Troubleshooting UV Curing Processes

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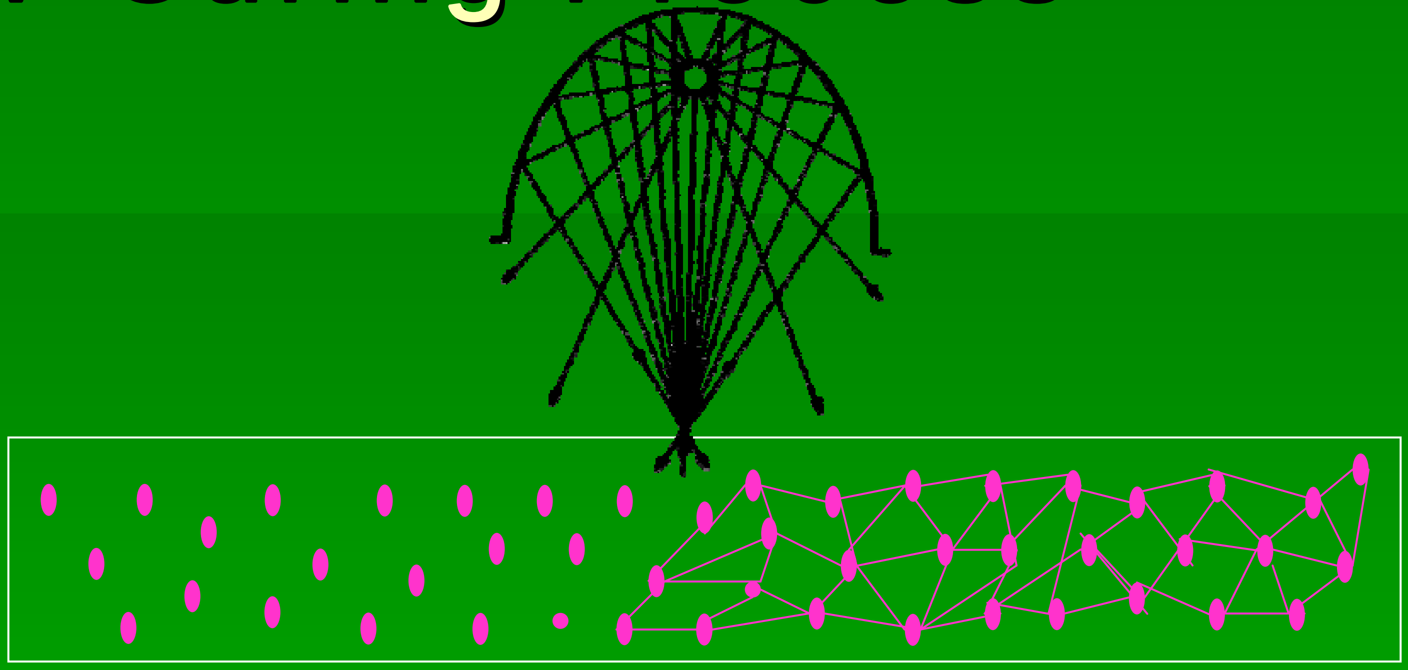
UV Curing Definitions

- **Ultraviolet (UV) Light** - Invisible wavelengths 200 to 400 nm most useful range for curing. Higher energy than visible light.

- **Curing** - Polymerization of monomers and oligomers. Usually includes polymer cross linking. Usually includes phase change from liquid to solid state.

