Experimental and Numerical Investigation Into Metallocene Polymer Melt Flow in Film Blowing Dies

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Abstract:
A frequent problem in the production of metallocene linear low-density polyethylene (mLLDPE) films is the occurrence of flow instabilities, e.g. sharkskin, or degradation of material, which limit the production rate and decrease the product quality. If such problems arise, the question is what causes these phenomena and how they can be avoided. With the aim of understanding these problems and providing some guidelines for their suppression, rheological measurements together with modelling of these melt flows are often employed. In the present study, flow behaviour of two commercially available mLLDPEs was determined and used for the process simulation. The paper shows that the capillary-rheology data together with 2D finite element method can be used for the prediction of sharkskin phenomenon as well as degradation of mLLDPE melts in film blowing dies. It also reveals that the degradation of the materials in these dies can be quantified through wall shear stress. Finally, the paper describes how these findings can help optimize the flow channel in the film blowing die to avoid the undesirable flow phenomena.

Zusammenfassung:
Ein häufiges Problem bei der Produktion von "metallocene linear low-density polyethylene" (mLLDPE) Filmen ist das Auftreten von Strömungsinstabilitäten (z.B. "sharkskin"-Effekt) oder die Degradierung des Materials, welches die Produktionsrate einschränkt und die Produktqualität herabsetzt. Wenn solche Probleme auftreten, stellt sich die Frage, wieso diese Phänomene auftreten und wie sie vermieden werden können. Um diese Probleme zu verstehen und um Richtilinien zu deren Vermeidung aufzustellen, werden häufig rheologische Messungen zusammen mit Modellierung der Schmelzenströmung verwendet. In dieser Arbeit wurde das Fliessverhalten zwei kommerziell erhältlichen mLLDPs bestimmt und für die Prozesssimulation verwendet. Es wird gezeigt, dass die Kapillarrheometerdaten zusammen mit einer 2D-Finitelementemethode verwendet werden können, um den "sharkskin"-Effekt sowie die Degradierung von mLLDPE-Schmelzen in Folienblasdüsen vorherzusagen. Es wird auch dargelegt, dass die Degradierung von Material in diesen Düsen anhand der Scherspannung an der Wand quantifiziert werden kann. Schlussendlich beschreibt diese Arbeit, wie diese Ergebnisse benutzt werden können, um den Strömungskanal im Folienblasdüsen und um diese unerwünschten Strömungsphänomene zu vermeiden.

Résumé:
Un problème fréquent dans la production de films de polyéthylène basse densité linéaire avec synthèse métallocène (mLLDPE) est l'apparition d'instabilités d'écoulement, comme par exemple la peau de requin, ou la dégradation du matériau, qui limitent la vitesse de production et diminuent la qualité du produit. Si de tels problèmes émergent, les questions à poser sont quelles sont les causes de ces phénomènes et comment peuvent-ils être évités. Dans le but de comprendre ces problèmes et d'apporter des idées principales pour leur suppression, des mesures rhéologiques ainsi que la modélisation de l'écoulement de ces fondus sont souvent employées. Dans la présente étude, le comportement en écoulement de 2 mLLDPE commerciaux a été mesuré et utilisé pour la modélisation. Cet article montre que les données de rhéologie capillaire utilisées avec une méthode d'éléments finis à deux dimensions peuvent être employées pour la prédiction du phénomène de peau de requin et la dégradation des fondus de mLLDPE lors du soufflage de fondus. Il est aussi révélé que la dégradation des matériaux lors du soufflage peut être quantifiée grâce à la contrainte de cisaillement aux parois. Enfin, cet article décrit comment ces découvertes peuvent aider à optimiser l'écoulement lors du soufflage de films afin d'éviter les phénomènes d'écoulement indésirables.

Key words: film blowing, sharkskin, degradation, simulation, rheology

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calculated. It was found that the minimum wall shear stress (about 4 kPa) occurs along the spider legs which support the mandrel of the die (Fig. 9). Such a low wall shear stress seems to cause the creation of a thin layer on the die wall (channeling), which moves very slowly (Fig. 10). The calculated residence time in this case is 256 minutes. Thus, polymer degradation occurs in this area, as the time is much higher than 91 min revealed in the thermal stability test (see Fig. 8).

Weld line occurrence in the samples (Fig. 7), on the other hand, can be explained by the fact that the polymer melt stream is split by the spider legs and the degradation of the material causes limited mobility of the molecules to re-entangle upon melt streams joining at the end of the spider legs section.

