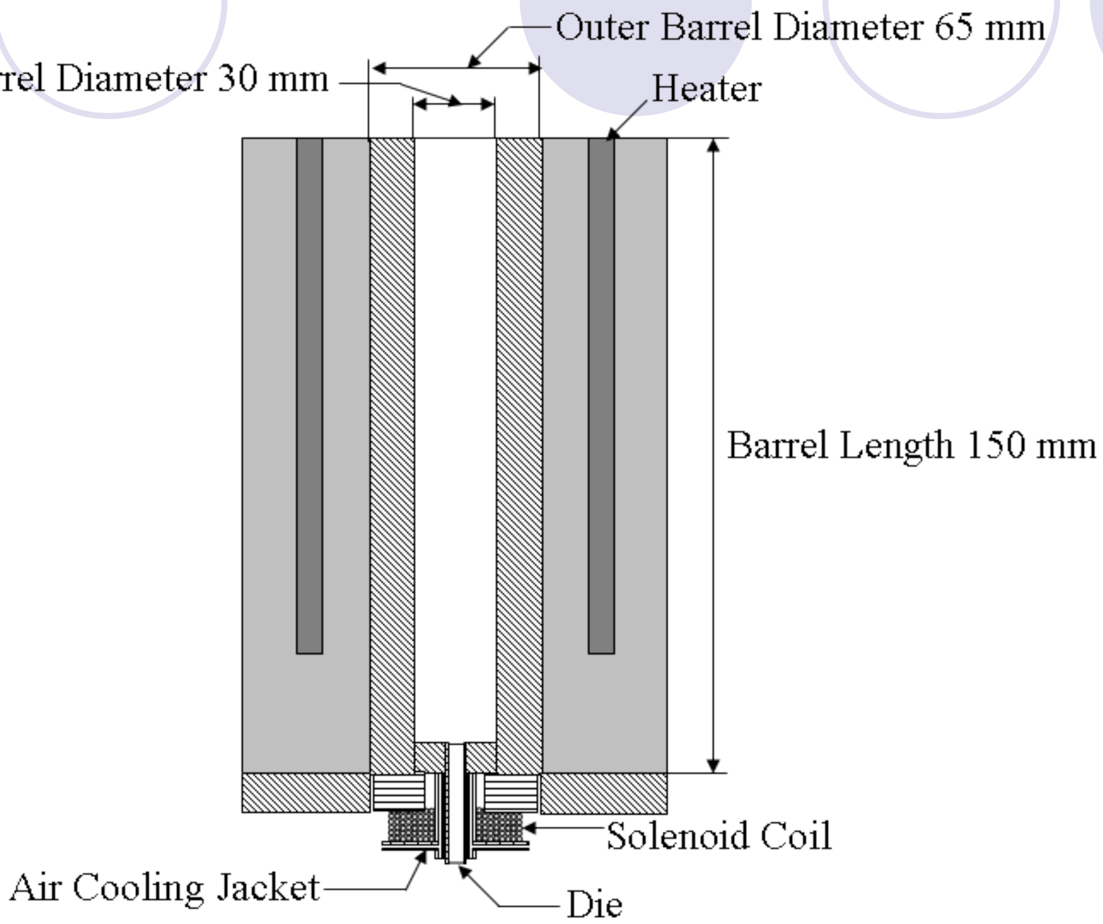
Effect of magnetic field on extrudate swell

