing. There is an extensive variety of handling techniques which might be utilized for plastics. As a rule the selection of techniques depends on the state of the segment and whether it is thermoplastic or thermosetting.It is important therefore that through-out the design process, the designer must have a basic understanding of the range of processing methods for plastics since an ill-conceived shape of design detail may limit the choice of moulding methods. Crawford .

Extrusion is a plastic deformation process in which a block of billet is forced to flow by compression through the die opening of a smaller cross-sectional area.

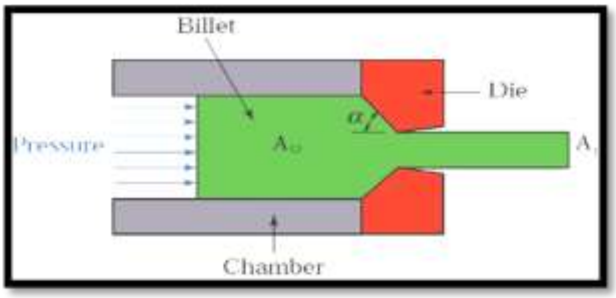

Figure 1.2 Definitions and Principle of Extrusion. Scribed

SINGLE SCREW

In infusion shaping the reason for the screw extruder is just to get a dissolve, a dedicated expulsion machine takes a shot at a similar rule additionally should blend, homogenize and soften the material. Higher back weight might be created in single screw expulsion machines contrasted with infusion forming machines and the screws might

ISSN 2277–5528
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be longer for better blending. In mix with the barrel, the reason for the screw is to change over sol-id material to the dissolve zone, soften, and blend and pump material to the kick the bucket in a proficient way. The screw outline and length of screw will rely on upon the polymer being prepared and additionally the application. Expanding the limit by "pumping" more mama terial through the screw should be possible by expanding the length of the screw as well as flight dept, yet this exclusive serves to a point.For hard to melt materials or to increase melt homogeneity, a second or third flight may be added to a screw in order to prevent unmelted material from reaching the die. Scribd

MECHANISM OF FLOW

As the plastic moves along the screw, it melts by the following mechanism. Initially a thin film of molten material is composed at the barrel walls. As the screw rotates it scrapes this film off and molten plastic moves down the front face of the screw flight. When it reaches the core of the screw it sweeps up again, establishing a rotary kineticism in front of the leading edge of the screw flight. Initially the screw flight contains solid granules but these incline to be swept into the molten pool by the rotary kineticism. As the screw rotates, the material passes further along the barrel and more and more solid material is swept into the molten pool until eventually only melted material subsists between the screw flights. Crawford

As the screw rotates inside the barrel, the kineticism of the plastic along the screw is dependent on whether or not it adheres to the screw and barrel. In theory there are two extremes. In one case the material sticks to the screw only and ergo the screw and material rotate as a solid cylinder inside the barrel. This would result in zero output and is pellucidly undesirable. In the second case the material slips on the screw and has a high resistance to rotation inside the barrel. This results in a pristinely axial kineticism of the
melt and is the ideal situation. In practice the demeanor is somewhere between these lim-its as the material adheres to both the screw and the barrel. The utilizable output from the extruder is the result of a drag flow due to the interaction of the rotating screw and sta-tionary barrel. This is equipollent to the flow of a viscous liquid between two parallel plates when one plate is stationary and the other is moving. Superimposed on this is a flow due to the pressure gradient which is built up along the screw. Since the high pres-sure is at the cessation of the extruder the pressure flow will reduce the output. In integration, the clearance between the screw flights and the barrel sanctions material to leak back along the screw and efficaciously reduces the output. This leakage will be worse when the screw becomes worn.Crawford .
The external heating and cooling on the extruder also plays an important part in the melting process. In high output extruders the material passes along the barrel so quickly that sufficient heat for melting is generated by the shearing action and the barrel heaters are not required. In these circumstances it is the barrel cooling which is critical if excess heat is generated in the melt. In some cases the screw may also be cooled. This is not intended to influence the melt temperature but rather to reduce the frictional effect be-tween the plastic and the screw. In all extruders, barrel cooling is essential at the feed pocket to ensure an unrestricted supply of feedstock. Crawford

Die Design

Die characteristic for rectangular cross section can be extracted using the following formula. Where

$Q = KP$

$K = Fbd^3/12\eta L_d$ (2.0)

$Q = (Fbd^3/12\eta L_d) * P$ (2.1)

Where b is the greater dimension of the cross-section d is the least dimension of the cross-section

F is a non-dimensional factor (Flow coefficient).

L_d is the length of the Die.

