Rheology Of Reinforced Polypropylene Melt Flow

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Abstract:

Different techniques are applied for the fabrication of ceramic materials for resolving different engineering applications. In this paper a composed material from thermoplastc materials was replaced by reinforced polypropylene (PP). The mathematical model of viscoelastic behavior was applied. This process is well modeled by fluid flow correlations in the single screw extruder. The operating point of the extruder is calculated by solving the mathematical model when the flow rate and the pressure drop in the extruder are calculated. Also in this paper

melt flow of reinforced ceramic materials, where 90 % of poly propylene is reinforced with 10% fiberglass is mathematically modeled and analyzed.

Key words - creep, ceramic materials, processing of composite materials, melt flow

1. introduction:

The interests of Mobile Ad-Hoc Networks (MANETs) have been widely expanded from environmental monitoring applications to infrastructure monitoring emergency medical response and military surveillance applications (Becker, 2007). In Mobile Ad-Hoc networks, routing mechanisms for reliable data communication with less power consumption is one of the most important aspects due to the limited power availability in each wireless node (Perkins, 2000). Since the communication between two Mobile Ad-Hoc nodes consumes more power, it is important to minimize the cost of power required for communication by exercising power aware routing strategy.

Polymers are processed into the final products techniques and shape of final item (sheets, films, three dimensional items ....etc.). Processing of plastics includes heating, flowing, chemical reaction and cooling ion molding.. Different process technologies are used including extrusion, compression molding, calendaring, and injection molding. Polymers are reinforced with different ceramic materials and they are melted and processed in extruder [1].

2. EXTRUSION :

During the process of extrusion, simultaneous operations occur in order to produce objects continuously- solid transport, melting, compacting and flow under pressure through a die that provides the ultimate shape.

Actually started in the rubber industry that preceded the plastics industry (mid-19th century). Since 1925, growing use occurred in the extrusion of thermoplastics followed by machine development, The theoretical analysis of the process has attained serious achievements since the 1930s while major effort in the mathematical analysis of the extrusion process started in the 1950s. The melt flow was simplified in order to obtain an initial analytic solution that relates the output to the operational variables. With time, more exact (numerical) solutions were developed considering complex liquids (viscoelastic, non-Newtonian) and the geometry of the fabrication process. The operational conditions were converted to computer control [2, 3].

3. GENERAL FEATURES OF A SINGLE SCREW EXTRUDER :

One of the most common methods of processing plastics is **Extrusion** using a screw inside a barrel as shown in figure (1). The reinforced plastic materials, usually in the form of granules or powder, is fed from a hopper on to the screw. It is then conveyed along the barrel where it is heated by conduction from the barrel heaters and shear due to its movement along the screw flights. The depth of the screw channel is reduced along the length of the screw so as to compact the material. At the end of the extruder the melt passes through a die to produce an extrudate of the desired shape.

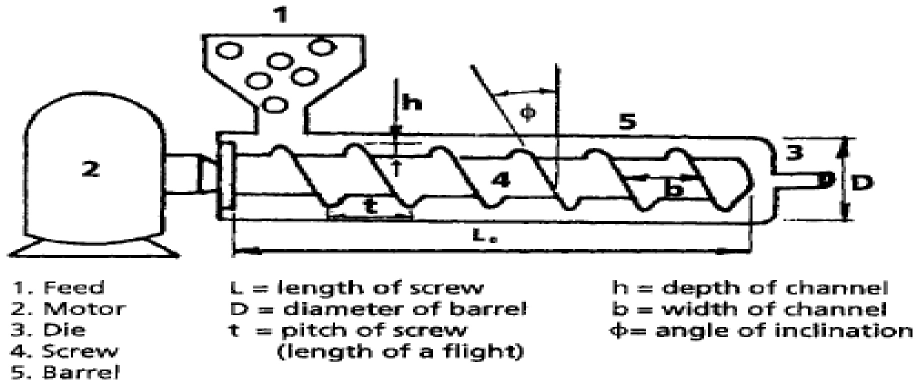


figure 1, single extruder with a die.

