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**SOLVENT-BASED TO WATERBASED ADHESIVE-COATED
SUBSTRATE RETROFIT
VOLUME II: PROCESS OVERVIEW**

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ABSTRACT

The coated and laminated substrate manufacturing industry was selected as part of AEERL's support of the 33/50 Program because of its significant air emissions of toluene and methyl ethyl ketone (MEK). AEERL reviewed the potential equipment cleaning benefits of retrofitting equipment for the use of waterbased adhesives. During the investigation, it became apparent that the retrofitting of solvent-based equipment to accept waterbased adhesives can be a very complicated task. This volume represents the results of a review of the issues and obstacles associated with retrofitting.

The volume is divided into six chapters. Chapter 2 contains information on the performance characteristics of adhesives and introduces many of the terms that are essential to an understanding of the adhesive coating industry. Chapter 3 contains information on the components of an adhesive coating and briefly describes some of the chemical functions and interactions of these components. Chapter 4 describes the coating process. Chapter 5 contains information on several issues affecting a facility's ability to convert its solvent-based coating capacity to a waterbased process, including equipment, chemistry, and operational considerations. Chapter 6 describes a preliminary environmental life cycle analysis.

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METRIC EQUIVALENTS

Certain non-metric units are used in this document for the reader's convenience. Readers more familiar with metric units may use the following equivalents to convert to that system.

<u>Non-metric</u>	<u>Multiplied by</u>	<u>Yields Metric</u>
gallon	0.00379	m ³
lb	0.454	kg
in	2.54	cm
lb/in ²	6.89	kPa
°F	subtract 32, then multiply by 5/9	°C

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

As a result of the Pollution Prevention Act of 1990, the Environmental Protection Agency (EPA) established the 33/50 Program which calls for voluntary industry reductions in releases of the following 17 high-priority toxic chemicals, which are listed by mass of emissions:

Toluene	Tetrachloroethylene
Xylenes	Benzene
1,1,1-Trichloroethane	Chloroform
Methyl Ethyl Ketone	Nickel and Compounds
Dichloromethane	Cyanide and Compounds
Chromium and Compounds	Carbon Tetrachloride
Lead and Compounds	Cadmium and Compounds
Trichloroethylene	Mercury and Compounds
Methyl Isobutyl Ketone	

The goal of the 33/50 Program is to reduce the total amount of these chemicals released into the environment and transferred off-site by 33 percent by the end of 1992 and by 50 percent by the end of 1995. These reductions will be based upon the Toxic Chemicals Release Inventory (TRI), with 1988 as the base year.¹

In support of the 33/50 Program and EPA's pollution prevention goals, EPA's Air and Energy Engineering Research Laboratory (AEERL) is investigating ways to reduce air emissions of these 17 chemicals through pollution prevention. The Pollution Prevention Act of 1990 defines pollution prevention as source reduction, or "any practice which reduces the amount of any hazardous substance, pollutant, or contaminant entering the waste stream or otherwise released to the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants."² Pollution prevention efforts offer economic and reduced health and ecological risk benefits to many sectors of society that may not be available through traditional pollution control methods.

In 1991, AEERL representatives met with industry, academia, and State environmental agency representatives to identify several source categories deserving of pollution prevention research. Two criteria were used to select the industrial categories for study: annual toxics emissions and the potential for pollution prevention opportunities. First, the TRI was reviewed to identify categories with the greatest mass emissions of the 33/50 chemicals. Categories with the greatest emissions were then ranked according to the potential for successful pollution prevention projects resulting in significant reductions of 33/50 chemical releases. One of the industries identified during the 1991 meeting was the adhesives-coated and laminated paper manufacturing industry [Standard Industrial Classification (SIC) 2672]. This industry was chosen because of significant air emissions of 33/50 Program chemicals methyl ethyl ketone (MEK) and toluene as reported through the TRI.

In October of 1991, a Focus Group Meeting was held between AEERL, pollution prevention experts, and representatives of the adhesives-coated and laminated paper manufacturing industry to discuss specific pollution prevention projects that would support the 33/50 Program. Meeting participants indicated that the coatings and coating application steps are the largest source of toluene and MEK emissions, and, therefore, retrofitting equipment for the use of waterbased adhesives would present a good opportunity for the implementation of pollution prevention techniques. As a result of this meeting and preliminary industry inquiries, the scope of the industry investigation was later expanded to include other coating and substrate varieties (such as those included in SIC 2671-Coated and Laminated Packaging Paper and Plastics Film) because the manufacturing methods are similar; therefore, technology transfer is possible over a wider range of industries. Figure 1-1 illustrates how the retrofit research project fulfills part of EPA's goal to stimulate the development and use of products and processes that result in reduced pollution.³

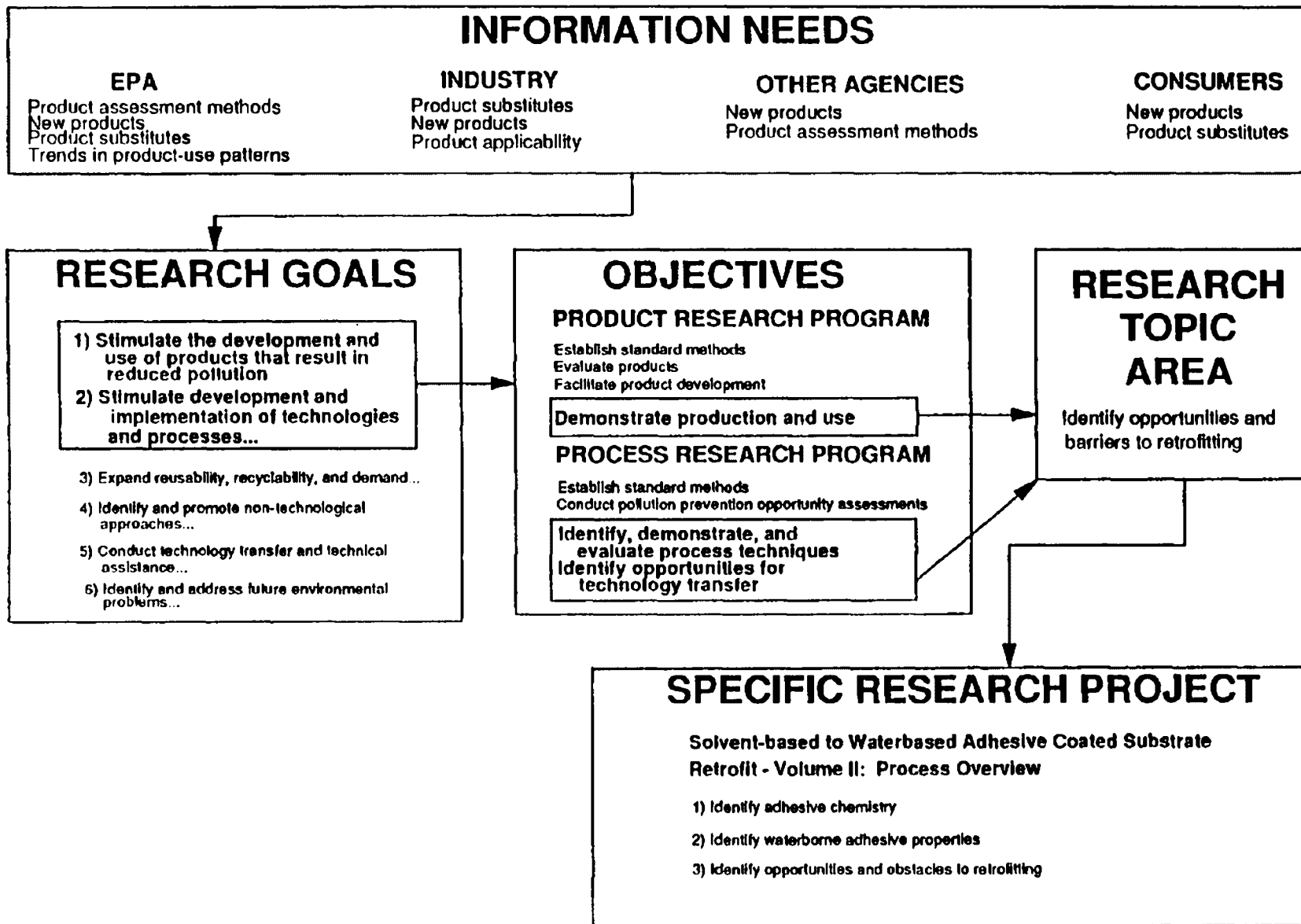


Figure 1-1. EPA's Pollution Prevention Research Plan.³

1.2 PROJECT OBJECTIVES

As part of the original scope of work for *Improved Equipment Cleaning in the Coated and Laminated Substrate Manufacturing Facilities (Phase I)*⁴, the potential equipment cleaning benefits of retrofitting equipment for the use of waterbased adhesives were reviewed. During the investigation, it became apparent that the conversion of solvent-based adhesive-coated products to waterbased adhesives can be a very complicated task. Therefore, EPA invested resources in documenting this conversion. The results of this study are presented in a five volume series, the titles of which follow.

TITLE OF SERIES: *Solvent-based to Waterbased Adhesive Coated Substrate Retrofit*

- Volume I: *Comparative Analysis*
- Volume II: *Process Overview*
- Volume III: *Label Manufacturing Case Study: Nashua Corporation*
- Volume IV: *Film and Label Case Study: FLEXcon Corporation*
- Volume V: *Tape Manufacturing Case Study: A Northeastern Tape Manufacturer*

This document is the Volume II report which presents the initial results of a study to identify the issues and barriers associated with retrofitting existing solvent-based equipment to accept waterbased adhesives. This volume is intended only as an introduction to the technical, economic, and environmental issues associated with converting from solvent-based to waterbased adhesive coating processes. Its purpose is to define the terms commonly used within the industry, introduce retrofit concepts, and identify issues requiring further investigation. The results of this follow-on examination are documented in the Volume I comparative analysis which overviews the results of a study to identify the issues and barriers associated with retrofitting existing solvent-based equipment to accept waterbased adhesives, and compares the compatibility of waterbased adhesive performance levels with current solvent-based adhesive applications. Using the Volume I report, AEERL is examining the technology transfer potential of documenting requirements for several coated and laminated substrate manufacturers who have converted some or all of their coating capacity from solvent-based to waterbased adhesives so that other manufacturers can consider the benefits of retrofitting. Volume III in this study

contains a case study of the waterbased retrofit for Nashua Corporation (Nashua). Volumes IV and V describe the implications of and barriers associated with waterbased adhesive use at FLEXcon Corporation (FLEXcon) and an unnamed northeastern tape manufacturer, respectively.

1.3 REPORT ORGANIZATION

This report is divided into six chapters. Chapter 2 contains information on the performance characteristics of adhesives, and introduces many of the terms that are essential to an understanding of the adhesive coating industry. Chapter 3 contains information on the components of an adhesive coating, and briefly describes some of the chemical functions and interactions of these components. Chapter 4 describes the coating process, offering descriptions of the various functions that must be executed to deliver liquid adhesives to a coating apparatus, apply them to a backing, and cure or dry the coated layer. Chapter 5 contains information on several issues affecting a facility's ability to convert its solvent-based coating capacity to a waterbased process, including equipment, chemistry, and operational considerations. Chapter 6 describes a preliminary environmental life cycle analysis, a tool for evaluating the multi-media pollution impacts of an industrial process, and identifies some of the issues involved in conducting such an analysis for the adhesive coating process.

