Water-based coatings: problems and solutions

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Film, foil, and paper converters can attain EPA compliance through the use of waterborne coatings.

Converters can attain compliance with the Environmental Protection Agency (EPA) clean air act through a variety of methods. These methods include the use of incinerators, solvent recovery, solvent-free reactive systems (ultraviolet curable, electron-beam curable), high-solids coatings, and waterborne coatings. Each of these options has advantages and disadvantages and requires a commitment on the part of the converter in terms of time and capital.

Some major converters are seeking to attain EPA compliance by using 100% water-based coatings. These converters are working closely with both coatings suppliers and end users to obtain an economical, quality product.

Waterborne coatings provide numerous benefits. They achieve emissions compliance, they are cost-effective, they perform well, and they minimize the use of and exposure to hazardous organic solvents. There are, however, disadvantages to the use of waterborne coatings. They show poor wetting and/or adhesion with some substrates, they can create foaming/machinability problems, and their increased drying/curing times can contribute to slower line speeds.

The earliest waterborne coatings did not perform as well as solvent-based coatings. However, recent advances in water-based resin technology have allowed formulation of coatings that perform as well or better than their solvent-based counterparts.

Waterborne coatings have been successfully used as:

- "Abhesives"
- Insulation coatings (foil coatings to which polyurethane foam is applied for building insulation)
- Caul-stock coatings (release coatings on protective sheets used in high-temperature and high-pressure manufacturing operations)
- Laminating adhesives
- Heat-seal coatings.

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While these represent successful applications of waterborne coatings, converters experienced initial difficulties during the transition from solvent-based materials to waterborne materials. This article presents some of the formulation methods that were used to resolve these problems and compares the performance of waterborne coatings with their solvent-based counterparts.

Coatings sometimes need to be modified for a particular production line. Successful formulation for specific applications requires time, patience, and trial and error. A reformulation that solves one performance problem can create new problems. For example, use of a defoamer to aid machinability can cause a significant loss of gloss in an overprint varnish.

Solvent systems now in use have already passed through their period of formula optimization. In each case, successful formulation was achieved through cooperation between the converter and the coating supplier.

Pressure-sensitive adhesives

Abhesives are coatings that provide full release of a coated face stock from a treated substrate. Abhesive performance is evaluated by how well the substrate releases the coated face stock. Performance evaluation is more qualitative than quantitative. If the substrate is paper, fiber tear is an obvious indication of failure. A success is judged on the ease with which the substrate and face stock come apart after they have been mechanically pressed together. (They should just slide apart without a trace of sticking.)

A recently developed waterborne coating provides full release from a treated paper substrate. This coating performs as well as its solvent-based counterpart. Three problems were encountered when switching from solvent to water-based adhesives: poor wetting of the substrate, slow drying times, and poor machinability.

The first attempt at a water-based abhesive for polyethylene (PE) treated paper provided a coating that would not fully wet the substrate. Wetting of olefinic substrates is difficult when using water-based coatings because the surface tension of water is quite high compared with that of organic compounds.

Table I lists the surface tensions of some common solvents and substrates (*1–3*). Wetting problems can be corrected through addition of cosolvents. Water/solvent mixtures have lower surface tensions than pure water, with the surface tension of the mixture decreasing with increasing solvent addition. Thus the addition of solvent allows the coating to flow more evenly onto a low-surface-tension substrate. Some cosolvents also swell the dispersion particles in the coating, giving a more continuous dry film than in the absence of solvent.

The wetting problem was solved by the introduction of a cosolvent. However, this also slowed the coating's drying time beyond what line conditions would tolerate. The cosolvent content was reduced as much as possible to (a) reduce the drying time and (b) minimize the volatile organic content (VOC) of the coating. A first modification was to lower the solvent by half the original amount thought necessary for wetting. This lowered the VOC from 2.86 lb of organic solvent less water to 1.43 lb of organic solvent less water. The modified coating then developed a streaking problem on a particular line. Interestingly, further reduction of solvent content decreased the streaking problem.