The flow coefficient can easily be obtained from figure 1.3

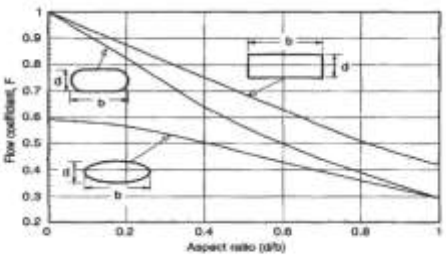

Figure 1.3. Flow coefficient as a function of channel geometry [Crawford (2, p.260)]

Using equation (2.1) it is possible to modify the expression for the operation pressure to the more general form. Crawford

$$P_{op} = \left\{ \frac{2\pi\eta D^2 NH sin\emptyset cos\emptyset}{\frac{Fbd^3}{3\pi Ld} + \left(\frac{DH^3 \sin^2 \emptyset}{3Ld}\right)} \right\} \quad (2.2)$$

Pressure Gauges

 ISSN 2277–5528
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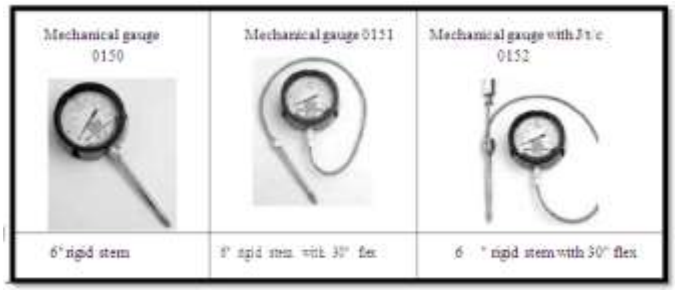
Gauges are simple to install and facile to utilize. Mechanical gauges do not require any wir-ing. Gauges are ideal for providing a general designation of processing conditions includ-ing contamination build-up on screen packs. Digital gauges can be acclimated to cease the operation of the extruder afore rupture disks are blown.

Gauge Types

Mechanical gauges

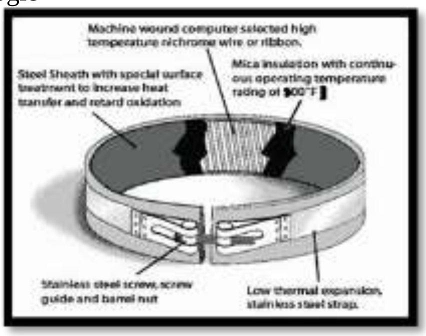


Digital gauges		
Digital gauge 0250	Digital gauge 0251	Digital gauge with J/t/c 0252
6" rigid stem	6" rigid stem with 30"flex	6" rigid stem with 30" flex

HEATING ELEMENTS

Thermal Corporation's band heaters are made to heat cylinders, such as pipes, barrels, or nozzles of injection molding and extruding machines. Mica band heaters are constructed by winding a resistance wire or ribbon around a sheet of mica, sandwiching that element between two other sheets of mica, and then forming coated steel around the assembly.

Mica-type band heaters have several advantages over other types of band heaters, but the thing that makes them the most used heater in the plastics industry is the combina-tion of reasonable high-watt density capabilities, reasonably high temperature capabili-ties (900 degrees Fahrenheit), good efficiency, good lifetime and low cost. Google



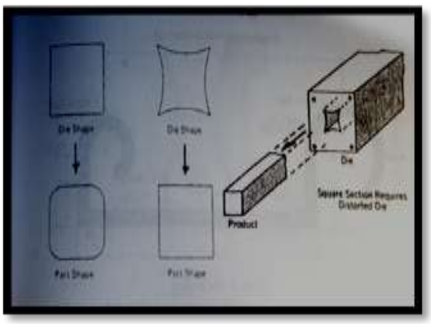


Figure 2.4. Standard mica band heaters. Figure2.5. Effect of die orifice shape on a square extrudate. Rosato

COSTING

In an engenderment line that has relatively long run, the cost of equipment includes its financial amortization, and could be about 5%. Plastic material cost could be as high 80% for high volume engenderment. The other costs include potency, dihydrogen monoxide, labor, overhead and taxes. With precision, short run costs could be equipment as 20-30%, and materials at 45-50%. So, as it is customarily verbalized, do not buy equipment just because it costs less, since more profit can occur with the more extravagant equipment. Of course, the inversion is pos-sibly true. So, buyer has to ken what is wanted when injuctively authorizing. A line with 1000-4000lb/h output would cost $0.5-1 million.

When you want to change a screw to see how your process is running, it seems expensive to take such action. Consequently, many people tend to run a poorly performing screw long after it should have been changed. Converting the cost of screw into an equivalent volume of plastic or into a profit per day will determine payback. Rauwendaal When you optate to transmute a screw to optically discern how your process is running, it seems expensive to take such action. Consequently, many people incline to run a poorly performing screw long after it should have been transmuted. Converting the cost of screw into an equipollent volume of plastic or into a profit per day will determine payback. Rauwendaal

Whenever possible, observing the following practices will help to reduce costs:

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1. Strive for the simplest shape and form
2. Combine parts into single extrusions or use more than one die to extrude products/use multiple die heads and openings
3. Make gradual changes in thickness to reduce frozen stress
4. Where bends occur, use maximum permissible radii
5. Purchase plastic material as economical as possible and
6. Keep customers tolerance as liberal as possible, but once in production aim for tighter tolerances to save material costs and also probably reduce production costs.

DIE LANDING

A very consequential dimension is the length of the parallel die land. In general, it should be made as astronomically immense as possible. However, the total resistance of the die should not be in-creased to the point where exorbitant power consumption and melt overheating occur. The required land length depends not only the type and temperature of the thermoplastic melt but additionally on the flow rate. The deformation of the melt in the ingress section of the die invariably causes strain which only gradually decreases with time (relaxation). Customarily the target is to sanction the melt to relax afore reaching the die. Otherwise the product dimensions and the mechanical properties may vary, categorically with rapid cooling.