1.4 REFERENCES

1. U.S. Environmental Protection Agency. *Pollution Prevention Fact Sheet: EPA's 33/50 Program*. Office of Pollution Prevention, Washington, DC. August 1991.
2. Pollution Prevention Act of 1990, 42 U.S.C. §13101, et seq.
3. U.S. Environmental Protection Agency. *Pollution Prevention Research Plan: Report to Congress*. EPA-600/9-90-015. Office of Research and Development, Washington, DC. March 1990.
4. McMinn, B.W. and J.B. Vitas. *Improved Equipment Cleaning in Coated and Laminated Substrate Manufacturing Facilities (Phase I)*. EPA-600/R-94-007 (NTIS PB94-141157). Air and Energy Engineering Research Laboratory. Research Triangle Park, NC. January 1994.

CHAPTER 2

PERFORMANCE CHARACTERISTICS OF PRESSURE-SENSITIVE ADHESIVES

2.1 GENERAL

This section introduces the common terms used in the production and use of pressure sensitive adhesives (PSAs). The definitions in this section describe the general properties of adhesives and the environmental factors that impact their performance. More detailed information is provided throughout the remainder of this report.

The term **PSA** is used in this report to refer to a formulation of rubber, acrylic, or silicone resins, which provides a bond between two surfaces. A PSA is a material which, in dry form and at room temperature, will firmly adhere to a variety of surfaces. The activating force for this adhesion is light pressure, that might be applied by gently pressing the adhesive with one's fingers. The term pressure-sensitive is used to describe such adhesives because the strength of the initial bond between a PSA and any surface to which it is applied is influenced by the degree of contact pressure.¹

PSA formulations consist of bonding solids (*e.g.*, elastomers or polymers and tackifying resins), additives, and carriers. The primary **elastomers/polymers** used in PSA formulations are rubber, acrylic, and silicone. Tackifying resins (**tackifiers**) are included in PSA formulations, especially rubber-based, to increase their tack and peel adhesion (refer to Section 2.2.4). **Additives** are sometimes included with PSA formulations to alter physical characteristics, lower cost, or provide color. **Carriers** are liquids which transport the solid adhesive to its backing. Carriers may be either organic solvents or water. In traditional adhesive formulations, solvents are used exclusively as the carrier to form **solvent-based** formulations. In recent years, water has been able to effectively replace solvent in some **waterbased** adhesive applications. Hot melt PSAs (HMPSAs) and radiation-curable applications are 100 percent solid adhesives and contain no carrier. For a complete discussion of PSA solvent-based and waterbased formulations refer to Chapter 3 of this document.

The term **substrate** refers to both the material to which the adhesive is applied to make the appropriate form of product (*e.g.* tape or label), and the surface to which the adhesive product is applied (*e.g.*, an automobile body for automotive masking tape). In this report, the term

backing applies to the former meaning, and the term **adherend** refers to the latter. The adhesive plus its backing (and/or release coating) is referred to as the **adherent**. For example, a label backing refers to the material (*e.g.*, paper or plastic film) on which an adhesive coating is applied; the combination of backing and adhesive is termed **adherent** (*i.e.*, the label); and the box or packaging to which the label (**adherent**) is attached is called the **adherend**. The functional purpose or end use of any **adherent** is the **application**. An application is defined by the task accomplished by the **adherent**, the **environmental constraints** to **adherent performance**, and the performance level required of the **adherent**.

As in the label example, a **backing** provides the means for handling and applying the adhesive. In most cases, the **backing** is the functional component being anchored to the **adherend** by the adhesive, but in some instances it is a removable carrier that is discarded once the adhesive is applied. When the **backing** is used as the removable carrier to transport the PSA, the product is referred to as a **transfer adhesive**. Backings typically come in long, continuous rolls of product (**webs**) or in sheet form and include paper, film, and foil. Backing materials may provide strength, protection, and a colorable or printable surface for the adhesive. A **release coating** may be applied to the side of the **backing** opposite the PSA to provide a non-stick surface for products which are produced in roll form (*i.e.*, tape) so the product may be unwound.

The term **adhesive bond** refers to the attraction between the **adherent** and **adherend**, and should not be confused with the bond between the adhesive and its backing. The interface between the **adherent** and **adherend** surfaces is known as the **bond-line**. **Tack** is the tendency of an adhesive to immediately form a measurable bond with a contacted surface. High tack adhesives are said to be **aggressive**.

Bond strength relies upon the **relative surface energies** of the adhesive and **adherend**. Surface energy is the tendency of a material (here, the adhesive-coated product) to attract other materials (*e.g.*, the **adherend**) at the molecular level, and is considered to be an **adhesive force**. The ability of the molecules in a material (*e.g.*, adhesive) to attract other similar molecules (also in the adhesive) is frequently termed **surface tension**. Surface tension is a **cohesive force**. If the cohesive force of an adhesive is less than the adhesive force between the adhesive and **adherent**, the adhesive will tend to spread out evenly on the **adherend's** surface.² The ability of an adhesive to spread out evenly is termed **wetout**. For a more detailed discussion of how these

properties are related to an adhesive's performance characteristics please refer to Section 2.2.4 of this report.

Two types of mechanical failure of an adhesive bond can occur, **cohesive failure** or **adhesive failure**. In cohesive failures, the molecules of the adhesive fail to remain bonded to one another, and the adherent and adherend separate, each retaining some of the adhesive. Adhesive failure occurs when the bond between the adhesive and the adherend surface is broken. Bond failures are tested by a variety of methods. **Peel testing** refers to a measurement of the force required to remove an adherent from an adherend. Peel tests are conducted in two ways; with the peel force oriented perpendicular to the adherend surface, and with the peel force parallel to the adherend surface. A second type of bond test measures the **shear strength** of an adhesive bond. Shear strength is the ability of an adhesive to withstand a force in the same plane as the bond-line.

2.2 PERFORMANCE REQUIREMENTS

2.2.1 Introduction

The performance of a PSA is generally measured in two basic dimensions: (1) the ability to form an initial bond with an adherend (*i.e.*, tack), and (2) the ability to resist detachment from that surface (*i.e.*, adhesive bond strength).¹ Additional parameters that are descriptive of a PSA's performance are resistance to extremes of temperature and humidity, ability to withstand solvent and corrosive exposures, and ability to withstand mechanical forces such as shear and peel. Maximizing adhesive performance requires that these characteristics be carefully balanced to satisfy the demands of the application. Many properties of the adherent, the adherend, and the application environment must be considered when developing an adhesive formulation for a given application.

The performance required of a PSA is dependent on the application. In some cases, permanent bonding (force of removal greater than 5.0 lb/in² of contact surface)* is necessary, while in others a weaker bond is sufficient. When an adherent is bonded to a vertical surface,

*Metric equivalents are provided on p. vii.

it requires different properties than one that is bonded to a horizontal surface because of the additional gravitational forces. The surface energy, porosity, and texture of the adherend, as well as the cohesive/adhesive properties of the PSA, all impact on the ability of a particular adherent to serve in a given application. The environment in which the adherent will be used also affects the suitability of a particular adhesive. This section discusses some of the factors that influence the performance characteristics of adhesives.

2.2.2 Adherend Impacts

The following discussion on adherend impacts is also applicable to the backing used to develop an adherent. In the majority of cases, the manufacturer has greater control over the backing material than over the adherend; therefore, this report assumes that the backing is compatible with the adhesive to which it is applied. Backing compatibility with the adhesive is a critical part of the coating/laminating process, and failure to select the appropriate backing material can result in a failure of the bond between the adhesive and its backing.

In order to maximize the adhesive bond between the adherend and the adherent, the adhesive on the adherent must sufficiently wetout the adherend's surface. Wetout occurs when the adhesive is spread out in a uniform coating, without any voids, over the entire adherend surface. The critical property in determining surface wettability is the surface energy of both the adherent and adherend. Surface energy can be visualized by considering the effect of placing a drop of water on a material. On a high surface energy material, such as untreated wood, the molecular forces holding the drop together will be overcome, and the water will spread out over the surface. On a low surface energy material, such as polypropylene, the water will bead, demonstrating the inability of the surface energy to overcome the surface tension of the drop.

Adherend surfaces are classified as either low- or high-energy surfaces, depending on the solubility parameters of the adhesive and adherend material. The solubility parameter (δ) of a material is a measure of the total intermolecular bond energy holding the molecules of the material together, and is a function of molecular weight (MW). For one material to be soluble in another, the values of δ for the two materials must be close. In general, the higher the MW of one or both materials, the closer the values of δ must be for the materials to be miscible (*i.e.*, uniformly mixed in all proportions).³

The classification of substrate and adherend surfaces as low- or high-energy is combination dependent. In other words, a surface may be classified as a low-energy surface with respect to one type of adhesive and be considered a high-energy surface with respect to another. A given PSA will sufficiently wetout a surface that is classified as a high-energy surface with respect to that particular PSA.² To achieve maximum bond strength, the surface energy of the adherend should be higher than surface tension of the adherent. Maximum bond strength is approached when the adhesive has a surface tension close to, but not exceeding, the surface energy of the adherend.¹

Most adhesive formulations have functional groups in their polymer molecules that are available to bond with similar sites on the adherend's (or backing's) surface. The greater the affinity between the chemical structures of the adhesive and adherend, the more likely it is that wetout will occur. Polar regions (areas with a surplus or deficiency of electrons) on the adhesive molecule will secondarily bond to opposite polar sites on the adherend's surface. The absence of such secondary bonds can reduce the strength of the adhesive's attraction (*i.e.*, tack) to the adherend. For example, bonding to polyethylene or polypropylene is difficult because the polymer molecules do not contain polar groups that allow for the interaction with polar groups on the adhesive molecule.²

Adherend surface impurities, such as residual oils or dirt, can prevent both functional group and secondary polar bonding from occurring. In these cases, and especially for high performance applications, some type of surface preparation is required.² The amount of surface preparation necessary depends upon the extent of adherend surface contamination. Minor preparation may include simply dusting with a clean cloth while major preparation may include chemical pretreatment. The compatibility of the surface energy, texture, and porosity of the adherent and the adherend is critical to bond strength. This is especially important for PSAs, since the activating force (*i.e.*, light pressure) for such adhesives is usually insufficient to overcome any incompatibilities.¹

Cleaning may not be the only reason for surface preparation. If the adherend has a textured or porous surface, it may require sanding or filling to maximize bond strength. Textured surfaces often result in contact voids between the adherent and adherend, undermining the strength of the bond between the two. Extremely porous surfaces can result in excessive flow of adhesive into the pores, resulting in a phenomenon known as starved bond-line.² Depending

on their surface texture and/or porosity, some adherents may require preparation before adhesive application can occur. Proper preparation ensures the best possible bond between the adherent and adherend.

