CZECH TECHNICAL UNIVERSITY
PRAGUE

FACULTY OF MECHANICAL ENGINEERING

Department of Process Engineering

Master Thesis

Model of polymer melt flow in extruder screw

MASTER'S THESIS ASSIGNMENT

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II. Master's thesis details

Master's thesis title in English:

Model of polymer melt flow in extruder screw

Master's thesis title in Czech:

Model of polymer melt flow in extruder screw

Guidelines:

The extrusion production process plays important role in the process industry. It is important to know the velocity field in the cavity of screw when screw design for melt transportation is performed. The melt has to be homogenized also considering heat transfer into the mass from heated screw cylinder. The objective of the thesis are:

1. Perform the literature search concerning the extrusion process, devices and fluid flow phenomena in the extrusion screw.
2. Create a model of melt flow in the screw of extruder for given geometric parameters of screw, physical parameters of melt and operation conditions of process. The screw revolution is constant and model will not include heat transfer.
3. Investigate the velocity field in the cavity of screw and perform approximately comparison of pressure loss with calculation or values from literature.

Bibliography / sources:

Baird D.G., Collias D.I.: Polymer Processing, Principle and Design, Wiley, 2014.
Barnes H.A.: A Handbook of Elementary Rheology, University of Wales, 2000.
Osswald T.A. et. al.: International Plastics Handbook, The Resource for Plastics Enginneers Hanser, 2006.
Margolis J.M.: Engineering Plastics Handbook, McGraw-Hill, 2006.

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Date of master's thesis assignment: **23.04.2018** Deadline for master's thesis submission: **08.06.2018**

Assignment valid until: ____________

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III. Assignment receipt

The student acknowledges that the master's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

30-04-2018

Date of assignment receipt

Student's signature

Declaration

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I declare that I have produced the submitted work independently and that I have provided all the information sources used in accordance with the Methodological Guideline on Ethical Principles in the Preparation of Graduate Final Theses.

In Prague on .... …………….

UDIT NEGI

THANKING YOU

The warm thanks go to my supervisor Mr. Ing. Jan Skočilas for the time spent in the consultations and for the perfect leadership in my Master’s thesis.

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Abstract

First part of diploma thesis shows research in polymer melt flow in Extruder. In the next part Velocity and pressure drop from obtained data from the literature is found . With volumetric flow and pressure drop is obtained. Next part of diploma thesis is CFD analysis and its results are compared with data from analytical solution In the penultimate part, are investigated the CFD analysis changes in the pressure drop, depending on the model and voundary conditions.

1. Introduction

The diploma thesis deals with polymer melt flow in extruder screw.It is important to know the velocity field in the cavity of screw when screw design for melt transportation is performed. The melt has to be homogenized also considering heat transfer into the mass from heated screw cylinder. Create model of melt flow in the screw of extruder for given geometric parameters of screw, physical parameters of melt and operation conditions of process. The screw revolution is constant, and model will not include heat transfer. The results of thesis will be the determination of velocity field in the cavity of screw and approximately comparison of pressure loss with calculation or values from literature

The screw extruder is one of the most important processing machines of polymer ,and it also takes over a growing number of tasks in the processing of chemical or pharmaceutical product and food industries .Example are blending and compounding of polymers, mixing and compacting of detergent and processing of corn .In such extruders, mixing takes place due to the high interaction of rotating screw and stationary wall, in twin screw system also due to the strong screw-screw interaction, effective convective flow and shear stresses. The flow patterns in Single screw system can be viewed as a modified coquette flow, the complexity of flow in a twin – screw system is drastically magnified by the high stresses in the intermeshing region between the screws. The resulting flow is 3D due to the passage of the screw flights, periodic and for the common application with highly viscous fluid, laminar. There is a periodicity of geometry that makes it sufficient to analyse only one spatial rotation of the screw flight. The computational fluid dynamic (CFD) program FLUENT, using the finite volume method with a collocated variable arrangement, is employed for simulation in 3D domain. Simulation by computational fluid dynamic (CFD) is becoming an increasingly useful tool in analysis of the flow In Extruder .However, the development of accurate and efficient modelling method is a continuing process. Several approaches have been taken to this problem Firstly, it deals with the research in the field of extruder, what is extruder, polymer and melt flow. Part of the research is also the Newtonian fluid and power law fluid as well. There are described basic types of extruder and their extrusion process in process industry. The research section includes the possibility of solving the pressure difference and velocity profile .Other parts of the diploma thesis deal with the solution of a specific case of velocity field in the cavity of screw and perform approximately comparison of pressure loss with analytical solution. Initially, simulation of extruder in the ANSYS Fluent program was carried out with the basic dimensions. The pressure drop was determined from this simulation. Furthermore, an analytical calculation of the pressure drop was carried out using parallel plates (stationary and movable). The resulting values were compared and the model was judged appropriate. Furthermore in the thesis comparing four models which are Newtonian fluid with rotation wall, Newtonian fluid with fixed wall, power law fluid with fixed plate and last power law fluid with movable plate .In Ansys CFD w have to give them properties, melt flow in the screw of extruder and the very important point to remember in our model there is no heat transfer included. For the result i have to compare all the results of pressure drop from simulations and analytical solution.

2. Literature search

2.1 Extrusion process

Extruder process is described in [1], author: Chandramouli"*Extrusion is a compressive deformation process in which block of metal or small -2 ball of hard plastic or polymer is squeezed through the orifice or die in order to obtain a reduction in diameter and increase length of the metal,plastic or polymer block. The resultant product will have the desired cross section.Extrusion involves forming of axisymmetric parts. Dies of circular or noncircular cross section are used for extrusion. Generally, extrusion involves greater forming forces and hydrostatic stress in extrusion helps in the process by enhancing the ductility and hardness of the material. Metals like aluminum, which are easily workable, can be extrude at room temperature .On the other hand other difficult to work metal or material are usually hot extrude or warm extrude .Both circular and noncircular parts can be obtain by extrusion. Extrusion is very vast process now these days and used to produce ton of products in different industries like Channels, angel'srods, frames, aluminum fins, wires,tires, in different food industries as well. Difficult to form materials such as stainless steels, nickel alloys are extruding due to its inherent advantages such as no surface cracking due to reaction between the billets and the extrusion containers. Extrusion result in better grain structure, better accuracy and highly surface finish of the components. Less wastage of material and easily recycle of material is another attractive feature of extrusion process.*"

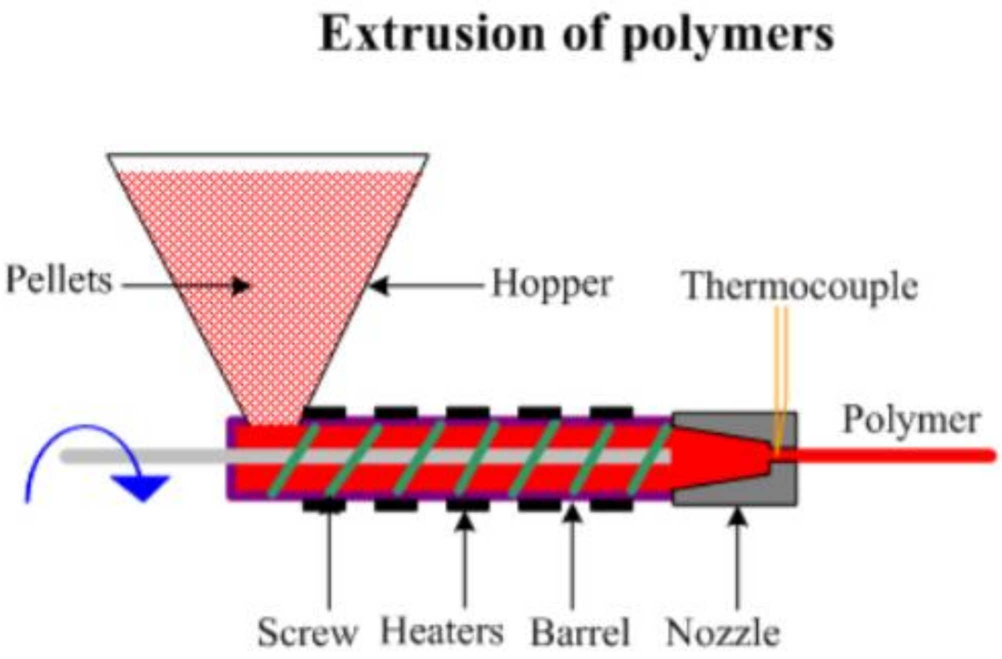


Figure 1.Extrusion of polymer.[2]

Extrusion of polymer is described in[2] author: Kopeliovich "*Especially for polymer,Polymer material in form of pellets is fed into an extruder through hopper. The material is then conveyed forward by a feeding screw and forces through a die, converting to continuous polymer product. Heating element, placed over the barrel for the purpose of soften and melt the polymer. The temperature of material of controlled by thermocouples. The product going out of the die is cooled by blown air or in water bath. Extrusion of polymer in comparison to extrusion of metal is continuous process lasting as long as raw pellets of polymer are supplied. Extrusion is mainly for Thermoplastic.*"

2.1.1 Hot Extrusion

Hot extrusion is described in [3] "*Hot Extrusion uses heated feedstock, called a billet, that ranges in temperature from 200° to 2,300° Fahrenheit, or 90° to 1,260° Celsius depending on the material.*

Aluminium is the most common hot extruded material, with billet temperatures ranging from 575° to 1,100° Fahrenheit, or 300° to 600° Celsius. Hot extrusion is always performed at temperatures much higher than the recrystallization temperature of the material to be *extruded. The heated billet is confined in a container, force is applied and the billet is extruded through a die or dies.*

Hot extrusion is used to produce close tolerance dimensions as well as smooth, fine surfaces. Additionally, and depending on the metal used, improved microstructures are obtained. The process is also very economical in that most of the metal extruded is usable.

The primary type of hot extrusion is direct, or forward, extrusion. Direct extrusion is commonly performed in horizontal hydraulic presses. The heated billet is loaded into a thick-walled container from which it is pushed through the extrusion die by a ram. Between the ram and the billet is an intermediate dummy block.

Lubrication is used to reduce friction along the billet length and its container. In operation, force increases rapidly as the billet is upset to fill the container, then increases further as breakthrough force before extrusion begins. Upon breakthrough, the force declines as billet length decreases until a minimum force is reached. As the billet thins, the force rapidly rises again to continue metal flow radially toward the die opening."

2.1.2 Plastics Extrusion

Plastics extrusion is described in [3]. "*Plastics extrusion is a continuous process in which thermoplastic feedstock is converted to a molten, viscous fluid and then extruded into various shapes such as bar, rod, tube, and pipe. Plastic extrusion is also used to produce various profiles such as angles and channel shapes as well as mono-filaments and wiring insulation.*

The most commonly extruded thermoplastics include nylon, polycarbonate, polyethylene, and polyvinyl chloride. Plastic extrusions are performed in a screw extrusion machine, with the machine's main components including a hopper, externally heated feed barrel, helically fluted extruder screw, and die assembly.

As the feedstock enters the feed barrel it is moved forward by the rotating screw. The feedstock is heated by its frictional movement as it is dragged forward. External heating bands help to bring the material to its final temperature.

Typical extruder screws move the thermoplastic material through four zones:

Feed zone – in which trapped air is forced from the stock. The feed zone has a constant flight depth. The flight depth is the distance between the major diameter at the top of the flight, and minor diameter of the screw at the base of the flight.

Transition zone – in this zone the flight depth decreases, compressing and plasticized the thermoplastic material.

Mixing zone – here the flight depth is constant and there may be a special mixing element to ensure the feedstock is completely plasticized and mixed into a homogenous blend.
Metering zone – the flight depth here is also constant but much smaller than in the mixing zone. This section acts as a pump forcing the material through the extruder die assembly.
The two principal plastic extrusion processes are:

- *Profile extrusion*
- *Blown film extrusion*

Profile extrusion is a horizontal process producing long continuous shapes which are cooled in long cooling tanks filled with water after exiting the die assembly. A final cutting operation reduces the extrusion to stock lengths for later use.
Blown film extrusion is a vertical process where molten plastic passes through a die having a 360 degree annular opening. The tubular film produced is then filled with air. As a result, the tube expands out into a bubble having a diameter larger than the diameter of the annular opening of the die. As the tube cools, it is pulled up and flattened as it passes through a series of rolls. These rolls maintain tension on the plastic film as it is eventually wound into a coil for later use."

Products of Extrusion is defined in [4] as:
The extrusion products include:

- *Plastic Film: This is generally used for packaging or sealed into bags.*
- *Plastic Tubing: Used for tubing and hose for laboratories, automobiles, etc.*
- *Plastic Pipe: Used for water, drains, gas, etc.*
- *Plastic Insulated Wire and Cable: Used in the industry and home for appliances, for communications, electric power distribution, etc.*
- *Feedstock for Other Plastics Processes: Extruders are widely used as compounders, or mixers The output from an extruder compounded is chopped or granulated to form the feed for another process, such as extrusion or injection molding.*
- *Plastic Coated Paper and Metal: Used for packaging.*
- *Sheet: Used for lighting, glazing, signs, etc.*
- *Filaments: Used for ropes, twine, brushes, etc.*
- *Nets: Used for soil stabilization, packaging, etc.*
- *Profile: Used for home siding, gaskets, windows, doors, tracks, etc.*

Monomer	Polymer	Properties	Uses
Ethene	Poly(ethene)	Flexible, cheap, electrical insulator	Plastic bags and bottles, coating on electrical wires
Propene	Poly(propene)	Flexible and strong	Buckets and crates
Chloroethane	Poly(chloroethene) or PVC	Tough, cheap and lost lasting	Window frames
tetrafluoroethene	Poly(tetrafluoroethene) or PTFE	Tough and non-stick	Non-stick coating on pans

Table 1. Polymer properties and uses [4]

2.2 Extruder – device and machines

The definition of extruder is prescribed, e.g. from this source [12]: ”*An ‘Extruder’ is an extruding machine that is used to extrude metals like copper, steel, aluminium and plastics. Some brittle metals can be extruded very easily through the extruder. The main function of an extruder is conversion of raw material directly into finished goods ready for supply and packaging.*”

In the extruding process the extruder creates enough pressure in the billet such that it can forcefully push or pull the material through the cross section of the die orifice and extrude the finished product.