Laboratory testing was not sufficient to eliminate all problems during the modification period. Some of the coating problems did not develop until the coating was run on the production equipment. An effective coating with low VOC was developed through work on the line and in the lab.

Insulation coating

Insulation coating is applied to foil before application of polyurethane foam. The final structure is used as building insulation. The coating must adhere well to the foil so that once the foam is applied, the whole structure is stable to various environmental conditions. If the adhesive coating fails, the foam will not stay in place. The coating must also have heat, water, and solvent resistance (2–6 methyl ethyl ketone rubs) to withstand the foam-application process and subsequent weather exposure. Finally, the coating must have a high surface tension to allow a uniform flow of polyurethane foam across the web and for good adhesion of the foam to the foil.

The solvent-based materials originally used in this application did not have a sufficiently high surface tension for an adequate flow of foam. The surface tension of the original water-based coating was also too low, although its surface tension was higher than that of the solvent-based material. Addition of a surface-active inorganic material raised the surface tension to an acceptable level for effective flow of foam. It is thought that this material also enhances adhesion of the foam to the coating by giving the foam particles something to "grab" onto. The amount of inorganic material had to be carefully formulated because of its tendency to settle. The level of the additive had to be carefully controlled on one line because of mechanical problems in handling the coated substrate.

The time required for curing and adhesion of the waterborne coating to the foil was longer than that of its solvent-based counterpart. An acid catalyst at a loading level of approximately 2–3% on solids gave no appreciable increase in line speeds. The production line was modified by adding a longer oven operating at a slightly higher temperature. Resultant line speeds were comparable with the speeds obtained using solvent-based materials.

I. Surface tensions of common solvents and substrates

Substance	*Surface tension, dyne/cm*
Water	72.7
Ethylene glycol	48.4
Isopropyl alcohol	21.7
Melamine resin	57.6
Polyvinyl chloride	41.9
Aluminum	45
Molded polyester	23

Caul-stock coating

Caul-stock coatings are used in the production of laminates for furniture and counter tops. The process of making these laminates involves pressing melamine sheets with resin-treated paper at elevated temperature and pressure. A protective sheet is placed over the top melamine sheet to prevent it from sticking to the press. When the laminate is removed from the press, the protective sheet is taken off (or falls off) without sticking to the laminate surface. This protective sheet is called the caul stock. Caul stock is either foil, paper, film, or stainless steel plates. If there are any imperfections in the caul-stock coating, flaws will appear in the laminate.

Caul-stock coatings for foil were originally supplied at approximately 97.5% solvent and 2.5% solids. This coating was easily marred (lightly touching the surface left fingerprints). A recently developed water-based coating at 19.8% solids provides superior mar resistance and toughness over its solvent-based counterpart. The result is better performance of the foil caul stock and fewer rejected laminates. In addition, the converter wastes less foil because there are fewer rejections of coated stock.

The caul-stock coating had to be carefully formulated for the converter's line conditions. A coating with too much resin solids left smeared on the web. These smears then appeared on the laminate. A coating that was too low in resin left void areas on the web, which caused the foil to stick to the laminate. An appropriate mix of resin, solvents, and water was formulated through cooperation of the converter and the coating supplier.

Laminating adhesives

Two recently developed water-based laminating adhesives provide superior performance over their solvent-based counterparts.

The first adhesive was developed for lamination of oriented polypropylene (OPP) to paper for the production of labels for polyethylene terephthalate (PET) bottles. The requirements for this application were: clear dry film (for cosmetic effect), bond stability following 6–8 h immersion in cold water, and at least 200-g/in. peel strength. The solvent system in use was a two-component urethane system. One of the two components was relatively unstable. Upon mixing, the life of the adhesive was 12 h or less. The newly developed one-component water-based system

II. Bond strengths of three heat-seal coatings at five heat-seal temperatures*

	Bond strength, g/in.				
	250°F	275°F	300°F	325°F	350°F
Waterborne A	100	177	440	553	143
Waterborne B	122	540	916	1185	1032
Solvent	963	1009	1118	1009	1225

*Substrates were foil/PET and high-impact polystyrene. Coating weight = 3 lb/ream. Heat seal was at 40 psi and 0.5-s duration.

has a shelf life of six months or more. The bond strength of the adhesive can be easily varied through viscosity control (application weight). Bonds vary from approximately 200 g/in. at low viscosity to fiber tear at higher viscosities. The coating exhibits the required water resistance. It can either be hot nipped or wet laminated.