If the adherend surface cannot be modified to improve the adhesive bond (*e.g.* mechanically texturing the surface of a molded plastic part), then the adhesive itself must be modified. Such modifications could include adding a plasticizer to the formulation to increase the tack of the adhesive, or using a thicker coating of adhesive to improve the flow of adhesive into surface imperfections. Modifications generally require surrendering some degree of final bond strength; however, if the minimum required strength is retained, they can allow the use of an otherwise unsuitable formulation.

2.2.3 Service Environment Constraints

The environment in which the adherent is to be used (*i.e.*, the **service environment**) largely determines the strength and flexibility requirements of the adhesive bond and often dictates the most appropriate type of adhesive/backing combination. The service environment may expose the bond-line to temperature extremes, humidity, solvents, or corrosive agents. Although many of these factors are common to both outdoor and indoor use, outdoor service environments are normally more demanding than indoor ones. Additional problems associated with outdoor use may include exposure to ultraviolet (UV) light, ozone, and acid rain. This section briefly addresses each of these environmental influences and the implications they may have on an adhesive bond.

Temperature. At elevated temperatures, PSAs normally become soft and viscous, and lose their elasticity. This results in cohesive failure. The temperature at which cohesive failure occurs is termed the **splitting temperature**. Generally, the splitting temperature is higher for higher MW adhesives.³ Low temperatures may cause an adhesive to become brittle. Few adhesives can experience wide variations in temperature without loss of bond strength.²

Humidity. Water and high relative humidity combined with warm temperatures can degrade certain types of adhesives by encouraging fungal growth. High humidity applications, such as labels on steam equipment, would require the addition of fungicides to the adhesive formulation.²

Solvent Exposure. The types of solvents which may come in contact with the bond-line are also an important factor in PSA formulations. Certain types of organic solvents may attack adhesives bonds. Many manufacturers of adhesives test their products against solvent exposures to gasoline, nail-polish remover, and perchloroethylene. In some cases, the release coating applied to the backing in roll products will serve as a shield to protect the adherent from solvent attack.^{2,3}

Corrosive Agents. Salt and other corrosives can cause deterioration of both the bond-line, and the adherent and adherend substrates. Corrosion of this type can reduce the contact area and weaken the overall bond of adherent to adherend.

Ultraviolet Light. UV has sufficient energy to break chemical bonds and change the characteristics of the polymer molecules making up the adhesive. Photoabsorbers are sometimes formulated into PSAs (especially rubber-based) to reduce the effect of UV light degradation. Other adhesive formulations (*e.g.*, acrylic-based) are inherently resistant to UV light.

Air Pollutants. Ozone (O_3) is a very reactive species found in photochemical smog and may attack adhesive bonds. O_3 exposure is primarily a problem in outdoor applications such as wrapping utility equipment. Acid rain, which is primarily caused by sulfur dioxide (SO_2) and nitric oxides (NO_x) in the atmosphere, is a corrosive and can also degrade adhesive bonds.²

2.2.4 General Adhesive Performance Dimensions

Adhesive performance properties are the fundamental criteria of any adhesive formulation bonded to any given adherend. These properties are the criteria by which all adhesives are judged for suitability in a given application. The general properties discussed in this section include tack, peel adhesion, and creep.

Tack is defined by the American Society for Testing and Materials (ASTM) as the property of a material which enables it to form a bond of measurable strength immediately on contact with another surface.¹ Tack is quantified by measuring the force necessary to break such a bond. The value of tack varies depending on the pressure used in making contact of the PSA with an adherend surface, the dwell time of contact, and the rate of removal.¹ Tack increases with increasing temperature, as the polymer becomes more flexible and deformable and can thus develop better contact on a molecular scale during a short contact time.

Peel adhesion is the force required to break the bond between adherend and adherent. It is quantified by measuring the force required to remove an adhesive (and its backing) from a specified adherend surface at a specified rate of peel. Adhesion tests are commonly conducted at very short dwell times to measure tack, and after longer dwell periods to measure ultimate bond strength. The peel force required to unbond is actually a measurement of the viscoelastic deformability of the adhesive.¹ It should be noted that tack and adhesion of polymers are not fundamental material properties like the elastic modules or the viscosity, instead they depend on the test methods and the conditions of the measurement.⁴

Cohesive strength, described earlier as the force that attracts the molecules of a material to each another, is the major factor in determining the shear strength of a PSA. The Pressure-Sensitive Tape Council (PSTC) defines cohesive strength as the ability of an adhesive to resist splitting. The internal (molecular) strength of the adhesive allows the adherent to maintain its position relative to the adherend when experiencing a shearing force. When the cohesive strength of the adhesive is not sufficient to withstand the shearing force, the adhesive is said to flow, or **creep**. This results in displacement of the adherent. Upon cohesive deformation or failure, the PSA will split, leaving a residue on the adherend surface.¹

2.3 REFERENCES

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CHAPTER 3

PRESSURE-SENSITIVE ADHESIVE FORMULATIONS

3.1 GENERAL

PSA formulations are normally composed of bonding solids (*e.g.*, an elastomer or polymer and a tackifying resin), additives, carriers, and oils. The general categories of elastomers and polymers used in PSAs include rubbers, acrylics, and silicones. In some cases, more than one resin is used to provide additional properties not available with single resin formulations. Other additives or fillers may be used to improve performance characteristics such as viscosity or specific gravity, lower cost, or alter adhesive color. Tackifying resins are normally added (especially to rubber-based PSAs) to increase the tack and peel adhesion, however, at a loss of cohesion strength. Antioxidants may also be used to protect the adhesive from excessive heat, UV light, and oxidant exposures.¹ This chapter briefly explains the categories of PSAs, their additives, and to what extent each is formulated as a solvent-based or waterbased PSA.

3.2 RUBBER-BASED PSAs

The category of rubber-based adhesives includes products manufactured with both synthetic elastomers and natural rubber (NR). Natural rubber was the first material used to formulate PSAs and is still widely used today. Other rubber-based adhesive resins include block copolymers, styrene-butadiene rubber (SBR) copolymers, and polyisobutylene (PIB) and butyl rubber.²

3.2.1 Natural-Rubber PSAs

Natural rubber (*cis*-1,4-polyisoprene) is available as a natural latex, however, the major raw material for PSAs is baled gum rubber. Baled rubber must be pelletized and ground to lower its viscosity and increase the surface area available for use in solvent-based PSAs. Most NR-based PSAs are solvent-based and comprised of about 35 percent solids blended with toluene. Almost any tackifier or tackifier mixture can be used with NR-based PSAs, but terpenes and

C₅ hydrocarbon types are generally preferred by adhesive formulators because of low cost and good solvency. The PSA composition may include fillers such as clay to lower costs, and plasticizers and antioxidants to alter performance characteristics. Natural rubber latex (waterbased) is used for PSAs to a small extent and requires an aqueous dispersion tackifier.

3.2.2 Block Copolymers

The most commonly used hydrocarbon elastomer in PSAs is the A-B-A triblock copolymer; where A is polystyrene and B is either polyisoprene or polybutadiene. These triblock copolymers can be used either in solvent-based solution or in hot melt form. The overall molecular weight of these copolymers is about 100,000, and they contain about 15 to 30 percent polystyrene by weight. Tackification of triblock copolymers requires the use of two tackifiers which have quite different solubility parameters. One tackifier is compatible with the midblock (C₅ hydrocarbon resins or terpene) while the other is compatible with the endblocks (α -methylstyrene polymers or coumarone-indene resins). Oils are often included in the adhesive formulation to lower the melt viscosity.² Almost 100 percent of the hot melt PSA market uses triblock copolymers. The lower MW (compared to NR-based adhesives) allows for higher solids content solvent-based adhesives.

3.2.3 Styrene-Butadiene Copolymers

As a whole, the solvent-based adhesive formulations market consumes approximately the same quantity of SBR as NR. Most of the SBR used in PSAs is purchased as gum rubber and compounded as solvent-based adhesives for its primary use in the label manufacturing industry. Preferred tackifiers are rosin esters and β -pinene resins. Styrene-butadiene latexes have been developed for PSAs, however, the higher cost of tackifier dispersions and the competition of the more oxidatively stable acrylic PSAs (see Section 3.3) have limited their use. The minor amount of SBR latex that is used is mainly in the label and decal area.²

3.2.4 Polyisobutylene Polymers and Butyl Rubber

Polyisobutylene and butyl rubber are elastomeric polymers that are used widely in PSAs both as primary elastomers and as tackifiers and modifiers.¹ PIB is available commercially in a wide range of MWs. Pressure-sensitive PIB adhesive formulations consist of a high-MW polymer (725,000 to 2,000,000) blended with a low MW PIB which functions as a plasticizer and provides the low MW necessary to promote adhesive wetout. Tackifiers include C₅ hydrocarbon resins and polyterpenes. Because PIB is a relatively low-energy polymer, rosin esters are often added for adhesion to more polar surfaces. Most PIB adhesives are used in solvent-based form with petroleum fractions (naphthas) as suitable solvents. The major use of PIB PSAs is for removable labels, where low tack and adhesion are desirable.²

Butyl rubber is a copolymer of isobutylene with a minor amount of isoprene.² The basic properties of butyl rubber PSAs are very similar to PIB formulations. One difference is that butyl rubber latexes are available as PSAs.¹ The major use of butyl rubber is in anticorrosion wrap for gas and oil transmission pipes.²

3.3 ACRYLIC PSAs

Polyacrylate esters, or acrylics, currently account for about one-fourth of the domestic PSA market. The acrylate esters of C₄ to C₁₂ alcohols are the major constituents of acrylic PSAs. Early research in PSAs revealed that the normal tacky polymers of certain acrylic esters could be converted to adhesives by incorporating up to 10 percent of a polar monomer. Due to economic considerations, the dominant esters used worldwide are butyl and 2-ethylhexyl acrylate. Others are available and, to some extent, are being used, but they are currently too expensive for high-volume commercial consumption. Acrylic acid is the most commonly used comonomer, however, others used include acrylamide, acrylonitrile, hydroxyethyl acrylate, and certain amine-functional monomers. Modifying monomers, such as vinyl acetate or ethyl acrylate, are also very frequently included in acrylic PSA compositions.²

Acrylic PSAs surpass the rubber-based PSAs in terms of aging stability because of their saturated hydrocarbon backbone. They are also colorless and can be tailored to specific applications by adjusting the monomer ratios. In general, acrylics adhere better to polar surfaces

than rubber-based PSAs, however, they exhibit a lower adherence to low-energy surfaces. Although acrylics do not discolor or lose adhesive properties during outdoor exposure, their tack and peel strength are somewhat less than that of the best rubber-based adhesives. Many commercial PSA acrylics contain tackifying resins to increase peel adhesion and tack.²

Acrylics were originally developed as solvent-based adhesives, however, acrylic waterbased adhesives volume currently exceeds that of acrylic solvent-based formulations. It is expected that this trend will continue. Hot melt acrylic PSAs with adequate PSA performance properties have been difficult to develop.²

