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Considerations for Extruding Water-Sensitive Polymers

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Background

Water is beneficial in the extrusion process in a number of ways. First, it is an efficient cooling agent with a high heat capacity. In addition, it is also a useful lubricant for sizing devices.

However, some polymers are particularly sensitive to water, which can pose problems to using water in any of these beneficial functions. Water can still be used in extruding these polymers, but controls are necessary to mitigate any harmful effects.

Three important factors in controlling water sensitive polymer extrusion are time, temperature, and the specific manner in which a polymer interacts with the water.

Use of Water in Extrusion

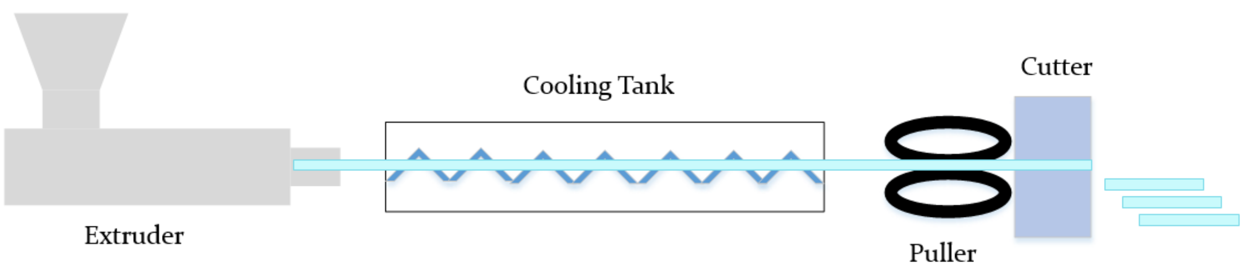

Figure 1: Block diagram of the extrusion process using a cooling tank with water

Types of Issues with Water

The first concept to understand in extruding water sensitive polymers is equilibrium. Equilibrium represents the point at which a system will stop dynamic changes and reach a steady state that will continue absent outside interference.

The equilibrium constant, generally represented as K, is a measure of where a physical or chemical process comes to rest in equilibrium at a given temperature. K is a numerical representation of the relative concentrations or states of various interrelated components in a system expressed as a ratio.

Water Soluble Polymers

The equilibrium ratio of a soluble polymer can be represented as follows:

- K_s = solubility constant
- $K_s = [A]^x[B]^y$
- Where [A] is the molar concentration of A and [B] is the molar concentration of B and x and y are dissociation levels

Generally, things that dissociate into multiple incidents of a specific component will dissolve more slowly and to a lower degree. If the polymer will not break down into constituents, it is just an expression of the saturated molar solution.

Manufacturers can keep the polymer from dissolving by adding an additional amount of A or B to the water to begin with.

Water Soluble Additives

Soluble additive use can be calculated as follows:

- K_p = partition constant for additive
- $K_p = \frac{[Polymer]}{[water]}$
- Where each term is the relative molar concentration in that substance

Keep in mind that when it comes to water-absorbing polymers, higher concentrations of additives will always diffuse more into water, regardless of affinity for the polymer. The more affinity for the polymer, the more of the additive will stay in the polymer.

Water Sensitive Polymers

When dealing with water absorbing polymers, manufacturers can use the following calculation method:

- K_p = partition constant for water
- $K_p = \frac{[water]_{polymer}}{[water]_{water}}$
- Where each term is the relative molar concentration of water in that substance

Water does have a molar concentration in itself: 55.5. It can be guessed how readily water absorption happens by knowing how much water your polymer will absorb in atmospheric conditions. However, the polymer can behave very differently in pure water because the concentration of the water is much higher. In addition, other effects can take place like surface adsorption or molecular entangulation. There are commercial polymers that will exceed 30% water by weight when immersed and retain less than 3% water at 50% relative humidity.

Temperature Effects

When addressing temperature, represented as T, in the extrusion process, remember that K is constant for a given temperature. When the temperature changes, K will be different. Manufacturers generally follow the Arrhenius equation for estimation, which means the effect of T is exponential.