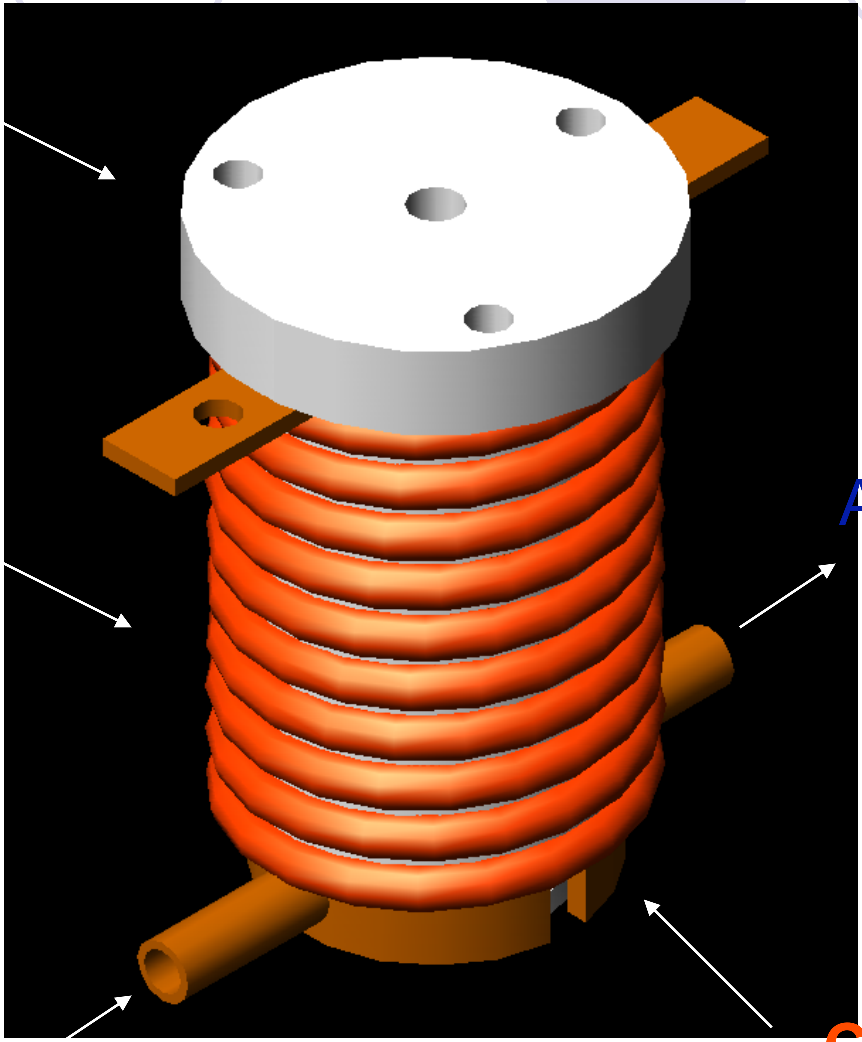


A Capillary rheometer with eletro-magnetized die system

Magnetic induction

Die

Cu wire

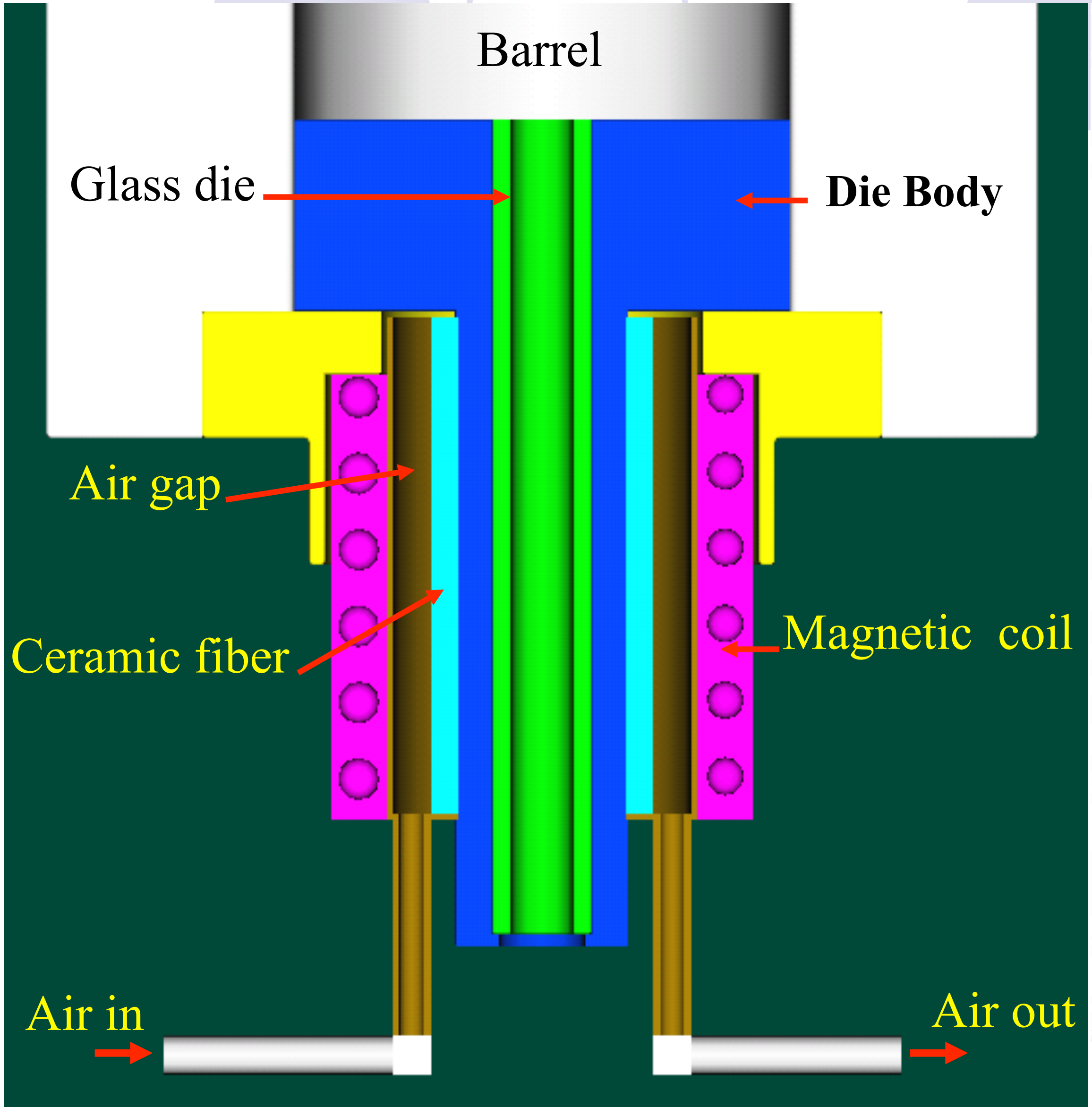


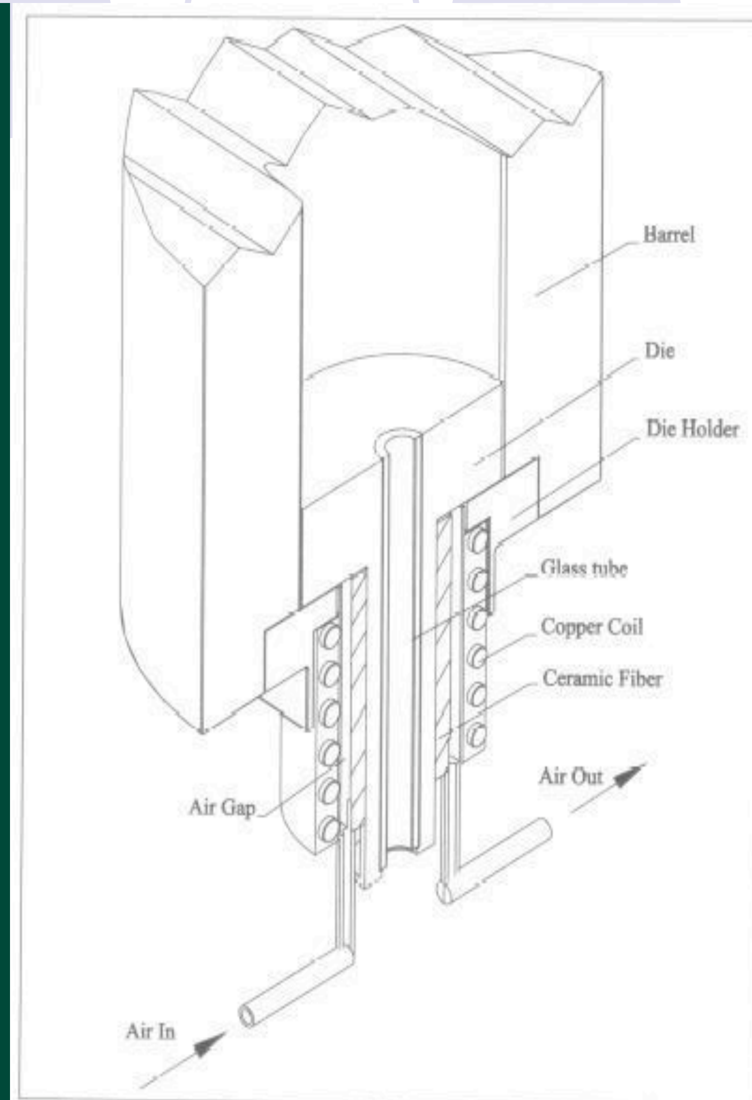
Air out

Air in

Cooling jacket

Electro-magnetic die system

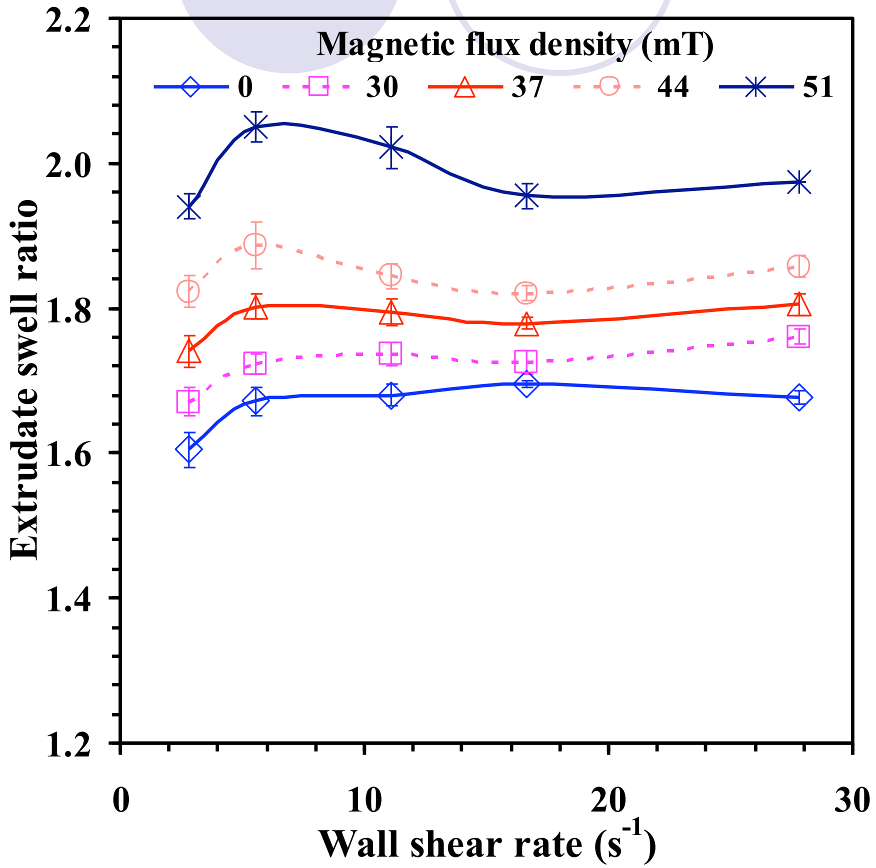


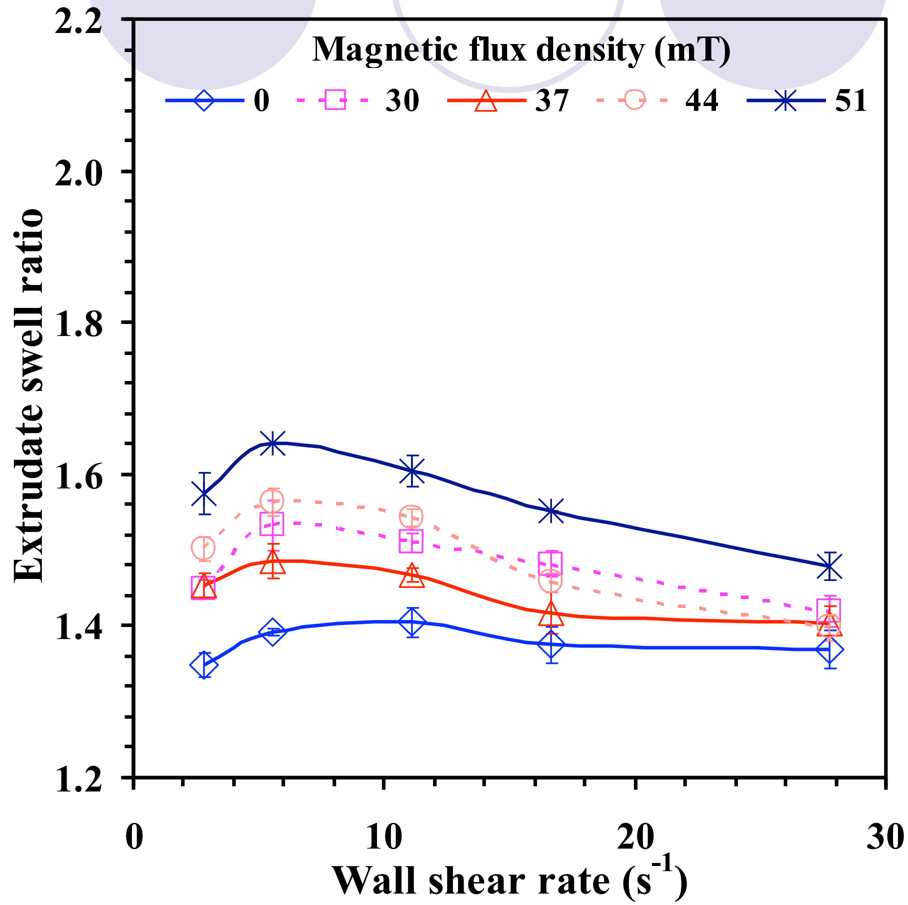


Materials and test variables

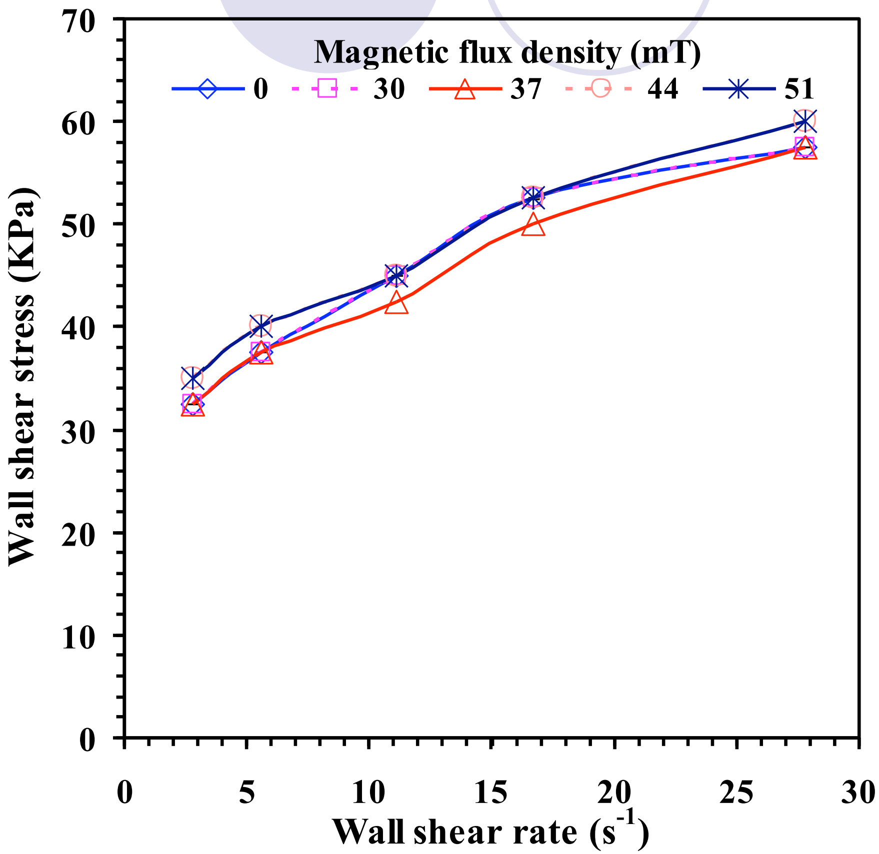
1. All the measurements were carried out in a capillary extrusion rheometer.
2. Three thermoplastics: PS, PC and ABS. (LLDPE and PVC melts used for comparison)
3. Magnetic flux density: 0-51 mTesla
4. Test/die temperature: depending on the types of polymers used.
5. Low wall shear rates used: 2-28 s^{-1}.