Solvent-based acrylic adhesives are limited in MW due to the increasing solution viscosity that occurs at higher MWs. To compensate for the intrinsically low MW of solvent-based adhesives, it is common practice to cure the dried adhesive in the oven drying line. Melamine resins and the soluble derivative of a multifunctional metal (*i.e.*, aluminum acetyl acetonate) are used for this purpose. In contrast, the MW of the polymer has no effect on waterbased acrylic adhesives' viscosity although a molecular weight reducing agent is usually incorporated into an acrylic waterbased adhesive to increase tack.²

Acrylic PSAs are used in some labels and a wide variety of tapes including transparent office, strapping, transfer, medical, and metal foil tapes. Because acrylics do not require antioxidants and tackifiers, they are regarded as less irritating to the skin and are often preferred for medical applications.²

3.4 SILICONE PSAs

Use of silicone PSAs is generally restricted because of their high cost relative to other adhesives. In general, they possess excellent adhesion to surfaces of both high and low surface energy, and have the ability to function acceptably at temperatures up to 932°F. The two basic components of a silicone PSA are a tackifying resin and a gum, analogous to the tackifier and elastomer used in organic adhesives. The MW of the resin is usually less than 5,000 although the MW of the gum is higher. The simplest method of silicone PSA preparation is mixing resin and gum in a suitable solvent, usually toluene. The resulting solution can be used for coating as is, or can be heated to give a product with higher cohesive strength. The physical properties

of the PSA are a function of resin/gum ratio, type of gum, and amount of heating prior to application.²

Silicone PSAs are used almost exclusively in tape formulations. Some end uses on polyester film include the backing for tapes used to mask printed circuit boards during plating operations, for electrical insulation, and in paper splicing tapes. High performance backings used for silicone PSA tapes include glass cloth, polyimide and poly(tetrafluoroethylene).²

3.5 MISCELLANEOUS PSAs

PSA formulations based on polymers other than rubber, acrylic, and silicone, have experienced little commercial success. Efforts have been made to use polyurethanes, polyurethane-acrylic hybrids, ionomers, and polyester block elastomers, among others, but so far only re-pulpable adhesives have reached the marketplace. Re-pulpable adhesives do not inhibit the paper recycling process. Two systems that have achieved some commercial success are vinyl acetate copolymers and poly (vinyl alkyl ether) blends.² These systems are briefly described in this section.

3.5.1 Vinyl Acetate Copolymers

Vinyl acetate copolymers are available only as waterbased PSAs. Their use is relatively small and confined almost exclusively to permanent labels. Some end users of vinyl acetate copolymers use the formulation directly out of the shipping container while others blend the vinyl acetate copolymer with an acrylic latex before application. The adhesives which are produced tend to have an excellent balance of tack, peel strength, and shear resistance. They are similar to acrylics in that adhesive strength builds with time. The only United States manufacturer of vinyl acetate copolymers does not reveal the composition of its PSAs.²

3.5.2 Poly (Vinyl Alkyl Ether) Blends

Vinyl ethyl ether polymers are used in medical products due to their high moisture vapor permeability, which is valuable for patient comfort during long term application to the skin. Poly

(vinyl isobutyl ether) is also used to a smaller extent. These adhesives are formulated by blending high and low MW polymers similar to that of PIB. As with PIB, the low MW polymer promotes wetout of the adherend surface and the high MW polymer provides cohesive strength. The major drawback of this category of adhesives is poor shear resistance because they are not readily crosslinkable.²

3.6 TACKIFIERS

Tackifiers are an essential ingredient of rubber-based PSAs and are also used with other types of elastomers and polymers. These diverse chemicals can be either liquids or brittle solids with low MW materials ranging from about 300 to 3,000. This section briefly describes some tackifiers and their derivation. The uses of each tackifier vary by adhesive category, and are described in the appropriate sections of this chapter.

The primary purpose of tackifier addition is to raise the glass transition temperature (T_g) of a PSA formulation so that the PSA has a higher modulus at high strain rates. The T_g is the temperature at which a material no longer exhibits elastic deformation but instead exhibits viscous (liquid-like) deformation.^{1,2} Tackifiers have typical T_g values in the range of 86° to 140°F. The optimum T_g range for a typical PSA formulation is 14° to 50°F, however, this varies substantially depending on the product end use.

For the most effective performance property enhancements, the tackifier should be similar in solubility to the elastomer with which it is blended. For example, aliphatic hydrocarbon tackifiers are not generally used with polar acrylic PSAs. Rubber-based adhesives normally incorporate 35 to 50 percent tackifiers by weight. Tackifiers used with latex adhesives are produced as aqueous dispersions and must be compatible with the surfactant in the polymer emulsions.²

Originally, tackifiers were produced from wood rosins. Wood rosins derived from aged tree stumps, so-called naval stores, contain various unsaturated acids as a major constituent. In order to give these acids more aging stability and more compatibility with base polymers, they are modified by hydrogenation, disproportionation, and esterification with glycerol or pentaerythritol. Little unmodified rosin is used today.²

Wood turpentine from tree stumps is also used and is the source of terpene tackifiers. Cationic polymerization of dipentene and α - and β -pinene, the major constituents of turpentine, yields these terpene tackifiers. Tall oil is a by-product of the paper industry and surpasses naval stores as another rosin source. These rosins are very similar to wood rosins and are similarly modified.²

The most heavily used tackifiers in PSA manufacture are lower cost tackifiers derived from unsaturated petroleum fractions. Although both C_5 and C_9 fractions are used, C_5 has the greater industrial importance due to broader compatibility with PSA base polymers. Tackifiers with aromatic content, particularly α -methyl styrene and vinyl toluene copolymers and coumarone-indene resins, are also used.²

3.7 OTHER ADDITIVES FOR PSAs

PSAs generally require other additives to enhance the adhesive performance characteristics and to make the end adhesive formulation widely applicable. These additives may include but are not limited to plasticizers, fillers, antioxidants, surfactants (emulsifiers), and defoamers. The latter two of these additives are primarily used in waterbased adhesives. Chapter 5 of this report will present more detail concerning the use of surfactants and defoamers. The remainder of this section gives a brief description of plasticizers, fillers, and antioxidants and identifies some typical applications.

3.7.1 Plasticizers

Plasticizers may be added to some adhesive formulations to increase their ease of deformation in short time spans. The difference between a tackifier and a plasticizer is that a plasticizer decreases the elastic modulus at all temperatures, times, and frequencies (strain rates), while a tackifier increases or decreases the modulus depending on the temperature, time, and frequency. Plasticizers used in PSAs are most commonly oils such as mineral oil, liquid polybutenes and polyacrylates, and lanolin. By measuring the melt viscosity of a plasticized polymer, determining the dilution ratio, reading the viscosity of dilute solutions of the polymer in the plasticizer, and measuring electrical or mechanical properties of the plasticized polymer,

the optimum plasticizer can be selected for a particular PSA. Some adhesives contain no plasticizers.¹

Addition of plasticizers to natural rubber adhesives lowers their cohesive strength, generally reduces their peel adhesion, and has a variable effect on tack depending on the plasticizer used. Plasticizers such as mineral oil or lanolin tend to reduce the cost of the adhesive mass and reduce the peel adhesion, which can be useful for certain applications like peelable labels or printed tapes.¹

Plasticizers used in block copolymers tend to decrease hardness and modulus at room temperature, eliminate drawing, enhance tack, reduce melt and solution viscosity, decrease cohesive strength, increase plasticity, and substantially reduce raw material costs. Various (aromatic, naphthenic, and paraffinic) hydrocarbon oils meet these necessary requirements.¹

A common plasticizer used in the PIB family of adhesives is polybutene which is available in a number of molecular weights so the viscosity and volatility can be selected for the specific application. Other liquid materials used as plasticizers in this category include paraffinic oils, petrolatum, and certain phthalates with long aliphatic side chains such as ditridecyl phthalate.¹

The addition of a plasticizer to an acrylic adhesive has a similar effect to that of tackifying resins: improved tack and peel adhesion. Sometimes flame-retardant properties are incorporated into an acrylic PSA by the addition of phosphate plasticizers and antimony oxide.¹

3.7.2 Fillers

Fillers used in PSAs include calcium carbonate (CaCO_3), titanium dioxide (TiO_2), zinc oxide (ZnO), clays, pigments, and aluminum hydrates. The effects of fillers in adhesive formulations can be measured by tensile strength, elongation at break, and stiffness. Inert fillers, such as clay and CaO_3 have little effect on physical properties but do make an adhesive formulation easier to handle. Reinforcing fillers, such as hydrated silicas and calcium silicate, do have an effect on some physical properties, such as increasing tensile strength and stiffness.¹

Inert fillers such as clay, talc, and whiting (*i.e.*, finely ground chalk) are sometimes used in block copolymer adhesives to pigment the adhesive and lower raw material costs. Their use

is limited to the acceptable amount of stiffness increase and tack reduction they cause, although tack reduction may be beneficial in certain applications.¹

Filler pigments are frequently added to NR-based adhesives for several purposes [*e.g.*, coloring, reducing the cost of adhesive (by increasing the volume), and improving adhesive performance]. The most common coloring pigment additive is TiO_2 , used in brown colored case sealing tapes. Clay and whiting fillers are used to reduce adhesive cost in applications such as cloth-based tapes and masking tapes. The addition of ZnO pigment to NR adhesives tends to make the adhesive more viscous. Silica is also claimed to improve aging and tack retention after aging of NR adhesives on fabric-based tapes.¹

3.7.3 Antioxidants

Antioxidants are commonly used to stabilize an adhesive against oxidation and heat and light degradation (aging). Oxidation of the adhesive results in loss of cohesive strength and the loss rate is normally increased by exposure to elevated temperature or UV light. Degradation by exposure to UV light is evidenced by discoloration and brittleness or weakening of adhesive compounds and is particularly a problem with direct exposure to sunlight. Consequently, NR-based adhesives require antioxidants to ensure both oxidation protection and adequate shelf-life after mixing. In general, three main types of antioxidants are used with NR adhesives: amines, phenolics, and dithiocarbamates. Amines are efficient antioxidants, but have an undesirable staining effect. Phenolic antioxidants are used most often because they are nonstaining and are particularly effective in protecting adhesives from UV and sunlight. Dithiocarbamates are nonstaining and are particularly effective against heat aging and impart some resistance from UV light. Consequently, antioxidants are often blended to achieve optimum performance.¹

Unsaturated block copolymers are susceptible to attack by oxygen, O_3 , and UV light. Antioxidants (stabilizers) are usually incorporated into the formulation to provide resistance to these attacks. It is important to note that the midblock, either polybutadiene or polyisoprene, is more susceptible to attack than the endblock polystyrenes, therefore, stabilizers are used to protect double bonds along the midblock. As with NR adhesives, combinations of antioxidants

may provide more effective protection than one alone.¹ Antioxidants are also used in butyl- and PIB-based adhesives to protect against severe environmental exposure to UV light and heat.