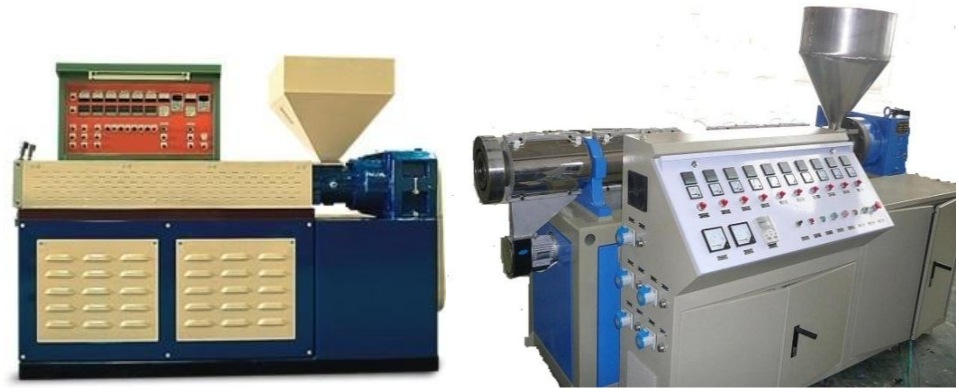


figure (2) Single Screw Extruder.

The extruder screw has three different zones :

1. 1. 1 FEED ZONE :

The function of this zone is to preheat the plastic and convey it to the subsequent zones. The design of this section is important since the constant screw depth must supply sufficient material to the metering zone so as not to starve it, but on the other hand not supply so much material that the metering zone is overrun .

1. **1. 2 COMPRESSION ZONE :**

In this zone the screw depth gradually decreases so as to compact the plastic. This compaction has the dual role of squeezing any trapped air pockets back into the feed zone and improving the heat transfer through the reduced thickness of material.

1. 1. 3 METERING ZONE :

In this section the screw depth is again constant but much less than the feed zone. In the metering zone the melt is homogenized so as to supply at a constant rate, material of uniform temperature and pressure to the die. This zone is the most straight-forward to analyze since it involves a viscous melt flowing along a uniform channel. All zones are illustrated in Fig (2).

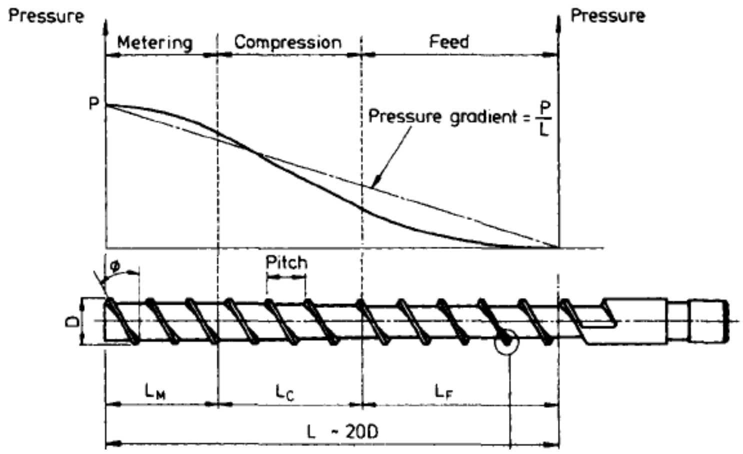


Figure (3), Different melt zones in extruder

As the plastic moves along the screw, it melts by the following mechanism. Initially a thin film of molten material is formed at the barrel wall. As the screw rotates, it scrapes this film off and the molten plastic moves down the front face of the screw flight. When it reaches the core of the screw it sweeps up again, setting up a rotary movement in front of the leading edge of the screw flight. Initially the screw flight contains solid granules but these tend to be swept into the molten pool by the rotary movement. 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 exists between the screw flights .

