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Calculation and Simulation of Single Screw Extruder Metering zone for polypropylene using Ansys Polyflow

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Abstract
Extruder output of a single screw extruder depends on the type of extruder, and it is determined either by the geometry of the solids feeding zone or by raising the pressure of the melting and metering zones to force the melt through the extruder die. There are many parameters that can affect to the extruder output and the pressure drop. In this work these parameters were studied using computer package and analytical calculations and the results of the two methods were compared. One flight was studied with dimensions (diameter = 6 cm, flight width = 0.6 cm, flight clearance = 0.1 cm, flight depth = 0.6 cm, angle of inclination =17.7°*, screw rotation = 60 rpm, screw length = 6 cm). The Carreau Yasuda's viscosity law model of polypropylene was used, the maximum output value and maximum pressure at the flight depth and in the clearance were calculated represent the extruder lines. The simulation was run under these conditions, as well as the effect of the values of flight width (0.2,0.3,0.4,0.5,0.6cm), flight clearance (0.05,0.06,0.07,0.08,0.09,and 0.1cm), depth of flight (0.3,0.4,0.5,and 0.6) and screw speed (30,45,60,75, and 90 RPM) and screw length (6,12,18,24,and 30cm).The result of simulation model gave a point with output and pressure values, and this point is close to the value of the calculated extruder line at the clearance of the flight, which proves that the value of the shear rate and the viscosity value between the calculated and the programare similar in values.*

Keywords:*Single screw extruder, Metering Zone, Extruder lines, one flight, Simulation Ansys polyflow, Extruder deign parameters.*

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I. INTRODUCTION

One of the methods of forming plastics is the extrusion process, which is a continuous process in which solid polymeric materials, whether granules or powders, are shredded, and then heated during transportation by a single or twin-screw extruder to become a compact molten. The pressurized molten flows through an opening known as the extrusion dies. There are types of dies for many products such as bags, tubes, profiles, etc. [1]

Therefore, the plastics and polymers engineer must be familiar with melt rheology, which describes the flow and deformation behavior of the melt. Thus, designing machines and molds for this process requires a quantitative description of the properties related to the flow of a molten polymer. Starting with relationships with solids and the final product [2].

The mold design for a new product is developed on the basis of previous experience and expertise. In many cases costly experiments and experiments can be replaced by computer simulations. Many commercial polymer flow simulation programs are used for extrusion die design today. For example: Ansys Polyflow, Flow 2000, NEXTRUCAD Dieflow, HyperXtrude, Compuplast. Numerical simulations have the potential to reveal important internal details of the extrusion process, such as velocity, shear stress, pressure, and temperature in the region of interest, which cannot be done experimentally[1].

Ansys Polyflow is a finite element computational fluid dynamics (CFD) software primarily designed for simulation of applications where viscoelastic and viscoelastic flows play an important role. The flows can be isothermal or isothermal, two-dimensional or three-dimensional, constant or time-dependent. Ansys Polyflow is mainly used to solve flow problems in polymer and rubber processing, food rheology, glass furnaces, and many other rheological applications[3].

Some authors have shown that how to simulate single screw extrusion using Polyflow to Sold convening and metering zones for Starch-Based Snack Products [4].

Factors affecting extrusion can be categorized into resin-dependent parameters which are not constant by measuring the physical properties of polymeric materials such as melting temperature and pressure, which affect product quality, not only dependent on the type of resin but also on the grade of resin used.

Machine related parameters They are more influenced by the geometry of the machine such as the extrusion screw and dies than by the properties of the resin. For single screw extrusion, show the effect of machine geometry on process target quantities.

Extruder output from a single screw extruder depends on the type of extruder, the output is determined either by the geometry of the solids feed area alone as in the case of the grooved extruder or the solids and melt areas to be found in a smooth barrel extruder[5]

The metering zone in the single screw extruder is to raise the pressure needed to force the melt through the forming mold. The derivation of the output equation assumes that the melt in the measurement region has a constant viscosity and that its flow is isothermal. It consists of three components are (drag flow, Pressure flow, and leakage flow) see Equation 1 and Equation 2of the total output.