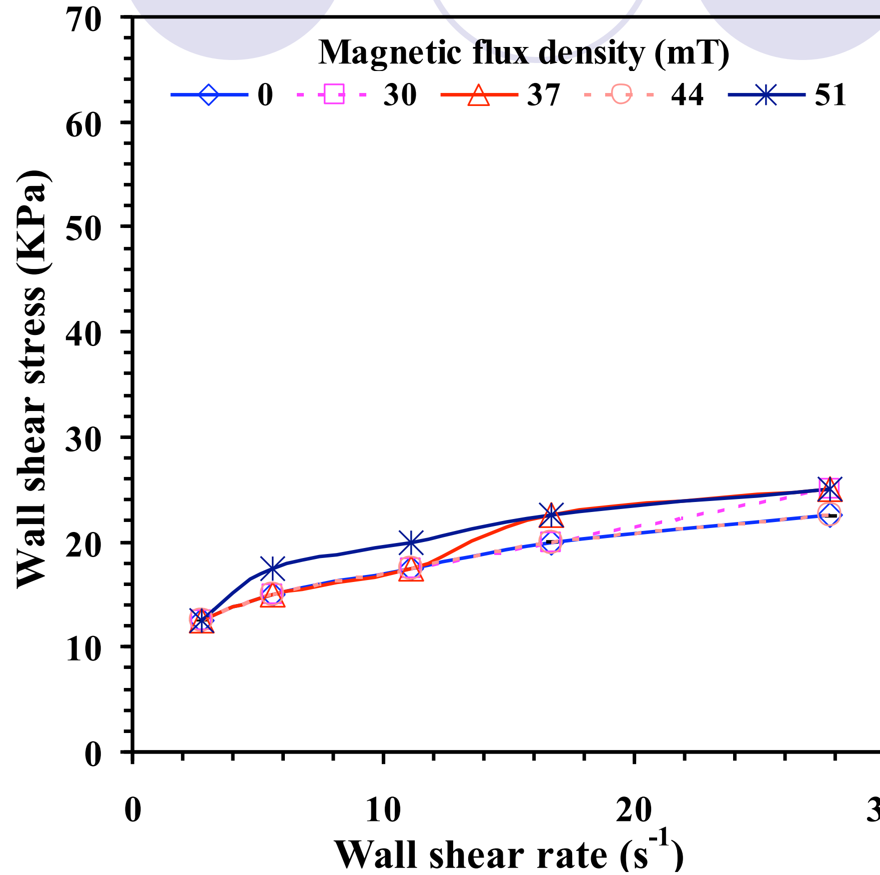
Experimental Results





Extrudate swell ratio of PS melt VS wall shear rate and magnetic flux density (Left) 180 °C and (Right) 210°C





Flow curves of PS melt VS wall shear rate and magnetic flux density (Left) 180 °C and (Right) 210°C

Proposed explanations

In this case, we proposed that in order for a polymer melt to be induced by magnetic field, the melt has to possess two concurrent anisotropic characters:

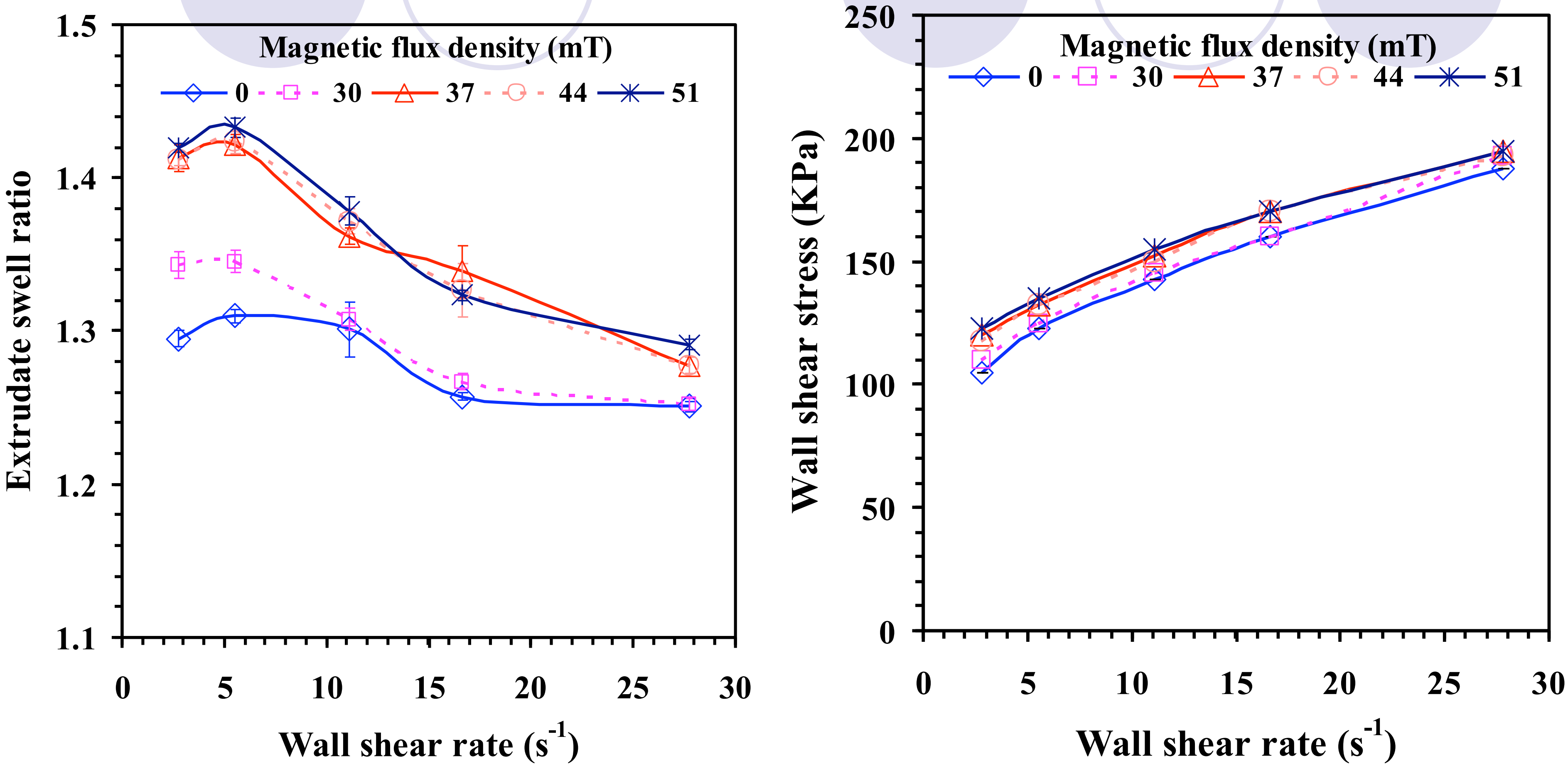
1. Rheological anisotropy
2. Diamagnetic anisotropy

Rheological anisotropic character

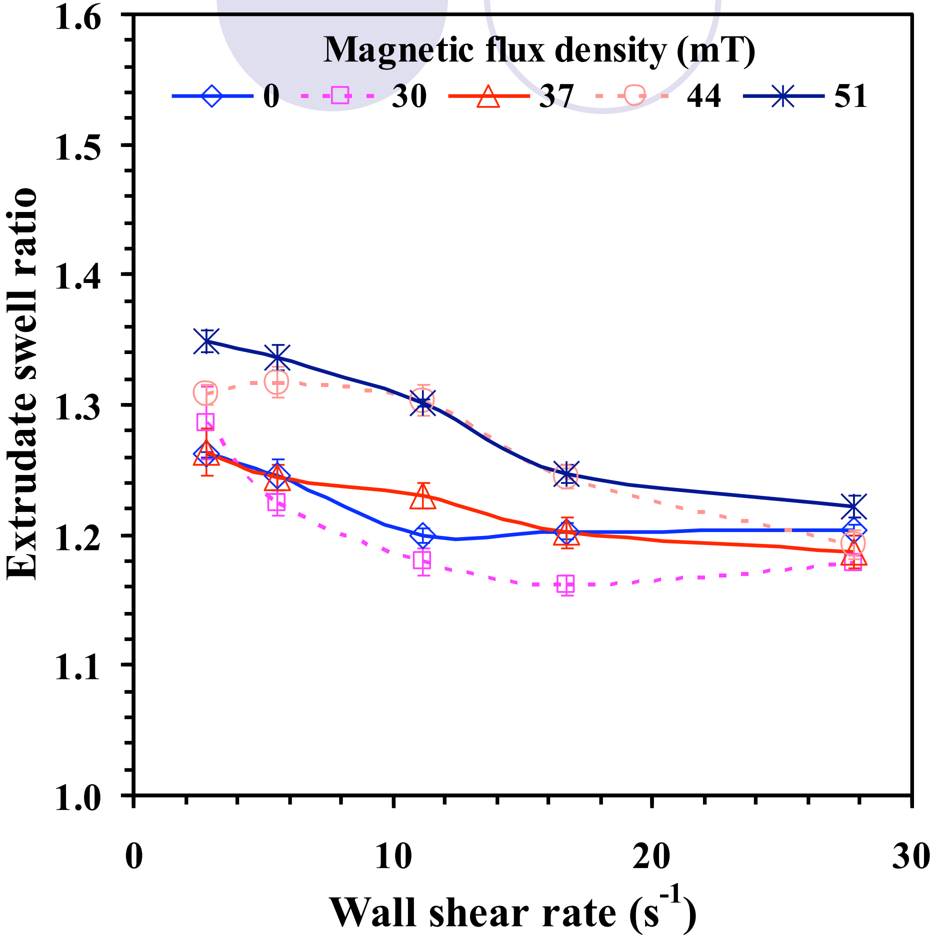
- It was proposed that all the polymers in molten state do not have anisotropic structure to be induced by magnetic field.
- In this work, as the melt *was flowing* (during the extrudate swell measurement) in the die, the molecular orientation inevitably took place, this creating anisotropic character of the melt, and thus was induced by the magnetic field.