UV Curing Process



Liquid Film

Solid Film

100 % Solids System

Near Zero VOC's

High Gloss

High Scuff Resistance

High Solvent Resistance

High Abrasion Resistance

Flexible

Advantages of UV/EB Curing

- Can eliminate solvent emissions
- High line speeds
- Can be used on heat sensitive substrates
- Reduced production space requirements compared to thermal curing ovens
- Energy savings
- Improved aesthetics
- Resulting cured films have excellent resistance properties
- Unique physical properties including: high gloss, high hardness, release, and adhesives

The UV Curing Process

APPLICATION
-method
-film weight
-speed
-substrate

LAMPS
-irradiance
-wavelength
-focus
-heat

FORMULATION
-rheology
-absorbance
-cure response
-film properties

Outline

- Basics of UV chemistry/formulations
- Lamp basics
- Radiometers
- Defining Cure
- Troubleshooting examples

UV Curing Chemistry

- Free Radical Curing of Acrylates
- Cationic Curing of Epoxies
- Other
  - Thiol/Ene
  - Unsaturated Polyester/Styrene
  - Methacrylates
  - Maleate/Vinyl Ether

Free Radical Curing of Acrylates

- Most widely used chemistry (>80%)
- Wide range of available raw materials
- Wide range of formulated inks, coatings and adhesives
- Wide range of properties (from pressure sensitive materials to hardcoats)
- Inhibited by atmospheric oxygen

Cationic Curing of Epoxies

- Utilizes photoacid initiators (onium salts)
- Lower shrinkage (stress) upon cure compared to acrylates
- Cure can continue after light exposure (post-cure or dark-cure)
- Can provide enhanced mechanical properties and adhesion on select substrates (metals)
- Cure can be inhibited by basic (nucleophilic) contaminates, moisture, and substrates
- Common applications: metal deco coatings, release coatings

UV Formulation Components

- Oligomers – larger reactive molecules; primarily determine physical properties
- Monomers – smaller reactive molecules; provide low viscosity; multifunctional monomers provide crosslinking
- Photoinitiators – respond to UV light and initiate reaction
- Additives – pigments, fillers, tackifiers, surfactants, defoamers, etc.

Optical Density of UV Curable Materials

- Non-pigmented, optically thin materials (coatings and adhesives)
  - Total UV energy is more important than peak irradiance
  - Film thickness has little effect on cure
  - Standard mercury lamps are often preferred
- Pigmented, optically thick materials (inks)
  - Peak irradiance and total energy are important
  - Film thickness can have great effect on cure
  - Longer wavelength doped lamps may be preferred

Ultraviolet Lamps

- Medium Pressure Mercury Vapor Lamps
  - Conventional electrode type (arc lamps)
    - 200 to 750 watt/in power
    - Lengths up to 72 inches
    - 2 to 3 min start-up time
    - 1000 hour typical life
  - Microwave powered lamps (Fusion Systems)
    - 300 to 600 watts/in power
    - 10 inch maximum length
    - 10 sec start-up time
    - 3000 hour typical life
    - Consistent doped lamp output

Ultraviolet Lamps (cont.)

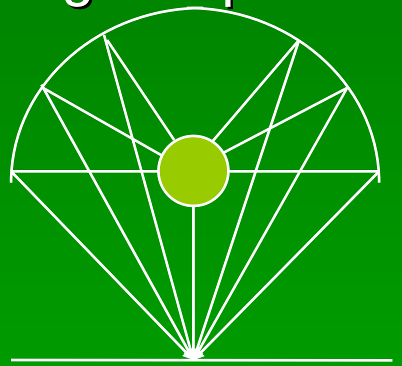
- Doped Mercury Vapor Lamps
  - Dopants added to shift spectral output (D,X, M, V, A types)
  - Longer wavelengths useful for pigmented systems
- Germicidal Lamps
  - Low pressure mercury lamps
  - Low power, main output at 254 nm
  - Used to produce wrinkled surface cure (Lindy method) when used in combination with nitrogen and conventional lamps

Ultraviolet Lamps (cont.)