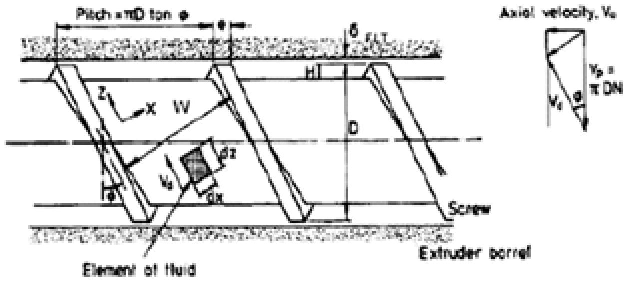


Figure 1: Analysis flow in metering zone

$$QTotal = Qd + Qp + QL ------1$$

$$QTotal = 12\pi^2 D^2 NHsin\emptyset cos\emptyset \left(1 - \frac{ne}{\pi Dtan\emptyset}\right) - \frac{\pi DH^3 sin^2\emptyset}{12\mu}\left(1 - \frac{ne}{\pi Dtan\emptyset}\right)\frac{dP}{dL} - \frac{\pi^2 D^2 \delta FLT^2}{12\mu . e} tan\emptyset \frac{dP}{dL} -------2$$

Where:

D: Flight diameter, H: Flight depth, e: flight width, N: screw speed (rev/sec), δ_{FLT} : flight clearance,
L: Length of metering zone, dP: Pressure difference across the metering zone
. $\emptyset$: flight angle, n: numer of flight, μ: viscosity at metering zone.

For many practical purposes sufficient accuracy is obtained by neglecting the leakage flow term and consider (e is small) and in addition the pressure gradient is often considered as linear$\frac{dP}{dL} = \frac{P}{L}$ so become Equation3.

$$QTotal = 12\pi^2 D^2 NHsin\emptyset cos\emptyset - \frac{\pi DH^3 sin^2\emptyset}{12\mu}\frac{.P}{L} ------3$$

Where 'L' is the length of the extruder. In the above analysis, it is the melt flow which is being considered and so the relevant pressure gradient will be that in the metering zone. If all other physical dimensions and conditions are constant then the variation of output with screw flight angle at the barrel, $\emptyset$ was studied maximum output would be obtained if the screw flight angle was about 35° In practice a screw flight angle of 17.7 ° is frequently used because this is the angle which occurs if the pitch of the screw is equal to the diameter and so it is convenient to manufacture. For a considerable portion of the extruder length, the screw is acting as a solid conveying device and it is known that the optimum angle in such cases is 17 ° to 20 °. Two cases were considered in Equation 3describe the extruder operation line.

One is the case of free discharge where there is no pressure build up at the end of the extruder ($\frac{dP}{dL} = 0$) in Equation 4.

$$QTotal = Qd = Qmax = 12\pi^2 D^2 NHsin\emptyset cos\emptyset ------4$$

An anther where the pressure at the end of the extruder is large enough to stop the output ($Q_{Total} = 0$) see in Equation 5,shear rate at depth Equation6 and shear rate at flight clearance Equation7.[6]

$$Pmax = \frac{6\pi DNL\mu}{H^2 tan\emptyset} ------5$$

$$\dot{\gamma}_H = \frac{\pi DN}{H} ------6$$

$$\dot{\gamma}_{FLT} = \frac{\pi DN}{\delta_{FLT}} ------7$$

With the help of Equation 3the effect of different parameters on the extruder output is presented in Figure 2by changing one variable at a time and keeping all other variables constant.

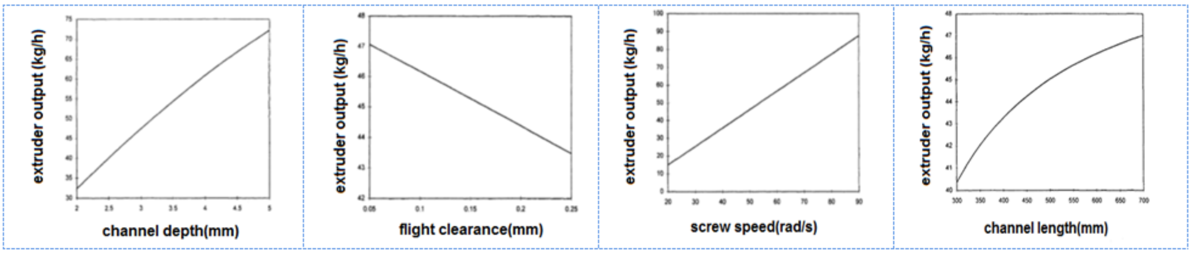


Figure 2:The effect of different parameters on the extruder output[5]

II. Material and Method

2.1 Material: Polypropylene was used according to Carreau Yasuda's viscosity law as a result in a previous work where the used the Ansys program and the Melt Flow index tester, but other models of viscosity can be used or used as a fixed value when calculations and in the program[7].

$$\mu = \mu_\infty + (\mu_0 - \mu_\infty)(1 + (\beta\dot{\gamma})^a)^{\frac{n-1}{a}} ------8$$