The extruder extrudes shapes of constant cross section and thickness and both hollow as well as solid sections. The extruder can extrude continuous cross sections of the finished product or semi continuous cross sections depending on the sizes and application of the extruded product.

The Hot and Cold method is primarily used for metal extrusion. Some metals are melted completely before the process of extrusion and some metals are cold pressed also known as forging. Aluminum is the most common metal to be extruded. This process increases the material strength of the object that is extruded. Extruders are used to produce long continuous products such as tubing, tire treads, and wire coverings. They are also used to produce various profiles that can later be cut to length. Multirole calendars are used to make wide sheeting. In transfer and injection molds, the rubber mix is forced through channels into a mold chamber of the required shape, where it is cured under pressure. Tires are made of several components: bead wire, sidewall compound, inner liner, cord plies, belt package, and tread; these are brought together and assembled as a complete tire before being transferred to the curing press.

2.2.1TYPES OF EXTRUDER

Types of extruder is described in [5] author: Rauwendaal "*Extruders in the polymer industry come in many different designs. The main distinction between the various extruders is their mode of operation: continuous or discontinuous. The latter type extruder delivers polymer in an intermittent fashion and, therefore, is ideally suited for batch type processes, such as injection moulding and blow moulding. As mentioned earlier, continuous extruders have a rotating member, whereas batch extruders have a reciprocating member. A classification of the various extruders is shown in Table 2.*

The Single Screw Extruder

The Single Screw Extruder Screw extruders are divided into single screw and multi screw extruders. The single screw extruder is the most important type of extruder used in the polymer industry. Its key advantages are relatively low cost, straightforward design, ruggedness and reliability, and a favourable performance/cost ratio. The extruder screw of a conventional plasticising extruder has three geometrically different sections; see Fig. 2.. This geometry is also referred to as a "single stage." The single stage refers to the fact that the screw has only one compression section, even though the screw has three distinct geometrical sections! The first section (closest to the feed opening) generally has deep flights. The material in this section will be mostly in the solid state. This section is referred to as the feed section of the screw. The last section (closest to the die) usually has shallow flights. The material in this section will be mostly in the molten state. This screw section is referred to as the metering section or pump section. The third screw section connects the *feed section and the metering section. This section is called the transition section or compression section. In most cases, the depth of the screw channel (or the height of the screw flight) reduces in a linear fashion, going from the feed section towards the metering section, thus causing a compression of the material in the screw channel. Later, it will be shown that this compression, in many cases, is essential to the proper functioning of the extruder. Different Types of Extruders 14 2 Different Types of Extruders The extruder is usually designated by the diameter of the extruder barrel. In the U. S., the standard extruder sizes are 3/4, 1, 1–1/2, 2, 2–1/2, 3–1/2, 4–1/2, 6, 8, 10, 12, 14, 16, 18, 20, and 24 inches. Obviously, the very large machines are much less common than the smaller extruders. Some machines go up in size as large as 35 inches. These machines are used in specialty operations, such as melt removal directly from a polymerization reactor. In Europe, the standard extruder sizes are 20, 25, 30, 35, 40, 50, 60, 90, 120, 150, 200, 250, 300, 350, 400, 450, 500, and 600 millimetres. Most extruders range in size from 1 to 6 inches or from 25 to 150 mm. An additional designation often used is the length of the extruder, generally expressed as length to diameter (L /D) ratio. Typical L /D ratios range from 20 to 30, with 24 being very common. Extruders used for extraction of volatiles (vented extruders, see Section 2.1.2) can have an L /D ratio as high as 35 or 40 and sometimes even higher.”*

<table>
<tr><td rowspan="9">Screw extruder(Continuous)</td><td rowspan="5">Single screw extruders</td><td>Melt fed</td></tr>
<tr><td>Plasticizing</td></tr>
<tr><td>Single stage</td></tr>
<tr><td>Multi stage</td></tr>
<tr><td>Compounding</td></tr>
<tr><td rowspan="4">Multi Screw Extruders</td><td>Twin Screw extruder</td></tr>
<tr><td>Gear pumps</td></tr>
<tr><td>Planetary gear extruder</td></tr>
<tr><td>MULTI(>2)SCREW EXTRUDER</td></tr>
</table>

Table 2: Types of Screw extruder

Author [5] also presents information about Basic operation:

“*Basic Operation*

The basic operation of a single screw extruder is rather straightforward. Material enters from the feed hopper. Generally, the feed material flows by gravity from the feed hopper down into the extruder barrel. Some materials do not flow easily in dry form and special measures have to be taken to prevent hang-up (bridging) of the material in the feed hopper. As material falls down into the extruder barrel, it is situated in the annular space between the extruder screw and barrel, and is further bounded by the passive and active flanks of the screw flight: the screw channel. The barrel is stationary and the screw is rotating. As a result, frictional forces will act on the material, both on the barrel as well as on the screw surface. These frictional forces are responsible for the forward transport of the material, at least as long as the material is in the solid state (below its melting point).”

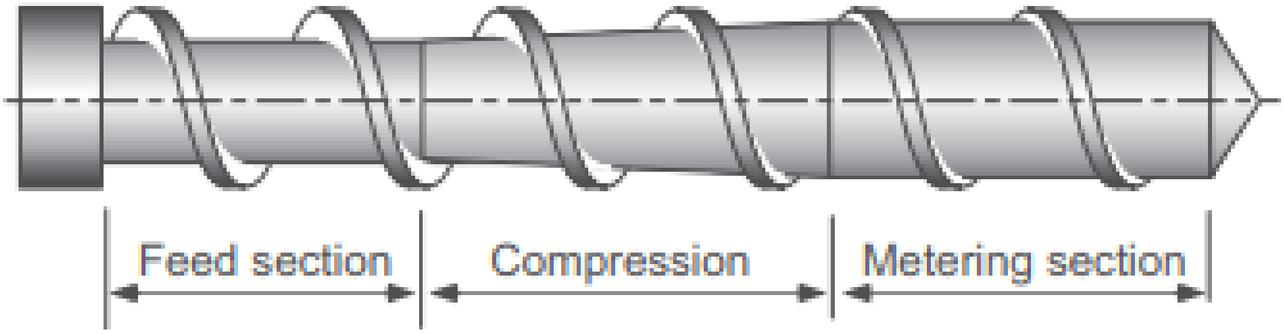


Figure 2Geometry of conventional extruder screw[4]

The author [5] continue: *“As the material moves forward, it will heat up as a result of frictional heat generation and because of heat conducted from the barrel heaters. When the temperature of the material exceeds the melting point, a melt film will form at the barrel surface. This is where the solids conveying zone ends and the plasticising zone starts. It should be noted that this point generally does not coincide with the start of the compression section. The boundaries of the functional zones will depend on polymer properties, machine geometry, and operating conditions. Thus, they can change as operating conditions change. However, the geometrical sections of the screw are determined by the design and will not change with operating conditions. As the material moves forward, the amount of solid material at each location will reduce as a result of melting. When all solid polymer has disappeared, the end of the plasticising zone has been reached and the melt conveying zone starts. In the melt-conveying zone, the polymer melt is simply pumped to the die. As the* *polymer flows through the die, it adopts the shape of the flow channel of the die. Thus, as the polymer leaves the die, its shape will more or less correspond to the cross-sectional shape of the final portion of the die flow channel. Since the die exerts a resistance to flow, a pressure is required to force the material through the die. This is generally referred to as the die head pressure. The die head pressure is determined by the shape of the die (particularly the flow channel), the temperature of the polymer melt, the flow rate through the die, and the rheological properties of the polymer melt. It is important to understand that the die head pressure is caused by the die, and not by the extruder! The extruder simply has to generate sufficient pressure to force the material through the die. If the polymer, the throughput, the die, and the temperatures in the die are the same, then it does not make any difference whether the extruder is a gear pump, a single screw extruder, a twin-screw extruder, etc.; the die head pressure will be the same. Thus, the die head pressure is caused by the die and by the flow process, taking place in the die flow channel. This is an important point to remember."*

TWIN SCREWE EXTRUDER

Twin screw extruder is described in [6] by author: Clextral "*Twin screw extruder consist of two intermeshing, Co-rotation screw mounted on splined shaft in a closed barrel. Due to a wide range of screw and barrel design, various screw profiles and process function can be set up according to process requirement. Hence a twin-screw extruder can ensure transporting, compression, mixing, cooking, shearing, heating, cooling, pumping, shapingetc with high level of flexibility. The major advantage of twin screw extruder is remarkable mixing capability which confer exceptional characteristics to extruded products and add significant values to processing unit. In twin screw extrusion process the raw material may be Solids, slurries, liquids. The Extruded product are plastic compounds, chemically modified polymers*".

General Parts of extruder

General parts of extruder is described in [7] by author: Fang, Q., Milford "*Extrusion refers to the forming of products to a desired shape and size by forcing the material through a die opening under pressure. It also involves thermal and mechanical energy input, which can trigger chemical reactions in the food being processed. Extrusion has been used extensively in the food industry to process a variety of raw materials into foods, including breakfast cereals, snacks, pastas, texturized vegetable protein, flat bread, meat products, and pet foods.*

Depending on the products being processed, a complete extrusion system generally consists of storage bins, dry mix feeders, liquid pumps and meters, a preconditioner, an extruder assembly, a die, and a cutter (Figure 1). Each of the components will be discussed in detail.

STORAGE BIN

A storage bin is used for the storage of dry ingredients. It provides a buffer of raw material so that an extruder has a continuous and stable supply of feed ingredients. This bin is usually equipped with rotating blades to prevent bridging.

DRY INGREDIENT FEEDERS

Two types of dry feeders are normally used to feed extruders: volumetric feeders and gravimetric feeders. A volumetric feeder provides a constant volume of dry ingredients, but cannot guarantee a constant mass flow rate due to changes in density of feed material. Gravimetric feeders, on the other hand, control feed flow rate based on the mass delivered and, therefore, are more accurate feeding devices.

Volumetric Feeding Devices

Volumetric feeders deliver dry ingredients on a volume basis. Several types of volumetric feeders are available. The most common are single-screw feeders. The volumetric feed rate is proportional to the screw speed. Use of a twin screw instead of a single screw improves the feeding accuracy, but with higher manufacturing cost.

Gravimetric Feeding Devices

Gravimetric feeders meter the weight of the dry ingredients, which gives more precision than the volume metering used with the volumetric devices. Gravimetric feeders are used more commonly in large-scale extrusion systems. They include weigh-belt and loss-in weight feeders. Both feeders monitor the quantity of dry ingredients and adjust the feed rate accordingly, if any deviation is detected.

LIQUID FEEDERS

Common liquid raw materials used in extrusion include water, fat, and syrup. Metering of liquid ingredients is critical for successful product manufacturing. Metering of liquids can be achieved either by volume or by mass. Mass flow meters are more accurate than volumetric meters. Devices include rotameters, differential pressure meters, fluid displacement meter, velocity flow meters, and mass flow meters.

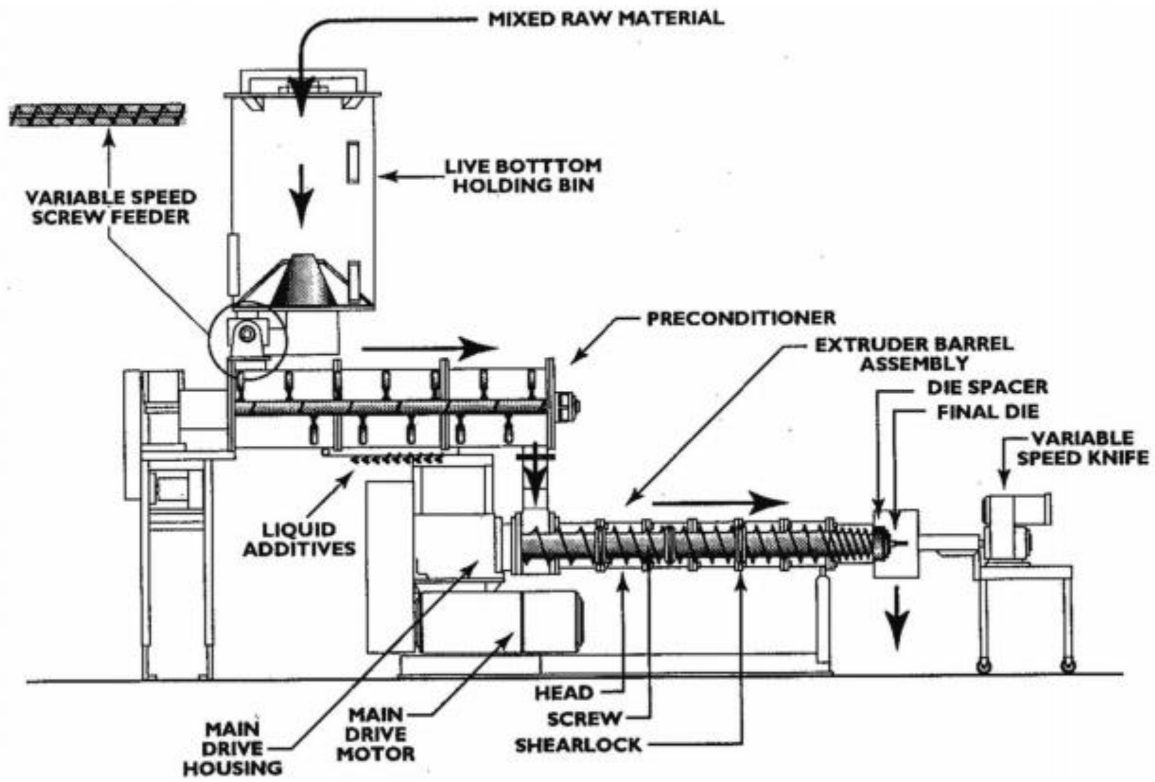


Figure 3General view of an extruder system. Source: Reprinted from Single screw extruder, in Extruders in Food Applications.[7]

PRECONDITIONER

The most important functions of a preconditioner are moisture adjustment and precooking of the raw materials prior to extrusion. During preconditioning, raw materials are held in a warm, moist environment where they are mixed for a prescribed time, and then discharged into the extruder. Preconditioning provides the benefits of improved product quality, reduced extruder wear, increased extruder capacity, and reduced power consumption. Preconditioners are mounted between the feeding device and the extruder. Originally, preconditioners were of a single-shaft design. The shaft, having mixing elements, rotated at relatively high speeds, resulting in retention times of 30 seconds or less. That was insufficient. Most modern preconditioners have a double-shaft design as shown in Figure 2.