2. ANALYSIS OF FLOW IN EXTRUDERS :

It is convenient to consider the output from the extruder as consisting of three components as follows :

2. 1 DRAG FLOW :

This is the typical flow when a liquid exists in the helical channels between the screw base and the surface of the cylindrical barrel as shown in figure (3), as a result of relative motion and friction between liquid and metal. As long as nonslipping is assumed, the liquid follows the motion of the screw and a velocity gradient between moving screw and stationary barrel is obtained. However, mathematically it is simpler to assume a rotating barrel and stationary screw. The inclination angle and the friction coefficient determine the amount of material that is dragged by the screw and moves with it.

For the small element of fluid ABCD the volume flow rate dQ is given by :

$$dQ = V \times dy = dz \quad \text{......................} \quad (1)$$

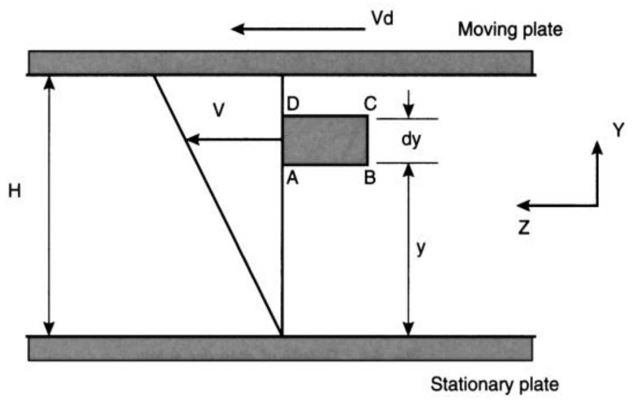


figure (4), a liquid exists in the helical channels in Single Screw extruder [2]

Assuming the velocity gradient is linear :

$$V = V_d \left[\frac{y}{H} \right] \text{................(2)}$$

Substituting in equation (1) and integrating over the channel depth, **H,** then the total drag flow, $\mathbf{Q_d}$ is given by:

$$Q_d = \frac{1}{2} THV_d \text{ .... (3)}$$

Figure (3) shows the position of the element of fluid and equation (2) may be modified to include terms relevant to the extruder dimensions:

$\mathbf{V_d} = \pi.D.N.\cos\acute{\varnothing}$

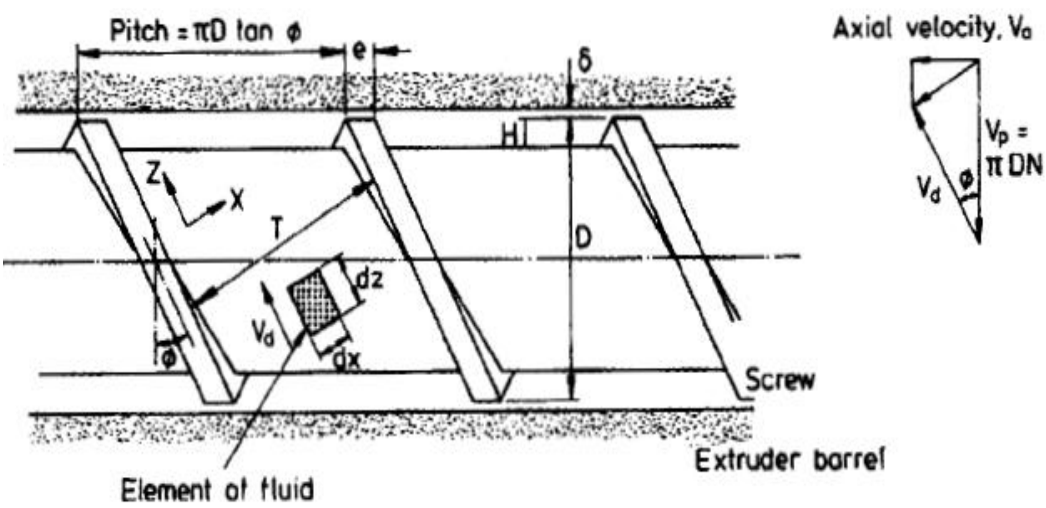


Figure (5), the position of the element of fluid in Single Screw extruder [2].