Were

$\mu\infty$= infinite-shear-rate viscosity =0.01445808 $poise$

$\mu 0$= zero-shear-rate viscosity =67380.02 $poise$

β = natural time (i.e., inverse of the shear rate at which the fluid changes from Newtonian to power-law behavior) =0.03531332 sec

a = index that controls the transition from the Newtonian plateau to the power-law region = 0.4534786

n = power-law index = 0.5375814E-05

2.2 Method:

2.2.1 Calculate the extruder lines

To calculate the extruder lines, the line is connected between maximum output using Equation 4 and maximum pressure in Equation 5. There are two calculated pressures depending on the viscosity value, one at the flight depth Equation 6 and the second at flight clearance Equation 7, thus there are two calculated operation lines of the extruder. The following design parameter were taking

$$here D = 6cm, H = 0.6cm, L = one flight = 6cm, N = 60RPM = \frac{1rev}{s}, \emptyset = 17.7, e = 0.6\ cm, \delta_{FLT} = 0.1cm,$$

$$\mu = from viscosity model at shear rate \text{ in } Eq\text{ution } 5\ and Eqution\ 6$$

Calculate maximum output of extruder by using Equation 4.

$$QTotal = Qd = Qmax = 12 \times \pi^2 \times 6^2 \times \left(\frac{60}{60}\right) \times 0.6 \times \sin(17.7) \times \cos(17.7) = 30.87\frac{cm^3}{s}$$

Calculate the maximum pressure: the following design parameter were taking

$$\dot{\gamma}H = \frac{\pi DN}{H} = \frac{\pi \times 6 \times (\frac{60}{60})}{0.6} = 31.4159\ sec^{-1} which gives \mu_H = 13864.4\ poise$$

$$Pmax_H = \frac{6 \times \pi \times 6 \times \left(\frac{60}{60}\right) \times 6 \times 13864.4}{0.6^2 \times tan17.7} = 81887950 \text{ dyne}/cm^2$$

$$\dot{\gamma}_{FLT} = \frac{\pi DN}{\delta_{FLT}} = \frac{\pi \times 6 \times (\frac{60}{60})}{0.1} = 188.4956 sec^{-1} which gives \mu_{FLT} = 4647.652\ poise$$

$$Pmax_{\delta_{FLT}} = \frac{6 \times \pi \times 6 \times (\frac{60}{60}) \times 6 \times 4647.652}{0.6^2 \times tan17.7} = 27450643 \text{ dyne}/cm^2$$

2.2.2 Simulation screw model in Ansys Polyflow:

Model: creating three sketches to the flight, screw roots and barrel (melt) on the XY Plane and set dimensions the flight sketch was sweep and revolves another sketch to complete 3D model, the flight and roots bodies combined to describe screw body then subtract it from melt body, the final body a sign to fluid.

Meshing: automatically generate medium meshing and assign to four faces as boundary input, output, barrel, screw

Setup (Polydata): the task is FEM, steady- state, isothermal, enter materials data (type of viscosity model Equation8the boundary set as:

Boundary 1: input = normal and tangential force imposed fn=0 ,fs=0

Boundary 2: output= normal and tangential force imposed fn=0 ,fs=0
Boundary 3: barrel = zero normal velocity and zero surface velocity condition Vn=0 ,Vs=0
Boundary 4: screw = angular velocity (rad/s)
Solution and Results: Contours of output parameters (shear rate, pressure drop, velocity, and viscosity) are graphically represented at every mesh of the structural geometry see Figure 3,Figure 4,Figure 5.
Generate results for multiple design points for study effect of screw parameters (flights width (e=0.2, 0.3, 0.4, 0.5, and 0.6cm), flight clearance (δFlT =0.1, 0.09, 61 0.08, 0.07, 0.06 and 0.05cm), depth (H =0.6, 0.5, 0.4, and 0.3cm), rotation speed (N=30, 45, 60, 75 and 90 RPM), and metering length (L=6, 12, 18, 24 and 30 cm) at the values of the parameters (maximum pressure drop was taken between max pressure at screw and min pressure at screw, Postprocessor of Flow rate at screw output, maximum and minimum shear rate) using the parameter and Design Points view, see the simulation of output and pressure in screw in set of Figures 5 and Figure 6.

