Wire-wound metering rod coating technology

Objectives: To investigate wire-wound metering rod coating of polymers on glass substrates.

Background:

The wire-wound metering rod is one type of a variety of liquid surface coating technologies. There are about two dozen major coating applicator techniques that can potentially apply any given coating solution to a web. Among this big group, the wire-wound metering rod is the third most popular technique in use today, behind gravure and reverse roll coating [1].

Liquid surface coating technologies have been used in a wide range of industrial coating applications such as paints for cars/houses/machines, color photographic films, X-ray films, printing plates for papers/books/magazines, magnetic storage media, optical disks, wallpaper, adhesive tapes of many kinds, etc. Table 1 summarizes some key parameters of some liquid surface coating technologies.

Table 1. Summary of some liquid surface coating technologies

Process	*Viscosity (Pa·s)*	*Wet Thickness (μm)*	*Coating Accuracy (%)*	*Speed Max (m/min)*	*Effect of Web Roughness*
Single layer					
Rod (wire wound)	0.02–1	5–50	10	250	Large
Reverse roll	0.1–50	5–400	5	300	Slight
Forward roll	0.02–1	10–200	8	150	
Air knife	0.005–0.5	2–40	5	500	Large
Knife over roll	0.1–50	25–750	10	150	Large
Blade	0.5–40	1–30		1500	Large
Gravure	0.001–5	1–25	2	700	
Slot	0.005–20	15–250	2	400	Slight
Extrusion	50–5000	15–750	5	700	
Multilayer					
Slide	0.005–0.5	15–250	2	300	Slight
Curtain, precision	0.005–0.5	2–500	2	300	Slight

[a] The numbers in this table are only for rough guidelines.
Note: 1 Pa·s = 1000 cP
1 μm = 1 cm^3/m^2 of wet coating
1 μm = 1 g/m^2 for a density of 1 g/cm^3
1 m/min = 3.28 ft/min.

<u>History:</u>
The wire-wound metering rod coating method was invented by Charles W. Mayer who founded the Mayer Coating Machines Company in 1905 in Rochester, New York. This coating technique is also called Mayer Bar, Meyer Bar, Meyer Rod, coating rods, equalizer bars, doctor rods. Among them, Mayer rod is the most frequently used name.

Theory:
A typical wire-wound metering rod is shown in Figure 1. A stainless steel rod is wound with a tight spiral of wire, also made of stainless steel. The diameter of wire can vary from 0.18 mils to 13.5 mils for different coating thickness. The grooves between the wire coils determine the precise amount of coating materials that will pass through as it is moved along the web. The thickness of wet film is directly proportional to the diameter of the wire used. After applying the metering rod, the initial shape of the coating is a series of stripes, spaced apart according to the spacing of the wire windings. Almost immediately, surface tension of the liquid film pulls these stripes together, forming a flat and smooth surface, ready for the following drying and curing process through heat or UV light sources.

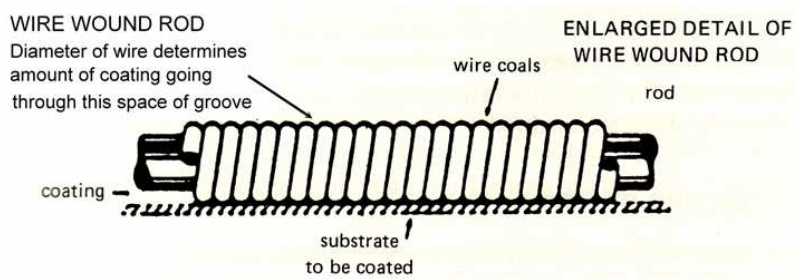

Figure 1. Wire-wound metering rod.

Using metering rods, wet film coating thickness can be controlled accurately within 0.1mil. Mathematical calculation indicates that the wet film coating thickness is 0.173 times the wire diameter. In practical coating production, many factors can influence the actual coating thickness, such as the viscosity of the liquid, web tension, moving speed of the web, wettability of the liquid, penetration of the liquid into the base material, et al. Also, not all the coating material passes through the grooves; some liquid adheres to the surface of the wire. This effect is quite significant when fine wires (5-25 mils) are used, or when viscosities are high. The sum of all these variations is usually less than a 20% difference from the theoretical coating weight. In practical, a trial-and-error procedure is generally used to select the ideal wire size for each coating application. A ratio of 1:10 between the wet coating thickness and wire diameter is accepted by most users as a rule for selecting wire size [2].