Where N is the screw speed:

T = (π.D.tanǾ - e).cosǾ …………(4)

so $Q_d = \frac{1}{2}$ (π.D.tanǾ - e)(π.D.N $\cos^2$Ǿ) ……….. (5)

In most cases the term, e, is small in comparison with (π.D.tanǾ) so this expression is reduced to:

$Q_d = \frac{1}{2}$. π^2.D^2.N.H.sinǾ.cosǾ ……….. (6)

Shear rate in the metering zone :

$\gamma = \frac{V_d}{H}$ …………(7)

2. 2 PRESSURE FLOW :

in figure (4), this type of flow does not occur when the die is missing. In that case, it is considered an open unhampered extruder, serving solely as a pump with only drag flow [2].

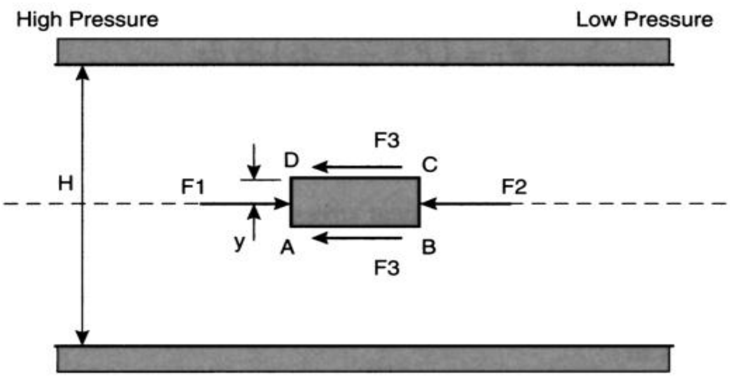


figure 6, Analysis of Flow in Extruder (pressure flow) [2].

$$F_1 = \left(P + \frac{\partial P}{\partial Z}\right) dZdydx................(8)$$

$$F_2 = P.dydx...............................(9)$$

$$F_3 = \tau ydzdx...............................(10)$$

where **P** is pressure and $d\tau$ is the shear stress acting on the element. For steady flow these forces are in equilibrium so they may be equated as follows:

$$F_1 = F_2 + 2F_3.....................................(11)$$

$$y\frac{dP}{dz} = \tau_y...(12)$$

Now for a Newtonian fluid, the shear stress, τ_y is related to the viscosity, η , and the shear rate, γ by the equation:

$$\tau_y = \eta\gamma = \eta\frac{dV}{dy}......................(13)$$

Using this in equation **(**12**)**:

$$y\frac{dP}{dz} = \eta\frac{dV}{dy}...................................(14)$$

This may lead to the pressure flow, **Qp**:

$$Q_p = -\frac{1}{12\eta}\frac{dP}{dz}.TH^3 ....(15)$$

Referring to the element of fluid between the screw flights as shown in Figure. (3) , this equation may be rearranged using the following substitutions. Assuming e is small:

$$\sin\phi = \frac{dL}{dz} so \frac{dP}{dz}\sin\phi \;.................................(16)$$

Thus the expression for $\mathbf{Q_p}$ becomes:

$$Q_p = \frac{\pi.D.H^3 \sin^2\theta}{12\eta}.\frac{dp}{Dl} ....(17)$$

2. 3 LEAKAGE FLOW

There exists a gap (albeit very small) between the flights of the screw and the interior of the barrel allowing some leakage. [4], where H = δ and T= $\pi.D/\cos\varphi$.

