CHAPTER VIII
CONCLUSIONS AND RECOMMENDATIONS

In this study, the rheological properties, extrudate swell, and melt fracture behavior of neat isotactic polypropylene (iPP) and iPP filled with calcium carbonate and titanium (IV) dioxide nanoparticles of varying content (i.e. ranging from 0 to 30 wt.%) and surface treatment (i.e., neat, silica-coated, and stearic acid-coated) during capillary extrusion were investigated. The conclusion of the results is as follows:

Effect of Calcium Carbonate

Melt rheology and extrudate swell of isotactic polypropylene (iPP) compounded with uncoated and stearic acid-coated $CaCO_3$ nanoparticles in various filler loadings, ranging from 5 to 25 wt.%, during capillary melt-extrusion were investigated. The wall shear stress for both neat iPP and iPP compounds was found to increase in a non-linear manner with increasing apparent shear rate. With increasing filler content, the difference between the wall shear stress values of iPP filled with uncoated $CaCO_3$ nanoparticles and neat iPP was found to increase, with the maximum of the difference being observed at the filler content of 25 wt.%. On the contrary, only iPP filled with 25 wt.% stearic acid-coated $CaCO_3$ nanoparticles showed a noticeable difference in the wall shear stress values from that of neat iPP. The apparent shear viscosity for all of the samples investigated was found to decrease in a non-linear manner with increasing apparent shear rate, an indication of a shear-thinning material. Addition of uncoated $CaCO_3$ nanoparticles was found to increase the apparent shear viscosity of the compounds, while stearic acid-coated ones did not affect the apparent shear viscosity of the iPP matrix as much.

In case of an increasing in shear rate, the flow curve occurred the plateau curve that meanwhile a critical shear stress on about 1100 s^{-1} of shear rate. The percentage of extrudate swell at a given real shear stress influenced with increasing shear rate in non linear manner. Without surface coating was found to reduce of swell values with increasing amount of filler. The slope of linear regression draw to the data obtained for uncoated nano composites was found to decrease with increasing filler loading. As the same time, stearic acid coated nano composites exhibited slope value not difference as much. And increasing L/D ratios tend to differences a linear regression on lower L/D ratio. Due to an increasing the L/D ratios, it also increased the residence time of the composites in the die. Which affect to the already-good dispersion of nano particles on PP matrix, the elongational flow behavior reveals that the nano composites exhibit a typical extensional thinning phenomenon. The nano composites increased the tensile stress following adjustment of the rate. They would destruct the entanglement of molecular chains and reorientation result in decreasing the elongational viscosity. As the same time, the viscosity was found increased with increasing amount of nano fillers.

Effect of Titanium Dioxide

Neat iPP and iPP/TiO_2 nanocomposites exhibited a shear thinning pseudoplastic behavior. The TiO_2 nanaparticles treated the surface by stearic acid and exhibited the property of hydrophobic, significantly reduced the rate of wall shear stress changing when increased amount of fillers as compared on hydrophilic surface composites. The shear viscosity on apparent shear rate of all samples presented not difference as much. Apparently, the extrudate swell was reduced with increasing amount of fillers due to its will be blocked the elastic recovery of the composites. The hydrophobic surface TiO_2 nanocomposites presented the critical of the extrudate swell and may suggest that the critical point is maximized for good dispersion and distribution of nanofillers in the polymer matrix. The relationship of extrudate swell was increased linearly with the wall shear stress. In various types of nanocomposites, the elongational viscosity and tensile stress as a function on elongational rate were investigated. Both neat iPP and the composites were presented the elongational viscosity on the elongational rate not difference as much. But, various amounts of fillers, the slope of tensile stress on elongational rate of nanocomposites increased with increasing the amount of the fillers and reached a maximum at the filler content of 30 wt%. So, the hydrophobic of the surface of nanoparticles should be more effective in elongational flow than the shear flow.

While the melt fracture phenomenon was observed by the addition of TiO_2 nanoparticles in iPP matrix at various filler loading, ranging from 5 to 30 wt% during capillary extrusion process. The frequency of all samples tested increased with increasing applied apparent shear rate. However, the frequency decreased as the amount of nanoparticles filled from 0 to 20 wt% while the frequency completely developed on 30 wt%. The TiO_2 nanoparticles as fillers have more effect on polymer molecular chains movement. Moreover, the nano TiO_2 particles on the composites would delay the onset of melt fracture as the same shear rate. The surface coating on nano particles also resulted in the severity of melt fracture. By applying the same shear rate, the hydrophobic surface TiO_2 particles exhibited greater frequency than hydrophilic surface coating due to the better dispersive and distribution on the iPP matrix. As for typical frequency length and frequency width at various shear rates, it can be seen that both increased as more amount of fillers added. The results on twist angle exhibited non-linearly manner at a given apparent shear rate. At the same time, the largest twist angle was on the maximum at 20 wt%. All of the results suggested that the introduction of the nano fillers could induce the increase in inner free volume and the effect elastic chains movement could be blocked leading to the change in the severity of melt fracture. In addition, the melt fracture phenomenon also depended on the die dimension, such as, die length. The longer the die used, the less the melt fracture took place.

Recommendations for Future Work

In the future work, the effects of shape and size of the nanoparticle should be studied in order to realize the actually mechanism of the interactions between the polymer and its fillers. Lastly, one should take into account the economic aspects in order to have an actual realization in the industries.