POLYMERIC MELT BEHAVIOR

RHEOLOGY

Rheology is the science of deformation and flow of materials. The Society of Rheology's Greek motto "Panta Rei" translates as "All things flow." Genuinely, all materials do flow, given adequate time. What makes polymeric materials intriguing in this context is the fact that their time constants for flow are of the same order of magnitude as their processing times for extrusion, injection molding and blow molding. In very short processing times, the polymer may deport as a solid, while in long processing times the material may deport as a fluid. This dual nature (fluid-solid) is referred to as Viscoelas-tic behavior. Richardson

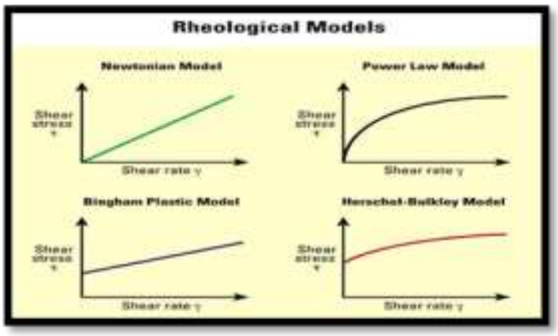

Figure 2.6. Rheological models [12]

Most polymer processes are dominated by the shear strain rate. Consequently, the viscosity used to characterize the fluid is predicated on shear deformation quantification devices. The rheological models that are utilized for these types of plows are conventionally termed Generalized Newtonian Fluids. In a Generalized Newtonian Fluids model, the stress in flu-id is dependent on the second invariant of the stain rate tensor, which is approximated by the shear rate in most shear dominated flows. The temperature dependence of GNF fluids is generally included in the coefficients of the viscosity model. Sundry models are currently being used to represent the temperature and strain rate dependence of the viscosity.Ricardson

VISCOELASTIC FLUID BEHAVIOR

This type of fluid comportment is characterized by the esse of yield stress which must be exceeded afore the fluid will deform or flow. Conversely, such a material will de-form elastically when the externally applied stress is more minute than the yield stress. Once the magnitude of the external stress has exceeded the value of the yield stress, the flow curve may be linear or non-linear but will now pass through inchoation. Hence in the absence of surface tension effects, such a material will not level out under gravity to compose an absolutely flat free surface. Once can however, expound this kind of fluid demeanor by postulation that the substance at rest consists of three-dimensional structures of sufficient rigidity to resist any external stress less than zero. For stress level more preponderant than zero. However, the structure breaks down and the substance deports like viscous material. In some cases, the buildup and breakdown of structure has been found to be reversible, i.e., the substance may regain its initial value of the yield stress. Richardson.

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A non-Newtonian fluid is a one whose flow curve (shear stress versus shear rate) is non-linear or does not pass through the inception, i.e. where the ostensible viscosity, shear stress divided by shear rate, is not constant at a given temperature and pressure but is dependent on flow conditions such as flow geometry, shear rate, etc. and sometimes even on the kinematic history of the fluid element under consideration. Such materials may be conveniently grouped into three general classes:

- o Fluids for which the rate of shear at any point is resolute only by the value of the shear stress at the point at that instant; these fluids are variously kenned as "time independent", "purely viscous", "inelastic" or "generalized Newtonian fluids.
- o More involutes fluids for which the cognation between shear stress and shear rate depends, in additament, upon the duration of shearing and there kinematic history; they are called "time dependent fluids. and determinately,
- o Substances exhibiting characteristics of both ideal fluids and elastic solids and exhibiting partial elastic instauration, after deformation; these are categorized as "visco-elastic fluids"

This relegation scheme is arbitrary in that most authentic materials often exhibit a combination of two or even all three types of non-Newtonian features. Generally, it is, however, possible to identify the ascendant non-Newtonian charactertics and to take this as the substratum for the subsequent process calculations. Additionally, as mentioned earlier, it is conve-nient to define an ostensible viscosity of these materials as the ratio of shear stress to shear rate, though the latter ration is a function of the shear stress or shear rate and /or of time. Richardson

MELT BEHAVIOR

A critical way to deal with dissolve stream conduct is to perceive that the extruder and pass on work as consolidated unit. The communication amongst screw and kick the bucket is generally spoken to by demonstrating the reliance of the yield on the soften weight between and the screw and bite the dust head. The screw requires that the thickness of the thermoplastic does not change either in the metering zone or in the bite the dust. This implies temperature and weight changes and different impacts on consistency must be maintained a strategic distance from however much as could reasonably be expected. The weight drop through a pass on fluctuates straightforwardly with the land length and conversely with the 3D square of the hole opening. Richardson

The non-Newtonian conduct of plastic makes its sparkle through a bite the dust fairly complicated. At the point when a liquefy is expelled from the pass on, there is generally some level of welling. In the wake of leaving the bite the dust, it is typically extended or attracted to a size equivalent to or littler than the bite the dust opening. The measurements are diminished relatively so that, in a perfect plastic, the draw down area is the same as the first segment however littler relatively in each measurement. The impacts of soften flexibility imply that the plastic does not drawdown in a basic corresponding way; along these lines the drawdown procedure is wellspring of blunders in the profile. The blunders are altogether lessened in a round exturdate, for example, pipe and wire covering .These mistakes are remedied by adjusting the bite the dust and downstream prepare ment.Richardson