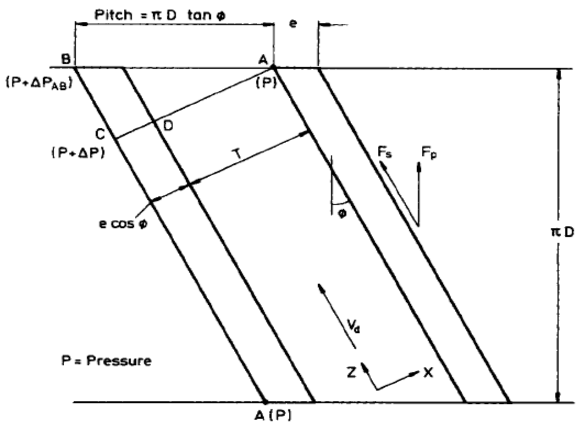


Figure (7), the flights of the screw and the interior of the barrel allowing some leakage

So the leakage flow, **QL,** is given by:

From figure (7):

Pressure gradient = $\dfrac{\Delta P}{e.\cos\phi}$

$$Q_l = \frac{\pi^2.D^2.\delta^3}{12\eta.e}\tan\theta.\frac{dP}{dl}\text{.................................}(18)$$

The total output is the combination of drag flow, back pressure flow and leakage. So from equations (15 , 17 and 18):

$Q = Q_d - Q_p - Q_L$

$$Q = \frac{1}{2}\pi^2.D^2H^2.\sin^2\varphi\cos\phi - .\frac{\pi DH^3\sin^2\phi}{12\eta}.\frac{dP}{dL} - \frac{\pi 2D2\delta 3}{12\eta e}\tan\varphi\frac{dP}{dL}\text{...........}(19)$$

3. EXTRUDER DIE CHARACTERISTICS

From equation (19) it may be seen that there are two interesting situations to consider. One is the case of free discharge where there is no pressure build up at the end of the extruder so:

$$Q = Q_{\max} = \frac{1}{2}\pi^2D^2NH\sin\phi\cos\phi\text{............................}(20)$$

Also, from equation (19) with Q = 0 and neglecting the leakage flow:

$$P = P_{max} = 6\frac{\pi DLN\eta}{H^2\tan\phi}\text{...}(21)$$

The extruder has a high output if the pressure at its outlet is low. However, the outlet from the extruder is the inlet to the die and the output of the latter increases with inlet pressure. As will be seen later the output, **Q,** of a Newtonian fluid from a die is given by a relation of the form:

Q = CP …………………………... (22)

Where : $C = \frac{\pi.R^4}{8.\eta.L_d}$ for a capillary die of radius R and length L_d .

Equation (22) enables the die characteristics to be plotted on Figure. (2. 6) and the intersection of the two characteristics is the operating point of the extruder [4].

The operating point for an extruder\die combination may also be determined from equations (19) and (22)**:**

The pressure at the opening point is given by:

$$:Q = \frac{1}{2}\pi^2 D^2 NH \sin\phi\cos\phi - \frac{\pi D H^3 \sin^2\phi}{12\eta}\frac{P}{L} = \frac{\pi H^4}{8\eta Ld} \text{.............(23)}$$

But:

$$POP = \frac{2\pi\eta D2NH\sin\theta\cos\theta}{(R^2/2L_d) + (D.H^3\sin^2\theta)/3L} \text{.............(24)}$$

Where:

Ǿ : screw flight angle.

D : screw diameter (mm).

H ; flight depth (metering zone) (mm).

N : max. screw speed (rev\min).

η : maximum melt viscosity (Ns\m^2).

Q : melt flow rate through die (m^3\s) .

P : pressure (MN\m^2)

R : radius of die (mm).

L : screw length.

L_d : length of die (mm).

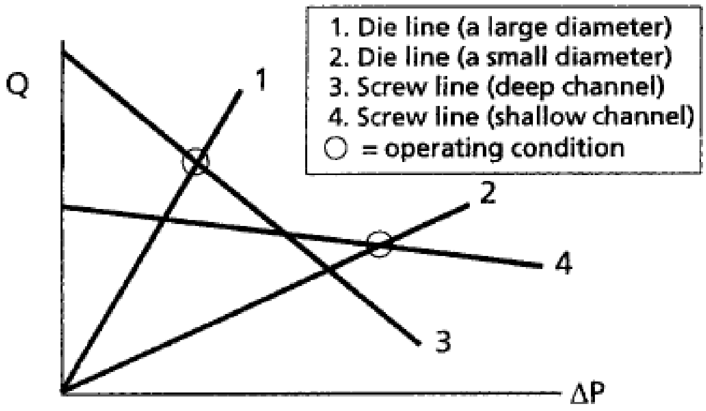


Figure (8), Operating lines for the screw and the die

4- THE CALCULATIONS :