The two shafts have different dimensions, and rotate at different speeds, which result in improved mixing, and retention times of between 2 and 4 minutes. Preconditioners can be operated at either atmospheric pressure or elevated pressure. Preconditioning at elevated pressure increases cooking temperature to above 100°C, which is sometimes advantageous. However, they are more complex and cost more to purchase and maintain. During preconditioning, steam and/or water are supplied to increase the temperature and moisture content of the raw materials. Steam is added from the bottom of the preconditioner while hot water (80–90°C) is added from the top through spray nozzles, for uniform distribution."

2.3 CFD models

For my thesis I was looking for so many research paper because there can be so many approaches to solve the problem which are starting from the simplification of model, type of meshing approach, to applying boundary conditions, to adopt the method for simulations approach. some of the data is there from the research articles are

2.3.1

The research paper is described in [8] author: Baalaganapathy Manohar1 "*CFD simulation of single screw extruder in cable industries. In this paper the author discuss about plastic extrusion in which plastic pallets are melted and formed into continuous profile. Extruder is having five distinct objectives to achieve in the extrusion process*

- *To provide correct temperature for polymer to melt properly without burning*
- *Maintain the constant melt temperature that was achieved finally.*
- *Maintain a uniform melt pressure in the die.*
- *To produce a well-mixed homogeneous polymer product.*
- *To find the correct melt pressure required in the die.*

Flighted length = 1600mm				
L/D = 10.12				
Compression ration = 1.8				
	Helical pitch(mm)	Length(mm)	Outer diameter (mm)	Shaft diameter(mm)
Feed	80	320	630158	98
Transition	50	630	158	98-125
metering	90	650	158	125

Table 3 Dimension of Screw [8]

The following assumptions are made for the model:

1. The polymer fluid is incompressible and has apseudoplastic characteristic.

2. The RPM of the screw rotation is very low, so the polymer fluid flow is laminar. Also, there is no slippage between fluids and the cylinder wall.

3. Only the viscousfluid forces are concerned, inertial force and gravity are neglected as they are miniscule

4. The fluid is assumed as completely homogeneous and the flow and heat transfer as steady state and quasi threedimensional.

5. Multiphase phase flow has not been considered for the polymer.

The model used for the analysis is power law fluid relationship. This model approximately describes the behaviour of a real non -Newtonian fluid

$\eta min < \eta = K\gamma^{n-1}e^{To/T} < \eta max$

k is a measure of the average viscosity of the fluid

(the consistency index);

n is a measure of the deviation of the fluid from Newtonian (the power-law index), as described below;

To is the reference temperature;

ηmin andηmax is, respectively, the lower and upper limits of the power law

Boundaries Conditions

The model was made in Ansys in design workbench. A Boolean operation was carried out to remove the screw from the barrel thereby giving the fluid portion. The barrel was split into 3 portions to supply heat from the 3 heating coils individually and these were named as zone1, zone 2 and zone3newtonion fluid approach ideal values at such large numbers of mesh nodes. The final mesh contained 2,964,227 elements and 628,915 nodes.

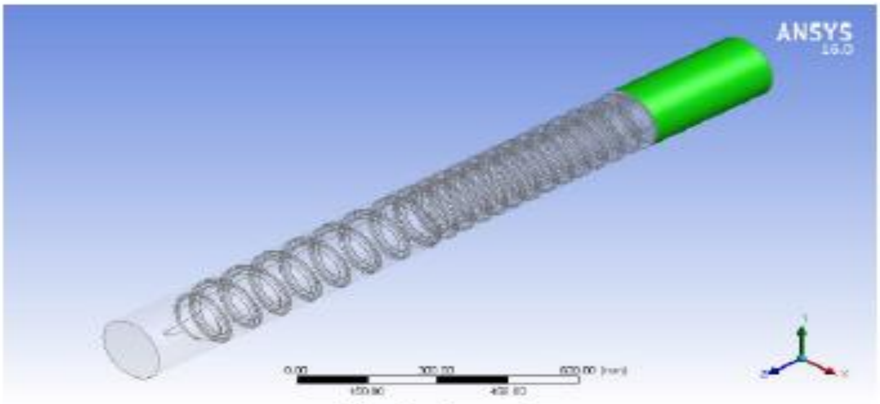


Fig 7: Zone 1

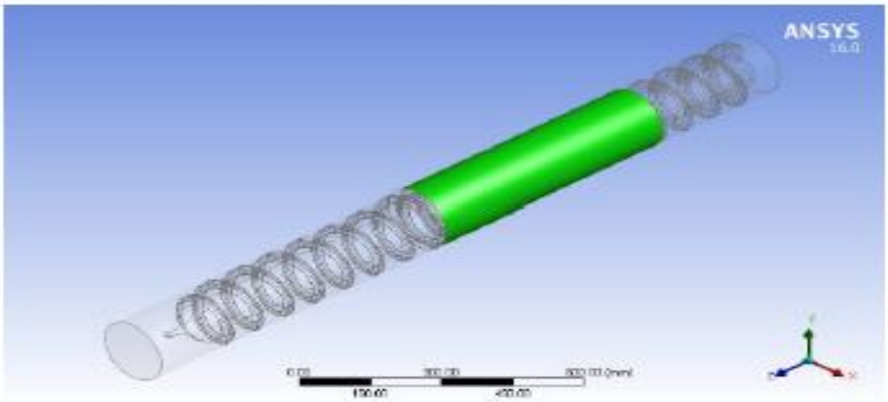


Fig 8: Zone 2

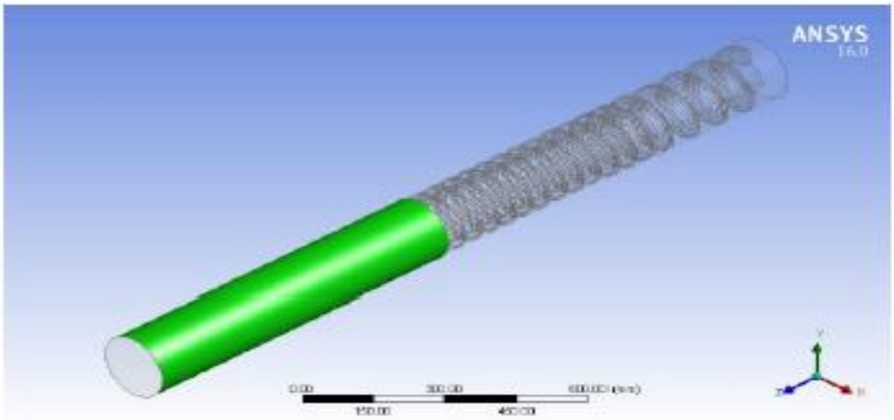


Fig 9: Zone 3

Figure 4Supply heat from the 3 heating coils individually [8]

For the boundary condition, the screw velocity was given as 12 rpm. A back pressure due to the wired mesh at the exit has been measured practically at 110 bars. The target mass flow *rate of the machine is 0.065 Kg/s. The three heater band values are mentioned in the table below.*

	Temperature(K)	Heat Generation(W/m^3)	Wall Thickness
Zone 1	468	164	40
Zone 2	478	93.5	40
Zone 3	489	64.72	40

Table 4Heater band values [8]

Result and Discussion

As can be seen from Fig 5the pressure keeps decreasing asthe fluid keeps reaching the outlet and finally is exposed to the atmosphere. The pressure is obtained due to the profile of the screw and due to the rotation of the screw.

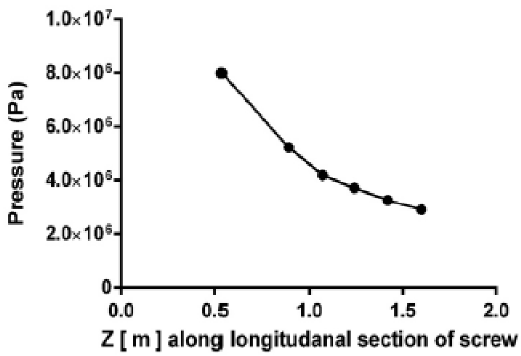


Figure 5Pressure along longitudinal section of the screw [8]

fluid is 477K (204°C) well over the cross-linkingtemperature of 463K (190°C) This is also close to the practical value of temperature of molten polymer at 212°C

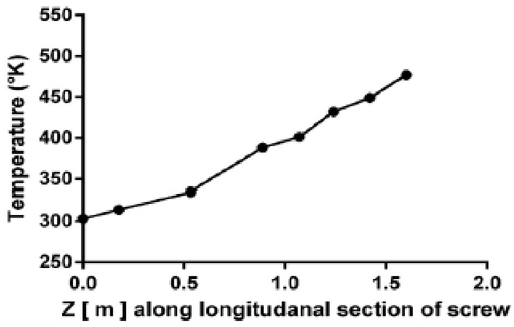


Figure 6Temperature along longitudinal section of screw [8]

1.14m/s. This high speed is attained in the transition section. Not only do the tightly spaced grooves hellmaintain high pressure in the feed section but also helpsincrease the rate of mixing the polymer. While the actuallax velocity cannot be determined for cross checking due to it being present in the transition section the result of the exit pressure is like that of practically obtained velocity. The value can be seen in Fig ***7***

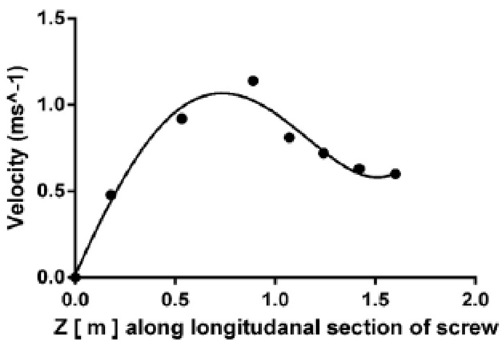


Figure 7velocity along longitudinal section of screw [8]

Conclusion

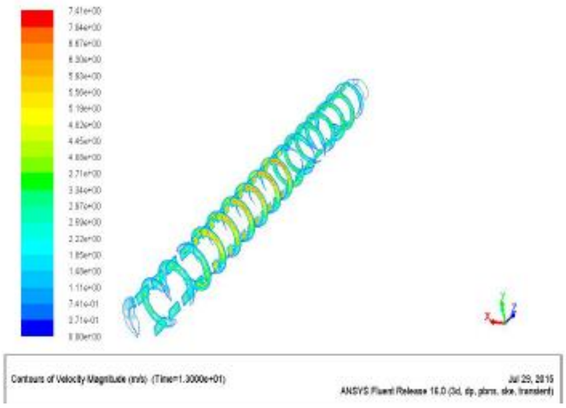


Figure 8 Vector contour [8]

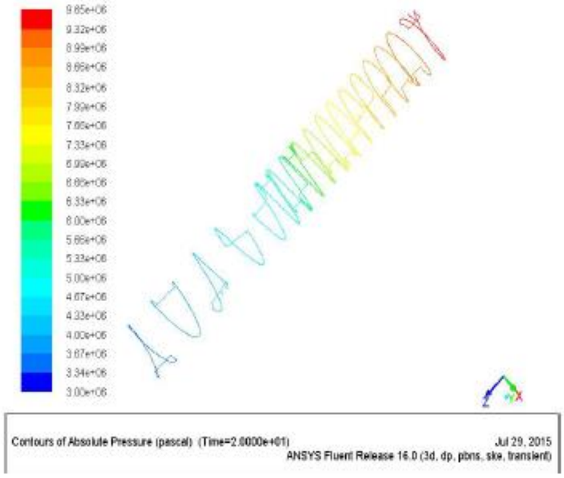


Figure 9Absolute pressure Contour [8]

It can be seen from the result obtained in the graph that thenumerical values obtained are in close proximity with that of practical values in the extruder. The research successfully validates the use of CFD for design of the extruder screw and barrel. More research needs to be done specially on how to avoid breakdown from occurring due to materials being stuck on the walls.

1.2.2

The design of a single-screw extruder for starch-based snack products was studied using 3-D Finite Element Modelling in Polyfold to simulate the flow of rice flour dough through an extruder. The generalized Newtonian model was used to characterize this material in the initial stages in order to develop an extruder than could properly mix and transport the material to the injection nozzle of the extruder. Using a screw speed of 50 rpm and a constant viscosity of 10,000 Pa s, the size of the motor required for the extruder was about 5.2 hp."