Another important characteristic is that melts are affected by the orifice shape. The effect of the orifice is related to the melt condition and the die design with a slow cooling rate having a significant influence, especially in thick products. Cooling is more rapid at the corners; in fact, a hot center section could cause a product to blow outward and /or include visible or invisible vacuum bubbles. The popular coat-hanger die, used for flat sheet and other products, illustrates an important principle in die design. The melt at the edges of the sheet must travel further through the die than the melt that goes through the center of the sheet. A diagonal melt channel with a triangular dam in the center is a way of restricting the direct flow to some degree. Richardson

DENSITY

Plastics pellets, granules or beads vary in sizes and in densities. The table below shows the most common plastics with their respective densities and melting points.

Table 1.1. Density and melting points of some common plastics. Charles

Material	Density(g/cm^3)	Melting Point(°C)
Low density polyethylene	0.93	115
High density polyethylene	0.96	137
Polycarbonate	1.20	265
Polypropylene	0.90	175
Polyamide	1.14	265

When a plastic is extruded it's very crucial to understand when to use the bulk density and melt density values.

Melt Density

The melt density of neat polymer is an inherent property of the polymer and can be al-tered by fillers. "The melt density is measured as function of temperature at ambient pressure. The output rate of the polymer will be proportional to the melt density of the polymer". Chung insists that "various polyethylene with different solid densities have the same melt density and the same compressibility. The melt density of a polyethylene at ambient pressure and 220C is 0.7432 g/cm^3" Chung

BULK DENSITY

"The mass thickness of a polymer is characterized as the heaviness of the encourage test, case as pellet, separated by the obvious volume of pellets or the compartment" According to Chung the mass thickness relies on upon the size, geometry and conveyance of pellets and additionally the polymer properties.. Chung contends that the mass thickness is specifically proportional to the yield rate per screw rpm and that the higher the mass thickness the higher the yield rate at a characterized screw speed. "For a solid bed the bulk density increase with in-creasing pressure as the pellets are compressed "Chung

BALANCE EQUATIONS

In extrusion, as well as in many other processes, one deals with the transport of mass, momentum and energy. Balance equations are used to describe the transport of these quantities. They are universal physical laws that apply to all media. A matter is considered as a continuum. Thus, the volume over which the balance equation is formulated must be larger enough to avoid discontinuities. Richardson

MOMENTUM BALANCE EQUATIONS

The momentum of a body is the product of its mass and velocity. Since velocity is a vector, momentum is withal vector. The momentum balance equation describes the conservation of momentum; it is additionally referred to as the equation of kineticism.

Momentum can be conveyed by convection and conduction. Convection of momentum is due to the bulk flow of the fluid across the surface; associated with it is a momentum flux. Conduction of momentum is due to intermolecular forces on each side of the surface. The momentum flux associated with conductive momentum conveys is the stress tensor. The general momentum balance equation is withal referred to as Cauchy's Equation. The Navier Stokes equations are as special case of the general equation of kineticism for which the density and viscosity are constant. The well known Euler equation is again a special case of the general equation of motion; it applies to flow systems in which the viscous effects are negligible. Richardson

ENERGY BALANCE EQUATIONS

The energy balance equation states that the rate of incrementation in concrete internal (thermal) energy in a control volume equals the rate of energy additament by conduction plus the rate of energy dissipation. The principle of energy conservation is additionally described by the first law of thermodynamics.

The energy equation has to be acclimated to analyze non-isothermal processes. In these situa-tions, there are generally four unknown variables: velocity, stress, pressure, and temper-ature. In order to solve such a non-isothermal quandary, one more equation is needed in additament to the three balance equations. The missing relationship is the constitutive equ-ation of the fluid; this relationship fundamentally describes the relationship between stress and deformation. In polymer extrusion the material undergoes sizably voluminous transmutations in tempera-ture as it is conveyed along the extruder. Consequently, the energy equation is utilized extensively in the analysis of the extrusion process. Richardson

MASS BALANCE EQUATIONS

The mass balance equation, withal referred to as equation of continuity, is simply formula-tion of principles of the conservation of mass. The principle states that the rate of mass accumulation in control volume equals the mass flow rate into the control volume minus the mass flow rate out of the control volume. Richardson

FLOW ANALYSIS

DRAG FLOW

Drag flow is flow caused by the relative kineticism of one or more boundaries with reverence to the other boundaries that contain the fluid. It's additionally referred to as Couette flow, al-though Couette flow is only a categorical type of drag flow. Drag flow is consequential in ex-trusion. The two major boundaries that contain the polymer in the extruder are the barrel surface and the screw surface. Since the screw is rotating in a stationary barrel, one boundary is moving relative to the other; this causes drag flow to occur. Rauwendaal