First: Determination of Q for composite material (95% polypropylene with 5% Fiber glass) at two components: drag flow, pressure flow and total Q with neglecting leakage flow from equations (15), (17) and (19):

Assumptions for single screw Extruder (uses lab Extruder):

Ǿ = 17.7^0

D = 25 mm

L = 500 mm

N = 100 rev\min

H = 2 mm

η = 400 Ns\m^2

R = 1.5 mm

L_d = 40 mm

1) for drag flow, using equation (15):

$$Q_d = \frac{1}{2}\pi^2 D^2 NH \sin\Phi \cos\Phi$$

$Q_d = \frac{1}{2} . \pi^2.(25*10^{-3})^2.(100\backslash 60).(2*10^{-3}).\sin 17.7.\cos 17.7$

$Q_d = 2.97*10^{-6}$ m^3\s

2) pressure flow: useing equation (3.5) at P = 10 MN\m^2:

$$Qp = \frac{\pi D H^3 \sin^3 \Phi}{12\eta} \frac{dP}{dl}$$

$Q_p = -[(\pi*(25*10^{-3})*(2*10^{-3})^3*\sin^2 17.7)\backslash(12*400)]*(20*10^6\backslash 0.5)$

$Q_p = 1.905*10^{-6}$ m^3\s

3) total flow:

$Q = Q_d - Q_P$

$Q = 2.97*10^{-6} - 1.905*10^{-6}$

$Q = 1.07*10^{-6}$ m^3\s

The shear rate, $\dot{\gamma}$ in the metering zone will be given by [5, 6]:

$$\dot{\gamma} = \frac{Vd}{H} = \frac{\pi D N \cos\phi}{H} \text{.............}(25)$$

$\gamma = [\ \pi\ (25\ X\ 10^{-3})(1\ 00/6O)\cos 17.7\ ]\backslash(\ 2*10^{-3}\ )$

$\gamma = 62.35\ S^{-1}$

Second: determination of operating point as figure (6):

1) Extruder characteristic: using equations (17) and (18):

$Q_{max} = \frac{1}{2}\ .\ \pi^2.D^2.N.H.\sin\acute{Ø}.\cos\acute{Ø}$

$Q_{max} = \frac{1}{2}\ .\ \pi^2.(25*10^{-3})^2.(100\backslash 60).(2*10^{-3}).\sin 17.7.\cos 17.7$