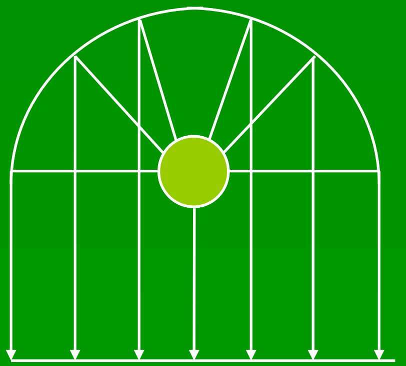
- Pulsed Xenon
  - High pulse rate can give effectively continuous output
  - Lower heat compared to mercury vapor lamps
  - Smaller lamps are suited to specialty applications
- Eximer Lamps
  - Narrow output at 308, 222, 172 nm
  - New, limited commercial use

Reflectors for UV Lamps

- Elliptical reflectors give focused output and highest peak intensity.



- Parabolic reflectors are useful for irregular surfaces and three dimensional objects.



UV Lamp Heat Output

- High Heat Output From Mercury Vapor Lamps (typical more than 50% of output is IR)
- Cooling is Required
  - Air cooling (inerting difficult)
  - Water cooling
  - Chill drums
  - Constant moving web
  - Shutters
  - IR filters
  - Dichroic reflectors

Characterizing UV Exposure

- UV Irradiance (W/cm2)
- Exposure Time (W/cm2 x seconds = J/cm2)
- Focus (exposure profile)
- UV Spectral Distribution (wavelength)
- IR Irradiance (heat output)

Lamp Recommendations

- Use the hour meter to track the time between bulb changes and other lamp maintenance. Note there are many factors that can cause bulb life to be shorter than the typical 1000 hours.
- Watch the amp meter. Power supplies are programmed to provide optimal current and voltage for start up and various run conditions. Changes from normal behavior may indicate lamp or electrical problems
- Open the lamp cassette often and perform a visual inspection of the lamp. The bulb should be clean and transparent and the reflectors bright and shiny.

Lamp Recommendations

- Maintain the reflectors. 60 to 80% of the light is reflected. Clean, polish, or replace reflectors as needed.
- Maintain the shutter mechanism. Most web installations use shutters to prevent burning when the web is stopped. Shutters must fully open and close at the proper time.
- Always inspect lamps after a web fire. Lamp maintenance will likely be required.
- Maintain the lamp cooling system. Lamps work best in a specific temperature range. Systems are designed to maintain this temperature. Do not modify the lamp temperature control mechanisms.

Factors Affecting Lamp Longevity

- Operating temperature
- Process cleanliness
  - Misting
  - Volatilization
  - Particulates (dust, paper fibers)
- System design
- System maintenance

Radiometric Monitoring of UV Lamp Output

- Provides a measurement of UV lamp output
- Different aspects of lamp performance may be measured: irradiance, total dose, irradiance profile, spectral distribution
- Many different types of devices are available
- Little correlation between different devices; few standards
- Relative measurements are preferred
- Correlations between relative lamp output and desired properties are useful

Radiometric Devices

- Self-contained electronic radiometer (light bug) – difficult to use in a web process
- Probe type electronic radiometer – provides static measurement
- Permanent lamp mounted electronic sensor/radiometer – performance may degrade in harsh lamp environment
- UV Sensitive tapes and strips – relies on chemical or color change for measurement

What You Should Know About Your Radiometer

- Spectral response – Is it measuring the wavelengths that are important to your curing process?
- Dynamic range – Is it sensitive in the irradiance range used in your process?
- Sampling rate – Does it respond fast enough for your process?
- Temperature tolerance – Does the temperature in the curing zone affect the response of the radiometer?

When is a Material Cured?