PRESSURE FLOW

Flow caused by the presence of pressure gradients in the fluid; in other words local dif-ferences in the pressure. One of the most common examples of pressure flow (pressure driven flow) is the flow of water that occurs when one opens a water faucet. This flow occurs because the pressure upstream is higher than the pressure at the faucet. There is no relative motion of fluid boundaries (wall of the water pipe); thus, this pure pressure flow. In most extruder dies, the flow through is a pure pressure driven flow. The poly-mer melts flow through the die as a result of the fact that the pressure at the die inlet is higher than the pressure at the outlet. The flow rate is determined by the pressure at the die inlet, often referred to as die head pressure. Rauwendaal

SHEAR RATE

The difference in velocity per unit normal distance (normal to the direction of flow). The rate of shearing or shear rate is one of the most important parameters in polymer melt processing. If the process is to be described qualitatively, the shear rate in the fluid at any location needs to be known. Rauwendaal

$$\text{Shear rate, } \gamma = \frac{6\,Q}{W\,H^2} \qquad (2.3)$$

SHEAR STRAIN

Displacement (in the direction of flow) per unit normal distance over a certain time pe-riod. The units of shear rate are s-1 and the shear strain is dimensionless number. Rauwendaal

SHEAR STRESS

The stress required to achieve a shearing type of deformation. Which a fluid is sheared, a certain force will be required to bring about the deformation. This force divided by the area over which it works is the shear stress. Rauwendaal

FLOW MODELS

NEWTONIAN AND NON-NEWTONIAN FLUIDS

The concepts of Newtonian and non-Newtonian fluids can be well acknowledged when viscosity is explicated. The viscosities of some fluids depend on shear rates whilst others are not. It may be recalled that the viscosity of fluid is result of internal friction of fluid molecules.

NEWTONIAN FLUIDS

Fluids with constant viscosity at constant temperature independent of shear rate are Newtonian fluids; example is dihydrogen monoxide. The figure below shows how fluids are characterized as Newtonian and non-Newtonian in cognation with shear.

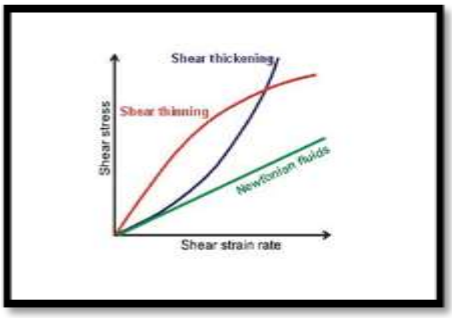

Figure 2.7. Newtonian Fluids

NON-NEWTONIAN FLUIDS

The viscosity of polymer melt (complex fluids) at a constant temperature depends on shear rate. The structures of the fluid change with shear rate. A fluid that has its viscosi-ty depending on a shear rate at constant temperature is called a non-Newtonian fluid (Chung, 2000). There are two types of non-Newtonian fluids. These are dilatants and pseduoplastics. “The viscosity of the dilatants fluid increase with shear” and “the vis-cosity of the pseduoplastics fluid decrease with shear” (Chung, 2000, p.102). The pse-duoplastics are shear thinning fluids whilst the dilatants are the shear thickening fluids. Polydynamics

POWER LAW MODEL

“The power law model is one of the simplest models for presenting the viscous-shear behavior of plastic melt. The law accurately demonstrate the shear thinning region in the viscosity versus strain rate curve”. The proponents of the law suggested the relationship between viscosity and shear rate as follows:

	$\eta = m(T^oC)\gamma^{n-1}$	(2.4)
Where	m = consistency index	
	n = power law index	

Table 1.2. Power law parameters for some common plastics. Charles

Polymer	$m(Pa\text{-}s)^n$	n	T(°C)
High density PE	2.00×10^4	0.41	180
Low density PE	6.00×10^3	0.39	160
PP	7.5 0x 10^3	0.38	200
PA 66	6.00×10^2	0.66	300
PC	6.00×10^2	0.98	300

The power law is usually represented as = m γ^{n-1}, where m is sometimes replaced by ‘k’ or other letter (Michaeli, 2003, p.22). The consistency index is said to include the temperature dependence of the viscosity whilst the power law index represents the shear thinning behavior of the polymer melt. “The limits of the law are zero (0) and infinity” Osswald

η approaches 0 when shear rate goes into infinity and η approaches infinity as shear rate becomes very infinitesimal.

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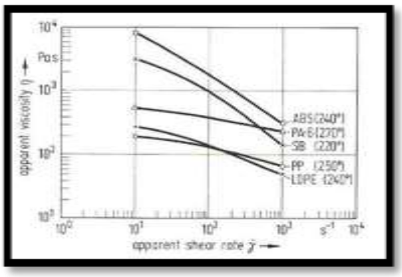

Figure 2.8. Viscosity - Shear rate curve for some common plastics

DRAG AND PRESSURE FLOWS

Once the extrusion process is started, it is important to know how much material is fed into the system and how much is extruded out, for example in a given time interval and a screw rpm. According to Eric A Grulke the flow process occurs in tow phases. These phases are drag and pressure phases. The flow due to the internal friction between the malt pool and the barrel walls and the shear action of the screw constitutes the drag flow [Eric Grulke, p.553]

