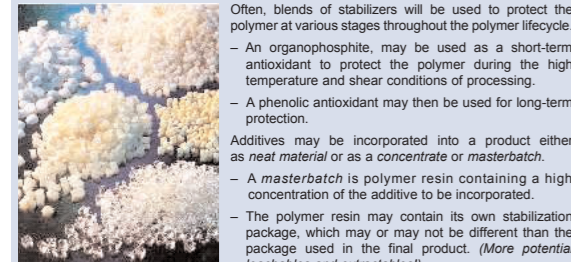


Introduction

Polymers are used in ALL aspects of our lives, including pharmaceutical packaging and medical device preparation.



Without the use of the proper stabilization package, polymers will degrade. Interaction with oxygen and light can cause significant degradation of the polymer. These degradation products are potential *leachables* and *extractables*.



Often, blends of stabilizers will be used to protect the polymer at various stages throughout the polymer lifecycle.

- An organophosphite, may be used as a short-term antioxidant to protect the polymer during the high temperature and shear conditions of processing.
- A phenolic antioxidant may then be used for long-term protection.

Additives may be incorporated into a product either as *neat material* or as a *concentrate* or *masterbatch*.

- A *masterbatch* is polymer resin containing a high concentration of the additive to be incorporated.
- The polymer resin may contain its own stabilization package, which may or may not be different than the package used in the final product. (*More potential leachables and extractables!*)

Some additives are designed to transform during use.

- An organophosphite, for example, will be oxidized to form the phosphate.
- In this case, BOTH the phosphite and phosphate are potential *leachables* and *extractables*.

Polymer stabilization is a dynamic process resulting in ever-changing transformation and degradation products – all potential *leachables* and *extractables*.

Additives can also provide special effects or properties to the polymer system.

- Benzophenones or benzotriazoles can provide UV protection to a polymer.
- Phenylglyoxylates can serve as photoinitiators in a UV curable coating.
- Colorants – dyes or pigments used to impart a particular color to a polymer system.

Each of these compounds poses the potential for *leachables* and *extractables*.

Degradation of Polyolefins

Technical preparation of “purest” polymer is simply not possible!
Structural defects and impurities can not be excluded

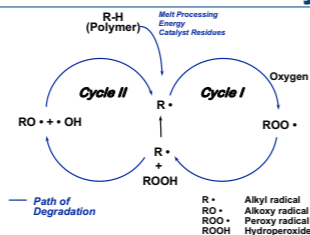
Organic materials undergo degradation in the presence of Oxygen.
Forming peroxides, alcohols, ketones, aldehydes, acids, peracids...

Oxidation is assisted by: Energy (e.g. mechanical stress, heat, light) metals/-ions (catalyst residual, impurities, co-add.)

Oxidation can affect mechanical properties
Discoloration, rougher surface, decreased tensile strength

Oxidation of hydrocarbon compounds proceeds autocatalytically

Polymer Auto-oxidation Cycle



Auto-oxidation: Most labile hydrogens

Polyamide:	-CO-NH-CH ₂ -
Polyester:	-CO-O-CH ₂ -
Polyacetal:	-O-CH ₂ -O-
Unsaturated system:	-CH=CH-CH ₂ -
Polypropylene/ Polyethylene	-CH ₂ -CH-CH ₂ - R

Lit.: F. Gugumus in *Plastics Additives*, Glöckner & Müller, Ed., 3rd Ed., Ch. 1

Products of polymer degradation

Active products: Intermediates of degradation	Alcyl radical (R·) (carbon centered free radical)
	Peroxy radical (R-OO·) (oxygen centered radical)
	Alkoxy radical (R-O·)
	Hydroperoxide (R-OOH → R-O· + ·OH) (hydroxy radical)
Inactive products: Influence organoleptics	Alcohol (R-OH)
	Aldehyde (R-C-H) (R-C-H)
	Ketone (R-C-C-R) O
Modified properties	Polymer

Polymer Stabilization

What are the differences between Additives, Stabilizers, Modifiers and Fillers ?

- **Additives** are ingredients added to the polymer to stabilize, modify or enhance it's performance
- **Stabilizers** are used to *maintain* the polymer's strength, flexibility and toughness; in other words, *the attributes of the polymer's original molecular architecture*
- **Modifiers** *improve / alter* the polymer's performance; e.g., Slip Agents, Antistats, Antiblocks, Processing Aids, Fillers
- **Fillers**, such as SiO₂, CaCO₃, Talc, or TiO₂ are used to *improve physical properties, or dilute the matrix with something less expensive* than the polymer itself

Role of Additives

Additives provide to Plastics:

■ Stabilization

To retain the original molecular architecture of the polymer under the effect heat, light etc.

and

■ Functionalization

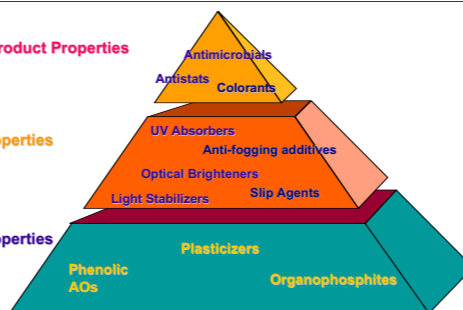
To provide additional attributes to the polymer which add value for end use application.

