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INFLUENCE OF FOOD EXTRUDER DIE DIMENSIONS ON EXTRUDED PRODUCTS EXPANSION

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Abstract

This paper studied the effects of food extruder die dimensions on the extrudate expansion indices using twin-screw extruder. The extruder has 59.6 mm screw diameter and screw L/D ratio of 20. The die dimensions considered are die length, die diameter and die temperature. The feed material used is yellow corn flour. Dies with diameter ranging from 2.5 – 5.0 were used to determine the effect of die nozzle diameter on extrudate expansion. Results obtained showed that radial expansion of the extrudate decreased with increasing die diameter. The regression model shows that SME decreased with increasing die diameter. Dies with length ranging from 16 – 54mm with a constant nozzle diameter of 3mm were used to determine the effects of die nozzle length on extrudate expansion. The die length significantly influenced axial expansion of extrudate. Axial expansion increased with increase in die length. A linear regression model was developed to relate die length to extruder SME. The quadratic effect is negligible in this case and as such was not included in the regression equation. Effects of die nozzle L/D on radial expansion of extrudate during extrusion were also studied. Experimental results on the effects of die diameter and die length on flow characteristics revealed that when all other extruder conditions are kept constant, increasing the diameter of the die nozzle causes increase in the volumetric flow rate of extrudate. Flow rate decrease proportionally with increasing die length.

Key words: *Dies; dimensions; extrudate; expansion; extruder*.

INTRODUCTION

Extrusion cooking has indeed revolutionized the food industry as it has obvious advantages over conventional food processes. The working time at high temperature is a matter of seconds, which has favorable effects in maintaining the properties of the ingredients and active substances while giving high rate of destruction of harmful microorganisms. The end products have long shelf life on account of their low process moisture content. Continuous extrusion cooking has economic advantage because it replaces many batch processes and because it is carried out almost entirely with the final moisture content, thus avoiding the necessity to evaporate huge quantity of water (Adekola, 1999).

The die is a major component of the extruder. The die area is the section of the extruder that occurs after the food material leaves the extruder screw. The die has been described as the transitional piece which changes the direction of dough flow from horizontal (as it leaves the extrusion screw) to vertical (as it passes through the die) It is a major component of extruder both for plastic and food production (Sors and Balazs, 1989). The die normally consists of three parts, which are the transition, distribution and die plate sections (Adekola, 2014b). The sections and the basic die terminology are shown in Figure. 1 and 2 respectively.

The die allows rapid expansion 'puffing' of the dough into various shapes and sizes depending on the configuration of the die section. When the dough leaves the die, the temperature and pressure drop abruptly and the product expands. A proper understanding of the material properties and the nature of flow in the extruder die are essential in controlling the extruder performance and extrudate quality (Adekola, et al, 1998).

The extruder die can also be used as a capillary rheometer to monitor on continuous basis the rheological properties of the dough since most rheometer cannot simulate the flow in the extruder. The entrance and exit effects, the product rheology and phase changes that occur at the die have a significant effect on flow pattern and die designs (Frame, 1993). Therefore, the importance of research works and understanding of extruder die in the overall performance of food extrusion and extruder cannot be overemphasized.

When dough enters a die from an extruder barrel, a velocity profile starts to develop and continues to change until it reaches a specific distance beyond which flow is fully developed. The flow of extrudate through the opening could be likened to fluid flow through an

