Thermal Curing

By Joni Karloske
Akzo Nobel Resins

Comparison to UV Cure Process

A prime success criterion for coatings is the achievement of a uniform layer as the outcome of the film formation and solidification process. This can be achieved by either conventional thermal curing or by UV Cure. A final film of uniform thickness implies good flow and leveling and the avoidance of undesired flaws in the course of film formation.

Conventional heating has long been the benchmark for curing most coatings, providing a fairly wide process window and predictable results across a broad range of operating conditions, such as time, temperature mass, etc. Although, convection ovens are widely used for this process, infrared (IR), near-infrared (NIR) and ultraviolet (UV) light energy has also been used to cure coatings. The type of curing method used depends on the application and the end-user's requirements, such as floor space, budget, production cycles, etc.

The current trend in thermal-cure technology is to move to a more powerful, but narrower process window. This requires more precision and control of the curing parameters. Coatings manufacturers generally agree that curing conditions outside the recommended level can cause performance and appearance problems with the finished film.

Regardless, of whether conventional thermal cure or UV cure resins are being used, the cure cycle must be long enough and have adequate energy to provide 100% cure.

Important Attributes

The goals of curing departments are twofold. They must ensure that coating on the parts is cured within the curing window; however, they must also cycle as many parts per hour as possible through the curing ovens. Temperature control is critical to achieving a proper cure and keeping lines moving quickly.

While temperature control is critical, curing ovens are generally not equipped with precise heating control equipment. Consequently, oven users in production environments are often left wondering whether their ovens will properly cure a particular part, especially when testing a new or critical coating.

Oven profiling methods haven't changed much over the years. A recording device, enclosed in a protective case, is used to measure oven air and part temperature relative to time. The device is hung from a part hanger with at least two thermocouples attached to the part and another thermocouple left unattached to measure oven temperature. The recorded information is then displayed as a graph on a chart.

If the oven is performing as it should, the resulting oven profiling graph should show the part temperature rapidly rising to the minimum cure temperature and staying at or close to that temperature for the duration of the oven stay. In addition, the oven air temperature should also be the same as indicated on the oven temperature controller.

Besides the air temperature, the oven must also control the air quality, exclusion of dirt, airflow patterns, and ventilation of paint fumes. Filters are installed on the heater housings for the make-up air to the oven zones. This fresh air make-up replaces the solvent-laden air that must be exhausted from the oven zones to prevent any potential risk of flash fires or explosions. Airflow patterns are maintained to distribute the heat evenly over the painted surface. A careful balance is required to ensure that both thin metal and thick metal parts reach and maintain the necessary cure temperature.

Oven-exhaust systems are engineered based on the designed operating temperatures. If temperatures are increased, extra compensation must be accounted for in the exhaust to accommodate the expanded air volume. If this is not done, the oven enclosure cannot contain the process, resulting in smoke and heat escaping the enclosure. Likewise, turning on exhaust fans in adjacent areas may upset the oven air balance. The airflow at the oven's exit, which should always be pulling air in, will now be drawn outward by an external ceiling exhaust fan.

A regularly scheduled preventive maintenance and housekeeping program can keep a curing-oven system operating efficiently.

Temperature measurement tools

Precise temperature measurement is a requirement in many process control and/ or monitoring situations. Whatever the application, manufacturing usually wants measurement accuracy at the lowest possible cost from both a financial and a computational perspective. There are two basic types of temperature measurement tools - contact temperature sensors and non-contact temperature sensors.

Contact temperature sensors measure their own temperature. One infers the temperature of the object to which the sensor is in contact by assuming or knowing that the two are in thermal equilibrium, that is, there is no heat flow between them. Temperatures of surfaces are especially tricky to measure by contact means and very difficult if the surface is moving. Many potential measurement error sources exist especially from too many unverified assumptions. The following are examples of contact temperature sensors.

1. Thermocouples are among the easiest temperature sensors to use. They are widely used in science and industry. They are based on the Seebeck effect that occurs in electronic conductors that experience a temperature gradient along their length. Thermocouples are pairs of dissimilar metal wires joined at least at one end, which generate a net thermoelectric voltage between the open pair according to the size of the temperature difference between the ends, the relative Seebeck coefficient of the wire pair and the uniformity of the wire-pair relative Seebeck coefficient.

2. Thermistors are tiny bits of inexpensive semiconductor materials with highly temperature sensitive electrical resistance. They are used in many applications where they are not seen because they are buried inside something else. They typically work over a relatively small temperature range and can be very accurate and precise within that range.

3. Resistance Temperature Detectors (RTDs) are wire wound and thin film devices that work on the physical principle of the temperature coefficient of electrical resistance of metals. They are nearly linear over a wide range of temperatures and can be made small enough to have response times of a fraction of a second. They require an electrical current to produce

a voltage drop across the sensor that can be then measured by a calibrated read-out device. RTDs among the most precise temperature sensors commercially used.

4. Labels, Crayons, Paints and Tabs are single use devices. They operate as a simple phase change devices. They are used as a quick, inexpensive check on a process or experimental temperature or as a record that the object has or has not exceeded a certain temperature.