2.3.2 Simulation of Flow through Extruder

This research paper is described by [9] author: Ram Yamsaengsung* and ChumpornNoomuang“*The geometry of the single-screw extruder was created using AutoCAD 2007. Fig. 3 depicts the drawing of the feed section of the extruder, the rotational direction of the screw, and the direction of flow of the material. The flow of the material is indicated by the space between the screw and the wall of the extruder*

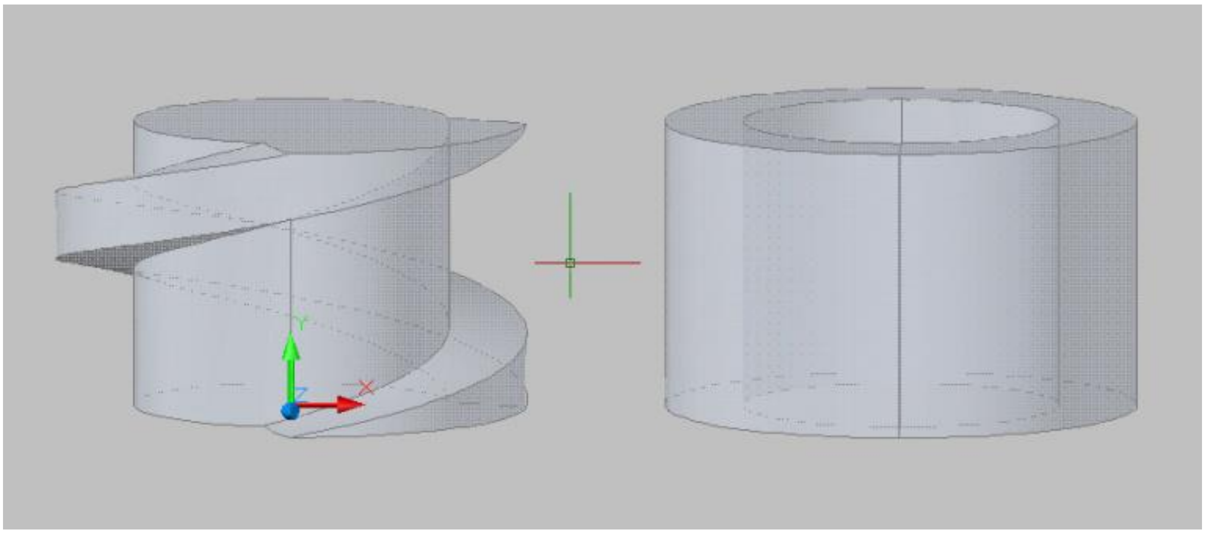
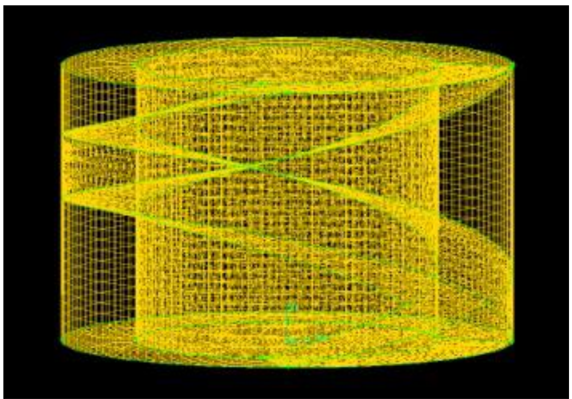


Figure 10Drawing of feed section of the extruder indicating rotational direction and flow direction for one screw section [9]

Once the AutoCAD drawing has been created, the meshing of the elements for the simulation process was conducted using GAMBIT 2.4.6. Hexagonal volume elements were used to represent 3-D modelling. The boundary regions for the volume elements were included (1)Inflow1 (origin of flow), Outflow2 (exit of flow), Wall3 (surface of screw), and Wall4 (inner surface of extruder). Next, the volume elements of the region between the boundary surfaces were assigned as Fluid1 which corresponds to the area of simulation, while the



screw and wall area were assigned as Solid2 indicating stationary solid plane. Finally, the quality of the mesh was analysed using the command Examine Mesh. If the value of the examination approached

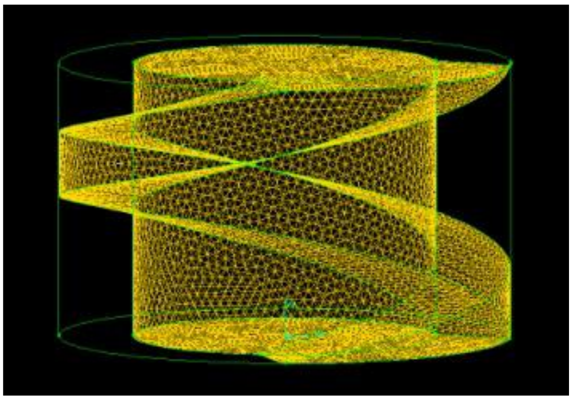


Figure 11Meshing of elements for the simulation of flow [9]

Once the volume elements have been created, the file was exported as Generic Neutral (. new) type and converted into POLYFLOW format mesh file using ANSYS POLYFLOW 3.12.2. In the POLYDATA section of ANSYS, a New Task was created and set as an F.E.M. (Finite Element Method) task and as a steady-state problem. In the Sub-Task box, the Generalized Newtonian Isothermal Flow Problem was selected and a Domain of the Sub-Task and the Sub-Domain were created. In the Material Data box, the choice of Shear-Rate Dependence of Viscosity included Constant Viscosity, Bird-Carrao Law, Power Law, Bingham Law, Herschel-Buckley Law, Cross Law, Log-Log Law, Modified Bingham Law, Modified Herschel-Buckley Law, Carrao-Yasuda Law and Modified Cross-Law. In this preliminary study, the value was set to Constant Viscosity indicating a Newtonian type fluid. Finally, the Flow Boundary Conditions were assigned as Inflow with a given flow rate and as Outflow which is acted upon by an Imposed Velocity. The results of the simulation were displayed using CFD-Post .

In this study, three different sections of the extruder were investigated: (1) the feed section, (2) the metering section, and (3) the die section. All three sections were drawn, meshed, and simulated separately to demonstrate the flow of material in each region.

Governing Equations

For a generalized Newtonian flow, POLYFLOW solves the momentum equations, the incompressibility equation, and (for non-isothermal flows) the energy equation [7]. The form of the momentum equations is

$$\rho a = -\nabla p + \nabla . T + f \quad (1)$$

wherep is pressure, T is extra-stress tensor, f is volume force, ρ is density, and a is acceleration. The incompressibility equation is

$$\nabla . v = 0 \quad (2)$$

wherev is velocity. The energy equation is presented as Equation (3) below.

$$\rho Cp \; DT/Dt = r - \nabla . \; q + (\sigma D) \quad (3)$$

where σ is the Cauchy stress tensor, D is the rate-of-deformation tensor and (σD) is the sum of the diagonal terms of σD (i.e., the trace operator).

DT/Dt is the material derivative of the temperature:

$$DT/Dt = T : \nabla v + r - \nabla . q \quad (4)$$

For a generalized Newtonian fluid,

$$T = 2\eta D \quad (5)$$

whereD is the rate-of-deformation tensor and η can be a function of local shear rateγ, temperature T, or both. The local shear rate is defined as

$$\gamma = \sqrt{2(D)\hat{}2} \quad (6)$$

In a simple shear flow, γ reduces to the velocity gradient.

When non-isothermal flow is modelled, POLYFLOW calculates the temperature, velocity, and pressure fields simultaneously (i.e., fully coupled, unless otherwise specified by a change in the default numerical parameters).

Input Parameters

To account for Newtonian flow, a constant velocity value of 10,000 Pa·s was used. This approximate value for the rice flour dough corresponded to the one used by Dhanasakharan and Kokini [2] for the extrusion of wheat dough across a single-screw extruder. Moreover, the speed of the screw was set to 50 rpm or 5.236 rad/s.

RESULTS AND DISCUSSION

Figs. 12-13 show the results of the simulation for the feed section for the velocity profile, the shear rate profile and the pressure gradient. From Fig. 12, the maximum velocity of the material (about 8 cm/s) is highest near the screw surface and smallest near the barrel wall (no slippage, zero velocity boundary condition). This corresponds to the rate of shear where the high shear rate at the wall results in zero velocity at the wall surface as shown in Fig. 13

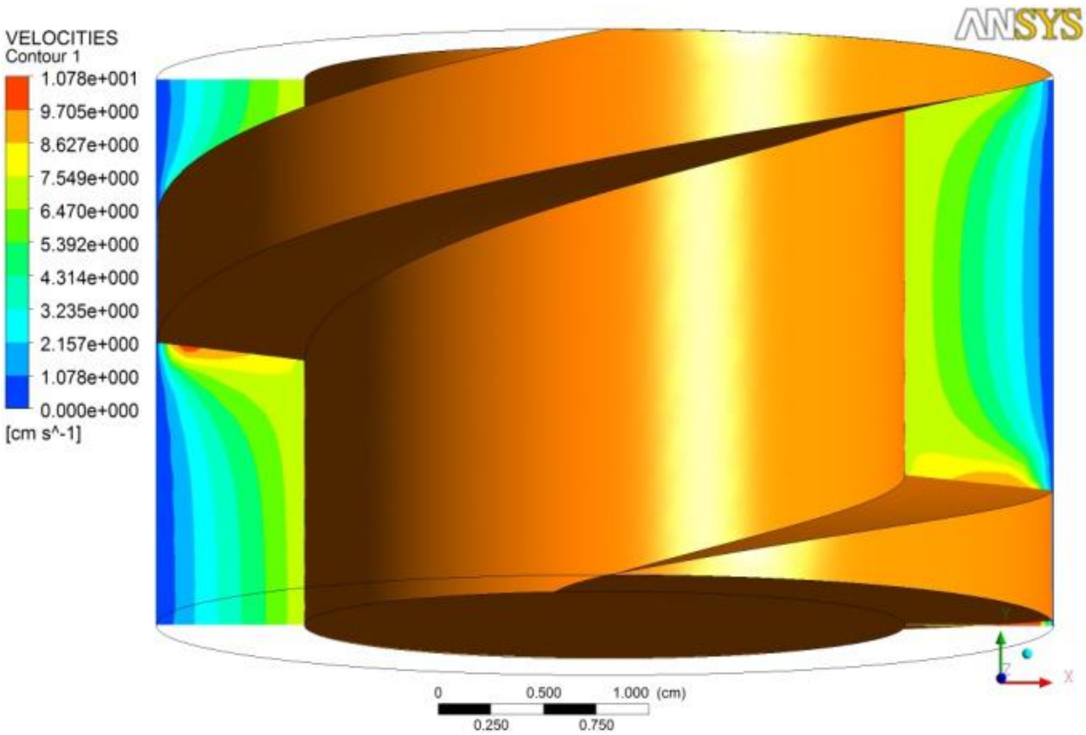


Figure 12Velocity distribution inside the feed section. [9]

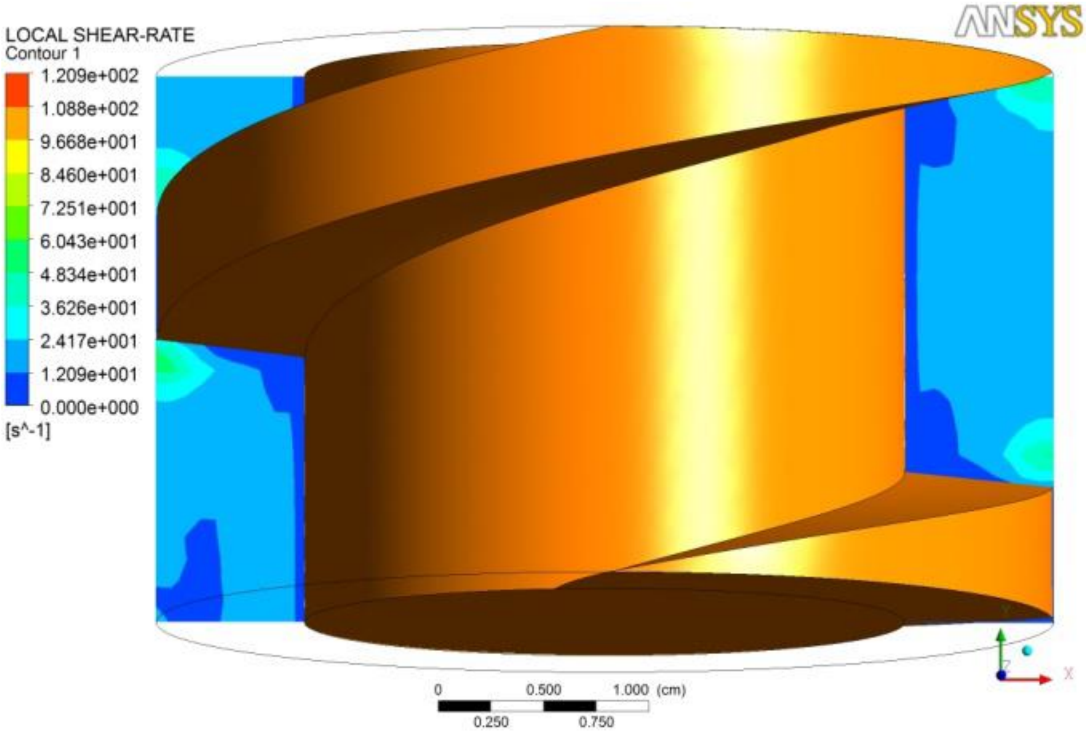


Figure 13Local shear rate inside the feed section [9]

For the meter section, the results are shown in Figs. 14-15. In this region, there has been continuous mixing of the flour and water (signified by the rotation of the screw) and the velocity distribution in the axial direction is much more uniform than that in Fig.12. Likewise, the local shear rate is nearly constant throughout the entire section with exception of the barrel wall. This shows good mixing of the product within the screw barrel indicating steady flow of the product toward the exiting point.