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CHAPTER 4

CURRENT MANUFACTURING PRACTICES

4.1 GENERAL

This chapter provides an overview of the coated and laminated substrate manufacturing industry. The chapter is divided into three sections: (1) industry structure, (2) raw materials and products, and (3) manufacturing process description. The industry structure section addresses the current market, materials used in the manufacturing process, products manufactured, and product end uses. The raw materials and products section addresses the materials used in the manufacturing process, products manufactured, and product end-uses. The manufacturing process section describes the various elements of the manufacturing process with emphasis on equipment and procedure.

4.2 INDUSTRY STRUCTURE

4.2.1 Introduction

This section gives an overview of the coated and laminated substrate manufacturing industry, including geographic distributions, production trends, industry issues, and the major subdivisions within the industry. Much data are based on SICs 2671 and 2672.

4.2.2 Industry Market

The coated and laminated substrate industry, as defined by SIC 2671 and 2672, consists of firms that manufacture coated or flexible materials made of combinations of paper, plastic films, metal foils, and similar materials for packaging (SIC 2671) and other purposes, including pressure sensitive tapes (SIC 2672). Some facilities continue to report SIC 2641, Paper Coating and Glazing, as their primary SIC even though SIC 2641 was discontinued in 1972. (During the information gathering phases of this project, several of these facilities were identified and contacted through a questionnaire.) In 1972, SIC 2641 was split into 2671 and 2672.^{1,2}

(Facilities operating under these SICs were contacted through separate questionnaires.) Because the current SICs are 2671 and 2672, this discussion will focus on these two classifications. However, Table 4-1 summarizes the effect of the SIC revisions on the industry and the corresponding employment data.

According to the 1987 Census of Manufactures, SIC 2671 employed 15,000 people in 21 states, and SIC 2672 employed nearly 31,000 people in 23 states. The leading states in employment of 2671 personnel, accounting for 42 percent of the industry's employment, were Wisconsin, Indiana, Pennsylvania, and Illinois. Similarly, Massachusetts, Ohio, Illinois, and Pennsylvania accounted for 38 percent of SIC 2672's employment. Over 93 percent of SIC 2671 and 55 percent of SIC 2672 plants are small facilities employing less than 20 people.² These smaller facilities often provide a highly customized product line marketed within a small geographic region. Some of the larger companies, however, own multiple manufacturing facilities and distribute products nationwide.

**TABLE 4-1. 1987 DISTRIBUTION OF SIC 2641 FACILITIES AMONG
SIC 2671 AND SIC 2672 FACILITIES**

Industry	No. of Facilities	No. of Companies	No. of Employees (thousands)	Cost of Materials (million \$)	Value of Shipments (million \$)	New Expenditures (million \$)
Old Industry SIC 2641, Paper Coating and Glazing	532	439	45.9	4,476.5	8,307.7	329.6
New Industry SIC 2671, Paper Coated and Laminated, Packaging	120	89	15.0	1,442.0	2,416.0	128.3
New Industry SIC 2672, Paper Coated and Laminated, N.E.C.*	412	362	30.9	3,034.5	5,891.7	201.3

* N.E.C. - Not Elsewhere Classified

Source: Reference 2

4.3 RAW MATERIALS AND PRODUCTS

The products manufactured by the coated and laminated substrate industry are used in a variety of applications. Generally, these products can be categorized as being either tapes, labels, or miscellaneous products. Each of these product types is composed of some combination of backings and coatings which can be described in terms of construction (often dictated by product backing) or function. End-use product categories include hospital and first aid products, office and graphic arts products, packaging and surface protection products, building industry materials, electrical products, and automotive industry products. This section includes information relating to raw materials, finished products, and product end-uses.

4.3.1 Raw Materials

The raw materials used in the coated and laminated substrate manufacturing process consist of product backings, adhesives, and other coatings. Commonly used raw materials for facilities in Standard Industrial Classification (SIC) codes 2671 and 2672 are listed in Table 4-2. A more detailed discussion of these raw materials is found in the report *Improved Equipment Cleaning in Coated and Laminated Substrate Manufacturing Facilities (Phase I)*.³ Adhesive formulations are discussed in detail in Chapter 3 of this report.

4.3.2 Finished Products and End-Uses

There are several types of products manufactured by coated and laminated substrate manufacturers. Two of the largest product categories are tapes and labels. Classes of tape, identified by construction, include woven and nonwoven fabric tape, paper tape, film tape, foil tape, and foam tapes. Some of the web materials mentioned previously are used in combination with glass, rayon, nylon, polyester, or acetate fibers to produce reinforced substrates. Films such as polyethylene, polyester, or polypropylene are often combined with these fibers to produce tapes used in heavy-duty packing and bundling applications. The type and number of reinforcing strands per area, the thickness of the coating applied, and the type of film used differentiate the grades and types of film tape.^{4,5} Two-faced tapes are substrates with an adhesive coating applied

TABLE 4-2. SIC CODES 2671 AND 2672 RAW MATERIALS

INDUSTRY 2671, PAPER COATED AND LAMINATED, PACKAGING

Paper

Glues and adhesives

Plastics resins consumed in the form of granules, pellets,
powders, liquids, etc.

Plastics, products consumed in the form of sheets, rods, tubes,
and other shapes

Printing ink (complete formulations)

Petroleum wax

Paperboard containers, boxes, and corrugated paperboard

Aluminum foil:

Plain

Converted

INDUSTRY 2672, PAPER COATED AND LAMINATED, N.E.C.^a

Paper

Glues and adhesives

Plastics resins consumed in the form of granules, pellets,
powders, liquids, etc.

Plastics, products consumed in the form of sheets, rods, tubes, and other shapes

Printing ink (complete formulations)

Petroleum wax

Paperboard containers, boxes, and corrugated paperboard

Aluminum foil:

Plain

Converted

^aN.E.C. - Not Elsewhere Classified

Source: Reference 2

on both sides of the substrate (usually foam or film). Two-faced tapes have both heavy-duty uses (*e.g.*, carpet tapes and for securing plates to a printing cylinder) and light-duty uses (*e.g.*, business forms and nametags).

Label manufacturing is similar to pressure sensitive tape manufacturing, with the primary properties being backing, printability, flatness, ease of die cutting, and release paper components. A label manufacturer may sell his product either in rolls or sheets as a final product, or as a raw product to printing and die cutting operations.^{4,6}

Other adhesive-coated and laminated product lines include adhesive-coated floor tiles, wall coverings, automotive and furniture woodgrain films, and decorative sheets.

4.4 MANUFACTURING PROCESS DESCRIPTION

Coated and laminated substrate facilities use numerous methods to process a wide variety of products. Manufacturing variables include the design and capabilities of the coating equipment, the type of substrate, the type and viscosity of the coatings being applied, and the drying or curing method. The manufacturing process generally consists of the following four steps:

- raw material mixing
- coating application
- drying/curing
- rolling, printing, cutting, and product shipment

4.4.1 Raw Material Mixing⁴⁻¹¹

Many coating and laminating facilities formulate their coatings on-site in a central mix room. The complexity of the mixing process depends on the size of the facility and the number of products manufactured. Large facilities operating dedicated lines usually formulate all of their own coatings from raw materials. Smaller coating and laminating facilities may purchase premixed coatings which they either use as-shipped or modify to satisfy customer needs. Modification typically consists of adding small amounts of performance-enhancing chemicals.

Saturants, release coatings, tie coatings, and some adhesives are typically manufactured in mix tanks using high- or variable-speed dispersers. Facilities that purchase pre-mixed coatings and add performance-enhancing chemicals often blend these chemicals directly into the coating drum. Facilities equipped with stainless steel mixing tanks and dispersers are capable of

preparing coatings of any chemical composition (*i.e.*, 100 percent solids, waterbased, solvent-based, radiation-curable).

Once the coatings are formulated, they are either pumped to storage tanks or transferred via tote vessels or dedicated piping to specific process lines for immediate use.

4.4.2 Coating Application

The application of a coating to a flexible web involves four major functions: (1) transport of the web, (2) delivery of the coating supply, (3) metering of the coating, and (4) transfer of the coating from the supply vessel to the substrate. This report does not discuss web transport, other than to note that the mechanisms used to tension and advance the web may require minor adjustments to compensate for the different speeds and transport requirements of waterbased coatings. These mechanisms include items such as rollers, gear boxes, belts, and equipment housings. Their design is influenced by the properties of waterbased and solvent-based adhesives. The mechanisms used to supply, meter, and apply coating may also require adjustment. The following sections describe the second, third and fourth coating application functions, along with some common coating equipment configurations.

4.4.2.1 *Delivery of the Coating Supply*

After mixing, coatings are stored in permanently installed tanks, movable tote vessels, or drums, depending on the size and production methods of the coating operation. In order to coat a backing web, the coating must be transferred from such storage locations to a reservoir, from which it can be made available to the coating apparatus. Depending on the size of the operation and production methods, this is accomplished through permanently installed piping and manifold systems, or portable lines that are attached to mobile storage vessels. Various types of pumps are used to maintain a flow of coating materials through these distribution networks. Most solvent-based coating operations periodically flush their pumps and transport lines with solvent to prevent a build-up of coating material on the interior surfaces. Some solvent-based coating facilities pack their lines with solvent during production shut-down periods to avoid the curing of coatings in the line. Waterbased coating operations normally use waterbased cleaning agents or disposable pipes to circumvent this problem.

The delivery system brings coating material into close proximity with the web and coating head, depositing the liquid at a steady rate into a reservoir. In some cases, this flow is subjected to continuous monitoring and adjustment, particularly on short runs. During longer production runs, the flow is adjusted to the proper rate and process control is then exercised with the metering mechanism. The reservoir normally uses dams and spill pans to capture any spilled coating.

4.4.2.2 *Metering of the Coating Supply*

The web's surface must be completely wet with coating, but not in excess of the design thickness for the application. The thickness of the applied coating can be partially controlled through adjustment of the supply system and the coating's viscosity. Fine adjustments are accomplished by a metering device. Metering can occur before or after the coating is applied to the web. The most common metering mechanisms are (1) a metering roller, (2) a doctor blade, (3) a metering rod, and (4) nip rollers.

A metering roller controls the amount of coating that reaches the web in roll coating applications. Metering rollers are very smooth and spin counter to the direction of the application roller. They are set at a predetermined distance from the application roller, with the metering roller restricting the amount of coating that can pass through the preset gap with the coating roller. Coating typically collects at the outer edges of this gap, so many coating heads incorporate a solvent drip that solubilizes this build-up, allowing it to wash away. A coating apparatus employing a metering roll to control coating thickness is depicted in Figure 4-1.

Doctor blades or floating knives are used to remove excess coating either from the surface of the transfer mechanism, or after the coating has been transferred to the web. Doctor blades have very clean, straight edges, and are finely adjustable to provide a level scraping effect over the surface of the coating. Doctor blades are most effective in providing metering of an already well-controlled coating layer. If a doctor blade is incorrectly set to remove too much coating, either from an application roller or from the surface of a web, it will begin to foul, resulting in adhesive voids on the web. Figure 4-2 shows a doctor blade-over-roll coater. Figure 4-3 shows various types of knives used to achieve different coating effects.