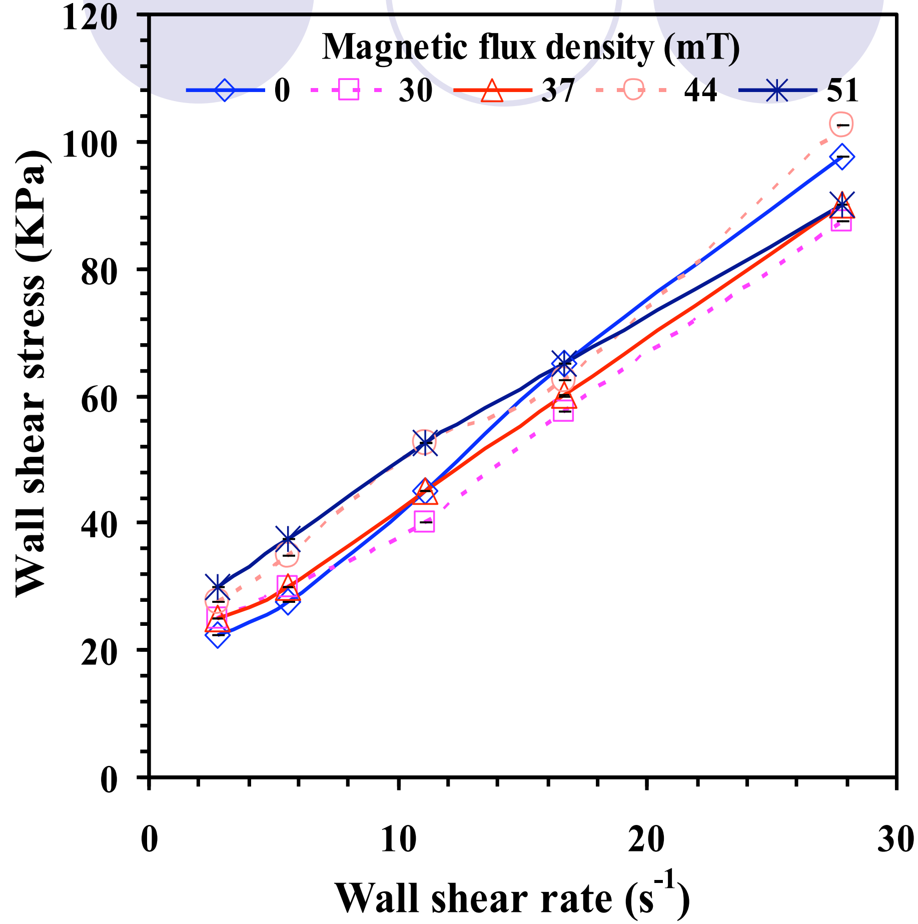
Diamagnetic anisotropic character

- The mechanism was associated with a large diamagnetic anisotropy of the benzene molecules within the PS structure, resulting in the magnetic torque acting on the polymer molecules.
- The magnetic torque could lead to a molecular rotation, and aromatic rings in the PS tend to align with the ring plane parallel to the applied field.

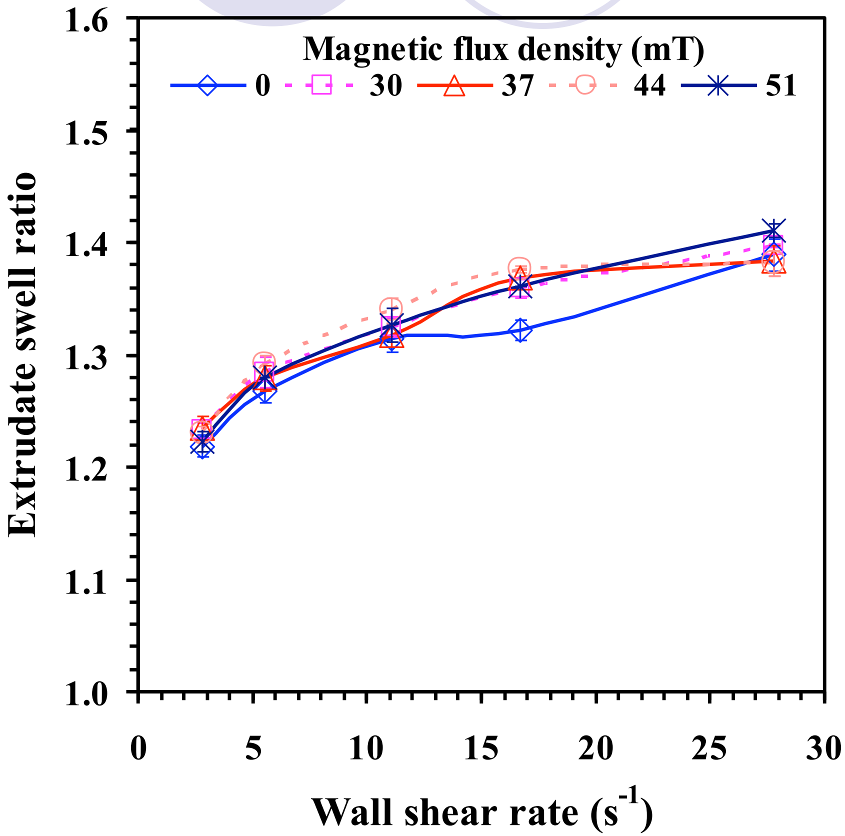


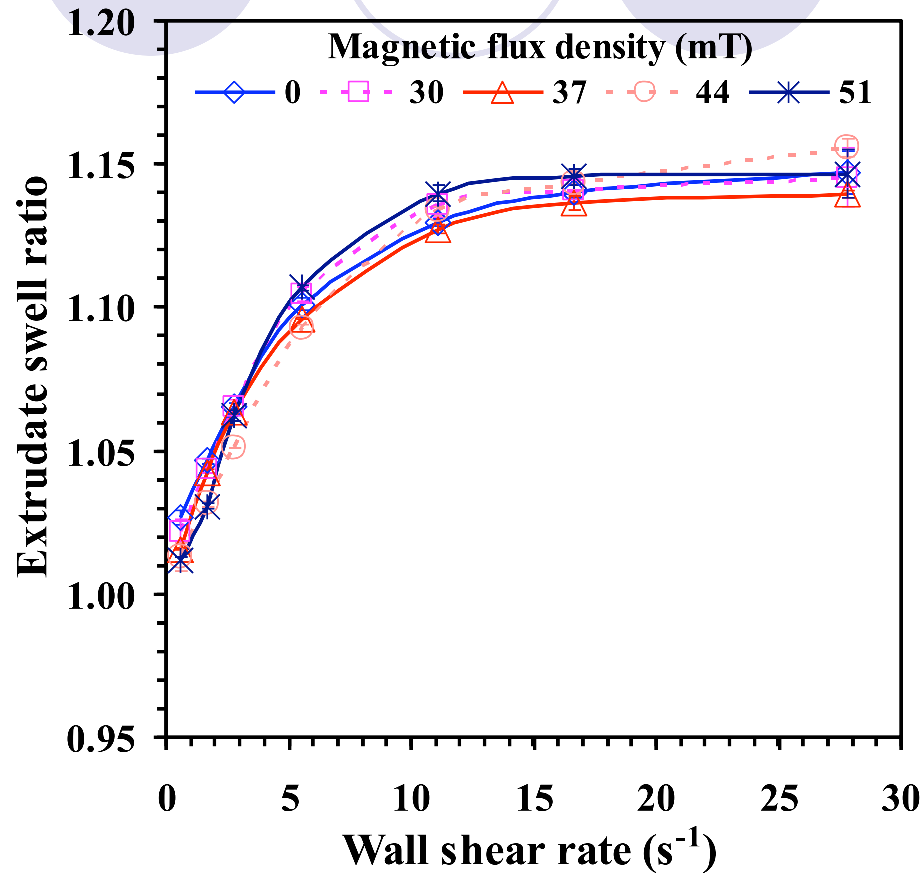
Extrudate swell ratio and flow curve of ABS melt VS wall shear rate and magnetic flux density (180°C)





Extrudate swell ratio and flow curves of PC melt VS wall shear rate and magnetic flux density (230°C)