- Under-cure
- Over-cure
- Cure window
- Chemical definition of cure
- Physical (practical) definitions of cure

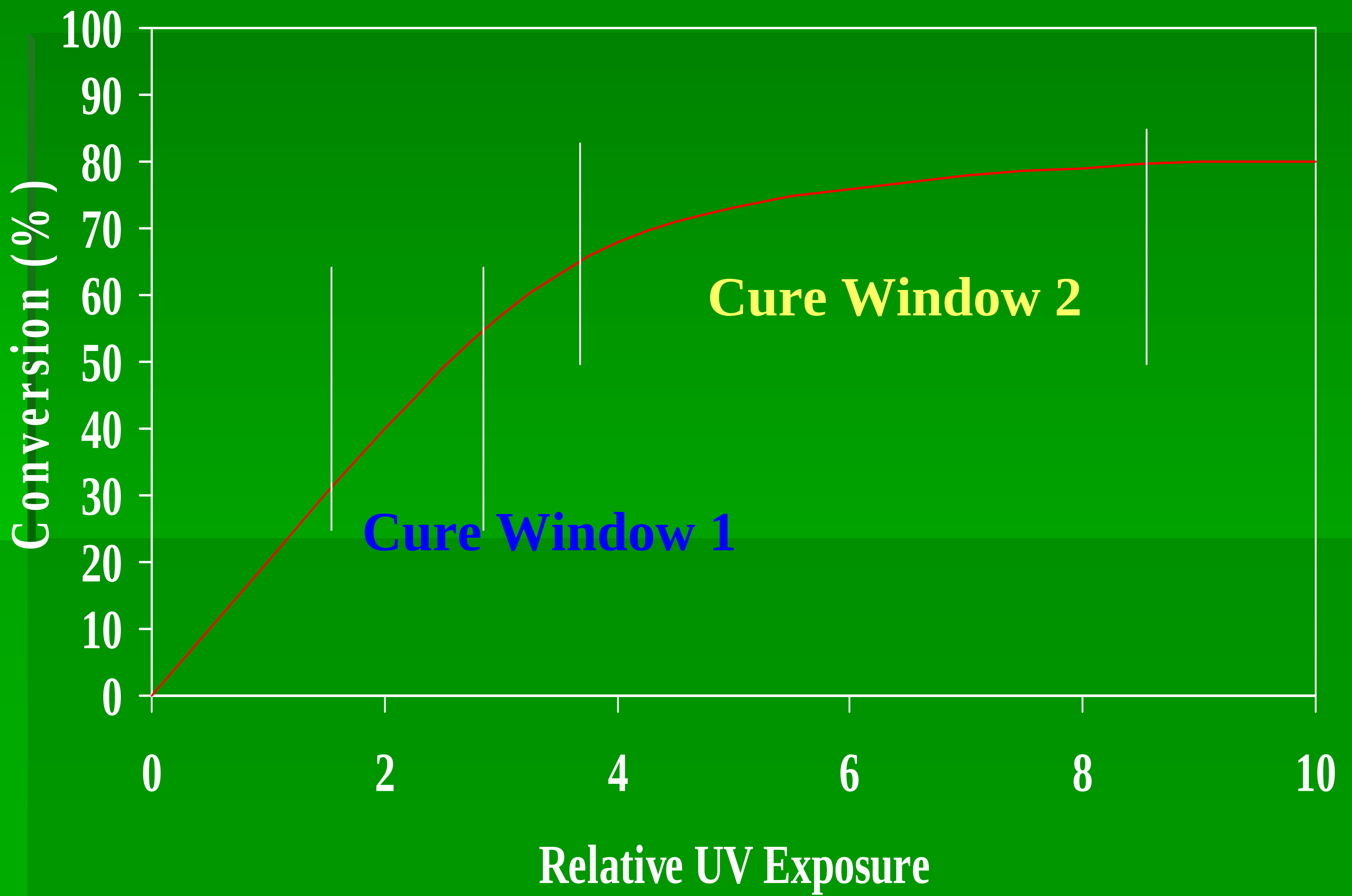
Chemical Definition of Cure

- Conversion of reactive groups to create polymer network
- 100% conversion is not achieved due to decrease in mobility (vitrification) with increasing degree of cure
- Soft films can achieve higher conversion compared to hard films
- Some materials are designed to perform with conversions as low 70 to 80%
- Direct measurement of chemical conversion is usually not practical in a production environment