Metering rods, like doctor blades, can control coating thickness before or after transfer to the web. A metering rod is a thin rod wrapped in wire. It is brought into tangential contact

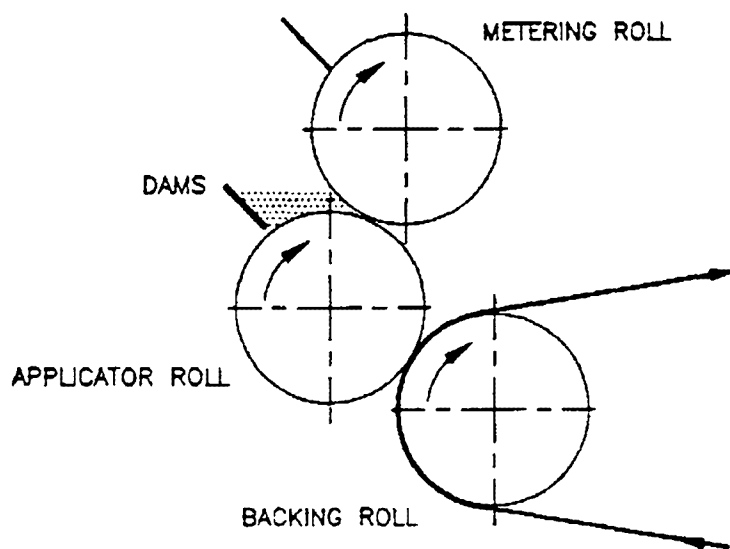


Figure 4-1. Metering Roll Control of Coating Thickness.

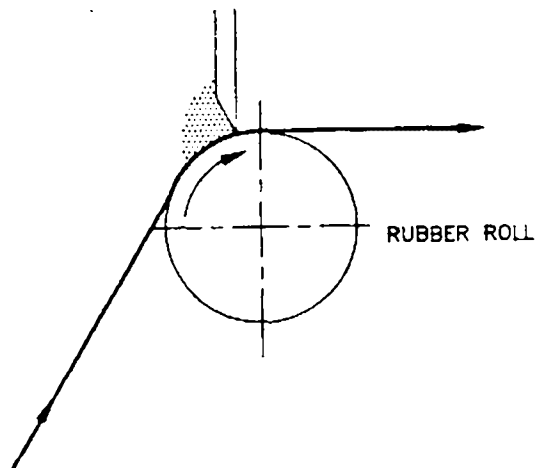


Figure 4-2. Blade-over-roll Coater.

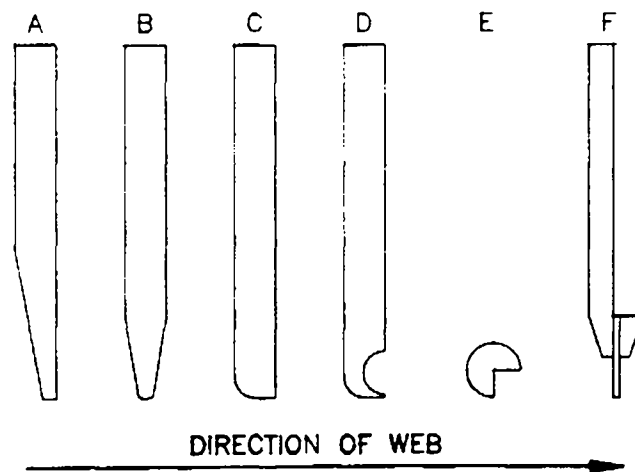


Figure 4-3. Coating Knives (A = beveled; B,C = rounded edge; D = hook; E = bull nose; F = spanishing knife)

with the coating-laden surface and coating passes through the grooves in the wire wraps. The diameter of the wire wrapping determines the amount of coating that is allowed to pass. The viscosity of the coating must be controlled to allow the coating to level after it has passed the metering rod. Figure 4-4 shows a typical metering rod set up to control the thickness of a coating applied by a direct roll coater. Figure 4-5 depicts the flow of coating through the grooves in a metering rod's wire wrapping.

Nip rollers squeeze a saturated web to remove excess coating. Nip rollers are adjacent rollers that rotate counter to one another, allowing the web to travel between them. They are usually covered with a flexible surface material, primarily rubber, allowing them to be set in contact with one another, but flex enough to accommodate passage of the web. Figure 4-6 shows a dip and squeeze coater using chilled iron rollers as nip rollers.

Additional metering mechanisms include air knives, shown in Figure 4-7, which are high speed curtains of air that literally blow excess coating back as an application roller rotates towards the web; and mechanisms uniquely associated with a single coating application, such as the engravings in a gravure cylinder. The arrows in Figure 4-7 indicate that the applicator roll can be either a reverse or direct roll. Gravure coaters are similar to roll coaters in that they transfer coating to the surface of a web through the rotational motion of a cylinder. The major difference is that gravure cylinders are engraved while the surface of standard coating rollers is mirror smooth. Gravure coating is a common method of selectively coating the surface of a web. Figure 4-8 depicts a simple gravure coating system. Regardless of the mechanism used, the metering device must be kept as clean as possible to allow it to effectively perform its task.

4.4.2.3 *Transfer of the Coating to the Substrate*

Transfer of a coating from a reservoir to a web is most commonly accomplished with a roll coating mechanism. Roll coaters are a series of one or more cylinders that remove coating from the reservoir and then contact the web, transferring a portion of the coating to the web surface. If the same cylinder that contacts the coating in the reservoir also contacts the web, such as the coater shown in Figure 4-9, the roll coater is known as a direct roll coater. If the supply roller transfers the coating to a counter-rotating cylinder before it reaches the web, the device is called an offset roll coater. Offset roll coaters are capable of greater control of the coating deposit, but require more exacting process control. Figure 4-10 shows an offset roll coater.

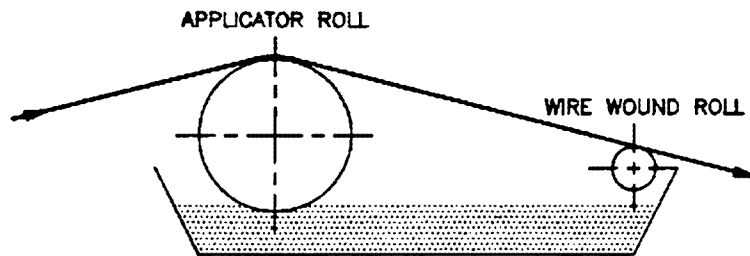


Figure 4-4. Metering Rod Coater.

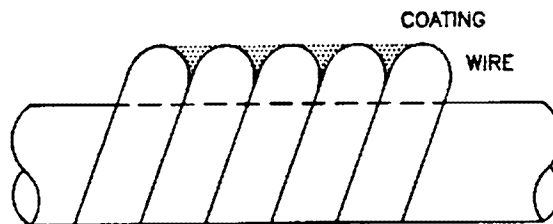


Figure 4-5. Metering Rod.

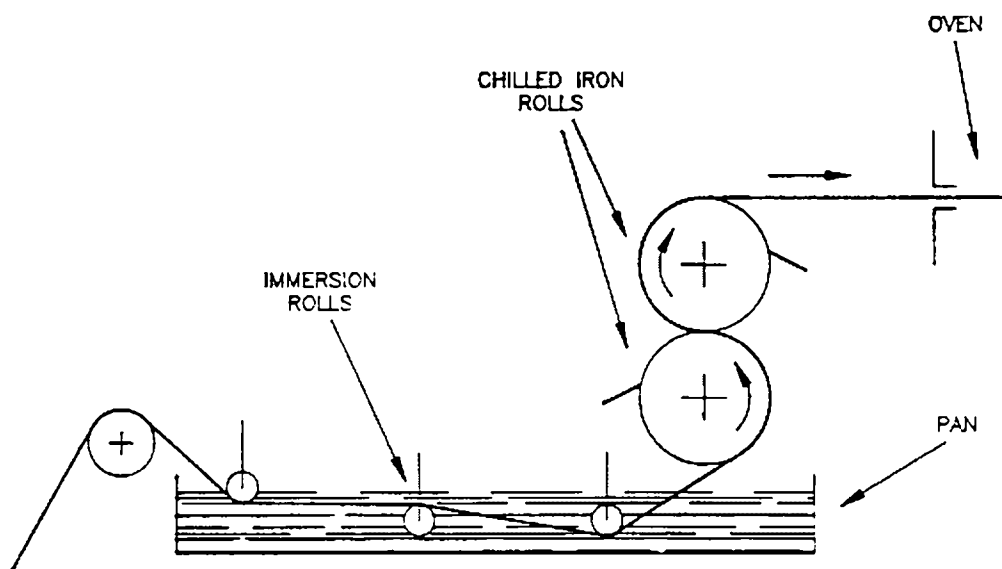


Figure 4-6. Dip and Squeeze Coater.¹²

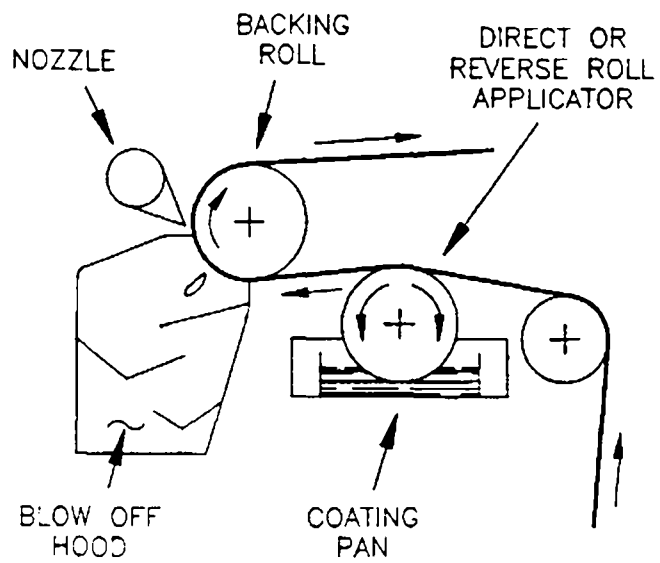


Figure 4-7. Air Knife Coater.¹²

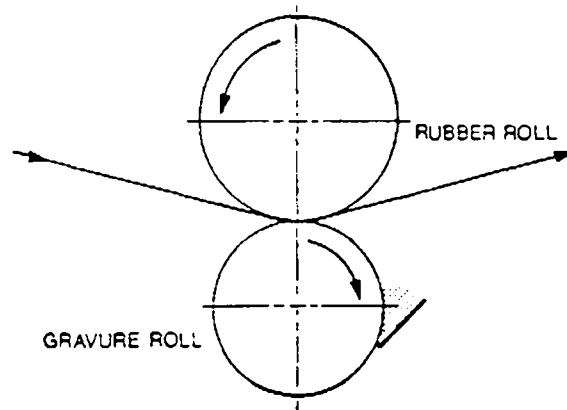


Figure 4-8. Direct Gravure Coater, Coating Reservoir Between the Roll and the Blade.