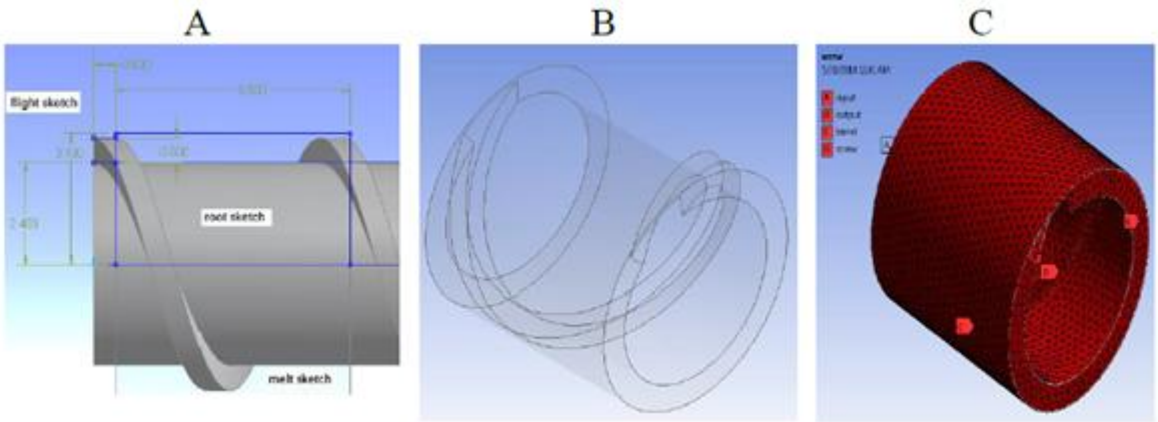


Figure 3: design one screw flight
(A)sketches and bodies, (B) melt body, (C)meshing and boundaries

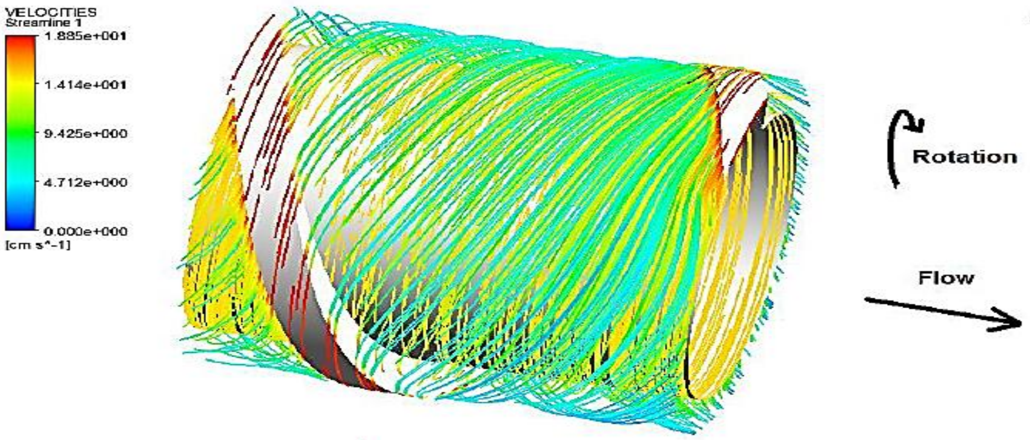
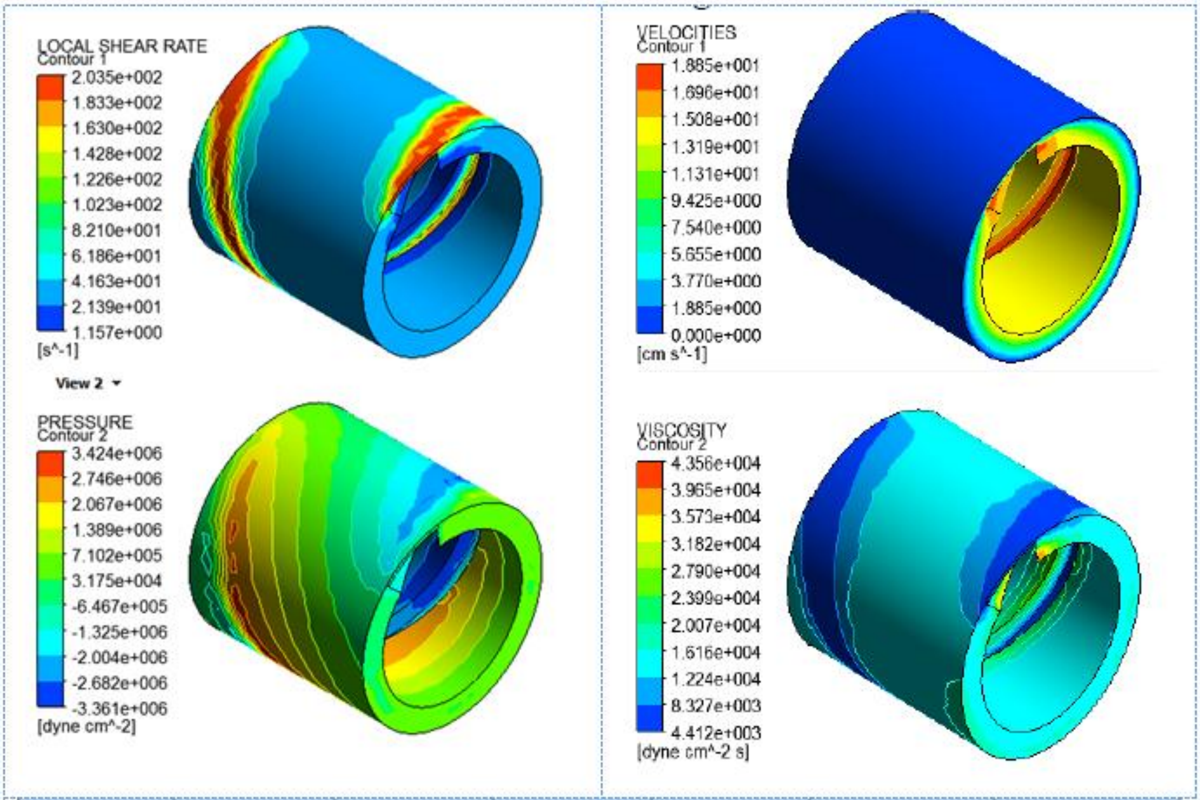