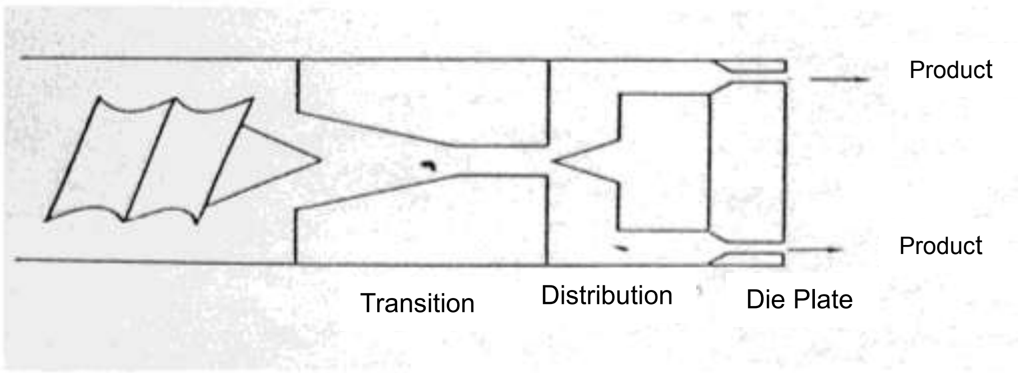

Figure1: Sections of an extruder die

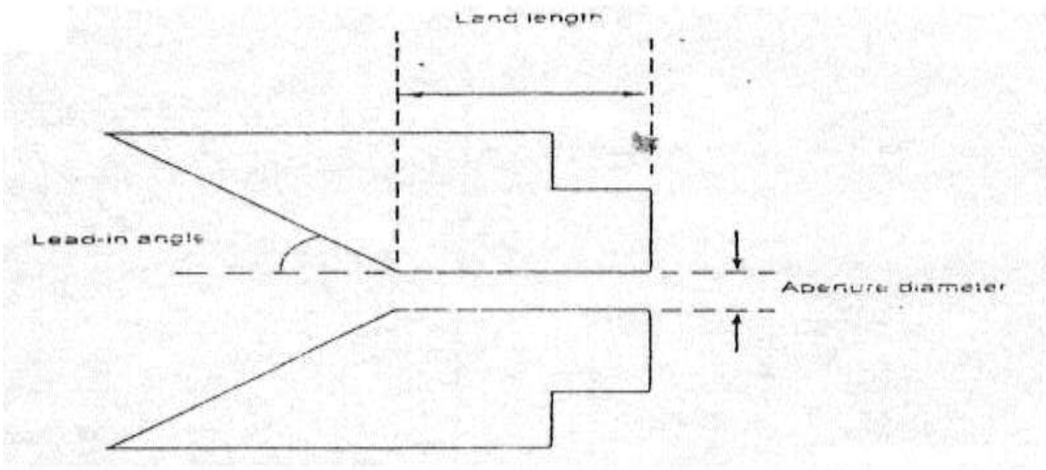

Figure 2: Basic die terminology

enclosed pipe under pressure. It is likely that the basic formulae of fluid dynamics can be used to model the flow through the die.

Entrance pressure drop of extruder dies increased with a decrease in the ratio of barrel to die diameter during the extrusion of corn. Entrance pressure drop affects barrel to die diameter ratio, flow within the die and shear stress among others. These factors are important in the design of food extruder, which is one of the areas of study in the present work. The expansion volume of starch is mainly dependent on its degree of gelatinization within the extruder (Stanley, 1986).

Die nozzle diameter and length play a very important role in starch extrusion expansion. In an experiment with single screw extruder, an optimum extrusion pressure was obtained for the best expansion of 14% moisture starch with a nozzle having an L/D ratio of 3.4 (Chinnaswamy and Hanna, 1987) . The back pressure in the extruder barrel is directly proportional to the nozzle L/D ratios.

A recent study was carried out to determine the effects of die dimensions on extruder performance (Sokhey et al, 1997). Yellow corn grits having 18% moisture content (db) were extrusion cooked in a single screw laboratory extruder at 140 ^{0}C barrel temperature and 140rpm screw speed. The nozzle diameter ranged from 2 to 6.2mm and the die nozzle lengths ranged from 5.48 to 50.3mm. The study concluded that die diameter affected the radial expansion of the extrudate. Axial and overall expansions were not affected by die diameter.

There is no reported work on the effect of die parameters on extruder performance for twin screw extruder despite the wider usage of twin screw extruder over single screw extruder. Most of the works on the effect of die dimensions on extruder performance where available are on single screw extruder.

Several research results are available on food extrusion technology and food extruder. Literature exists on the theory and application of extrusion cooking, process parameter optimization, modeling and computer simulation of food extrusion sections (Adekola 20114). Works on screw, metering, mixing and feed conveying