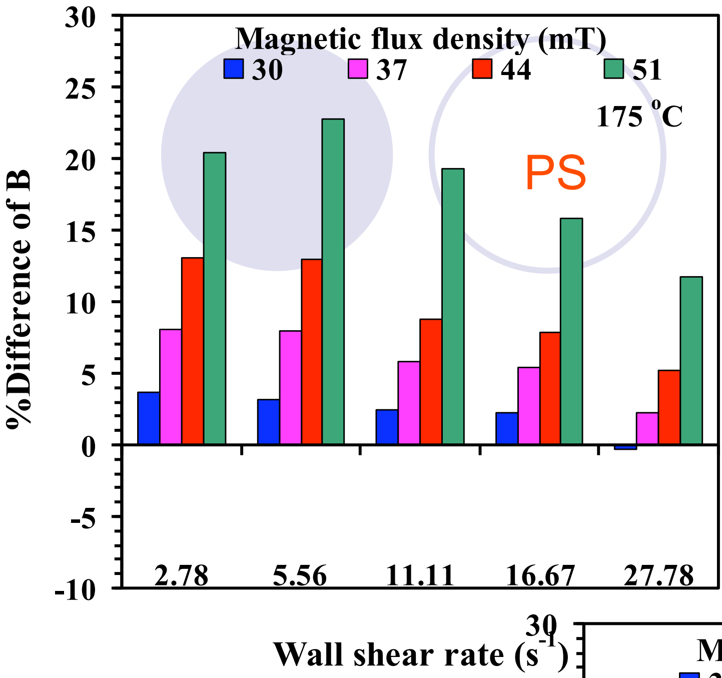


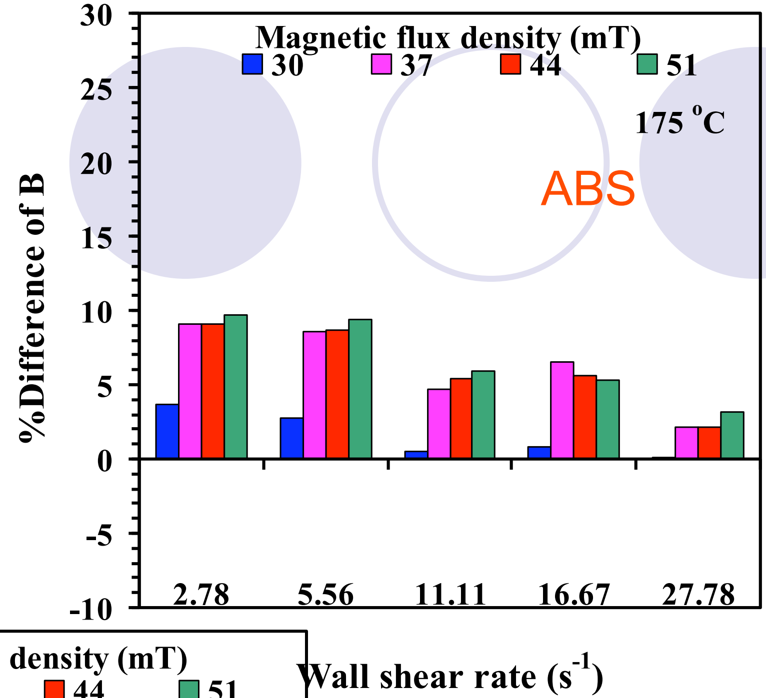
Extrudate swell ratio of LLDPE (left) and PVC (right) melts VS wall shear rate and magnetic flux density (190°C)

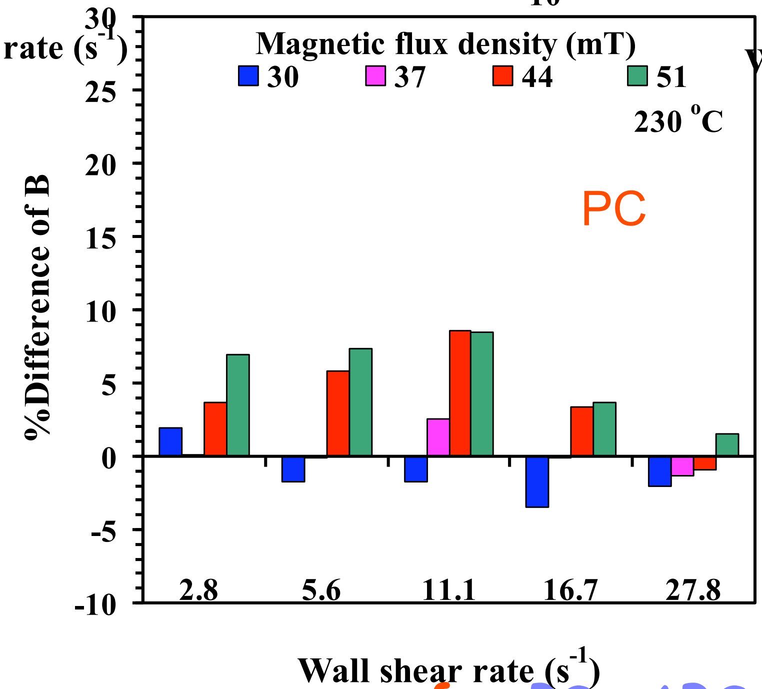
To quantify the magnitude changes in the swelling due to the magnetic field, the percentage differences (ΔB) were calculated as expressed in the below Equation.

$$(\Delta B) = \frac{B_m - B_n}{B_n} x100$$

B_n is the extrudate swell ratio *without* magnetic field
B_m is the extrudate swell ratio *with* magnetic field