Figure4: Stream line of screw simulation



P13 - e	P14 - H	P17 - Rr	P19 - Rb	P18 - L	P2 - extruder outpout	P1 - D pmax
						dyne cm^-2
0.6	0.6	2.4	3.1	6	19.896	6.7848E+06

Figure5: Counters of shear rate, pressure, velocity, viscosity, and the design point of screw simulation

III. RESULT AND DISCUSSION

The results obtained are as discussed below

Figure 6 shows the extruder lines calculated with the values of the shear rate at the depth of flight and the clearance, the extruder simulation gives a known point with the output and pressure, and the point is close to the value of the extruder line calculated at the clearance at the values of the shear rate and viscosity ($188 s^{-1}$, $4647.6\, poise$), respectively, the simulation values for shear rate and viscosity in Figure (6) are ($203 s^{-1}$, $4412\ poise$), respectively. The program describes the actual situation where the leakage flow was calculated.

Table (1), Figure (7)shows the effect of the width of the flight, the pressure increases and the extruder output oscillates up to this value 0.4cm of the flight width. Then the two decreases by increasing the flight width, which decreases channel flow width. The optimum value is (e = 0.4 / 6 = 0.07D).

Table (2), Figure (8) shows the effect of the flight clearance, the pressure and extruder output decrease when the clearance increases. Increasing the clearance reduces the shear rate which reduces the pressure and on the other hand increases the leakage flow which reduces the extruder output.

Table (3), Figure (9) shows the effect of the flight depth, when flight depth was increased deep channel increased amount of output and reduce pressure drop.

Table (4), Figure (10) shows the effect of screw speed. an increase in the output by increasing the drag flow and also increasing the pressure according to the increase shear rate when the screw speed is increased.

Table (5), Figure (11) shows the effect of screw length. It is noticeable that until 18 cm the output and pressure were uniform, and when the length increased, the output decreased and the pressure increased. The optimum length is 18 cm which is equivalent to a three number of flight (length of metering zone=3D).