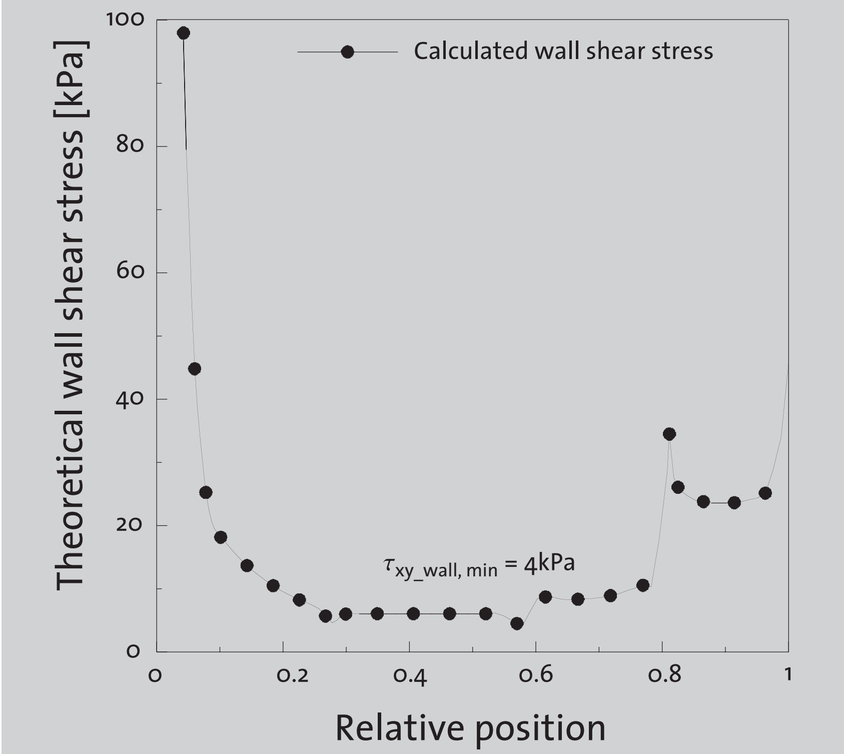
With the aim of seeing how the residence time is connected with the wall shear stress in the spider legs area, simulations of modified spider dies with decreased channel width in this area were performed. An exponential relationship between the minimum wall shear stress and the particular residence time was found, as depicted in Fig. 8. It means that degradation can be also discussed from the viewpoint of minimum wall shear stresses. In our case, the degradation occurs for wall shear stresses lower than 27 kPa (the residence time of 91 min).

To avoid the channeling phenomenon in the spider die, the flow channel has to be reduced to increase the wall shear stress up to at least 27 kPa at the spider legs area. This will decrease the residence time of the melt at the die wall, thus preventing the material from degradation. Similarly, to avoid the sharkskin phenomenon, the channel at the end of the die has to be open in such a way that the maximum shear stress at the end of the die will be lower than the critical one.

4 CONCLUSIONS

The research has shown that the critical wall shear stress, evaluated through measurements of capillary data, together with 2D FEM analysis, can be used to predict the sharkskin phenomenon as well as the degradation of mLLDPE melts in film blowing dies. Moreover, the flow simulation and the experimental results have revealed that the material degradation and the occurrence of the weld lines can be quantified by the minimum wall shear stress along the die body. In our case, the degradation of the melt in the flow channel disappeared at wall shear stress higher than 27 kPa.

Figure 9 (below): Wall shear stress along the length of the die body for mLLDPE Exact (10.6 kg/h, T = 170 °C, Relative position equal to 0 corresponds with the end of the die body, relative position between 0.3 and 0.5 is in the spider legs area).



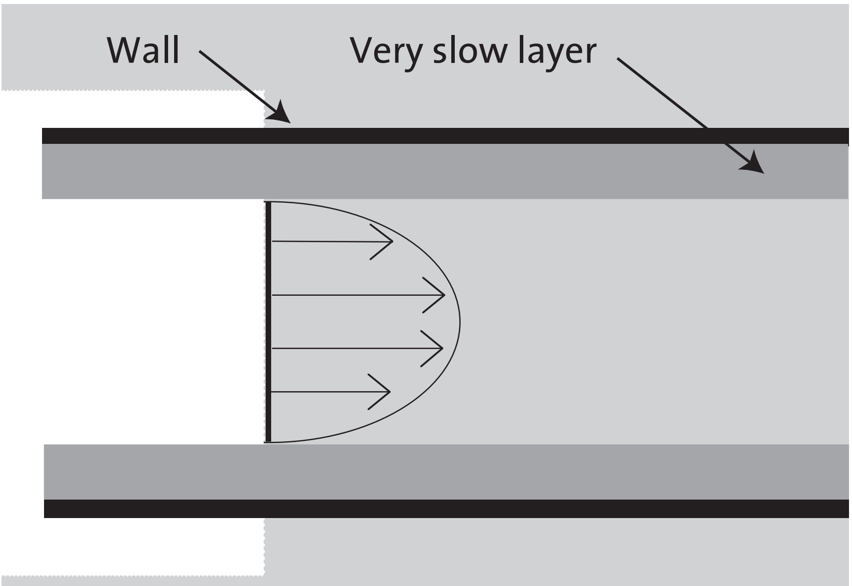


Figure 10 (above): Channeling. Material only uses as much of the channel as necessary.

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