Metering rod station:

In production coating, the web must first pass through a wetting station and then to the metering rod in order to be coated with a uniform liquid film[3]. The coating liquid can be applied to the web by different methods. For example, the web can be immersed directly into a tank as shown in Figure 2; or an applicator can be rotated in the reservoir to transfer the liquid to the web at the top of its rotation as shown in Figure 3. The metering rod usually rotates in the same or opposite direction to the web movement to even out the wear on the wire and to loosen any dirt particles caught between the web and the rod that could cause streaks. Whichever direction the rod rotates to produce the best coating, the wire should be wound in such a way that rotating the rod tightens the wire [4]. The web should pass above the rod, to allow the excess liquid to fall back into the tank. However, the web does not need to be perfectly horizontal, as long as the surplus coating can return to the tank through gravity.

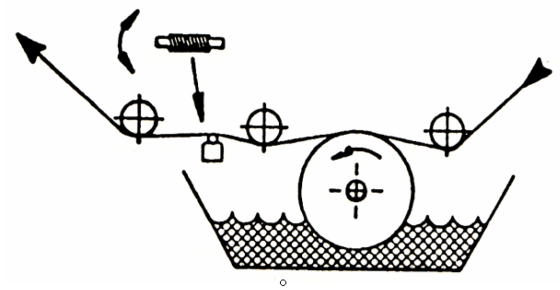

Figure 2. Applicator roller method

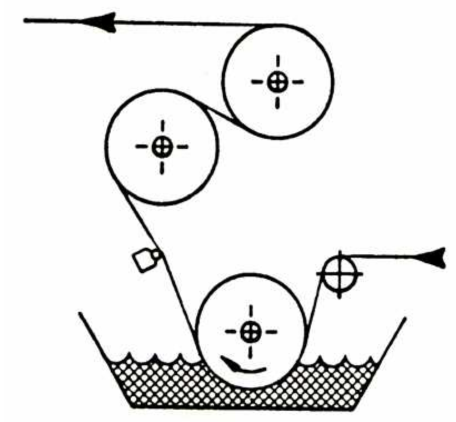

Figure 3. Web immersion method

One important factor for designing a coating station is wrap angle, which describes the change in direction of the moving web when it passes the metering rod as shown in Figure 4. Usually the wrap angle is 15^o for a heavy web tension, or up to 25^o for a light web tension. The ideal wrap angle is one that ensures that the web is tight enough to form intimate contact with the metering rod without causing any wrinkles.

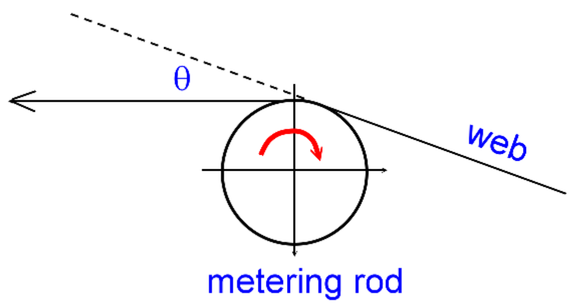

Figure 4. Wrap angle of metering rod coating station.

<u>Improvement:</u>

The wire-wound metering rod technology has been continuously improved since its invention. The early metering rods were made of ordinary carbon steel that experienced corrosion problems. It was soon upgraded to stainless steel wrapped with stainless steel wire. For some applications, metering rods are coated with hard nickel and titanium nitride to increase wear resistance. Rods coated with Teflon™ film are available where streaking and cleaning are a problem. Super-coat rods use a second, smaller wire wound around the primary wire of a normal metering rod, resulting in a wet coating more than twice as thick as a conventional metering rod. The gapped rod, having wires that are separated from each other, can coat higher viscosities and increased thicknesses. In a threaded rod, the grooves are machined into the rod to eliminate gaps between wires for better precision control. (Figure 5)