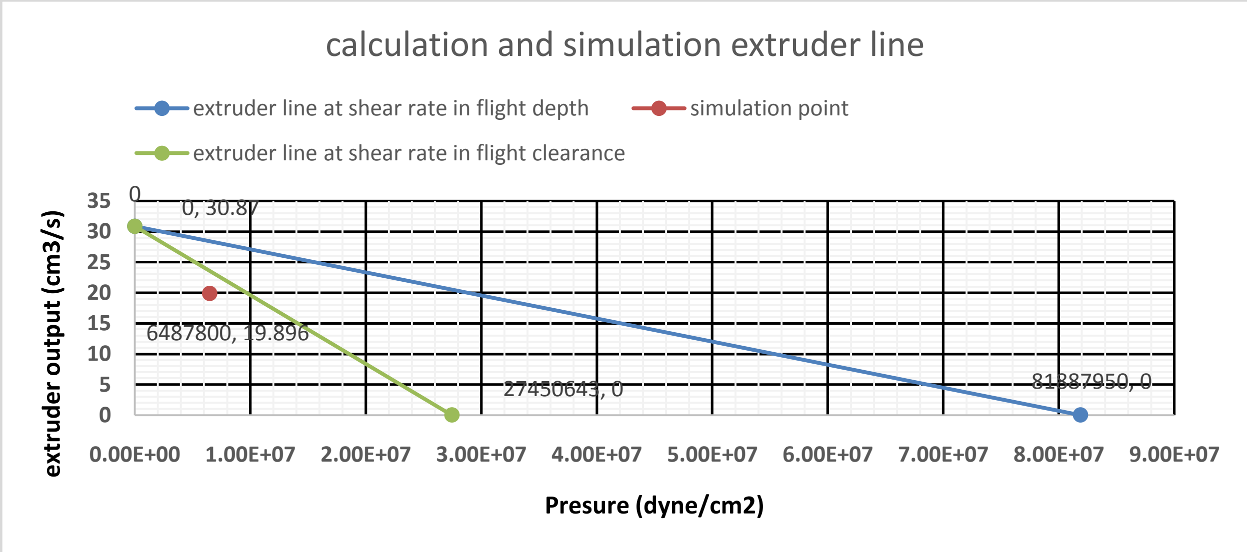


Figure 6: Calculation extruder line at depth and clearance with screw simulation

Table 1: Design point of extruder output and pressure in screw at different flight width

Table of Design Points

	A	B	C	D	E	F	G	H	I
1	Name	Update Order	P13 - e	P14 - H	P17 - Rr	P19 - Rb	P18 - L	P2 - extruder outpout	P1 - D pmax
2	Units								dyne cm^-2
3	Current	1	0.6	0.6	2.4	3.1	6	19.896	6.7848E+06
4	DP 1	2	0.5	0.6	2.4	3.1	6	20.143	6.99E+06
5	DP 2	3	0.4	0.6	2.4	3.1	6	20.346	7.1336E+06
6	DP 3	4	0.3	0.6	2.4	3.1	6	20.242	6.8435E+06
7	DP 4	5	0.2	0.6	2.4	3.1	6	20.362	6.7325E+06
*									

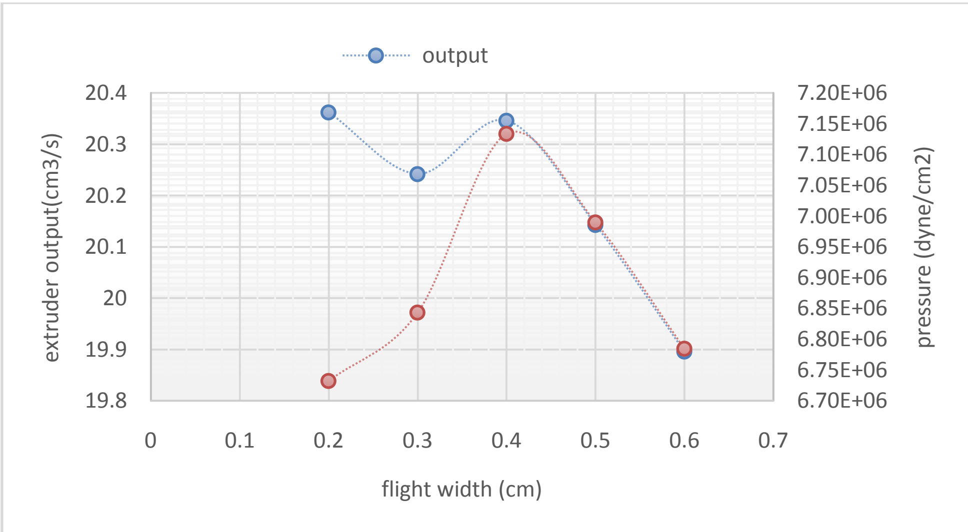


Figure 7: Extruder output and pressure at different flight width

Table 2: Design point of extruder output and pressure in screw at different flight clearance

Table of Design Points

	A	B	C	D	E	F	G	H	I	J
1	Name	Update Order	P13 - e	P14 - H	P17 - Rr	P19 - Rb	P1...	P20 - clearnce	P2 - extruder output	P1 - D pmax
2	Units									dyne cm^-2
3	Current	1	0.6	0.6	2.4	3.1	6	0.1	19.896	6.7848E+06
4	DP 1	2	0.6	0.6	2.4	3.09	6	0.09	19.881	7.257E+06
5	DP 2	3	0.6	0.6	2.4	3.08	6	0.08	19.836	7.7673E+06
6	DP 3	4	0.6	0.6	2.4	3.07	6	0.07	19.867	8.2001E+06
7	DP 4	5	0.6	0.6	2.4	3.06	6	0.06	19.944	8.4456E+06
8	DP 5	6	0.6	0.6	2.4	3.05	6	0.05	19.965	8.8658E+06
*										