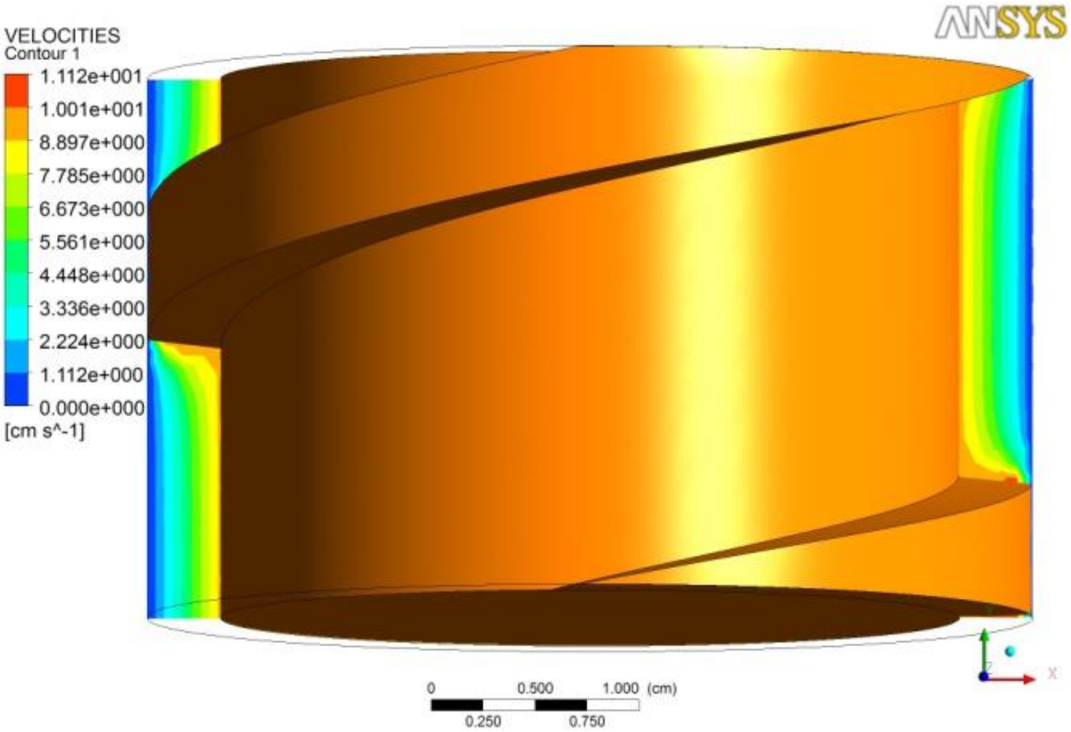


Figure 14Velocity distribution inside the metering section [9]

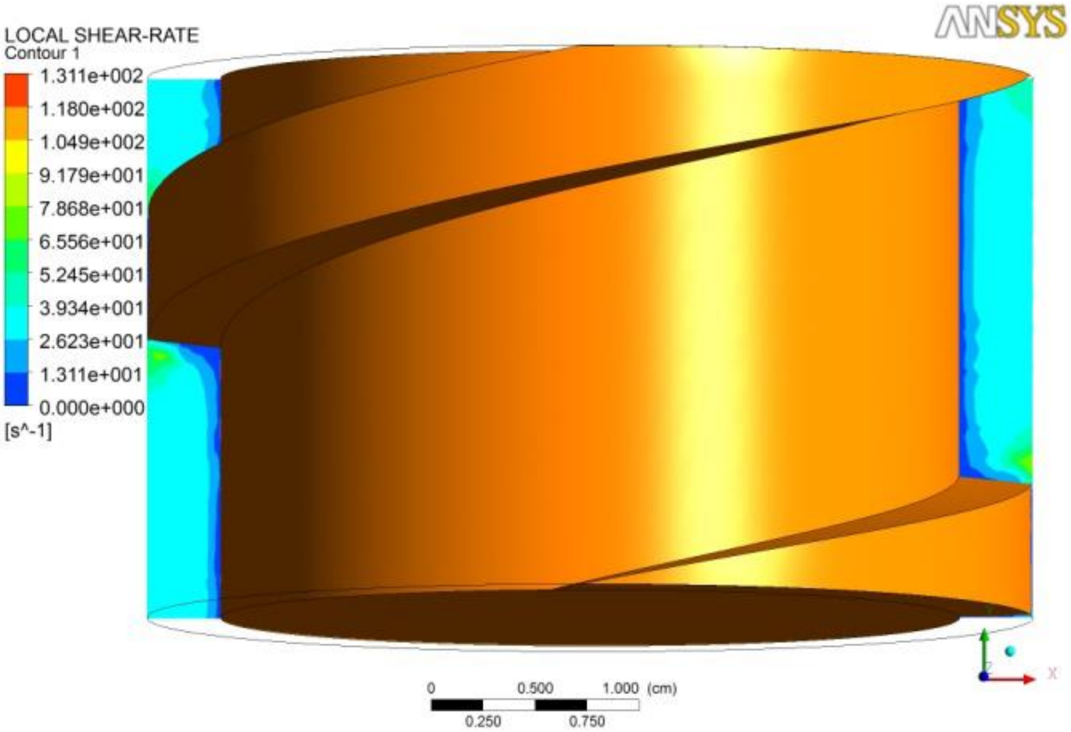


Figure 15Local shear rate distribution inside the metering section [9]

Finally, in the injection section, the velocity and local shear rate distribution are shown in Figs. 16-17. The velocity in this region increased to more than 26 cm/s compared to 8-10 cm/s in the feed and metering section. Moreover, the shear rate in the injection region of the *screw also increased dramatically from 5 s^{-1} in the metering section to more than 8 s^{-1} in the injection section. The gain in velocity is ideal for the expansion of snack product after it has been injected*

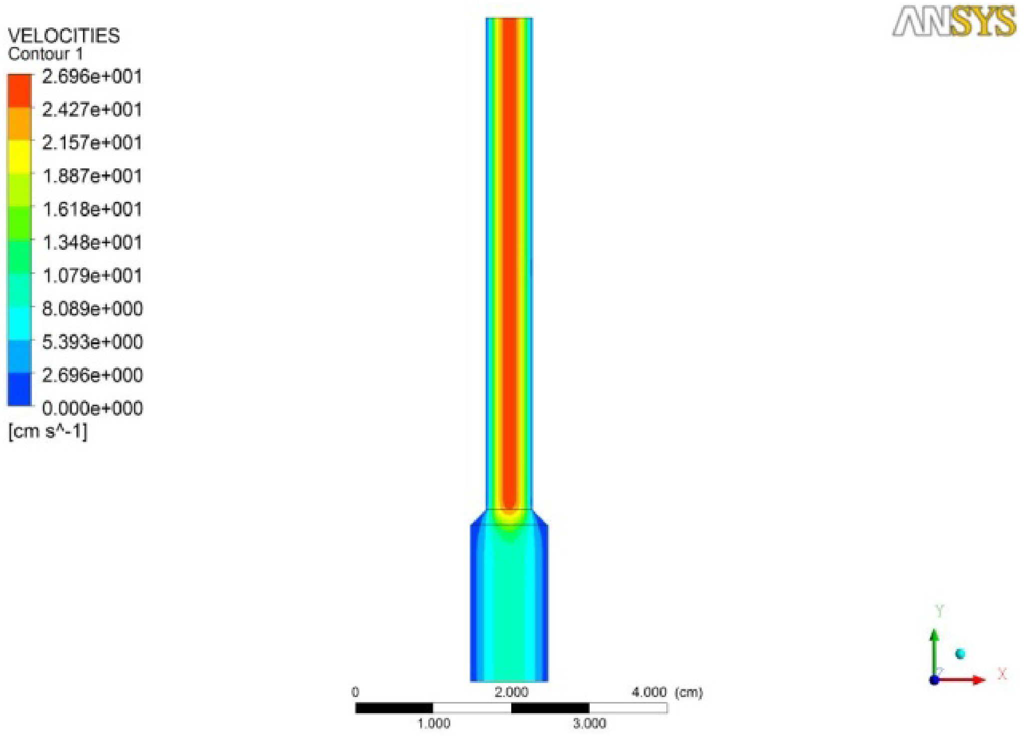


Figure 16 Velocity distribution inside the injection section [9]

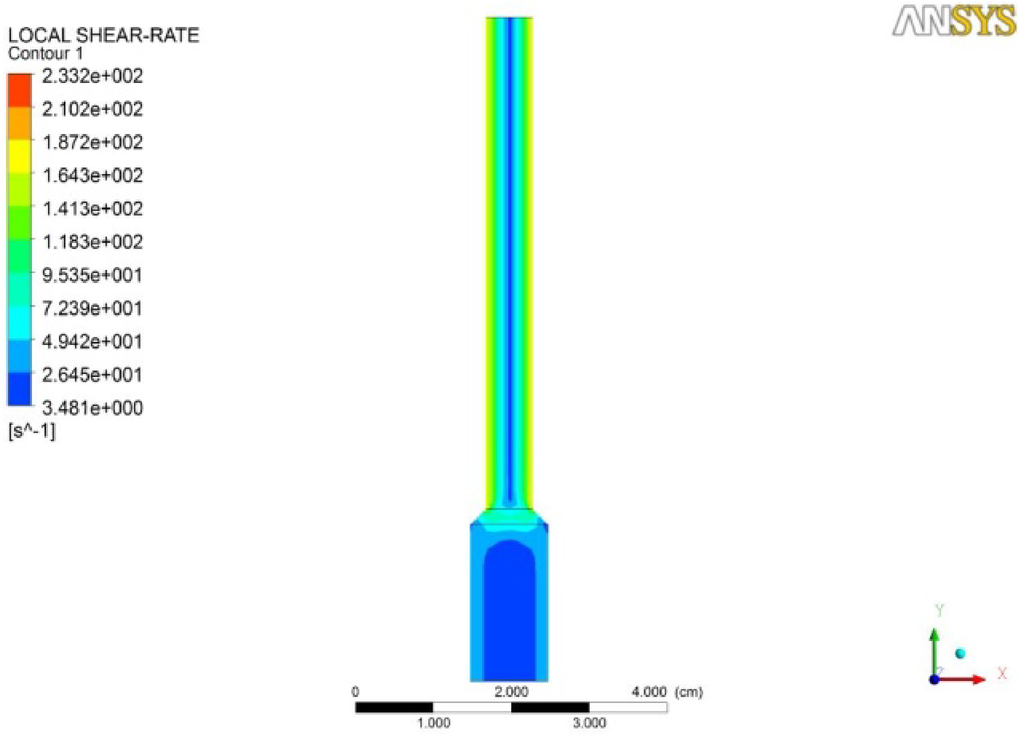


Figure 17 Local shear rate inside the injection section [9]

From the results of the local shear rate of the material inside the screw, the power of the motor required to operate the screw was determined. In this study, for a material with a viscosity of 10,000 Pa·s and a single-screw extruder speed of 50 rpm, the shear rate was approximated to be a 3.934 s^{-1} *in the metering section, the required motor power was approximately 5.2 hp.*

CONCLUSION

Hence, by modelling the flow of material inside the extruder, the behaviour of the material with shear rate and shearing time can be obtained. More research will have to be conducted to bring about the effect of varying the shear rate and the viscosity of the fluid on the shear stress development inside the screw extruder. This will help shed some light into the proper design of extrusion equipment for complicated food product. In addition, the development of a viscoelastic model for rice flour-based or wheat-based snacks products is essential to fully predict the flow of these types of materials to a single-screw extruder."

2.3 SUMMARY

Process is very complicated. Movement of the fluid is hard to describe by simple equations. Many approaches has been used for simulation of the flow of the polymer in screw gap by CFD method. I will use simplified approach CFD method using MRF method. Sliding mesh is also possible but it is too time consuming.

2.4 Flow polymer behavior

Polymer flow behavior is described in [10] "*The Polymer solutions, dispersions, and melts are usually non -Newtonian liquids. This means their apparent viscosity depends on the applied shear rate and increase rapidly with increase molecular weight. Thus, the viscosity of a polymer melt is always larger than that of the corresponding monomer. This is due to entanglement and intermolecular force between polymer molecules.*

The shear rate (γ) – shear stress (τ) relationship of the time independent non -Newtonian fluid can be describe by general equation

$$\gamma = f(\tau) \qquad (1)$$

Or graphically by a curve of shear stress as a function of shear rate. The four basic type of time -independent fluids are shown in figure 18 below

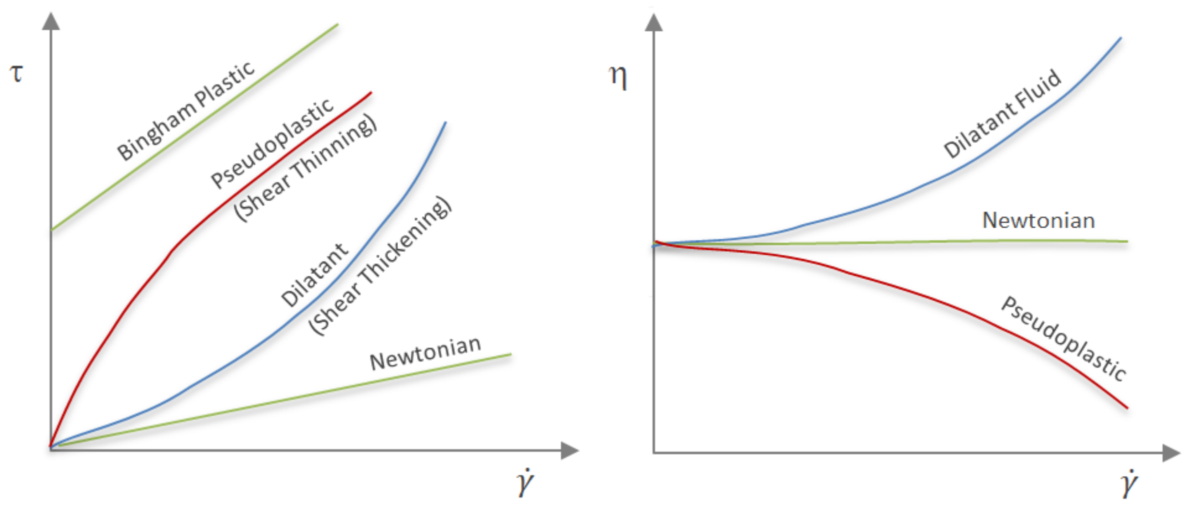


Figure 18Time-independent fluids [10]

It must be emphasised that these types are an idealization of the real flow behaviour of fluids. Most polymer solutions and melts exhibit shear thinning, that is, they belong to the class of pseudo plastic materials, whereas shear-thickening or dilatant behaviour is rarely observed. Some common examples of shear-thickening fluids are corn-starch in water and nanoparticles dispersed in a (polymer) solution.

The apparent viscosity is defined by

$$\eta = \frac{\tau}{\dot{\gamma}} \quad \text{(by definition)} \qquad (2)$$

If i combine this expression with the Oswald equation, i obtain a second power-law equation for the apparent viscosity:

$$\eta = K(T)\,\dot{\gamma}^{n-1} \qquad (3)$$

A power law can also be used to describe the behaviour of a dilatant (shear-thickening) liquid. In this case, the value of the exponent n will be greater than one. Again, noticeable deviations can be expected when the Oswald equation is applied over a wider range of shear rates.