The pressure flow of a fluid is cause by a pressure difference. “The pressure drop is li-near in direction of flow in channels with parallel walls. In the metering section an ex-truder screw, pressure flow is the relatively backward flow of material down the screw channel caused by pressure in the head” Polydynamics

Flow analysis

The pressure distribution of the flow in the extruder is the total output obtained from the drag flow, back pressure flow and leakage. Assuming that there is no leakage. The extruder and die characteristics graph can be extracted.

$$Q = \frac{1}{2}\pi^2 D^2 NH \sin\emptyset \cos\emptyset - \frac{\pi D H^3 \sin^2\emptyset}{12\eta}\frac{P}{L} = Q_d - Q_p$$

Where

Qd – Drag flow (m^3/s)

Qp – Pressure flow

D – Diameter of the screw (m)

N – Screw revolution (rpm)

H – Channel depth of the screw (m)

ϕ– Helix angle of screw

L – Length of the screw (m)

P – Operation pressure (Pa)

η–Viscosity (Pa.s) (Crawford, 1998. P.256)

When there is no pressure build up at the end of the extruder, any flow is due to drag and maximum flow rate Qmax can be obtained. The equation then can be reduced to only the drag term as follows.

$$Q = Q_{max} = \frac{1}{2}\pi^2 D^2 NH \sin\emptyset \cos\emptyset \qquad (2.5)$$

Similarly, when there is a high pressure drop at the end of the extruder the output of the extruder, Q becomes equal to zero (Q=0) and the maximum pressure is obtained from the equation.

$$\frac{1}{2}\pi^2 D^2 NH \sin\emptyset \cos\emptyset = \frac{\pi D H^3 \sin^2\emptyset}{12\eta}\frac{P}{L} \qquad (2.6)$$

$$\text{Hence } P = P_{max} = \frac{6\pi D L N\eta}{H^2 \tan\emptyset}$$

(Crawford, 1998, p.257)

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EXPERIMENTAL SETUP & ANALYSIS

DIE MODELING

Based on the theoretical framework an extrusion die has been modeled using Solid Edge ST software. The design is made for a rectangular profile that has dimension of 7mm X 2 mm.

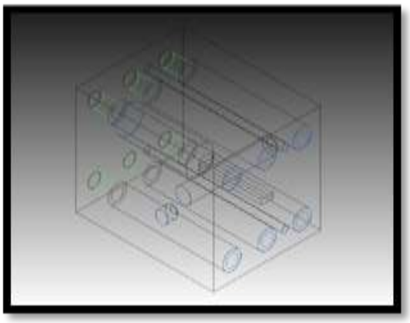


Figure 3.1. Solid Edge modeling of the Die

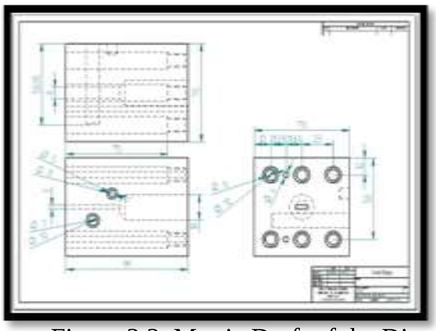
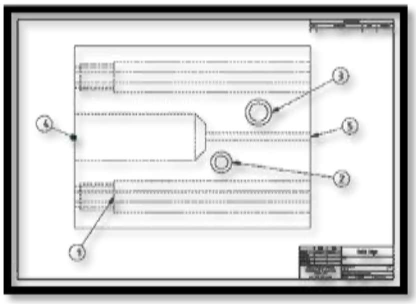


Figure 3.2. Metric Draft of the Die

The whole die body has a dimension of 80 mm*60mm*60mm. In order to minimize the amount of die swell the die land has to be long as much as possible. Therefore the die length has been given a size of 30mm. The metric draft of the die is shown below in Figure.

Figure 3.3. Die detailed drawing

1. Bolts
2. Heat sensor
3. Heating element
4. Die inlet
5. Die outlet



3.2 Extruder line calculation

From equation (2.5) and (2.6) the point for the extruder line can be obtained. Based on the above information the maximum flow rate has been calculated for the screw para-meter of D = 0.170m, ∅ = 14.5° , N = 30rpm L= 0.60m and H = 0.004m at P = 0.

$$Q_{max} = \frac{1}{2} \pi^2 (0.170m)^2 (\frac{30}{60} S)(0.004) \sin 14.5° \cos 14.5°$$
$$= 6.84 \times 10^{-7} m^3/s$$

Similarly, P_{max} can be determined when Q = 0

$$P_{max} = \frac{6\pi DLN\eta}{H^2 \tan\emptyset}$$

Viscosity, = m γ^{n-1} where n = 0.39 as shown in Table 2
Shear rate for a quadratic cross section is given by $\gamma = 6Q/WH^2$

Where W = width and H = height of the rectangular channel that the melt flows through. In this case Q is the experimental flow rate through the channel, in order to be able to get the shear rate or viscosity. Using formula (2.3) the shear rate can be extracted as follow.

$$= \frac{6(6.84*10^{-7})}{(0.008)*(0.003)^2} = 56.94.1 s^{-1}$$

Therefore

$= m\ \gamma^{n-1}$

$= (6*10^3\ Pa.s)\ (56.94 s^{-1})^{0.39-1}$

$= 509.73$ Pa.s

Based on the viscosity-shear rate curve this value is too high. Since the maximum vis-cosity for LDPE at 240ºC is 300 Pa.s. The shear rate value of 56.94 s^{-1} corresponds to ap-proximately 200 Pa.s.

$$P_{max} = \frac{6\pi DLN\eta}{H^2 tan\emptyset}$$

===

$= 6*\pi *(0.0170m)(0.60m)(30/60s)(200Pa.s) /(0.004m)^2$ tan14.5

= 4.8 MPa

When Q=0

This is the maximum pressure obtained when the flow rate is minimum.