Non-Contact Temperature Sensors are used in many industrial applications; however, the understanding of their use is relatively poor. In many industrial plants, they are not yet standardized to the extent that thermocouples and RTDs are. The following are some examples of non-contact temperature sensors:

1. Radiation Thermometers includes Pyrometers, Infrared Thermal Imaging Cameras (with temperature measurement capability), line-measuring thermometers, and Infrared Radiation Thermometers. Radiation thermometers are based on Planck's Law of the Thermal Emission of Electromagnetic Radiation. This group of sensors includes both spot or "point" measuring devices in addition to line measuring radiation thermometers, which product 1-D and, with relative motion, can produce 2-D temprature distributions. They also include thermal imaging, or area measuring thermometers, which measure over an area from which the resulting image can be viewed as a 2D temperature map of the region viewed. These are significant devices because they enable improvements in processes, maintenance, health and safety that can save both lives and money. They enable automation and feedback control that can boost productivity while improving yield and product quality. Some confusion exists about this whole class of sensors for a variety of reasons, including the wide variety of names given to the same devices in this class. This is due to a lack of standardization in the industry.

2. Optical Pyrometers are highly developed and well - accepted non-contact temperature devices with a long and varied past from its origins more than 100 years ago. Despite the fact that there are more modern and automatic devices available, they are still used in some industries. Optical Pyrometers work on the basic principle of using the human eye to match the brightness of the hot object with the brightness of a calibrated lamp filament inside the instrument.

3. Infrared Radiation Thermometers measure temperature without contact. The object being measured essentially broadcasts information about its temperature all of the time. A radiation thermometer collects some of the broadcast radiation and can measure the temperature of the object's surface. For semi-transparent objects, it measures the temperature within and/ or beyond the object. Since the radiation thermometer does not contact the object it is measuring:

- it does not need to be at the same temperature,
- it can measure very rapidly,
- it can measure distant objects,
- it can measure moving objects,
- it can measure very high temperatures,
- it does not interfere with the object's temperature distribution

Radiation thermometers can measure many more very unique things beyond the limits of contact temperature sensors. Radiation thermometers can be very accurate and precise; however, it is difficult to determine errors in use.

With either a contact or a non-contact thermometer, some type of data collection system is needed to maintain and analyze the data collected. Advances and improvements have also been made in data logger technology. Current models are more compact, can remain in the oven during operation, and have user-friendly software that can document the entire curing process. They also can process-specific data and analyze temperature profiles to optimize curing. In addition, the digital signal controller is a new class of processor that combines the best features of both micro-controllers and digital signal processors.

Choosing a temperature sensor is often straightforward, but can spell the difference between repeatable results and nonsense numbers. The key in measurement is to measure with an amount of inaccuracy or uncertainty that is acceptable.

Risks

Determining cure of coatings generally is difficult regardless of the method of cure. There are no universally reliable field tests for such purpose. Because a coating is dry or hard does not necessarily mean it is cured. In fact, hardness is not synonymous with cure for most coatings. Residual retained solvent or moisture may require a longer period of time to escape from the paint film. In some situations, this evaporation process may take as long as 2 – 3 weeks or more.

If the curing cycle is not performed properly, the coating can fall victim to a multitude of problems which include: hardness, flexibility, impact resistance, adhesion, gloss retention, texture, color stability, chemical resistance and service life.

Too little cure (less time or temperature) usually results in a:

- Decrease in hardness, corrosion resistance, brittleness, adhesion (within limits), poor weathering and color changes.
- Increase in gloss, marring and flexibility.

Over-curing usually has the opposite effect.

Line operators are often tempted to increase the line speed slightly to boost production, but doing this may move the time-temperature point outside of the curing window with possibly severe and\ or unexpected results.

Temperature is obviously important in determining the degree of cure taking place at a specified time. Higher curing temperatures usually mean more or faster cure. A common problem is in knowing the actual oven temperature. Large ovens are often equipped with a single thermometer, which is acceptable if the temperature is uniform from top to bottom and from end to end. Unfortunately, ovens often have a wide temperature variation from one curing zone to another. A difference of 20 - 30ºF is possible. Many curing reactions may double in rate with an increase of about 20ºF.

Another concern in curing is "hot spots". Hot spots occur when one area inside of the oven becomes hotter that another area, resulting in an inconsistent cure among parts that are being cured at the same time. Controlling the airflow is the best way to avoid this problem.

Problems also occur when the line stops during the cure cycle. Parts left in the oven too long may exhibit over-cure problems such as brittleness or failure to meet color or gloss specs. Many coatings have some tolerance for over-baking, especially at lower temperatures.

Another potential problem is fouled air, which can contain reactive chemicals resulting from incomplete burning of the oven fuel. These chemicals may affect the color or glass of the coating. In extreme cases, cracking may occur. Having the air-fuel ratio in the oven checked twice a year is one way to be certain that the oven is operating properly.

Finally, good operators are a valuable asset and their protection is critical. It is important to train them to use the proper safety equipment. The following safety equipment is recommended:

- Respirator or fresh-air system, depending on the system being used
- Lint-free paint suits and hoods, especially in topcoat booths
- Barrier creams or gloves to help keep hands clean and free of dirt
- Eye wash stations
- Fire extinguishers and sprinklers because fires in finishing facilities are common
- Spray booth, if that is the method of application used.

Training is an essential part of any coatings operation, whether conventional thermal or UV curing. Knowing how to safely handle and use the formulated inks and coatings reduces finishing costs, reduces pollution and results in greater finish quality.

****