Some other fluids require a threshold shear stress before they start to flow. This kind of fluid is called a plastic fluid and if the flowing liquid has a constant viscosity it is called a Bingham liquid. However, such behaviour is not observed in ordinary polymer melts and solutions. Typical examples for plastic flow behaviour are polymer/silica micro- and nanocomposites. The solid-like behaviour at low shear stress can be explained by the formation of a silica network structure arising from attractive particle-particle interactions due to hydrogen bonding between silanol groups. Once the particle network breaks down upon application of a critical yield stress (τ_y), the polymer shows normal flow behaviour.

The flow behaviour of plastic fluids having a constant viscosity η_P above the yield stress can be described with the Bingham equation:

$$\tau = \tau_y + \eta_P \dot{\gamma} \qquad (4)$$

whereas non-Newtonian (shear-thinning) behaviour of a plastic fluid can be described with the Herschel-Buckley model:

$$\tau = \tau_y + K(T) \dot{\gamma}^n \qquad (5)$$

Using the standard definition for viscosity: $\eta = \tau / \gamma$, the apparent viscosity of a Bingham viscoelastic material can be written as

$$\eta = \frac{\tau_y + \eta_P \dot{\gamma}}{\dot{\gamma}} = \eta_P + \frac{\tau_y}{\dot{\gamma}} \qquad (6)$$

Thus, the apparent viscosity of a Bingham fluid decreases with increasing shear rate and reaches at very high shear rates the constant limit η_P.

[1]The apparent viscosity is often given the symbol η instead of μ to distinguish it from the Newtonian viscosity.

[2]The second plateau is rarely observed for polymer melts because it requires extremely high shear rates which might also cause the polymer chains to break (shear-induced degradation).”

3.Task description and analysis

Polymer melt flow in extruder screw.It is important to know the velocity field in the cavity of screw when screw design for melt transportation is performed. The melt has to be homogenized also considering heat transfer into the mass from heated screw cylinder. Create model of melt flow in the screw of extruder for given geometric parameters of screw, physical parameters of melt and operation conditions of process. The screw revolution is constant, and model will not include heat transfer. The results of thesis will be the determination of velocity field in the cavity of screw and approximately comparison of pressure loss with calculation or values from literature.To simplify our geometry i am only only considering screw and cylinder for simlation purpose because of the number of meshing nodes and elements and i will simulate only one loop of the thread.

3.1 Assumption for simplification of Model:

The following assumption are made for the model:

- The fluid flow is Laminar and there is no slippage between fluid and the cylinder wall.
- only the viscous fluid force are concerned, inertial force and gravity are neglected as they are miniscule.
- The fluid is assumed as completely homogeneous and the flow and heat transfer as steady state.

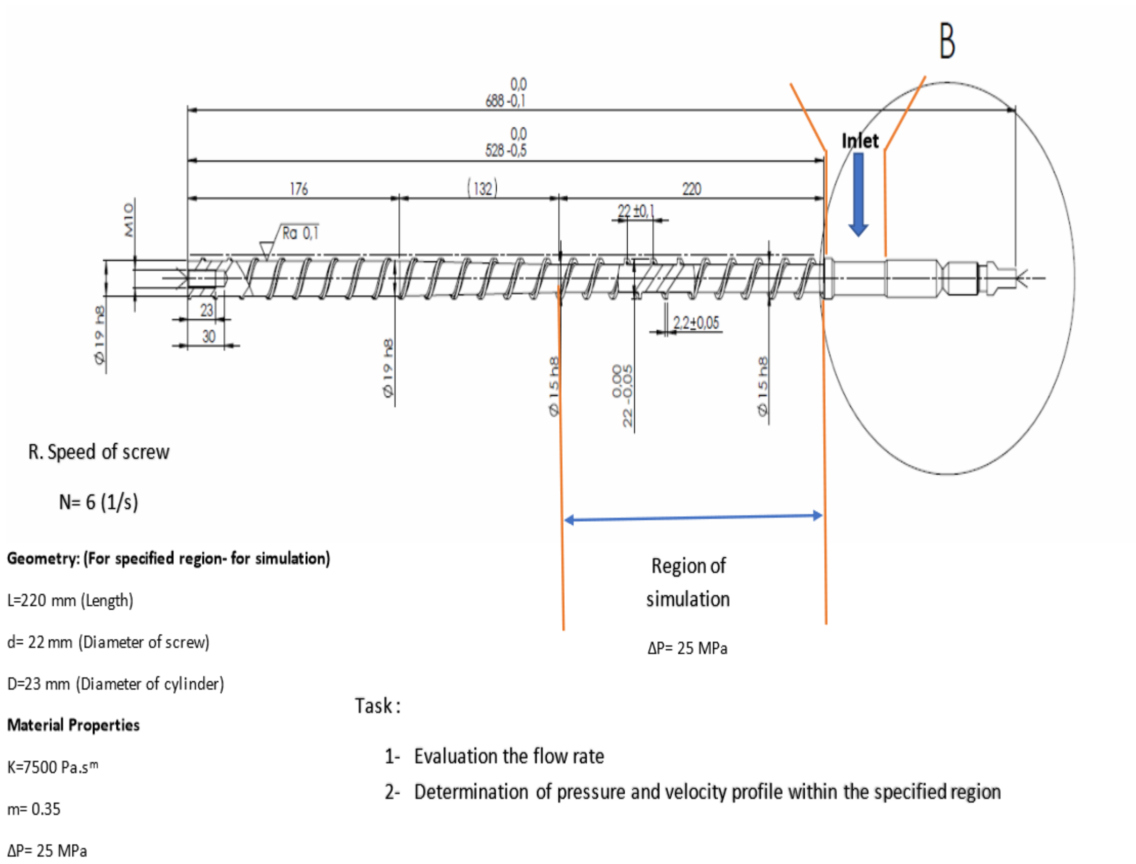


Figure 19Problem with given data

In this above picture i have given data related to our problem and then I created a 3D cad model of the problem with the given dimensions using Catia V5.

3.2Geometry and data

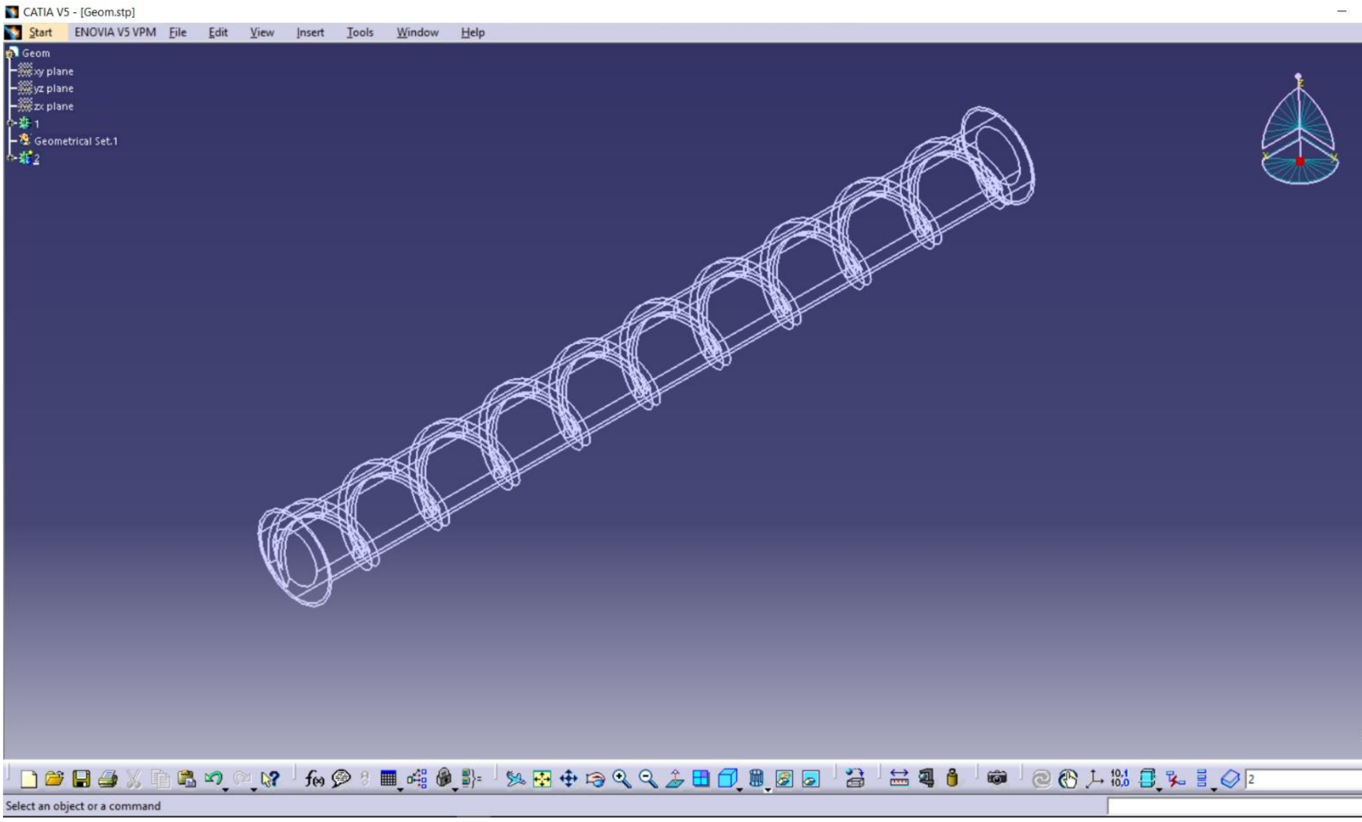


Figure 20 3D geometry of drawing

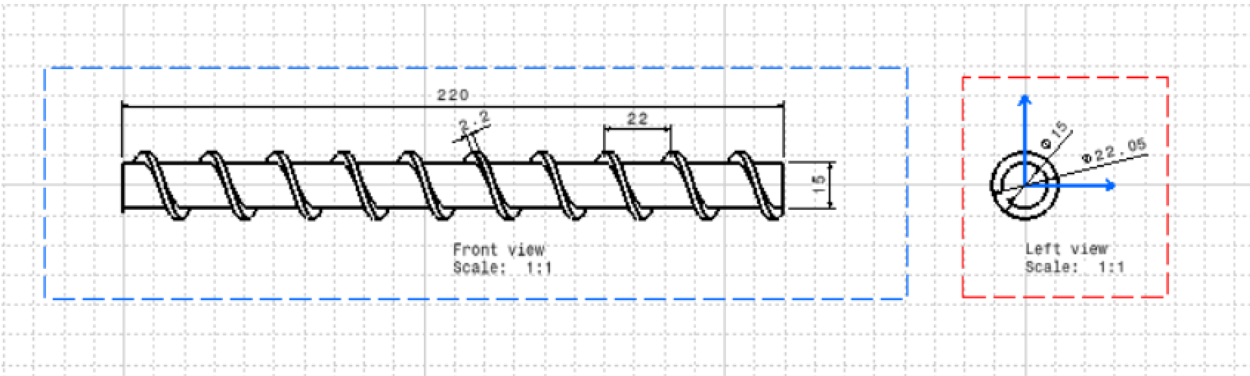


Figure 21: 2D geometry viewe of Extruder

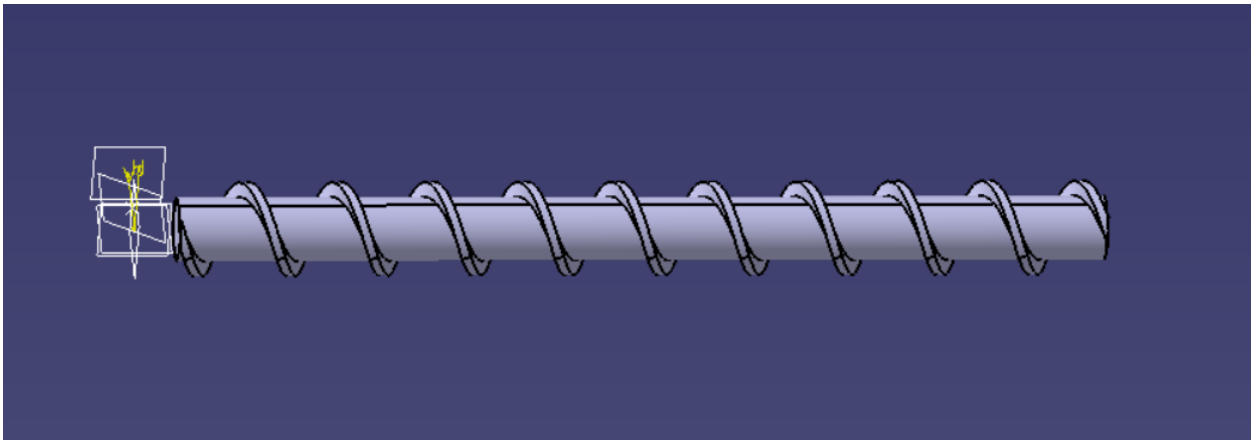


Figure 22According to the basis dimension I created the 2-dimensional (Fig 21) and 3-dimensional (Fig 20) profile of my model Single Screw Extruder.