Die characteristic for rectangular channel

The die characteristic for a rectangular profile can be calculated using formula (2.1)

$$Q = \left(\frac{(0.78)x(0.008m)x(0.003m)^3}{12(200Pa.s)0.09}\right) X\ 4.8x10^6 MPa$$

$= 3.46*\ 10^{-6} m^3/s$

And the operating pressure is obtained from

$$P_{op} = \left\{\frac{2*\pi*(200Pa.s)(0.0170m)^2\left(\frac{30}{60s}\right)(0.004m)sin14.5cos14.5}{\frac{(0.78)(0.008m)(0.003m)^3}{3*\pi*0.09} + \left(\frac{(0.0175m)(0.004m)^3\ sin^2 14.5}{3(0.09)}\right)}\right\}$$

= 0.39 MPa

Qop= K*Pop

Where K = Fbd3/12Ld

$$Q_{op} = \left\{\frac{(0.78)(0.008)(0.003)^3}{12(200Pa.s)0.09}\right\} X\ 0.39 MPa$$

$= 3.04*\ 10^{-7} m^3/s$ points

Table 1.4 Subdomain settings for LDPE

	Q x 10^{-7}(m^3/s)	P X 10^6(Pa)	m(kg/hr)
Extruder	7.33	0	1.96
	0	4.8	0
Die	0	0	0
	39.7	4.8	10.5

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Operating Point	3.04	0.39	

Viscosity model type	Carreau model
Density of melt LDPE (rho)	743 kg/m^3
Zero shear rate viscosity	1437.4 Pa.s
Model parameter (n)	0.39
Model Parameter (λ)	0.015s

The initial velocity value of the polymer was calculated based on the maximum extrusion output.

$$Q_{max} = \frac{1}{2}\pi^2(0.170m)^2(\frac{30}{60}s)(0.004)\sin 14.5^\circ \cos 14.5^\circ$$
$$= 7.03 \text{ X } 10^{7} \text{ m}^3/\text{s}$$

But since the software doesn't understand the unit we have to convert it into velocity by dividing it by the inlet area. The exact area of the inlet and the outlet of the die were extracted from the Comsol multi physics software. Utilizing the software it was possible to obtain the precise areas utilizing the Geometric properties option.

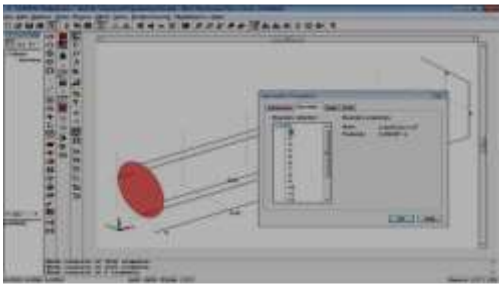

Figure 3.4. Die inlet area

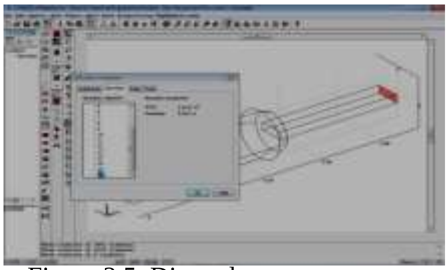

Figure 3.5. Die outlet area

The following stride is make sense of the speed drop at the delta of the pass on. This can be ascertained utilizing the drag stream, which is greatest toward the finish of the extruder (at the en-stupor of the bite the dust) and the passage region of the Die.

$$Q = \text{Velocity} * \text{Area}_{in}$$

$$V = Q / A$$

$$= 7.03 \text{ X } 10^{-7} \text{ m}^3/\text{s} / 2.51 \text{ X } 10^{-4} \text{ m}^2$$

$$= 1.08 \text{ X } 10^{-3} \text{ m/s}$$

Once the velocity is obtained, the next thing would be to analyze the die on Comsol software to get the suitable pressure that corresponds to the velocity.

Result & Discusison

POST PROCESSING

Here the mass flow rate of the die was analyzed at a pressure value of 0.39 MPa. This is the calculated operating pressure. The velocity field obtained at the center of the rectangular section of the die is as follow.