However, manufacturers should be careful in applying this rule, because one must first determine whether a reaction is endothermic or exothermic.

An exothermic reaction implies that a lower T drives a higher K. Endothermic, on the other hand, implies a higher T drives a higher K. It is best practice to assume your process is endothermic unless you know otherwise. In medical extrusion, the usual process is to fix the T for water and limit the T for the polymer to a very narrow range.

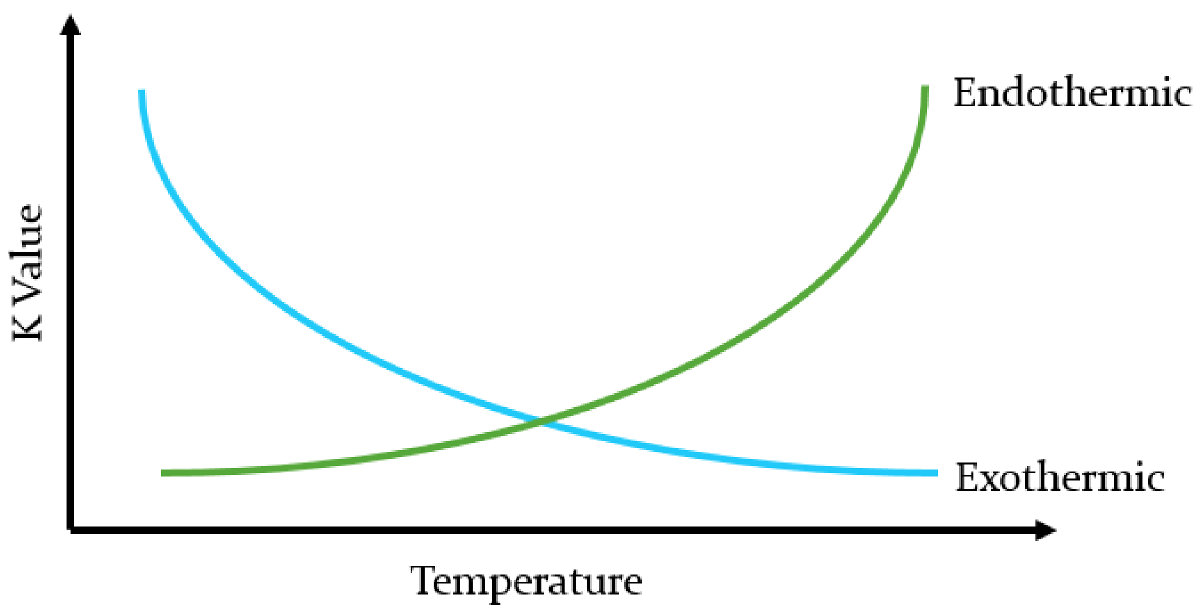

Figure 2: The relative effects of endothermic and exothermic reactions in extrusion

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Considerations for Processes

Extrusion is a dynamic system. The plastic being extruded is dropping in temperature and changing state. Contact time is constant, but usually very short, and water near or on a part may change in temperature. Therefore, it is very hard to predict what happens with certainty, but the system is only likely to approach K for the T at which the system operates.

Control What You Can

Manufacturers can only control the time a polymer is exposed to water, the temperature of the water, and the water contact distance. To manufacture a consistent product, it is important to be consistent in all of these variables. Extensive pre-line time lab testing can help you confirm and solidify the process. It is important to understand what is most critical before you get to IQ/OQ/PQ.

Control What Matters

Remember the following principles when it comes to mitigating the effects of water on water sensitive polymers:

- Seek a shorter contact time over less distance. Speed is your friend.
- Move K in your favor. Colder water is generally better.
- Get the least water involved. Consider spray instead of flood or a combination of flood and air.

Conclusion

Correctly designed processes can use water to extrude very water sensitive materials and additives, but pre-development testing of a materials and their interactions with water is critical to development. In the development process, it is important to remember all of the factors affecting the equilibrium and control each in your favor.

Once a stable process is developed, lock it down to control the end product.

For more information, please contact Christian Herrild.