3.3 Simplification

The simple geometry is assumed seen in figure 21. The spiral gap is uncoiled into the straight rectangular channel with following dimensions. The dimensions are calculated from geometrical characteristic of the thread see figure 24, see following equations. The rectangular channel with its dimensions is shown in the figure 23. According the superposing solution, the case could be divided into the two cases – flow of polymer in rectangular channel forced by pressure drop (injection pressure and atmospheric pressure) and flow of the polymer by moving the wall of the screw,

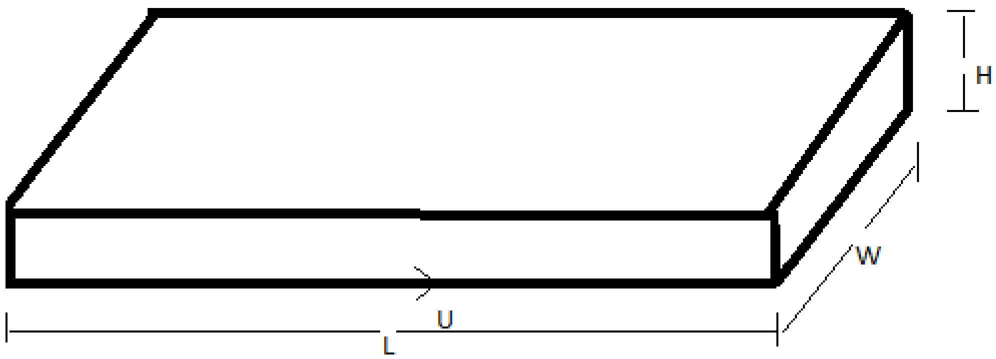


Figure 23 Channel (Thickness of the channel)

Width of the channel

$$W = t \, Cos\alpha \tag{7}$$

Lenght of the one coil

$$L = \sqrt{(\pi D)^2 + t^2} \tag{8}$$

Angular velocity

$$U = \omega R = 2\pi nR \tag{9}$$

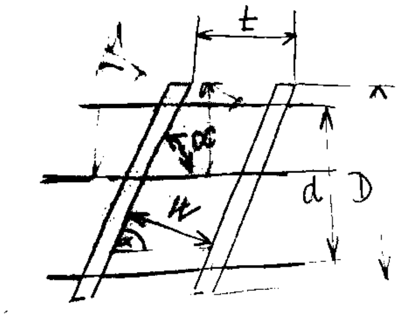


Figure 24 Angel between Screw thread

3.3.1 Newtonian fluid

Flow rate of the poplymer throught the channel wiht moving wall without sides

$$Vmw = ½HWU \tag{10}$$

Flow rate of the polymer throught the channel by pressure differnce with stationary wall without sides

$$Vp = \frac{1}{12\mu} \frac{\Delta p}{L} W H^3 \tag{11}$$

Pressure difference calculated from known flow rate, oppositely from the previous eq.

$$\Delta p = \frac{12\, uLV1}{WH\hat{}3} \qquad (12)$$

Total flow rate of tzhe polymer for given presssure drop

Vt = Vmw + Vp

More precisely, the case can be assumed with side wall. After that, the pressure drop (stationary

wall) can be calculated according to

$$\Delta p = f\, \rho \frac{L}{Dh} \frac{\mu 2}{2} \qquad (13)$$

Where friction factor

$$f = \frac{78.81}{Re} \qquad (14)$$

The constatnt 78.81 was taken from [ref.] for aspect ration of the submitted channel. I have a rectangular channel profile

b/a	f ReDh
0.0	96.00
0.05	89.91
0.1	84.68
0.125	82.34
0.167	78.81
0.25	72.93
0.4	65.47
0.5	62.19
0.75	57.89
1.0	56.91

Table 5: Forrectangularchannel[11]

Reanolds number

$$\text{ReDh} = \frac{\mu\rho Dh}{\mu} \tag{15}$$

After rearrangement the pressure drop is given

$$\Delta\text{p} = \frac{78.81\mu}{\mu\rho Dh}\rho\frac{L}{Dh}\frac{\mu^2}{2} \tag{16}$$

The flow rate can be then calculated from next eq.

$$Vpsw = uS = uHW \tag{17}$$

Where velocity is

$$u = \frac{2Dh^2\Delta\text{p}}{78.81\mu L} \tag{18}$$

And hydrolic diameter

$$Dh = \frac{4WH}{2(W+h)} \tag{19}$$

3.4 Simplification Non-Newtonian fluid

For Non-newtonian fliud flow throght rectanguilar channel esspecially the power law model fluid, the original equations exist in the literature [ref.] The volumetric flow rate of the power law fluid can be calculated as (the flow is driven by pressure drop and walls are stationary)

$$\text{VpPl} = \text{HW}(\frac{n}{2n+1})\left(\frac{1}{k}\frac{\Delta p}{L}\right)^{\frac{1}{n}}(\frac{H}{2})^{n+1/n} \quad (20)$$

The flow rate of the powwer law fluid throught the channel created by two parallel plate, when one is moving and second one is stationary can be calulcated by the same equation as for newtonian case. i.e.

$$\text{VmwPl} = \ ½\text{HWU} \quad (21)$$

Total flow rate of tzhe polymer for given presssure drop

Vt = Vmwpl + Vppl

3.4 Results of Analyticla soltion

Flow rate	Moving wall case parrallel plates	Pressure drop case rectangular channel	Pressure drop case parallel plates stationary walls
Newtonia	$1.5010^{-5} m^3\, s^{-1}$	$3.00\ 10^{-5} m^3\, s^{-1}$	$8.1910^{-3} m^3\, s^{-1}$
NonNewtonian Power law	$1.5010^{-5} m^3\, s^{-1}$	-	$6.79\ 10^{-7} m^3\, s^{-1}$

Table 5 Calculated result for each case

The pressure drop was 96,9 kPa.

4 CFD simulation

4.1 Geometry creation

According to the basis dimension I created the 2-dimensional (Fig 22) and 3-dimensional (Fig 21) profile of my model Single Screw Extruder. Then I import my File into Ansys Software in. stop format.

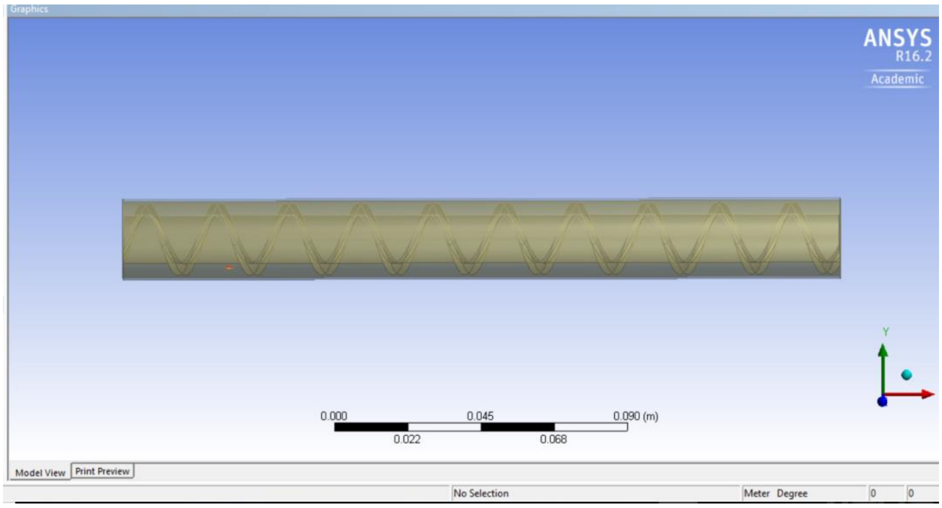


Figure 25Geometry in Ansys

Then I created a fluid body inside of my geometry and the applying the Boolean operation to subtract that liquid body from my Geometry to get the space between the screw where our melt starts to flow.

4.2 Meshing

Next step is to import that geometry in Meshing to provide fine meshing for better resultMeshing is defined as the process of dividing the whole Geometry into number of elements so that whenever the load is applied on the component it distributes the load uniformly called as meshing. That's why meshing is very important. Without meshing load distribution may not be uniform. In my Case used Automatic mesh with global setting and in the term of result I got 233780 Nodes and 8632308 Elements

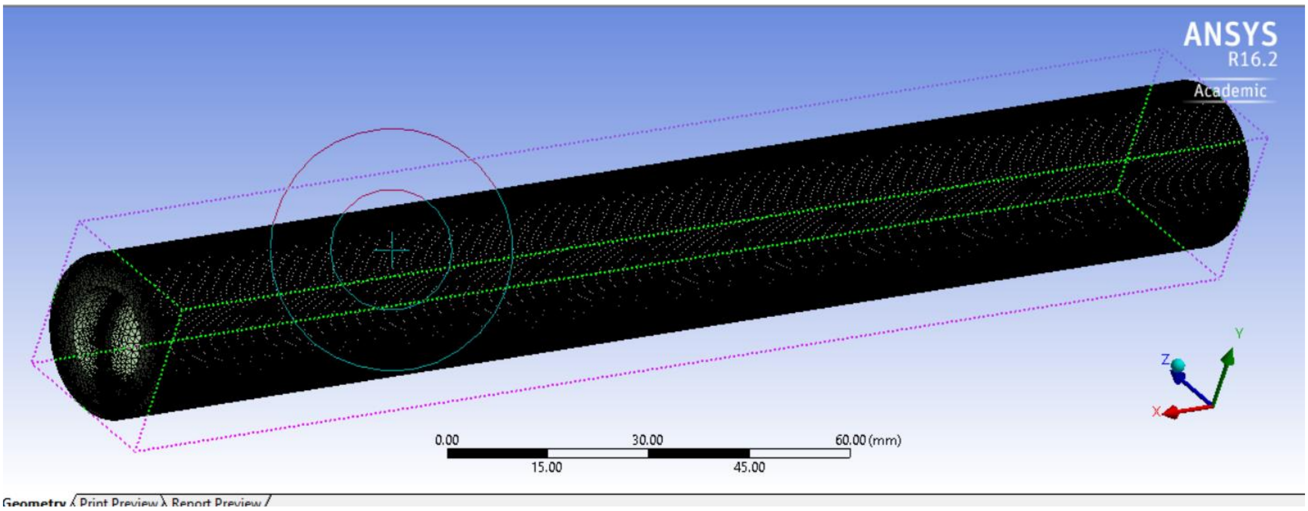


Figure 26Meshing in the Geometry

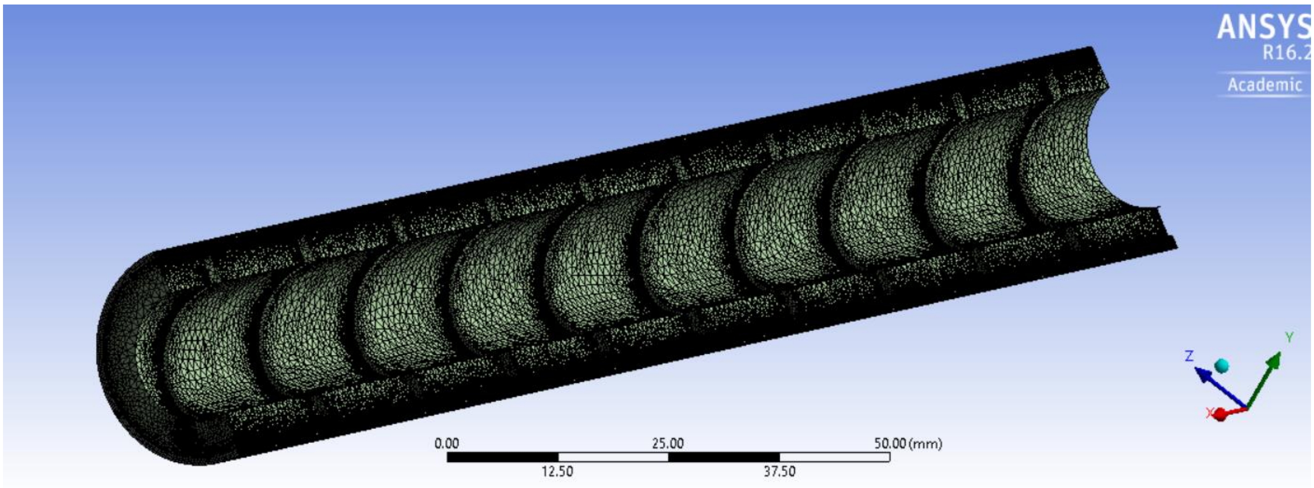


Figure 27. Section of the geometry

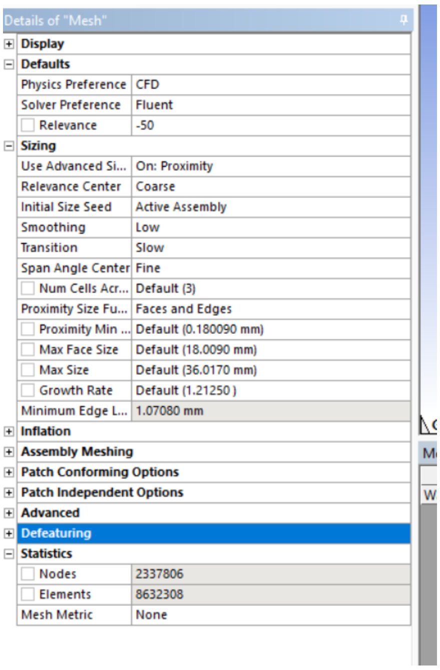


Figure 28Details (Meshing)

Once the meshing is done I have to provide the name of the name of each and every part of the body which Inlet fluid are, Outlet fluid, Outer wall, Inner wall, Fluid stator, Fluid rotor.

4.3 Boundary condition

After labelling move to next part which is fluent. ANSYS Fluent software contains the broad physical modelling capabilities needed to Pressure drop, difference, model flow, turbulence, Heat Transfer and reaction for industrial application. But before that i need to know what the Reynolds number of fluid in channel is. Because i need to set some parameters in fluent which are dependent on Reynolds number

$$Reynolds\ number = \frac{\rho u D_H}{\mu} \tag{22}$$

Where ρ = density of fluid (1000 kg/m^3)

u = velocity of fluid (0.1 m/s)

D_H = characteristic length = $\frac{4Area}{Perimeter}$ = 0.022

μ = dynamic viscosity of fluid (10 Pa-s)

From this calculation i get Reynolds number which is in this case is less than 2100 so its Laminar regime.