Extending Beyond Polymer Protection

Customer Product Properties Protection

Polymer Properties Extension

Polymer Properties Retention



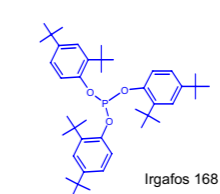
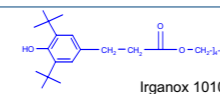
Additives can provide additional properties or effects beyond stabilization.

Stabilizers

- Good stabilization will reduce formation of aldehydes, ketones, and color bodies
- Some stabilizers, which can terminate alkyl radicals, are especially effective (vitamin E, lactone, hydroxyl amine)
- Systems for gamma irradiation have been developed
- Systems for reduction of organoleptics from slip agents are under development
- Auto-oxidation can be suppressed by the use of radical scavengers

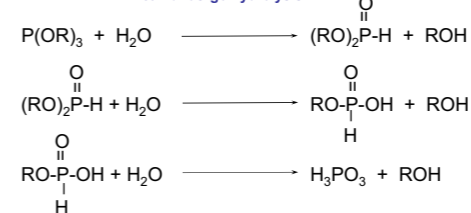
Stabilizers (cont'd)

- Most polyolefins contain one or more antioxidants at levels of 0.05 – 0.10%
- Primary antioxidants are generally radical scavengers or H-donors
 - i.e. hindered phenols such as BHT, Irganox 1010, or Irganox 1076
 - Long-term protection for the polymer
- Secondary antioxidants are typically hydroperoxide decomposers
 - i.e. trivalent phosphorus compounds such as Irgafos 168
 - Process stabilization (protects the primary AO against decomposition during processing)



Chemistry of Phosphite Hydrolysis

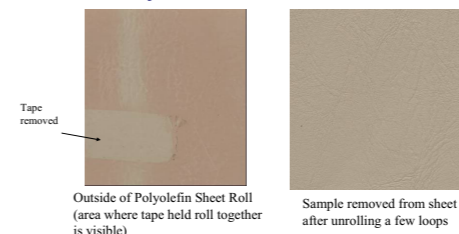
Some additives are **designed** to react and transform. For example, an active phosphite, such as Irgafos 168, can undergo hydrolysis:



Relative Discoloration

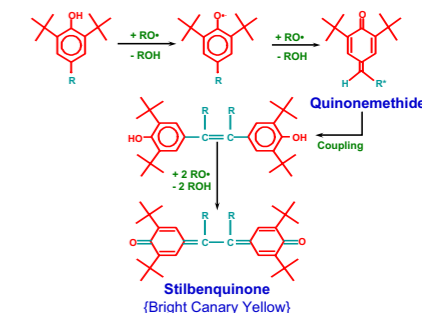
- Polymers stabilized with phenolic AO's can be susceptible to discoloration if the system is "abused"

Calendered Polyolefin Sheet

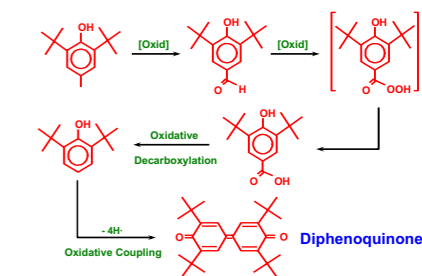


BHT and Irganox 1076 undergo similar chemical transformations leading to **chromophore** chemistries.

Phenolic AO Oxidation Chemistry



BHT Oxidation Chemistry



Conclusions

- Use of the proper stabilizer package can provide protection to the polymer.
 - A combination of *short-term* and *long-term* stabilizers may be employed.
 - Primary and secondary antioxidants
- Additives can also impart particular properties or effects to a polymer system
 - Colorants
 - Photoinitiators
 - Antistats
 - Antimicrobials
- Many additives will transform and/or degrade during use.
 - Each of these products must be taken into consideration when evaluating *leachables* and *extractables*.
- Stabilization is a *dynamic* process
 - Transformation and degradation products **must** be considered along with the intact additives as potential *leachables* and *extractables*.