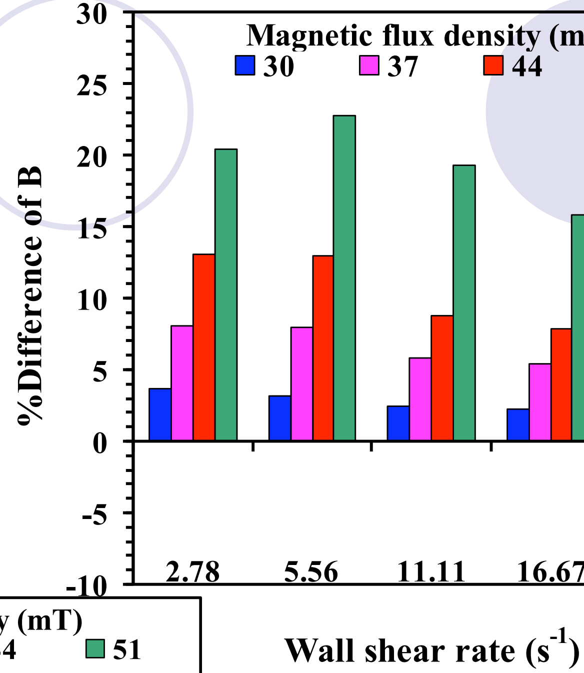


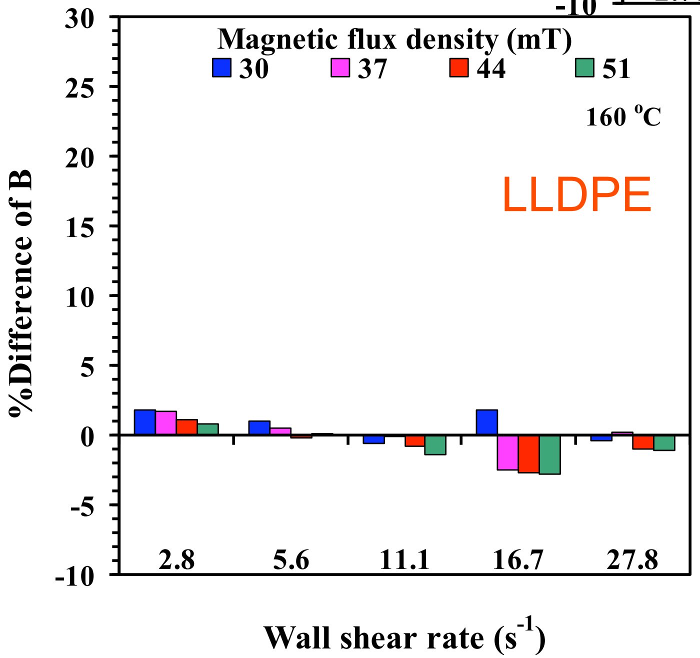


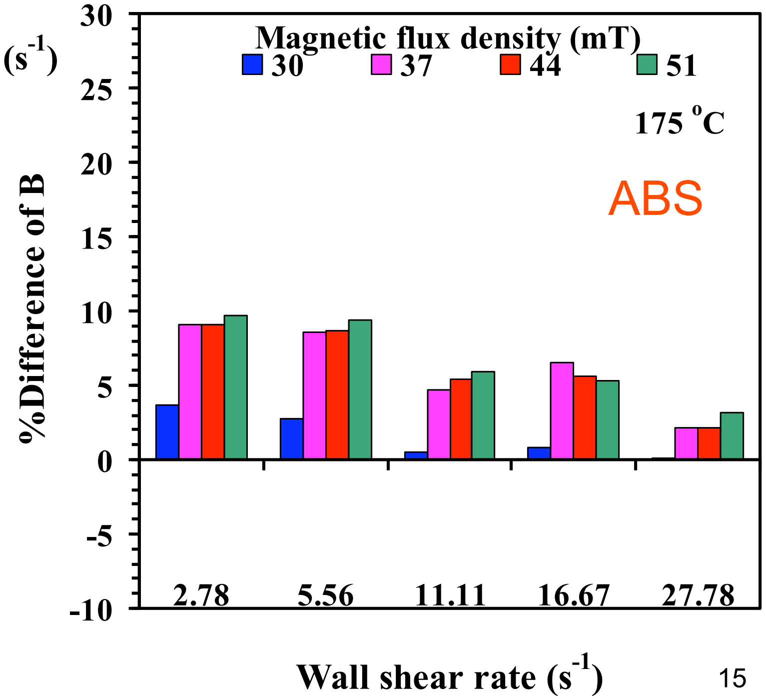


ΔB in extrudate swell ratio for PS, ABS and PC melt

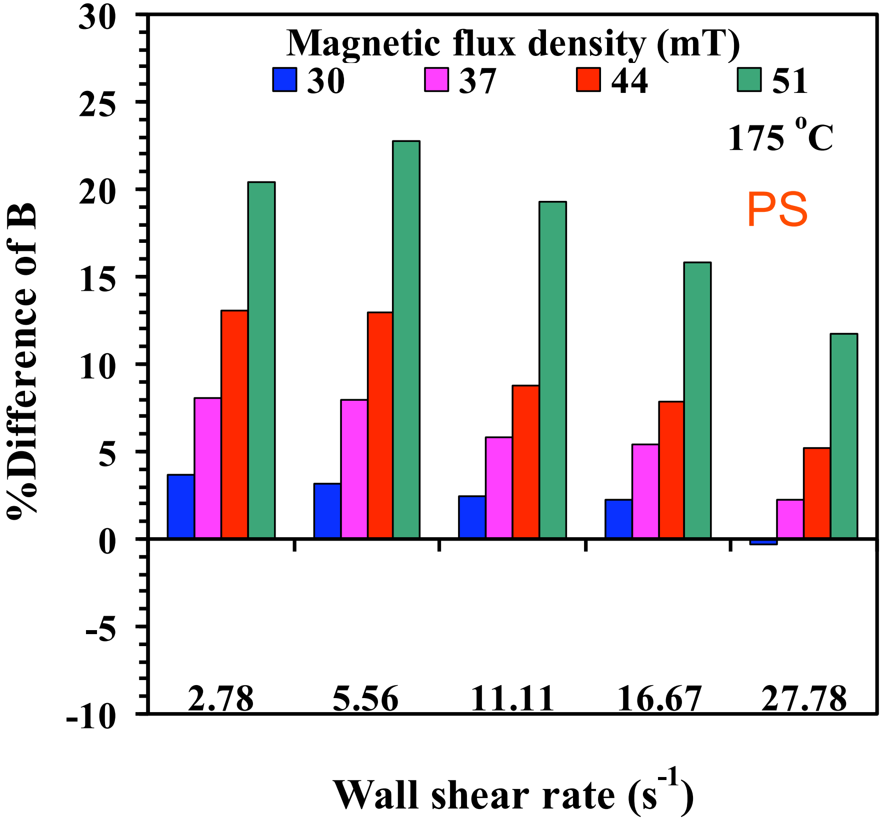
Benzene content effect

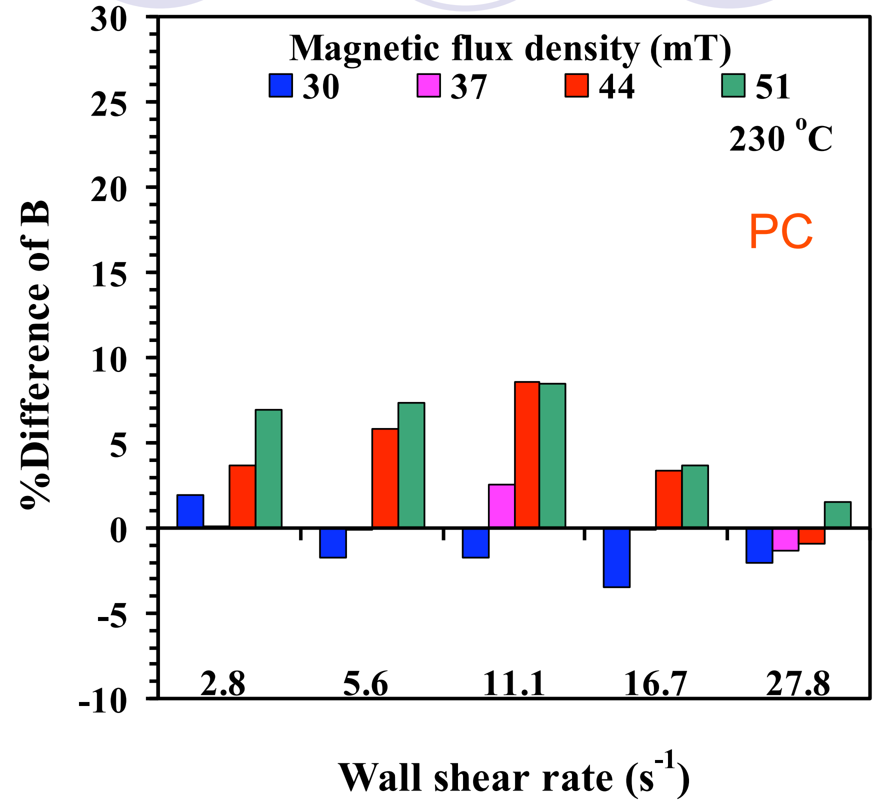




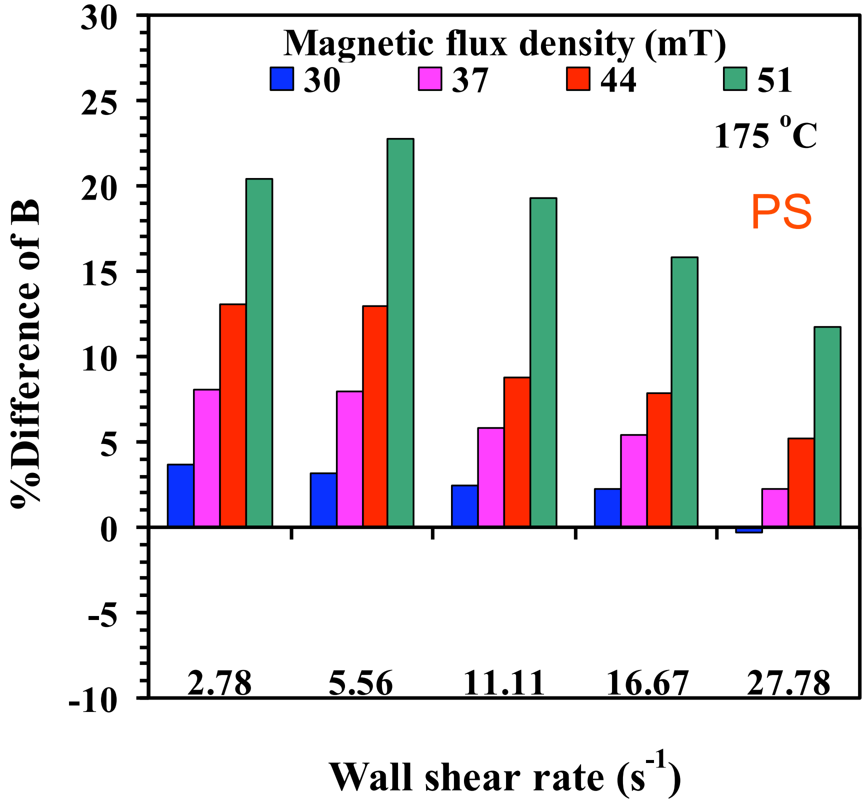


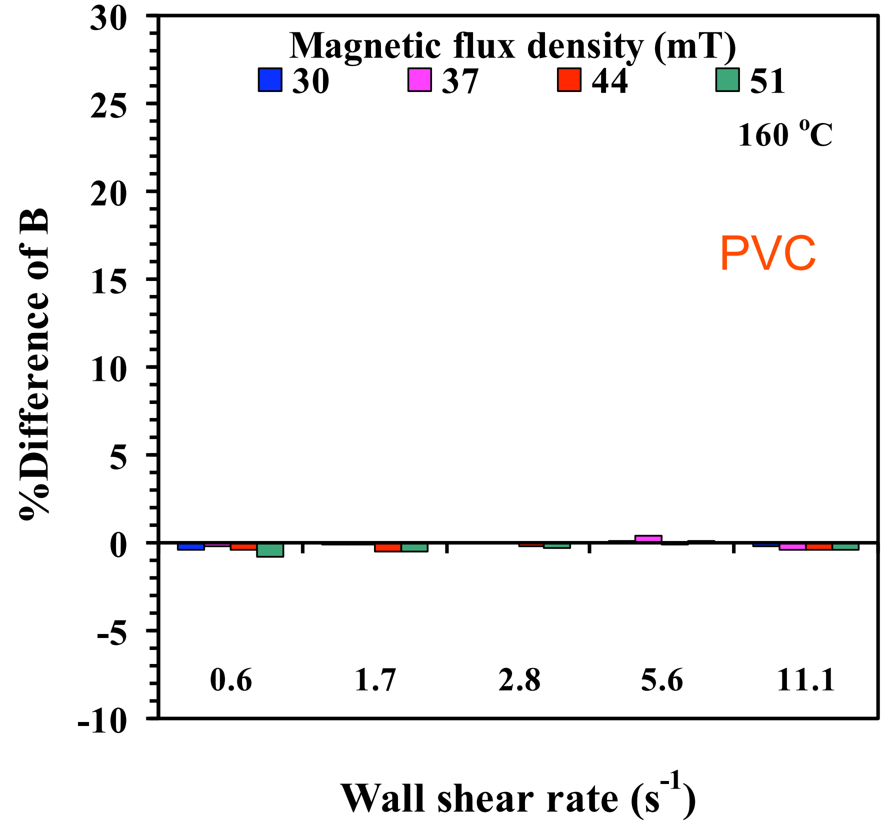
Benzene location effect