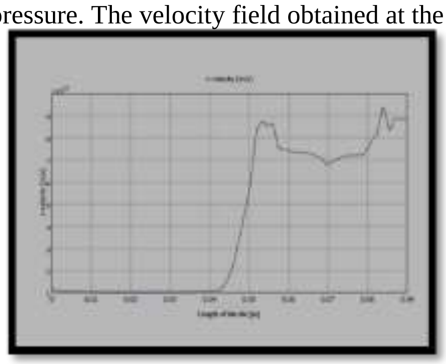

Figure 4.1 Velocity curve at 0.39 MPa

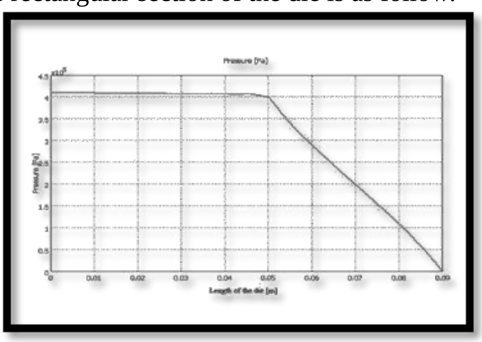

Figure 4.2 Pressure curve

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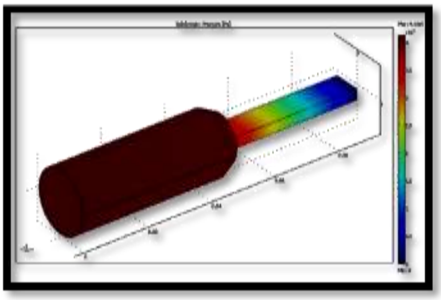
From this graph we can conclude that the pressure at the end of the extrude is always going down to zero. Since the objective is to find the mass flow rate at the pressure of 0.39MPa.



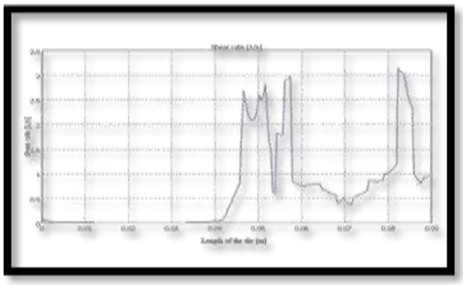
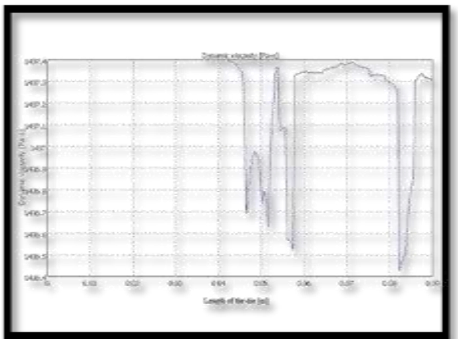


Figure 4.3. Pressure distribution in the die at 0.39MPa   Figure 4.4. Shear rate curve at 0.39MPa

In order to maintain a uniform flow, the ratios of inlet velocity to the outlet velocity has to be equal to the ratio of the outlet area to the inlet area in the direction of flow. Calculating the area ration from Figure 3.4 and 3.5 gives a value of 0.1.

The ratio of the velocites is

$$V_{in}/V_{out} = 1.13*10^{-3}/8.86*10^{-3} = 0.12$$



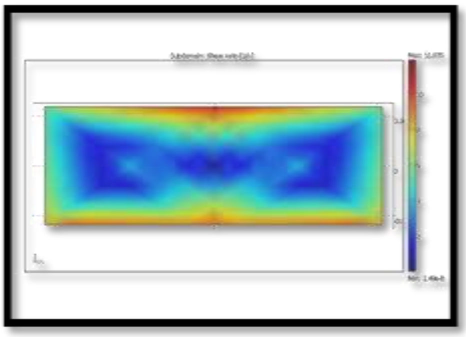


Figure 4.5. Dynamic Viscosity Curve   Figure 4.6. Uneven stress distribution at the corners

As shown in the above image the stress at the corners of the rectangular section is not even. This causes the extrude to swell and comes out with oval shape. This can be solved by optimizing the die geometry and trying to even the stresses at the corners.

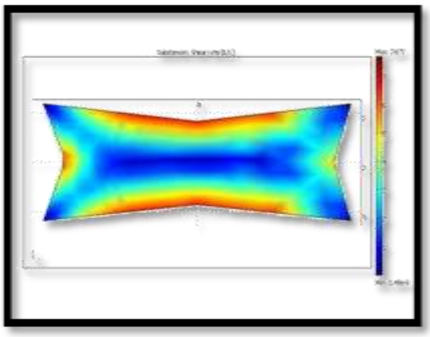


Figure 4.7. Optimized die geometry

In Figure 4.7 the die shape has been optimized in order to get nearly similar stresses at the corners of the die.

Conclusion

In this proposition work a pass on with rectangular hole has been demonstrated and recreated on PC programming. The working weight was computed and mass stream rate was acquired.
The Carreau model was utilized to dissect the pass on COMSOL multi material science programming and the pass on was intended for a LDPE plastic material at around 210 degree centigrade. In view of the extruder's fasten parameter the

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stream rate the extruder was computed. This gets the weight in the extruder. That is, the point at which the weight is at its minimum there will be most extreme yield and when the volume stream rate is at its base there will be greatest weight. Despite the fact that the bite the dust has been enhanced keeping in mind the end goal to get comparable shear push appropriations over the pass on. It was impractical to mimic the correct measurements of the pass on for a rectangular profile with COMSOL.

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