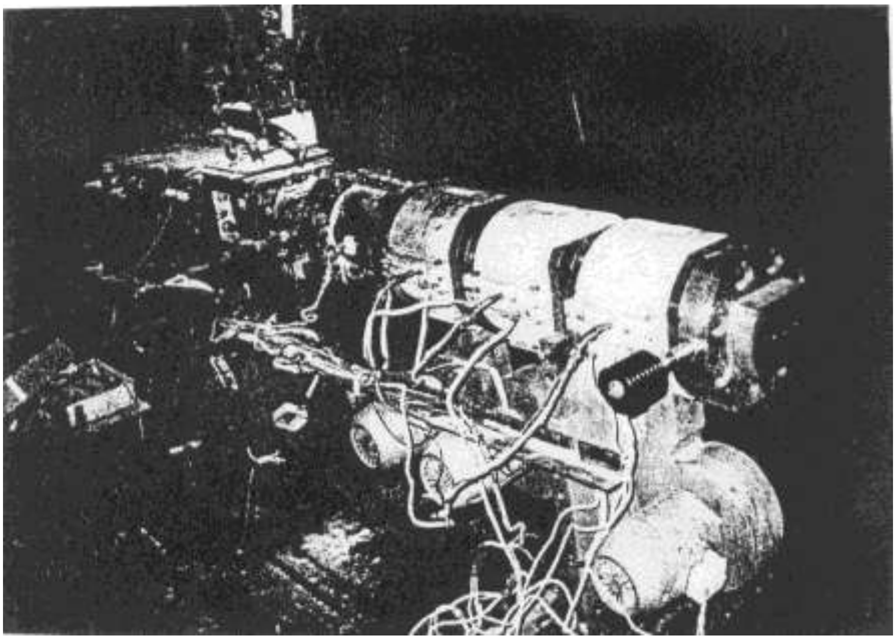

Figure 3: Locally improved TSSJ-60 Model Twin-Screw Extruder

sections are available, but very few of these studies focus on extruder die section. The effect of die is often neglected when studying twin screw extruder.

The importance of die in the extrusion process and the need for research works in this area has been emphasized (Sokhey et al, 1997; Tayeb et al, 1990). Recent experimental studies on food extrusion cooking by our study group further revealed the inadequacy of available published works to fully explain the phenomenon with food extruder die (Adekola, 1999)

Furthermore, there is the need for research works on food extruder die with an overall objective of improving the efficiency of food extrusion operation. Studies in food extrusion are scanty. The effect of die geometry and process parameters on extrudate quality using twin screw extruder has not been reported. This necessitated our studies on the effects of die dimensions on expansion indices for twin-screw extruder in this work.

EXPERIMENTAL PROCEDURE

The objective is to determine the effects of food extruder die dimensions on the extrudate expansion. The die dimension parameters considered are length of die, diameter of die, number of die and die temperature. The extruder used is TSSJ-60 model (Figure 3) and the feed material used is yellow corn flour.

Experimental Design and Analysis

The range of actual value for the experiments was 2.5 – 5mm for die diameter (D) and 16 – 54mm for the die length (L). The screw speed was also fixed at 160 rpm and the temperature at the last section of the barrel 160 ^{0}C. The moisture content of the yellow corn flour used for the experiment is 20% w.b. Six dies were used with different diameters and lengths. The dimensions of the dies used in the experiments are given in Table 1. Three replicates of each experiment were performed. The experiment was conducted with each die for 25 minutes and five samples were collected for each test. The L/D ratio of the die used varied from 5.33 to 18. The expansion properties of the collected samples were done and statistical analyses were carried out to determine the effects of diameter, length and the ratio of length and diameter on the measured expansion properties.

Machine and Equipment

The experiments carried out in this work made use of the TSSJ-60 twin-screw extruder model. The extruder is jointly manufactured by Jilin University of Technology and Jilin Province DunHua Northern Plastic Factory. The machine is equipped with a 37 kw three-phase electric motor with a maximum speed of 1480 rpm. With the use of speed reducer JPSB model, the screw speed is limited to between 0 and 300 rpm. Figure. 4 shows the dies used in the experiment.

MATERIALS AND METHODS

The yellow corn flour used for the experiment was procured from the Extension Unit of North East Agricultural University, Changchun. The proximate analysis conducted according to AOAC Standards

Table 1: Dimensions of Dies for Experiment Plan

Effect of die diameter			**Effect of die length**			**Effect of L/D ratio**			
D (mm)	**L(mm)**	**L(D)**	**D(mm)**	**L(mm)**	**L/D**	**D(mm)**	**L(mm)**	**L/D**	
2.5	16	6.4	3		16	5.33	2.5	16	6.4
3	16	5.33	3		44	14.7	3	16	5.33
3	44	14.7	3		54	18	3	44	14.7
4	44	11					3	54	18
3	54	18					4	44	11
5	54	10.8					5	54	10.8