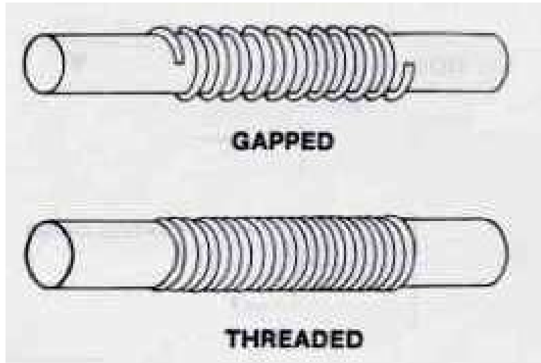

Figure 5. Gapped and threaded metering rods. [5]

Advantages and disadvantages:

Advantages:

- Low cost---replacing worn or damaged rods and changing from one coating weight to another, are both inexpensive and fast. The machine downtime for changing or cleaning rods is measured in minutes instead of hours, using much less labor than is required by other coating systems.
- Precise thickness control---without changing the coating formulation, metering rods can be selected to control the web coating thickness in 0.1-0.2 mil increments.
- Lower setup cost---in addition to lower labor costs for changeovers, faster setups mean more productive running time meeting the worldwide trend toward shorter production runs.

Disadvantages:

- Metering rods work best with low viscosity liquids, which will flow easily between the wire windings.
- Coating speeds of metering rod method are usually limited to 1000 ft/min. since the striations formed by the metering rod need a certain amount of time to level out before the web is dried.

Reference:

1. Tracton, Arthur A. 2006. Coatings Technology : Fundamentals, Testing, and Processing Techniques, CRC Press, p19-7

2. D.Satas, Arthur A. Tracton, Coatings Technology Handbook, Marcel Dekker, 2nd edition, 2000, p132
3. http://www.tciinc.com/coating.html
4. Weiss, H.L. 1977, Coating and Laminating Machines. Milwaukee, WI: Converting Technology Co., p236
5. http://www.webcoatingblog.com/blog/2005/07/mayer_rod_coate.html

Lab procedure:
Equipment/materials list:
Glass substrate 4″×4″
Meyer rods: #8, #12, #18, #24, #30, #34, [www.rdspecialties.com/Page.asp?Script=14]
Epoxy 301 part A and B. [www.epotek.com/SSCDocs/datasheets/301.PDF]
Clean glass substrates thoroughly with Sparkleen 1 solution (20 wt%) followed by blowing dry with N_2

1). Mix epoxy 301 part A and B as indicated by technical data sheet. [volume ratio ~ 3:1] Carefully stir the mixed epoxy liquid to make the solution more uniform. Try to avoid any air bubbles being trapped inside the solution during stirring.
2). Wait 15 minutes, then stir the mixed epoxy solution for 20 seconds, apply a few drops of mixed epoxy onto glass, slide Meyer rod #8 onto liquid epoxy to make a liquid film. Record the sliding rate that results in a good liquid film.
3). Repeat step 2 five times to make another 5 liquid epoxy films, the time intervals are: 30, 45, 60, 75, 90 minutes. Try to use the same sliding rate as #8.
4). When the waiting time is 60 minutes, using rod #8 to make several liquid films under different sliding rates. Record different behaviors of the wet films and select the best result.
5). When the waiting time is 60 minutes, besides Meyer rod #8, use *#12, #18, #24, #30, #34* to make five more liquid epoxy films. Try to use the same sliding rate as in step 2.
6). Leave liquid films at room temperature in a well ventilated area. The liquid films will be fully cured after 24 hours.

Analysis:

1). After making a precise step edge using a sharp razor blade, measure thickness using Alfa step profilometer. Plot thickness as function of wire diameter on Meyer rod.

2). Evaluate how viscosity determines the thickness of the coated film.

3). Plot thickness versus viscosity (waiting time). Calculate the theoretical thickness based on a volume calculation. First, show that the wet film coating thickness is 0.173 times the wire diameter. Compare actual thickness values with the theoretical value. Explain the difference. What combination of viscosity and sliding rate comes to the closest theoretical thickness?

4). Determine adhesion using Scotch Tape test. What is the expected adhesion strength that would quantify the Scotch Tape test? Obtain this data from reference materials.

5). What are the most important mechanical properties? Find a way to measure at least one mechanical property using equipment available in the department.

6). Use gloss meter to obtain gloss reading. Compare against a mirror surface as a reference value for the gloss measurement. What type of scale is used by the gloss meter?