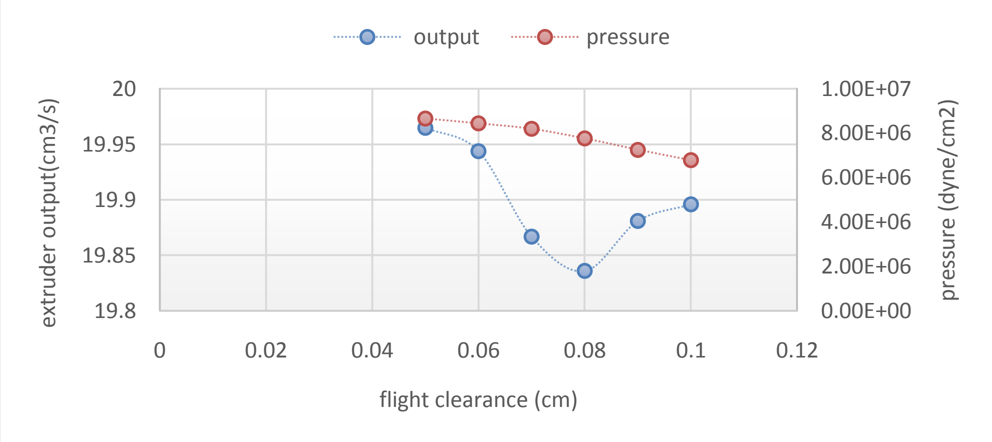


Figure 8: Extruder output and pressure at different flight clearance

Table 3: Design point of extruder output and pressure in screw at different flight depth

Table of Design Points

	A	B	C	D	E	F	G	H	I
1	Name	Update Order	P13 - e	P14 - H	P17 - Rr	P19 - Rb	P18 - L	P2 - extruder output	P1 - D pmax
2	Units								dyne cm^-2
3	Current	1	0.6	0.6	2.4	3.1	6	19.896	6.7848E+06
4	DP 1	2	0.6	0.5	2.5	3.1	6	16.294	7.9599E+06
5	DP 3	4	0.6	0.4	2.6	3.1	6	12.493	1.1827E+07
6	DP 4	5	0.6	0.3	2.7	3.1	6	8.7235	1.2484E+07

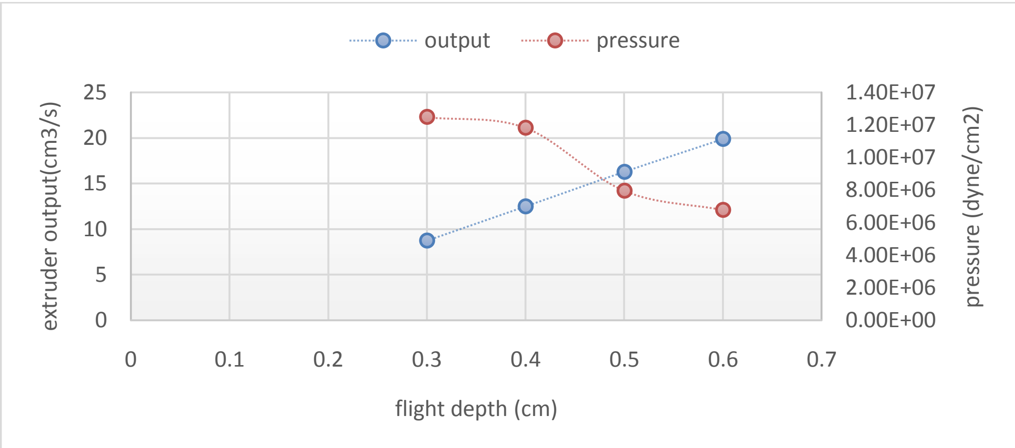


Figure 9: Extruder output and pressure at different flight depth

Table 4: Design point of extruder output and pressure in different screw speed

1	Name	Update Order	P13 - e	P14 - H	P17 - Rr	P19 - Rb	P18 - L	P20 - flow rate	P21 - delta P
2	Units								dyne cm^-2
3	Current	30	0.6	0.6	2.4	3.1	6	10.146	4.8556E+06
*	Current	45	0.6	0.6	2.4	3.1	6	15.05	5.9447E+06
3	Current	60	0.6	0.6	2.4	3.1	6	19.896	6.7848E+06
3	Current	75	0.6	0.6	2.4	3.1	6	24.699	7.4692E+06
3	Current	90	0.6	0.6	2.4	3.1	6	29.465	8.0471E+06