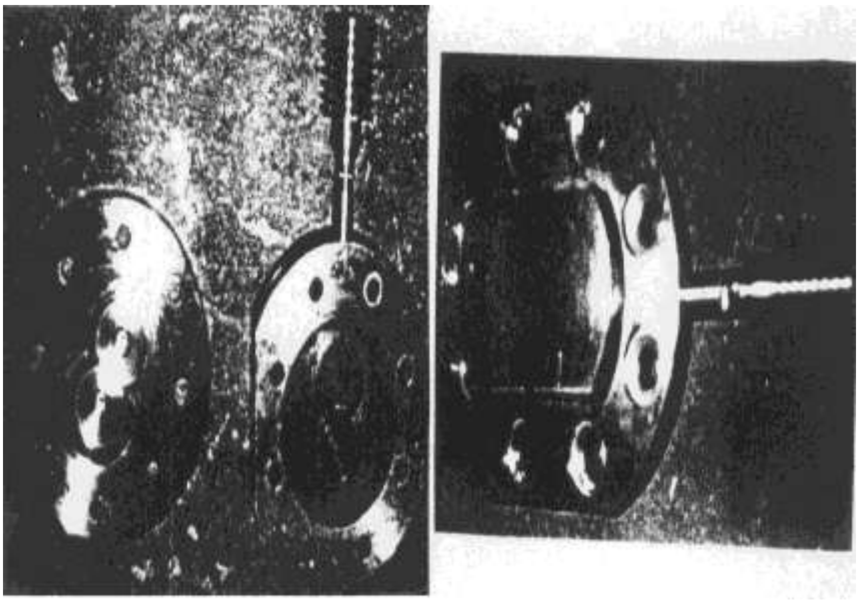

Figure 4: Dies used for the experiments

(AOAC, 1984) and data given by the Agricultural University Food Research Laboratory for the yellow corn flour is given as moisture 13.5%, starch 78.0%, protein 7.2%, ash 0.25%, fat 0.7%, and fiber 0.35%.

The moisture content of the sample was determined by drying in an electric oven at 103 ^{0}C until a constant dry weight of the sample is obtained. Sufficient water was added to the flour to bring the moisture content to the desired moisture content for different experimental runs. The samples were then refrigerated in sealed containers. Prior to extrusion, the samples were taken out and allowed to equilibrate with the room temperature.

The extruder throughput was put at 50 kg/h. Calibration of the feed rate and the water addition rate were carried out before each experimental run to ensure accuracy of the feed rate and water rate. These were done by having test runs for two minutes and the samples thus collected are measured. The value is then extrapolated to give the value on hour basis. Each experimental run is replicated thrice and the values reported are the average of the replicates.

The conduction of the experiment involves:

1. Test running the extruder for 30 – 45 minutes to ensure smooth operation. At the same time, the barrel is thoroughly washed with water. The test run also allows the extruder barrel to be heated to the designed temperatures for extrusion.
2. Loading the feed hopper with pre-conditioned feed material.
3. Feeding the extruder with the feed material and water.
4. The remaining process depends on the peculiarity of the experiment.
5. Finally, the extrudates are collected for post-extrusion treatment and analysis.

The conduction of the experiment involves:

6. Test running the extruder for 30 – 45 minutes to ensure smooth operation. At the same time, the barrel is thoroughly washed with water. The test run also allows