$Q_{max} = 2.97*10^{-6}$ m^3\s

$P_{max} = [6\pi(25)(500)(100)(400*10^{-6})]\backslash[60*(2)^2*\tan 17.7]$

$P_{max} = 123.048$ MN\m^2

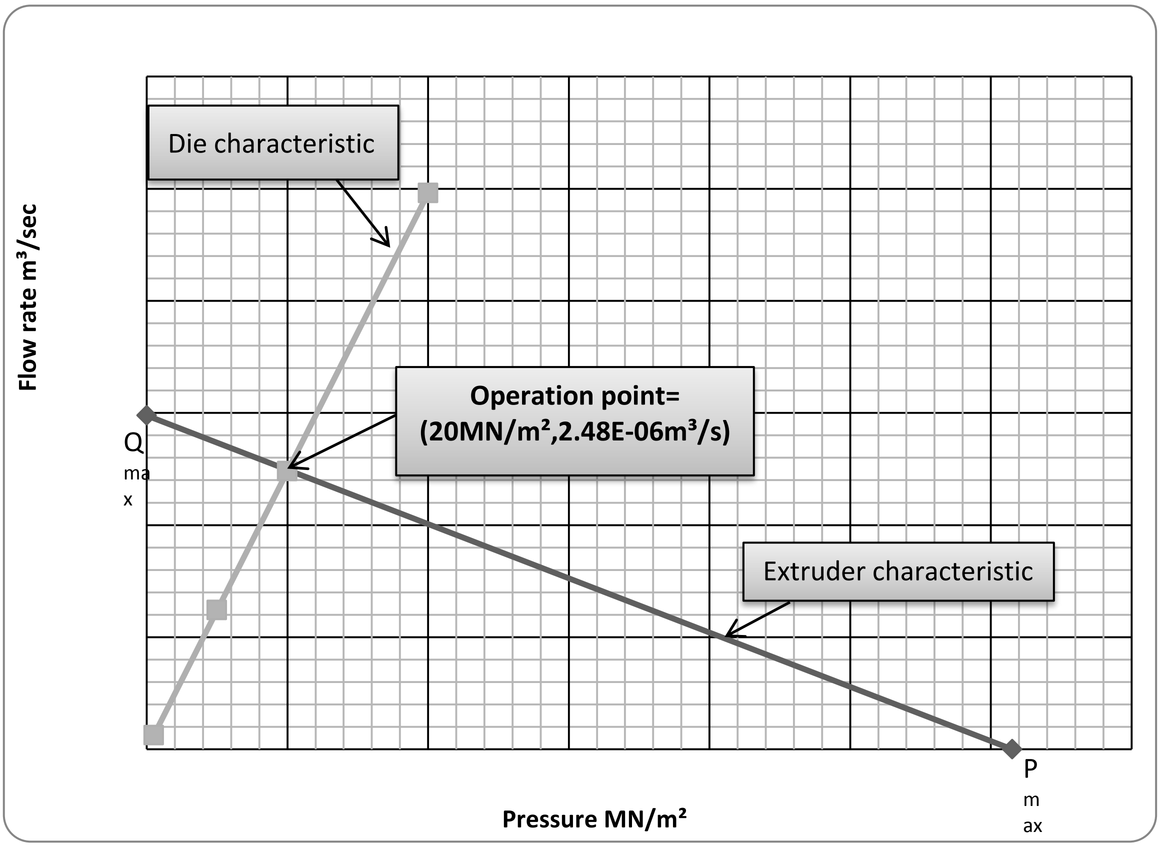
2) die characteristic: using equation (22):

Q = C P

$$Q = \frac{\pi * 1.5^4 * 10^{-9}}{8 * 400 * 40 * 10^{-5}}$$

$$C = \frac{\pi . R^4}{8\eta . L_d}$$

C = 1.24*10^{-7} (m^5\MNs)



Plotting die characteristic with Extruder characteristic, figure (7)

Figure (9) Extruder and die characteristics

From figure (7) the operating point is:

Output ,Q = 2.49*10^{-6} m^3\s

Table (1), the operating points (Q & P) at difference melting viscosity.

η_{mel} Ns\m^2	400	500	600	700
Q_{max}	$2.97*10^{-6}$	$2.97*10^{-6}$	$2.97*10^{-6}$	$2.97*10^{-6}$
P_{max}	123.048	153.81	184.57	215.33
C	$1.24*10^{-7}$	$0.99*10^{-7}$	$0.82*10^{-7}$	$0.71*10^{-7}$
Q_{op} m^3\s	$2.49*10^{-6}$	$2.49*10^{-6}$	$2.49*10^{-6}$	$2.49*10^{-6}$
P_{op} MN\m^2	20	25.5	30	36

5- CONCLUSIONS

Die characteristics with extruder dimensions are presented in this paper. Table 1 represents the operating point of the extruder. The out put flow and the pressure at the point of the extruder is calculated at /front melting viscosity. And listed in the table.

Melt flow of reinforced ceramic materials are analysed in this paper. Optimum operating points of reinforced ceramic materials are determined for fluid flow in the extruder on laboratory scale. Extension to large scale extruder is recommended for future work.

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