Physical Definition of Cure

- Cure is when the coating, ink, or adhesive has the desired performance properties. Cure requirements unique to each UV process must be defined.
- Properties used to check cure can include:
  - Tack free surface
  - Solvent resistance (MEK rubs)
  - Surface energy (pen reticulation)
  - Surface slip (C.O.F.)
  - Bond strength (for UV adhesives)
  - Flexibility
  - Abrasion/scuff resistance
  - Subsequent adhesion (for release coatings)

Defining a Cure "Window"



Sample UV Troubleshooting Problems

- No way to provide a complete troubleshooting guide in the context of this course
- Sample problems for illustration purposes only
- Understanding the total UV curing process is the most effective way to improve troubleshooting skills

Problem 1

UV Overprint coating has lower than expected gloss

- **Cause 1** – Coat weight is too low
- **Cause 2** – Porous substrate results in poor coating hold out
- **Cause 3** – Gloss decreases over time due to continued drying of underlying lithographic inks
- **Cause 4** – Poor coating flow
  - Poor surface wetting due to low surface energy of substrates and inks
  - Coating liquid surface energy is too high to wet the substrate
  - Rheology (viscosity) of coating not appropriate for application method, speed, or temperature

Problem 2

UV Topcoat has poor intercoat adhesion on printed substrate

- **Cause 1** – Ink or primer are not completely dry
- **Cause 2** – Surface active additives in the inks or primer
- **Cause 3** – Too little UV exposure
- **Cause 4** – Too much UV exposure
- **Cause 5** – Plasticizer is migrating from the substrate
- **Cause 6** – Wrong coating used in the application

Problem 3

UV Overprint coating has poor abrasion resistance

- Cause 1 – Too little UV exposure
- Cause 2 – Coating weight is too low
- Cause 3 – Wrong coating selected for the application
- Cause 4 – Substrate roughness

Problem 4

Dark color UV ink has poor adhesion to substrate

Cause 1 – Substrate surface energy too low

Cause 2 – Incorrect ink for selected substrate

Cause 3 – Incomplete trough cure

- Lamp peak irradiance too low
- Lamp spectral output not suited for ink
- Ink film too thick
- Ink photoinitiator package needs adjustment

Problem 5

Cationic silicone release coating does not provide consistent release performance

- **Cause 1** – Incomplete curing of silicone
  - Too little UV exposure
  - Silicone cure inhibited by underlying substrates or inks
  - Silicone coating contaminated in the application equipment
- **Cause 2** – Incomplete coverage of substrate by the silicone coating
- **Cause 3** - Incompatible silicone/adhesive system

Problem 6

Poor bonding of over-laminate film with UV curable laminating adhesive

- **Cause 1** – Migratory slip additives on the surface of the film
- **Cause 2** – Inadequate surface treatment of film (corona or flame treatment needed)
- **Cause 3** – UV energy absorbed by over-laminate film (issue with PET film)
- **Cause 4** – Incorrect adhesive for selected substrates
- **Cause 5** – Too little UV exposure
- **Cause 6** – Surface active slip additives in the inks

Problem 7

Inconsistent UV PSA performance

Cause 1 – Too little UV exposure

Cause 2 – Too much UV exposure

Cause 3 – Shift of lamp spectral output with age

Cause 4 – Inconsistent PSA application weight

Problem 8

Good curing is only maintained for a few hundred hours after bulb replacement

- **Cause 1** – UV lamp is being contaminated by deposits generated in the converting process (misting, volatilization, particulates)
- **Cause 2** – Inadequate control of lamp temperature is severely shortening bulb life
- **Cause 3** – Faulty UV power supply
- **Cause 4** – Marginal curing process operates only with maximum lamp output

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Conclusion

- Basic understanding of all aspects of the UV curing process is the most effective way to provide effective troubleshooting