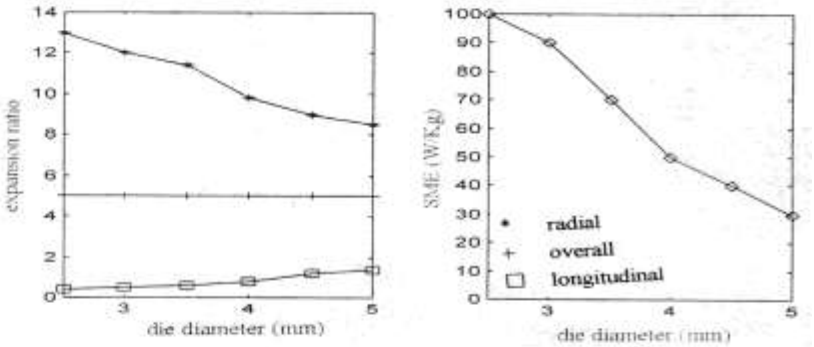

Figure 5: Influence of die diameter on extrudate expansion and SME

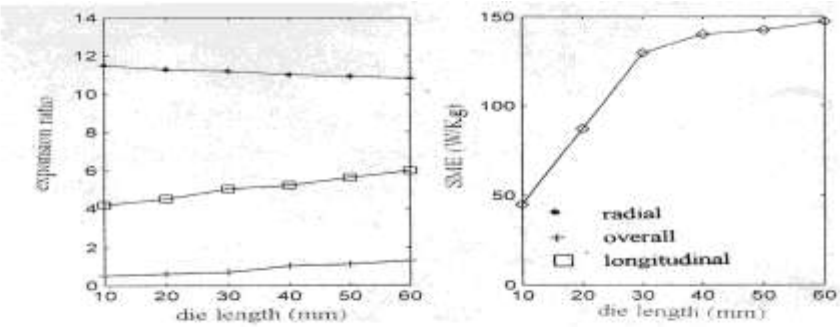

Figure 6: Influence of die length on extrudate expansion

the extruder barrel to be heated to the designed temperatures for extrusion.
7. Loading the feed hopper with pre-conditioned feed material.
8. Feeding the extruder with the feed material and water.
9. The remaining process depends on the peculiarity of the experiment.
10. Finally, the extrudates are collected for post-extrusion treatment and analysis.

RESULTS AND DISCUSSION

The objective of the plan is to determine the effects of food extruder die dimensions on the extrudate quality. The die dimension parameters considered are length of die (16 – 54 mm) and diameter of die (2.5 – 5 mm). The extruder used is TSSJ-60 model and the feed material used is yellow corn flour. The moisture content of the flour is 20 % w.b.

Figure. 5, 6 and 7 show the effect of die nozzle diameter, length and L/D on the radial, axial and overall expansion of extrudates respectively.

Effect of die diameter

Dies with diameters ranging from 2.5 to 5 mm were used to determine the effect of die nozzle diameter on extrudate expansion. Figure. 5 shows that radial expansion of the extrudate decreased with increasing die diameter for a constant die length. An average reduction of about 42 % in radial expansion was recorded for a difference of 2 mm in diameter. This result is expected because as the diameter increased the flow rate through the die increased and the flow becomes more laminar in nature. Consequently, the pressure force required to push the dough decreased, thus radial expansion decreased.

The overall expansion of the extrudate was not affected by changes in die nozzle diameter for all the diameters of die studied. This may be due to the fact that the same operating extrusion parameters and feed were used. There is the likelihood that with a different feed material and set of operating condition, a change in overall expansion may occur with the same die diameter and die length.

On the contrary, increase in die diameter caused increase in the longitudinal (axial) expansion of the extrudate (Figure. 5). The axial expansion with a 3-mm die diameter was 0.6, which increased to 1.2 for a 4-mm diameter die. Since longitudinal expansion is a ratio of overall expansion to radial expansion, a constant overall expansion and a decreased radial expansion will in increase of axial expansion.

As expected the regression model shows that SME is

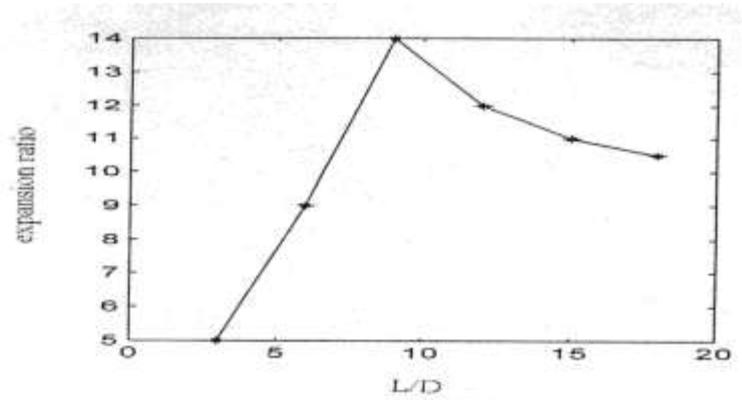

Figure 7: Influence of die L/D on extrudate expansion

reduced with increasing die nozzle diameter. For any flow system, the operating pressure will decrease with an increase in the size of the outlet. In a similar vein, for any given length, as the diameter increases the amount of work done on the extrusion system will be increased as well. This implies that the SME would decrease with increase in diameter (D). The regression model for SME is:

$$SME = -29.71D + 174.76$$

The correlation coefficient, r is 0.911

Effect of die nozzle length

Dies with lengths ranging from 16 to 54 mm with a constant diameter of 3 mm were used to determine the effects of die nozzle length on extrudate expansion (Figure. 6). The length of the die significantly influenced the axial expansion of extrudate. Axial expansion increased with increase in die length. This implies that for constant die diameter and increasing die length (L), more operating force is required to get the materials out of the die, therefore an increased SME is expected. A linear regression model of the form below represents the relationship obtained for this experiment.