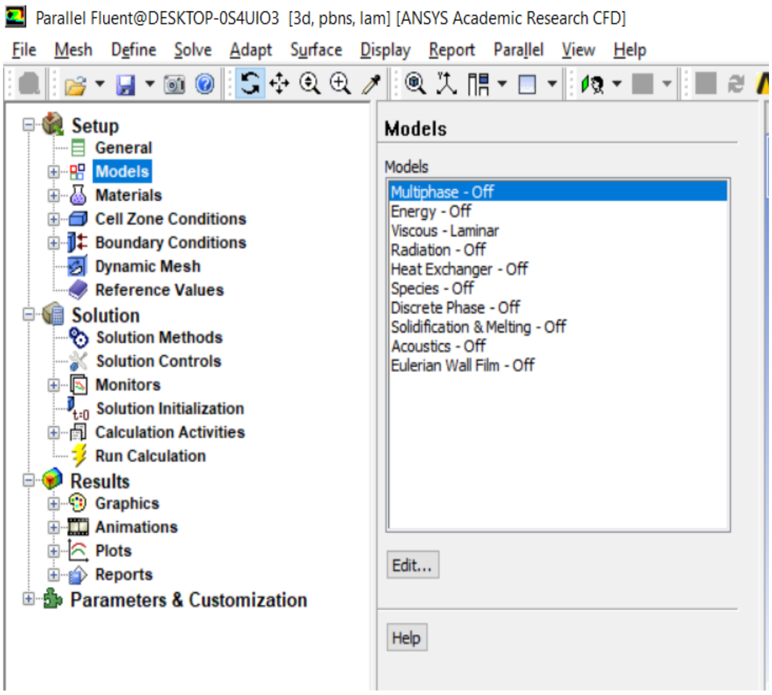


Figure 29 Model Task Page

Go to models and select Viscous. From Reynolds Number calculation i got laminar regime. So here it is important to check laminar box and uncheck the remaining box.

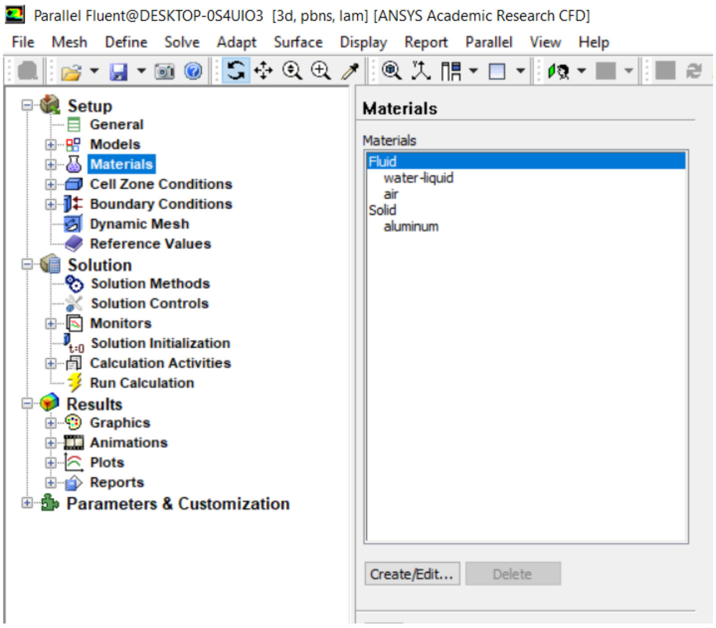


Figure 30Material task page

Then I have to provide the material properties which is fluid and set the parameter and provide the viscosity which is 10 Pa-s.

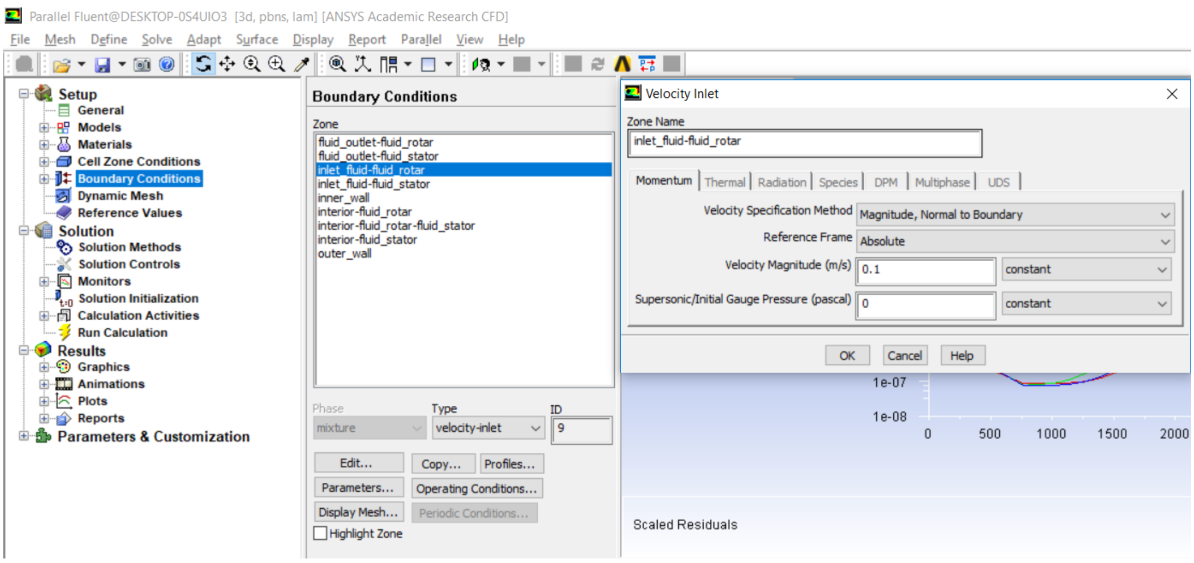


Figure 31Boundary conditions

In next step I have to provide Boundary condition to my Geometry like I know the velocity which is 0.1 m/s.

Before running the simulation for solutions, i need to consider that simulation will be done in 2 parts. First part will be done with first order method consist of 3000 iterations and second part with second order method with 2000 iterations at least. Select solution methods in tree specification and then select as follows.

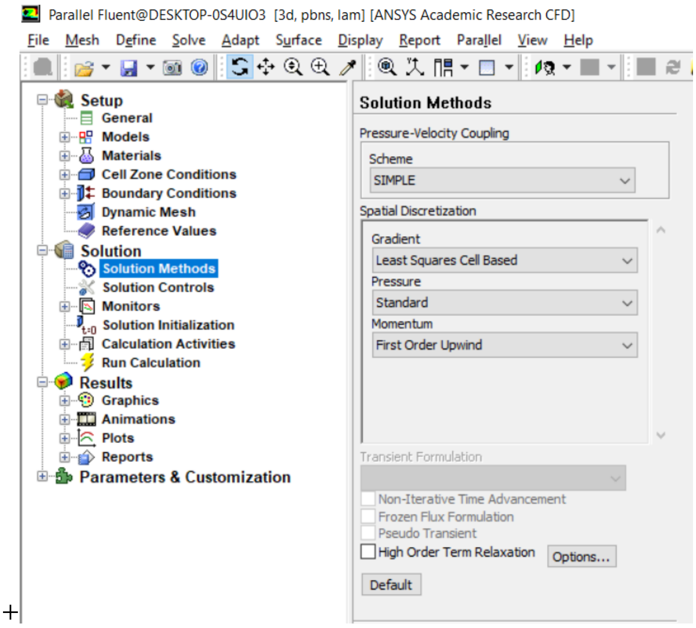


Figure 32Solution Methods

Just change the setting in Momentum field select Second order upwind Again, run calculation for more 2000 iterations. If the graph started to stabilize then stop the calculation.

4.4 Models description and simulation

Procedure of the model creation

There is a flow of the polymer through extruder by screw rotation and pressure drop at the inlet and outlet. There is no possibility to Set up in Fluent Zero pressure drop at the inlet and outlet. That is why I simulated revolution and pressure drop together to compare flow rate obtained by model with analytical solution. Because of that I haveto divide model into two separate cases – stationary case and with rotation, but both with given and same pressure drop.

Case 1

Newtonian fluid with stationary wall

Case 2

Newtonian fluid with Rotation

Case 3

Power law with rotation

Case 4

Power law without rotation

5 Results

5.1Case one – N.F stat dp

```
Done.
Reading "C:\Users\uditn\OneDrive\Desktop\thhesis 100\stationary wall\one_v2hyuvg.dat"...
Parallel variables...
Done.

                       Mass Flow Rate              (kg/s)
-------------------------------- --------------------
                               in_rot          0.29353568
                              in_stat        0.0056835326
                              out_rot         -0.29376241
                             out_stat       -0.0054568072
                ---------------- --------------------
                                  Net       -1.4805218e-10
```

Figure 33Stationary wall

5.2 Case two – N.F. mov. Dp

```
Done.
Reading "C:\Users\uditn\OneDrive\Desktop\thhesis 100\Rotational wall\one_v2.dat"...
Parallel variables...
Done.

                       Mass Flow Rate              (kg/s)
-------------------------------- --------------------
                               in_rot         0.075199618
                              in_stat        0.0010157267
                              out_rot           -0.075142
                             out_stat       -0.0010689803
                ---------------- --------------------
                                  Net        4.3646792e-06
```

Figure 34Rotational Wall

5.3 Case three NNF stat dp

Figure 35Power law without rotation

5.4 Case four NNF mov. Dp

```
      parallel,
Done.
Reading "H:\Models\2018 Udit\one_power_lawoutput_stat.dat"...
Parallel variables...
Done.

                    Mass Flow Rate                  (kg/s)
-------------------------------- --------------------
                            in_rot          0.0099148957
                           in_stat         0.00025315136
                           out_rot        -0.0099009274
                          out_stat       -0.00026711962
                ---------------- --------------------
                               Net          3.9989462e-11
```

Figure 36Power law without rotation

5.5 Summary and comparison

Results	Analytical	CFD	Error
Newtonian only pressure drop	1.00 10^{-4} $m^3\ s^{-1}$	2.88 10-4 m3. s-1	65.27%
Newtonian screw rotation	1.50 10^{-5} $m^3\ s^{-1}$	5.40 10^{-4} $m^3.\ s^{-1}$	97.22%
Power law only pressure drop	6.79 10^{-7} $m^3\ s^{-1}$	100.97 10-7 m3. s-1	93.27%
Power law screw rotation	1.5 10^{-5} $m^3.\ s^{-1}$	1.80 10-5 m3. s-1	16.66%

Table 6 Result comparison

6 Conclusion

In the diploma thesis firstly i described the polymer flow in the extruder followed by some of the cases like Newtonian fluid with fixed wall, rectangular channel, power law with pressure drop. Process is very complicated. Movement of the fluid is hard to describe by simple equations. Many approaches have been used for simulation of the flow of the polymer in screw gap by CFD method. Few of the possibilities of analyzing the solution but it was not used due to inadequate results. I will use simplified approach CFD method using MRF method. Sliding mesh is also possible but it is too time consuming. There is a flow of the polymer through extruder by screw rotation and pressure drop at the inlet and outlet. There is no possibility to set up tin Fluent zero pressure drop at the inlet and outlet. That is why I simulated revolution and pressure drop together to compare flow rate obtained by model with analytical solution. Because of it I must divide model to two separate cases – stationary case and with rotation, but both with given and same pressure drop.

Subsequently, Ansys FLUENT program was used in the diploma thesis, in which a simulation of one thread of extruder screw is used and the determination of the volumetric flow rate is governed with different properties of fluid in model. Therefore, the mass flow rate was calculated from the analytical calculations as well as from the calculation of the Ansys FLUENT program. Furthermore, the change of the flow rate was monitored when changing the model using simulations in the Ansys FLUENT program. For dimensional reasons, the models are identical but there is slightly change in the boundary conditions. The results were compared, and it is evident that the change is quite big in most of the part and making any decision is requires furthermore research and simplification of models and finding better analytical as well as simulations work.

REFERENCES

[1] Chandramouli, R. *Types of extrusion and extrusion equipment* [online]. SASTRA University. [cit. 1. 9 .2018].
Available at:
https://nptel.ac.in/courses/112106153/Module%205/Lecture%201/Module_5_Extrusion_Lecture_1.pdf

[2] Kopeliovich, D. *Extrusion of Polymers* [online]. SubsTech: 2014. [cit. 1. 9. 2018].
Available at:
http://www.substech.com/dokuwiki/doku.php?id=extrusion_of_polymers

[3] SME. Extrusion Processes [online]. Fundamental Manufacturing Processes Study Guide, DV04PUB12. [cit.1. 9. 2018]. Available at:
https://www.sme.org/WorkArea/DownloadAsset.aspx?id=73746.

[4]Dynisco. *An Introduction to Single Screw Extrusion* [online]. 2017. [cit. 1. 9. 2018]. Available at:
https://www.dynisco.com/userfiles/files/an_introduction_to_single_screw_extrusion.pdf

[5] Rauwendaal, C. Polymer Extrusion. 5th Edition. Munich: Hanser Publisher, 2014. p. 1-20. ISBN 978-1-56990-516-6.

[6] CLEXTRAL. *Twin screw extrusion technology* [online]. Firminy, France. [cit. 1. 9. 2018].
Available at:
http://www.clextral.com/technologies-and-lines/technologies-et-procedes/twin-screw-extrusiontechnology/

[7] Fang, Q., Milford, H. Extrusion Systems: Components [online]. *Biological Systems Engineering: Papers andPublications*,2010,310.[cit.1.9.2018]
Availableat: http://digitalcommons.unl.edu/biosysengfacpub/310

[8] Baalaganapathy, M., Periasamy, C. *Computational Fluid Dynamics Simulation of Single Screw Extruders inCable Industries.* International Journal of Research in Engineering and Technology, 2016, 5 (3), p. 85-89.ISSN: 2319-1163.

[9] Yamsaengsung, R., Noomuang, C. Finite Element Modeling for the Design of a Single-Screw Extruder forStarch-Based Snack Products. In: *Proceedings of the World Congress on Engineering 2010, Vol III.* London:Newswood Limited, 2010. p. 1944-1948. ISBN: 978-988-18210-8-9.

[10] *Flow Properties of Polymers: Time-independent Fluids* [online]. Polymer Properties Database. © 2015, polymerdatabase.com. [cit. 30. 6. 2018].
Available at:
http://polymerdatabase.com/polymer%20physics/Viscosity2.html

[11] WhiteF. M.:*Fluid Mechanics book.*Second edition, MCGRAW Hill ISBN: 0-07-069673-X. 1986

[12] What is an Extruder?[online]. WFM Construction industry marketplace. 2018.www.wfm.co.in [cit. 30.6.2018]
Available at: https://www.wfm.co.in/what-is-an-extruder/