The other adhesive has been used for a variety of treated film/paper, paper/paper, and paper/foil applications. It can withstand water exposure of at least 12 h, unlike solvent-based and other water-based counterparts, which exhibit 50% delamination after 12 h. Bond strength of this adhesive can be controlled by manipulating the viscosities and the coating weight.

The second adhesive coating exhibited machinability problems. A wetting problem on the application roll created a noticeable pattern in the lamination. The addition of a small amount (5–10% by volume) of a water/solvent mixture corrected this problem. Foaming at high viscosity was also a problem. While solvent addition reduced the foaming problem, solvent use was unacceptable because of curing constraints. (Not all of the solvent could be driven off during the given cure schedule). Many defoamers and combinations of defoamers were tested and failed.

Coating viscosity is the major factor affecting the tendency to foam (*4*). This is especially true for systems with a pH-dependent viscosity. In such cases, inherently low-foaming coatings are obtained by increasing the viscosity of the formulation with thickeners rather than by increasing the pH. After addition of thickeners to increase the coating viscosity, defoamers can be effectively used to control foaming by lowering the surface elasticity of the coatings. These two steps led to a machinable coating.

Heat-seal coatings

Two water-based heat-seal coatings have been developed for use in food and drug packaging. **Table II** shows the bond strengths of these two waterborne coatings and one solvent-based system on foil/PET sealed to uncoated, high-impact polystyrene (HIPS). The results show that the bond provided by waterborne coating A is inferior to that of the solvent-based system. Waterborne coating B has bond strengths close to the solvent system at heat-seal temperatures of 300°F and above. The appearance of both waterborne coatings is comparable with that of the solvent-based system. However, after they are peeled, the waterborne coatings have a much smoother, cleaner appearance than the solvent-based system, which appears gummy and tacky. Waterborne coating B also exhibits a high degree of scratch resistance.

The product resistance of these two water-based heat seals initially was unacceptable for some commercial applications. Product resistance of the coatings was increased in two ways. The first was addition of 20% (by weight) of an 80% water/20% solvent mixture. This caused the dispersion particles to swell, which provided better coalescence and resulted in a superior dry film. Use of a water-based acrylic primer on plain foil also helped increase product resistance of plain-foil lid stock. Package studies of ketchup, taco sauce, barbecue sauce, mayonnaise, and butter show that waterborne coating A performs as well as the solvent-based heat seal. Packages did not fail when inverted during exposure to 50% relative humidity at 100°F. Performance of waterborne coating B was close, with no failures in 3 h, but failing after 24 h exposure. Use of an acrylic primer improved the performance of waterborne coating A in mustard packs and of waterborne coating B in barbecue sauce packs.

Conclusion

Converters can attain compliance with EPA directives by using waterborne coatings. Problems encountered when using waterborne coatings include poor wetting, poor machinability, and longer drying/curing times. Wetting can be improved by adding small amounts of low-surface-tension solvents. Poor machinability can be handled through reformulation of the coating to one that is inherently low foaming. This is done by using defoamers and, occasionally, small amounts of solvent. Drying problems can be corrected through solvent adjustment, line adjustments (higher oven-air velocity), catalysis, or use of higher-molecular-weight crosslinkers.

The solvent-based coatings currently in use have already been through a period of optimization. The newer water-based systems are now going through their optimization phase. Water-based formulations can be used successfully if converters and coatings suppliers work closely together.

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