$$SME = 1.96L + 46.67$$

The correlation coefficient, r is 0.924

The quadratic effect is negligible in this case and as such not included in the regression equation. This observation is contrary to the result obtained (Sokhey et al, 1997) using single screw extruder. The difference may be accounted for by the different extrusion parameter employed in the two experiments. It is likely that above the die length of 60 mm, effect of quadratic relationship may be more glaring. There was a slight increase in the radial expansion of extrudate with increase in die length. Overall expansion recorded an increase with increase in die length.

The conclusion can then be drawn that die nozzle diameter significantly affected radial expansion of the extrudate while die nozzle length affected the axial expansion. The length of die affects the overall expansion of the extrudate. This conclusion provides vital information for the selection of die length in the design of food extruder die.

Effect of die nozzle L/D

Effects of die nozzle L/D on radial, longitudinal, overall expansions of extrudate during extrusion are shown below (Figure. 7). There was an initial sharp increase in the radial expansion of the extrudate from 8.9 to 13 as the nozzle L/D ratio increased from 5.33 to 6.4. The value then dropped to 10.5. This observation is different from the observation made (Sokhey et al, 1997) when working on the effect of die dimension on extruder performance for single screw extruders. They reported that the die nozzle L/D significantly affected none of the expansion properties.

Furthermore, the findings in this work show some similarities with previous work (Chinnaswamy and Hanna, 1987). They worked on nozzle die dimension effects on the expansion of extrusion cooked starch. They reported an expansion ratio increase from 4.5 to 13 as the nozzle L/D ratio increased from 2.5 to 3.4 and then decreased gradually to 8.5. Similar experimental results were reported (Sohkey *et al,* 1997)

The sharp initial increase in the expansion ratio with L/D ratio may be due to increase in the degree of starch gelatinization (Gomez and Aguilera, 1984). High extrusion pressure increased the residence time and eventually subjects the starch to high shear rates within the extruder, which increased the degree of starch gelatinization (Wang, 1989). The high shear rate is more severe with twin screw co-rotating extruder due to nature of the screw configuration.

However, at higher L/D ratio, the expansion ratio decreased. At this high L/D ratio corresponding to such a high extrusion pressure, the residence times and shear rates were high enough to cleave the starch molecule and thus reduce the expansion ratio. Also, high shear rates and residence times are known to induce starch degradation and reduce expansion ratio (Colonna et al, 1983).

Effect of die dimensions on flow velocity

On the effect of die diameter on flow characteristics, it was observed that increasing the diameter, D of the die nozzle causes increases in the volumetric flow rate of extrudate. Consequently, the pressure at the die decreased. This finding is consistent with the findings reported (Harper, 1981) and shows some similarities in results with the use of single screw extruder and twin screw extruder used in this present work. Flow through large and small die opening is a function of pressure difference and for a large die opening, flow rate increased sharply with pressure.

The effect of die length on flow rate showed that flow rate decreased proportional with increasing die length. Increasing the die length increased the die pressure, which in turn increased the SME.

CONCLUSIONS

Die nozzle diameter and length play very important role in starch extrusion expansion. The dies allow rapid expansion “puffing” of the dough into various shapes depending on the configuration of the die nozzles. In this study and for the die dimensions considered, it can be concluded as follows:

1. Radial expansion of the extrudate decrease with increasing die nozzle diameter, so large diameter and short die nozzle length should be used for better radial expansion. A slight increase in the radial expansion expansions of extrudate with increase in die nozzle length was recorded. L/D ratio of the die nozzle causes increase in radial expansion.
2. Extrudate axial expansion increased slightly with increasing die nozzle diameter but increased significantly with increase in die nozzle length.
3. Changes in nozzle diameter with constant length have no effect on the overall expansion of extrudate. Overall expansion increases with increase in die length.
4. SME decreases with increase in die nozzle diameter. SME increased with increase in die length
5. Increase in die diameter causes increase in volumetric floe rate of the extrudate, consequently the pressure at the die decreased.
6. Flow rate decreased proportionally with increasing die length.

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