Effects of polarity and electron density



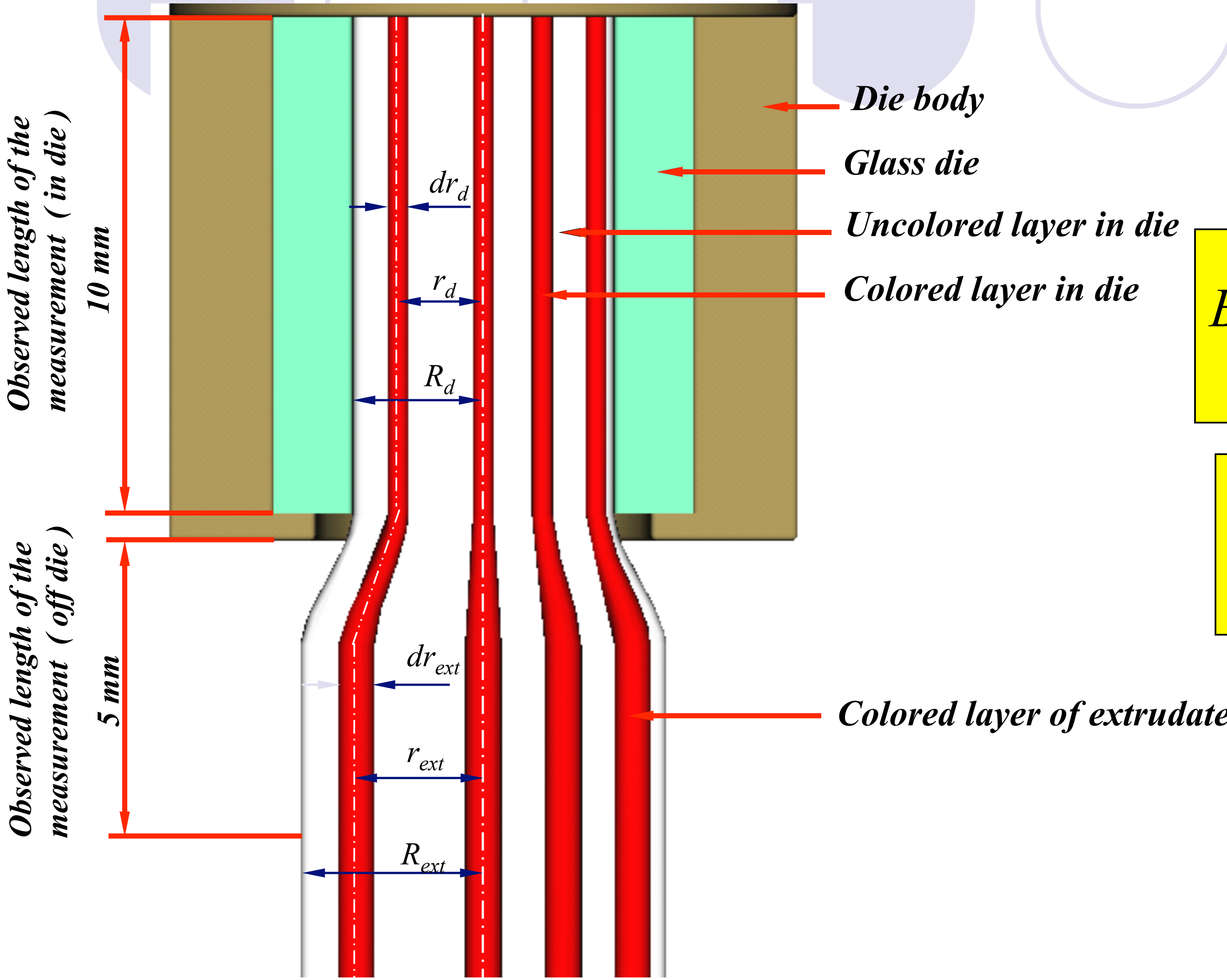


Are the swelling ratios of the melt at different positions across the die diameter equal?

To answer this question, radial extrudate swell measurements were carried out.

- The radial velocity profiles were then required to explain the radial extrudate swell changes.
- The swell and the velocity profiles data are very useful in co-extrusion processes.