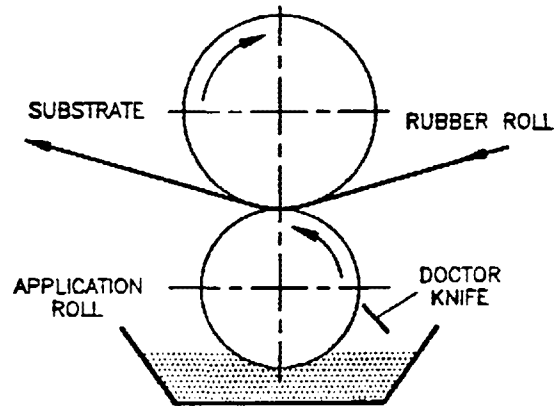


Figure 4-9. A Schematic Diagram of a Direct Roll Coater.

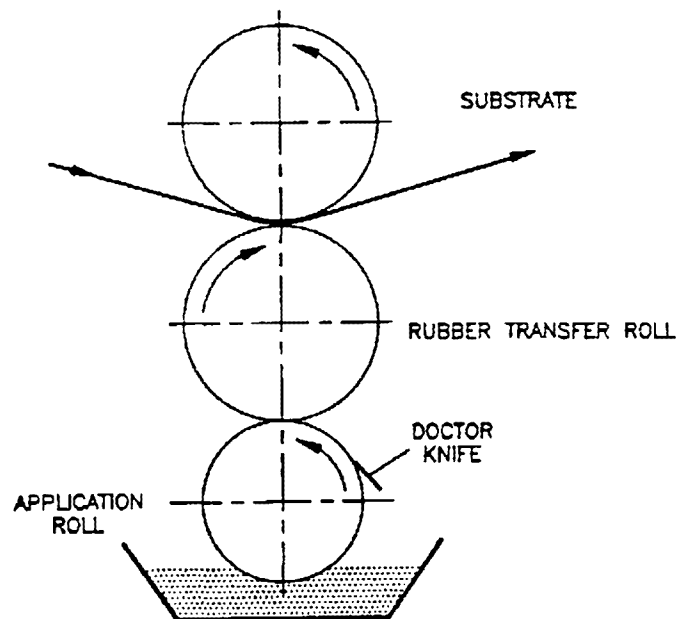


Figure 4-10. Offset Application Roll.

In addition to describing the transfer of coating from the reservoir to the web (*i.e.*, with a single roller), the term direct roll coater is also used to indicate that the web and the coating cylinder surface are moving in the same direction at their tangential point of contact. Figure 4-11 shows the relative direction of motion of the web and application roller in a direct roll coater. If these two surfaces are moving counter to one another at this point, then the system is described as a reverse roll coater, shown in Figure 4-12. Reverse roll coaters are capable of effecting a smoother and more uniform coated surface.

In some coating applications, there is less need for precision and coatings can be poured directly onto the web and metered using a metering roller, doctor blade, or metering rod. These applications generally incorporate a less viscous coating, and are intended for low performance environments, such as disposable labeling or general purpose masking tape. In such cases, the transfer mechanism is the pouring device, such as an aperture in the reservoir, or a weir (dam) that the coating pours over as the reservoir is fed. In such applications it is essential to control the flow of coating to the reservoir to ensure that the pouring mechanism does not deliver too much coating to the surface of the web. Figure 4-13 shows a floating knife coater, which meters the coating from a reservoir directly on the web.

4.4.3 Drying/Curing

Ovens serve two primary functions: to dry the coating by evaporating the vehicle (solvent or water) or to cure a polymer coating. Important characteristics of an oven are the source of heat, the operating temperature, the residence time (a function of web speed and the length of web path through the oven), the allowable hydrocarbon concentration, and the oven circulation (a function of air velocity).

Ovens are of two types: direct-fired and indirect-fired. An indirect-fired oven involves heat exchange. An incoming air stream exchanges heat with steam or combustion products, but does not mix with them. This heat transfer is often accomplished using shell-and-tube or plate type heat exchangers.^{4,12} Direct heating routes the hot products of combustion (blended with ambient air to achieve the desired temperature) directly into the drying zone. The fuels for a direct-fired oven are usually either natural gas or liquefied petroleum gas (*e.g.*, propane). Direct-

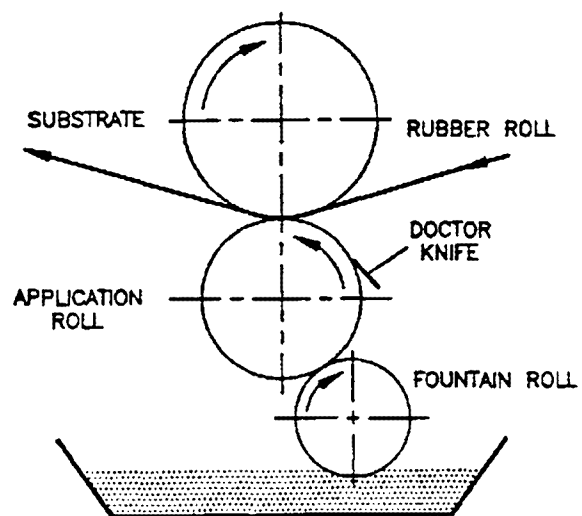


Figure 4-11. Direct Application Roll.

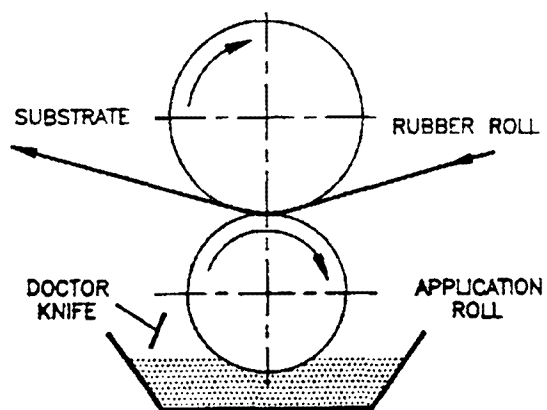


Figure 4-12. A Schematic Diagram of a Reverse Roll Coater.

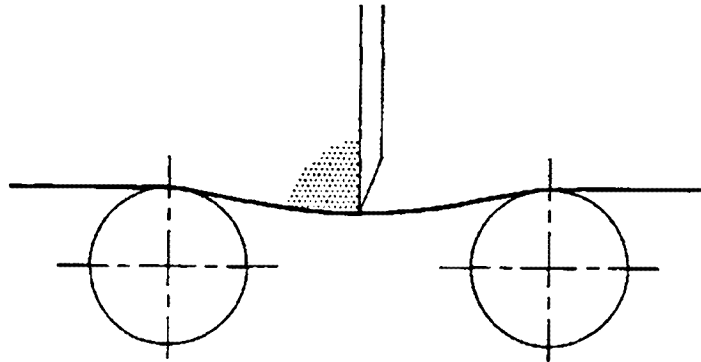


Figure 4-13. Floating Knife Coater.

fired ovens are used most frequently because of their higher thermal efficiency. Indirect-heated ovens lose efficiency in the production of steam and in the heat transfer process.^{4,12}

Oven drying involves raising a coating's temperature above the boiling point of the vehicle solvent and keeping the temperature elevated long enough for entrapped solvents to migrate to the surface and evaporate. The time required to drive off vehicle solvents at the boiling temperature is known as the drying residence time. During the drying process, heat is transferred to the coating and backing. In most coating processes, approximately 80 to 95 percent of the vehicle solvent evaporates and exits with the oven exhaust either to the atmosphere or to a control device, depending on the nature of the exhaust, the quantity of release, and the location of the facility.¹² The remaining trapped solvents generally migrate to the edge of the adhesive once it is used in its functional application. (This process is known as out-gassing, and is frequently a cause of adhesive failures.) Another important factor to consider is the oven's temperature profile. If the initial drying proceeds too quickly, voids may develop in the coating. Conversely, if drying occurs slowly at low temperatures, longer ovens may be necessary to achieve sufficient residence time.

Multi-zone ovens almost always overcome these difficulties. A typical two-zoned oven is illustrated in Figure 4-14. Zoned ovens are physically divided into several sections, each with its own exhaust and supply of hot air. The temperature in the first zone is typically low, but gradually increases in later zones. This structure allows for uniform drying. Large drying/curing ovens may have as many as six zones ranging in temperature from 110° to 400°F. Facilities may also employ recirculating ovens to provide better drying efficiency. Recirculation of the exhaust gas is an energy saving practice, however, care must be taken to ensure that sufficient makeup air is circulated to prevent solvent saturation and exceeding the solvents' lower explosive limit (LEL) inside the oven. Although zoned ovens are most always used with waterbased coatings, they are also applicable to solvent-based materials. Figure 4-15 illustrates oven exhaust recirculation.^{4-6,10-11}

4.4.4 Rolling, Printing, Cutting, and Product Shipment

Many coating operations also offer value-added converting services to their customers. Such services include custom slitting and roll winding, printing, die-cutting, and sheeting. A roll of coated product may weigh up to 5,000 lbs and be 30 inches wide when it comes off the production line. Such products are generally slit to a customer specified width, and automatically rolled onto standard cores for customer use in automatic dispensers. Many facilities have the ability to slit and wind product on-site, however, some facilities send finished rolls to contract converters to be sized.

In addition to slitting and winding of stock products, coaters often customize label and packaging products by printing a logo and die-cutting to size. Printing is typically done using flexographic or screen printing. The industry trend is towards the use of waterbased and radiation-curable inks for these processes. Die cutting typically uses hydraulic-ram presses and steel-rule dies. The product is generally cut to the liner with the waste removed and the web rolled and packaged for shipping.