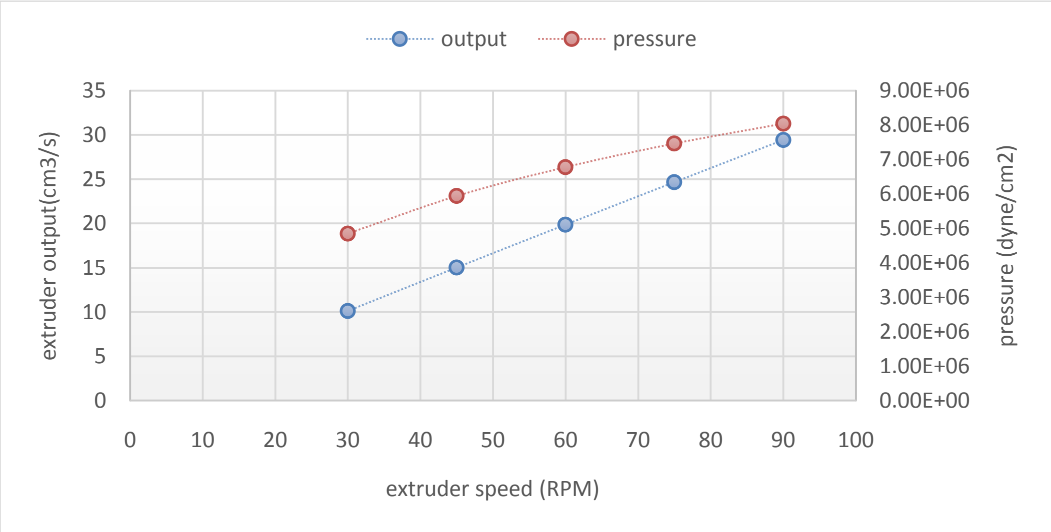


Figure 10: Extruder output and pressure at different screw speed

Table 5: Design point of extruder output and pressure at different screw length

Table of Design Points

	A	B	C	D	E	F	G	H	I
1	Name	Update Order	P13 - e	P14 - H	P17 - Rr	P19 - Rb	P18 - L	P2 - extruder outpout	P1 - D pmax
2	Units								dyne cm^-2
3	Current	1	0.6	0.6	2.4	3.1	6	19.896	6.7848E+06
4	DP 1	2	0.6	0.6	2.4	3.1	12	21.714	8.8876E+06
5	DP 2	3	0.6	0.6	2.4	3.1	18	21.308	8.9769E+06
6	DP 3	4	0.6	0.6	2.4	3.1	24	15.769	2.7369E+07
7	DP 4	5	0.6	0.6	2.4	3.1	30	13.352	2.5564E+07

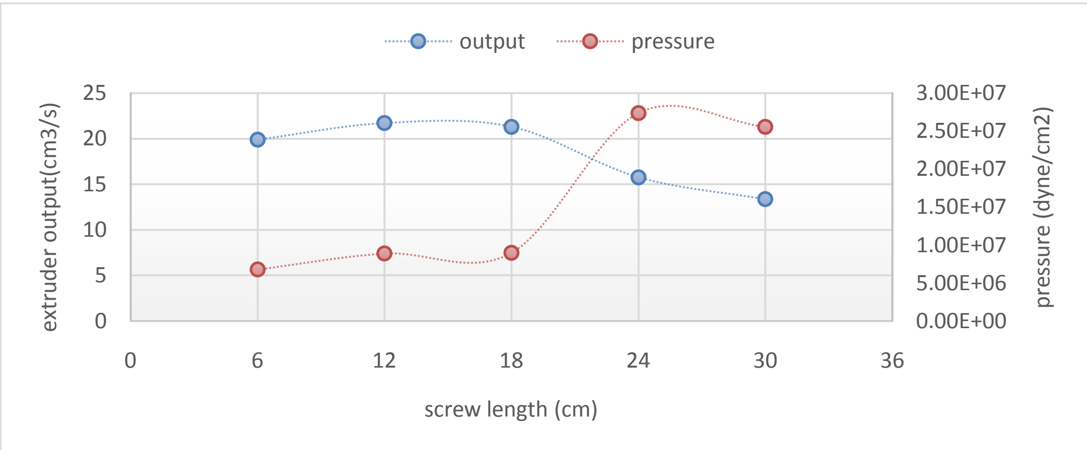


Figure 11: Extruder output and pressure at different screw length

IV. CONCLUSION

Extruder lines (maximum output and maximum pressure) were calculated theoretically at a values of shear rate in flight depth and clearance, the extruder simulation give a known point with the output and pressure, and the point is close to the value of the extruder line calculated at the clearance. The pressure increased and the extruder output oscillated up to the value 0.4cm of the flight width, then the two decreased by increasing the flight width more, the optimum value is ($e = 0.4 / 6 = 0.07D$). The pressure and extruder output decreased when the clearance increased. When flight depth was increased the output increased and decreased pressure. an increased in the output and pressure according to the increased the screw speed. It is noticeable that until 18 cm the output and pressure were uniform, and when the length increased more, the output decreased and the pressure increased, the optimum length is 18 cm which is equivalent to a three number of flight (length of metering zone=3D).

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