Radial extrudate swell profiles



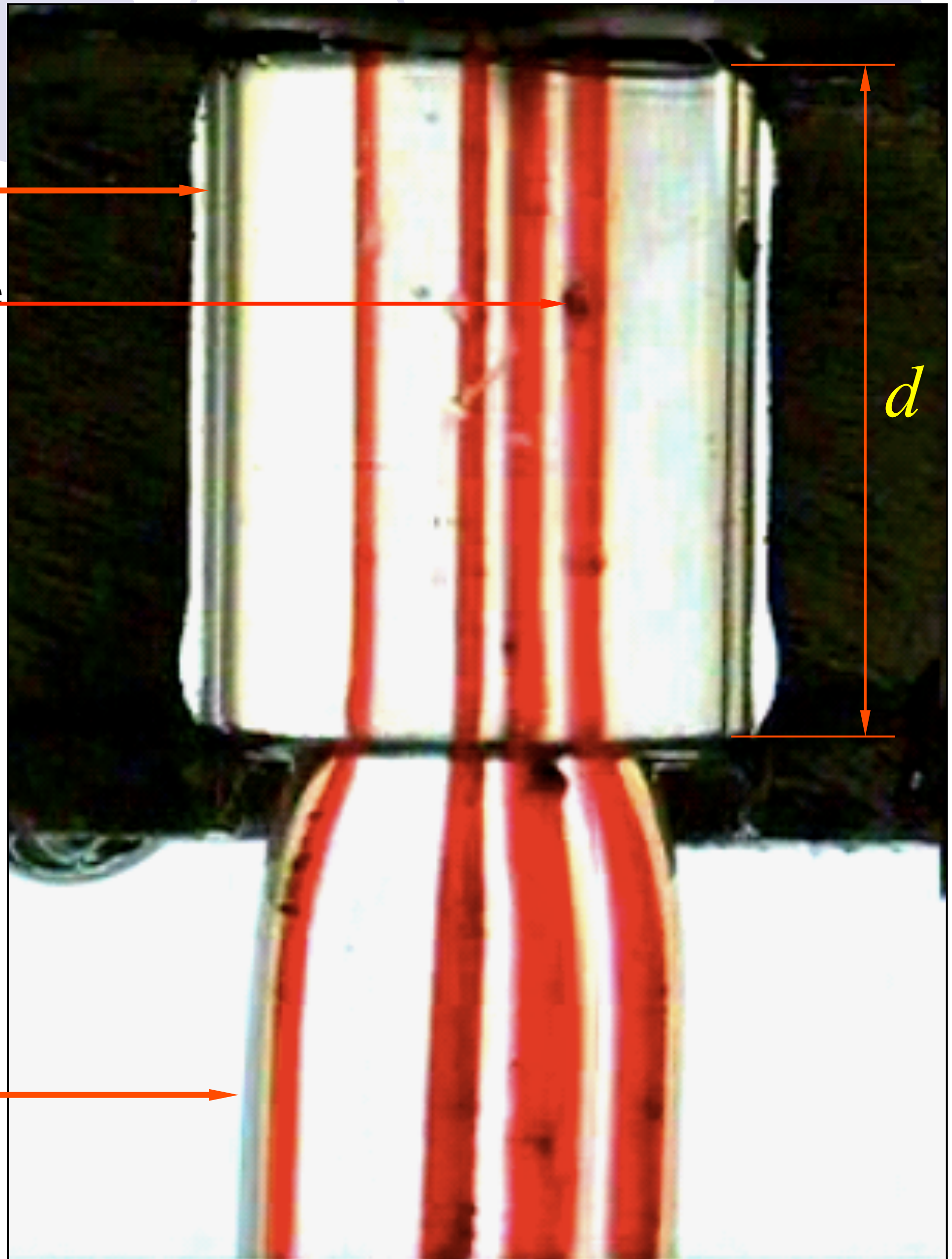
$$B_{overall} = \frac{R_{ext}}{R_d}$$

$$B_r = \frac{dr_{ext}}{dr_d}$$

Radial velocity profiles

Glass Die

Corn Particle



Extrudate

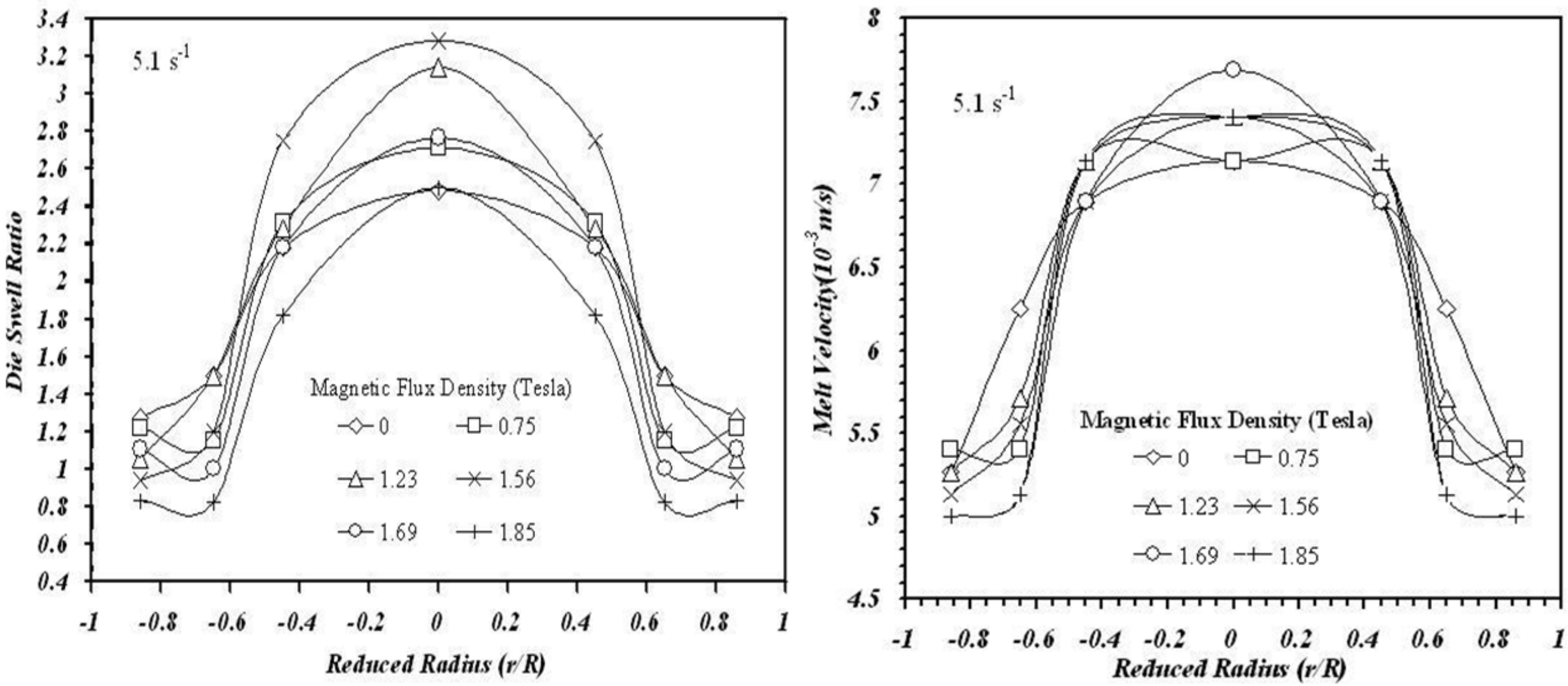
$$V = \frac{d}{t}$$

V **= Velocity (mm/min)**

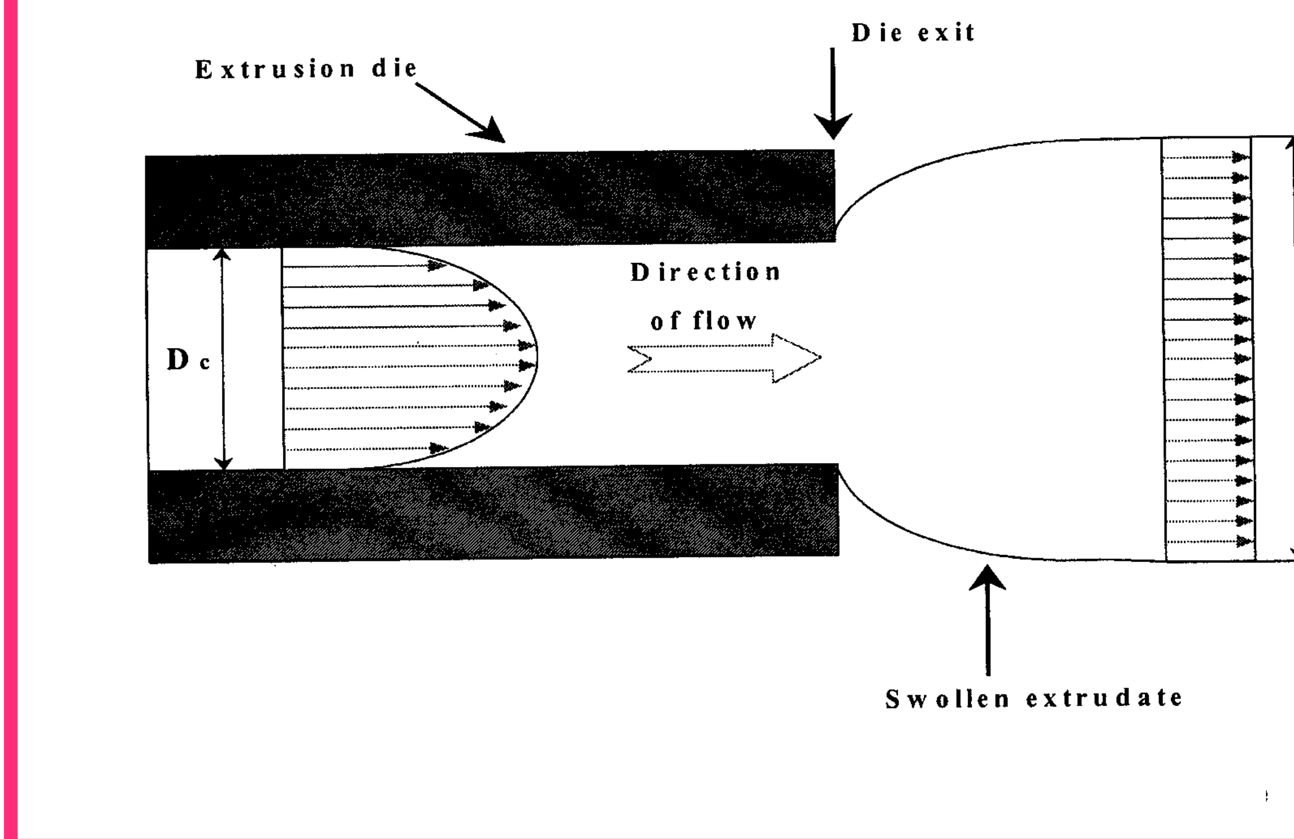
D **= Distance (10 mm)**

t **= Time (s)**

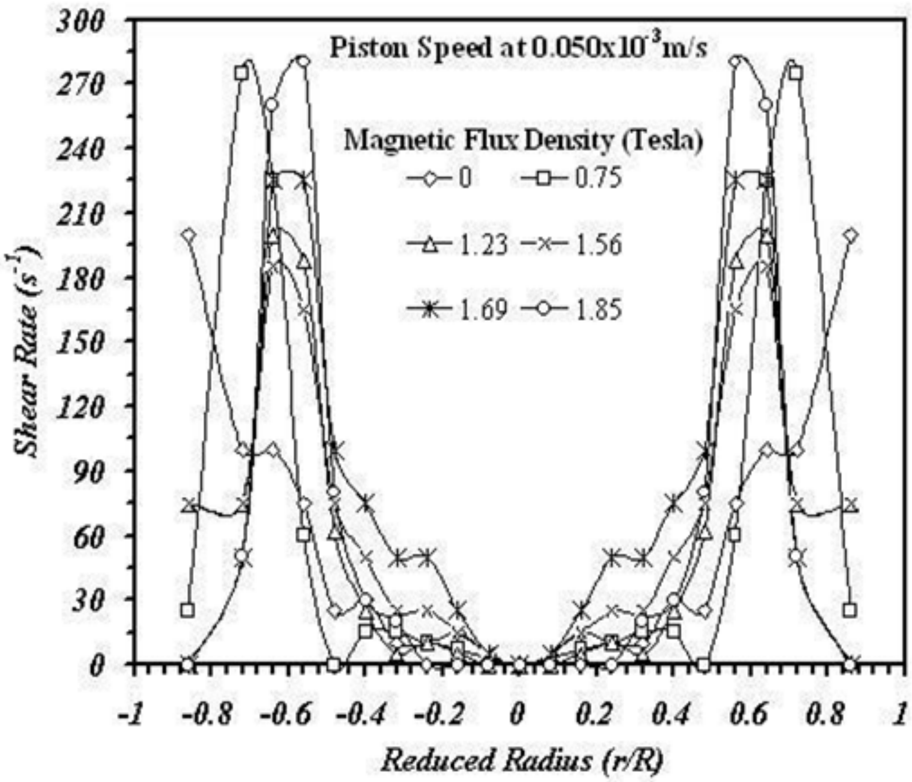
Additional Experimental Results

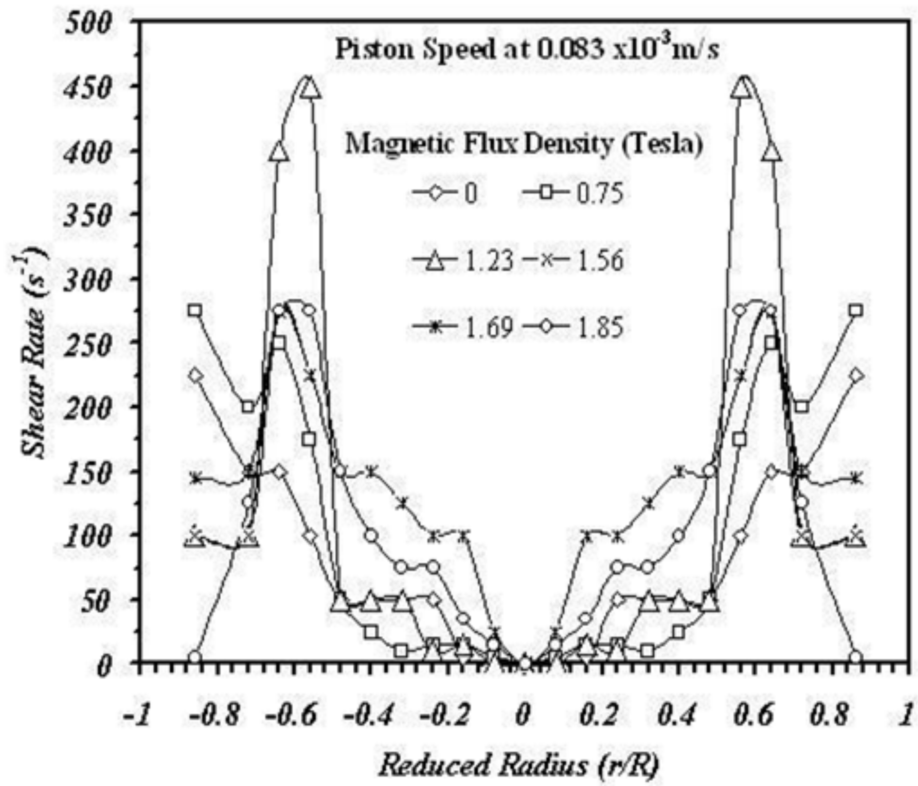


Relationship between extrudate swell VS velocity profiles



Additional Experimental Results





Conclusions

1. Increasing wall shear rate increased the swelling ratio for PS melt, but the opposite effect was observed for the ABS and PC melts.

2. The extrudate swell for all polymer melts decreased with increasing die temperature.

3. The effect of the magnetic field on the extrudate swell ratio decreased in the order of PS → ABS → PC. The changes in the extrudate swell of the LLDPE and PVC melts were independent of the magnetic field.

Conclusions (cont.)

4. Under magnetic field, the extrudate swell behaviour cannot be explained by the flow curves.

5. Thermoplastic melts with higher benzene content at the side-chain and with anisotropic character were more affected by the magnetic field, the extrudate swell increasing with increasing magnetic flux density.

6. The extrudate swell changed more significantly at the centre position of the die.

Swell of PS under magnetic field