When coating and all custom conversion is finished, the product rolls are ready for shipment. Finished products are wound on cardboard cores with plastic caps inserted into the

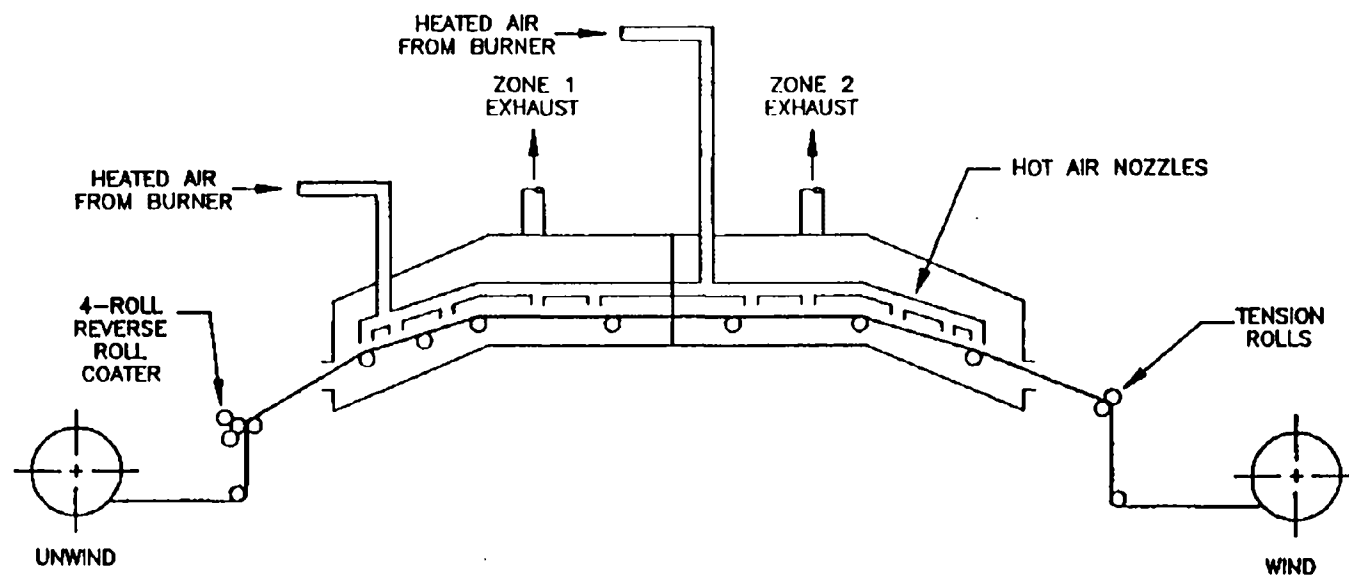


Figure 4-14. Coating Line with Two-Zoned Drying Oven (no recirculation).¹²

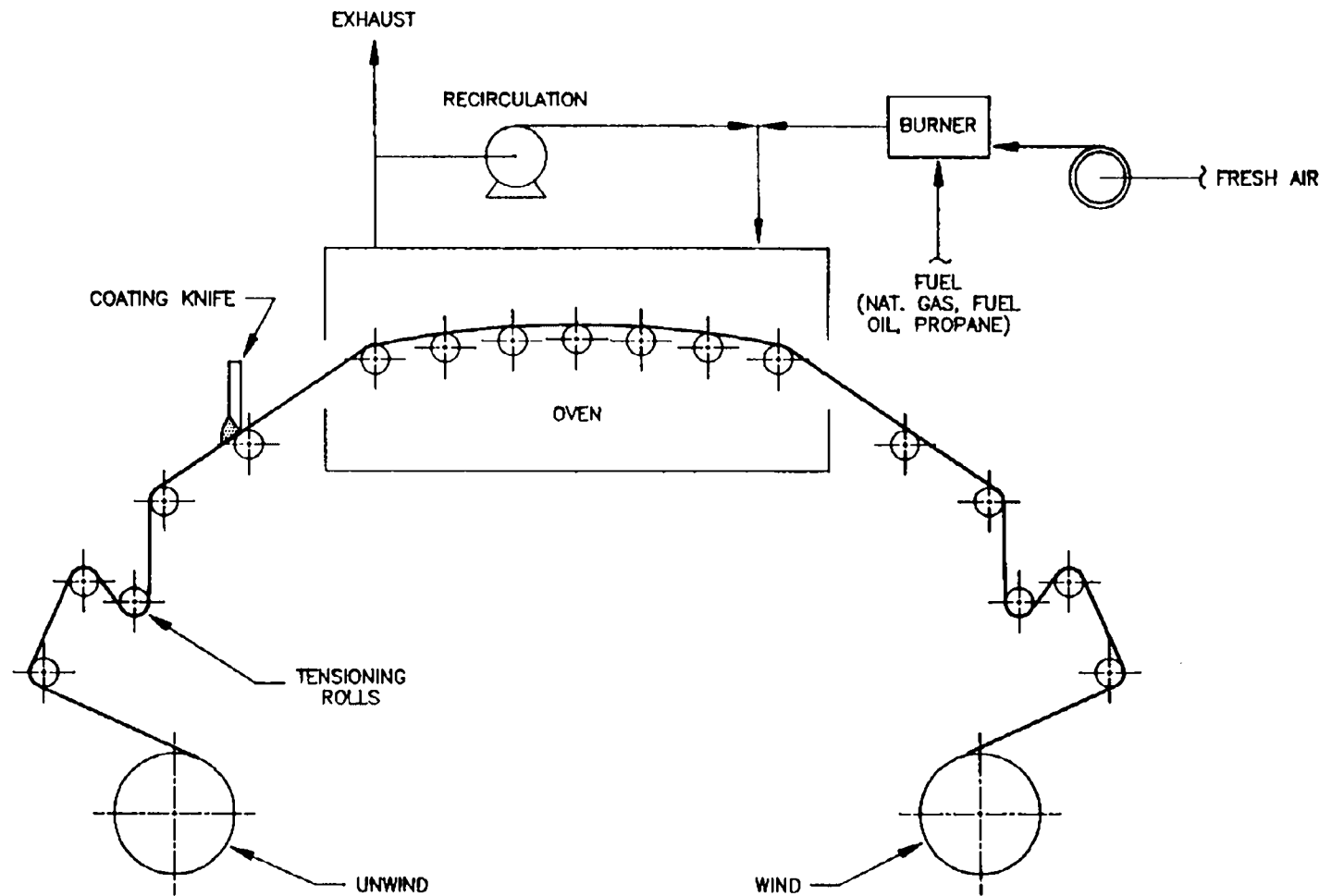


Figure 4-15. Coating Line with Exhaust Recirculation.¹²

ends of the roll to prevent damage to the edges of the product. The rolls are then placed in containers (e.g., cardboard boxes) for shipment. Large rolls which have not been cut and sized are shipped in open rolls with wood-end caps, and metal straps around the rolls for support.

4.5 REFERENCES

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CHAPTER 5

ISSUES AFFECTING THE RETROFIT OF COATING EQUIPMENT

5.1 GENERAL

Waterbased PSAs differ from solvent-based PSAs in many respects. Differences in manufacturing equipment, end-product markets, production styles (batch processing versus dedicated lines), and chemistry must be considered when deciding whether to convert solvent-based products and processes to the use of waterbased adhesives. Although waterbased PSAs may be formulated for nearly any adhesive category (*i.e.*, natural rubber, styrene-butadiene copolymers, butyl rubber, acrylic, etc.), most advances in waterbased PSA technology have occurred in the acrylic category. For this reason, most of the discussion in this chapter is primarily applicable to comparisons between waterbased acrylic and solvent-based PSAs. Similar information for other PSA categories is included where available or where inferences may be drawn from the acrylic PSA industry.

The acceptance of early waterbased acrylics was slowed by problems associated with their adaptability to conventional coating equipment including poor mechanical stability, streaking or channeling of coating, poor wetout on release liner, and high levels of foaming.¹ More recently, advances have been made in these and other areas to ease the transition from solvent-based to waterbased acrylic PSAs. The resulting increase in interest in waterbased adhesives has led many companies to consider modifying their processes to incorporate waterbased manufacturing capacity.

The purpose of this chapter is to provide an understanding of the technological considerations associated with the retrofit of solvent-based coating equipment to produce waterbased adhesive-coated products. Most of the information contained in this chapter was obtained from the recorded experiences of actual sources in the PSA industry.

5.2 EQUIPMENT ISSUES

This section discusses manufacturing equipment issues critical to a retrofit plan and is divided into four subsections: (1) storage, transfer, and pumping equipment, (2) application equipment, (3) drying ovens, and (4) other manufacturing equipment issues.

5.2.1 Storage, Transfer, and Pumping Equipment

Storage of waterbased adhesives is significantly different from storage of solvent-based adhesives. If waterbased adhesive is left in a storage container for long periods of time, it is likely that the solids content of the formulation will collect and dry along the walls of the storage container. Unlike settled solids from a solvent-based adhesive, this dried material will not redissolve. In addition to potentially clogging lines and pumps, dried particles entrained during adhesive transfer to the application equipment may lead to defects in the coated adhesive film.

Another problem associated with the storage of waterbased adhesives is the requirement of controlled storage temperatures. Many facilities store adhesives in bulk storage tanks that are located outdoors, or in unheated shelters. Waterbased adhesives should not be allowed to freeze, nor should they be exposed to excessive temperatures for lengthy periods due to the increased opportunity for coagulation or agglomeration of their solids content.² Therefore, facilities may require heat jackets on their adhesive storage tanks to maintain an acceptable temperature.

Waterbased PSAs are generally composed of a solid or semi-solid binder dispersed in water. Agitation is normally necessary to prevent settling of solids and maintain the consistency of this dispersion.^{2,3} Few solvent-based adhesive formulations require similar agitation, therefore, it is likely that a facility considering equipment retrofit would have to install the systems necessary to provide this agitation.

Uniform dispersion is needed to ensure consistent performance of the adhesive. However, because of the presence of surfactants necessary to stabilize the polymer latex, vigorous agitation may lead to foaming. The "soapy" nature of most surfactants causes waterbased adhesives to foam during high-shear mixing or transfer. The high-shear agitation of high-speed dispersers pulls air into the adhesive and encourages foaming. For this reason, formulation of waterbased coatings should be by slower, controlled stirring, manually or by motor driven or air-powered

paddles operating at or below 60 revolutions per minute (rpm). Waterbased adhesives should be stirred for a minimum of eight hours after long storage. Two to three hours of stirring is sufficient if the adhesive has only been stored for a few days.²

The general assumption that slower and longer agitation produces more favorable results with waterbased coatings is disputed by some experimental results. One study performed on waterbased acrylic adhesives showed that an increased agitation rate corresponded to improvement in some process performance measures. This study showed a significant improvement in wetout as the agitation rate increased from 200 to 700 rpm. The level of adhesive foaming (foamability) also decreased as the agitation rate increased. The study also indicated that there was an inverse relationship between agitation time and these performance properties: less mixing time allowed for a wider range of formulations with acceptable wetout and foamability. The reason for this improvement was unclear, however, the enhanced properties appeared to remain stable as the test samples aged.⁴

Many adhesive formulations (both solvent-based and waterbased) are classified as thixotropic fluids, meaning they undergo a decrease in viscosity when subjected to shear force and return to normal viscosity when at rest.^{3,5} Adhesive formulations can also be classified as non-Newtonian fluids, meaning the material will not flow until a specific level of stress required to overcome static viscosity (the yield point) is exceeded. Flow then proceeds due to dynamic viscosity.⁵ Both thixotropic and non-Newtonian materials can present pumping and dispensing problems. Therefore, the viscosity characteristics of waterbased adhesives must be checked before pumps, transfer lines, and coating configurations are designed and installed.³ Viscosity is a major factor in determining the required characteristics of the dispensing equipment used to move and apply adhesive material; however, waterbased adhesive viscosity is virtually independent of molecular weight (*i.e.*, solids content). Waterbased may have a higher solids content and still be easily pumped and coated on substrates.⁶

The use of waterbased adhesives requires water-resistant pumps, motors, and piping (*e.g.*, stainless steel, PVC). Also, the pump seals used must be made from a material compatible with the material being pumped.⁵ In addition, the increased solids content of waterbased adhesives may result in increased power consumption and wear on motors and bearings relative to solvent-based adhesives. Piping, pumps, reservoirs, and oven interiors may also become subject to corrosion, and stainless steel equipment may be necessary for these applications as well.⁷

There are numerous recorded instances of facilities effectively modifying their equipment to coat waterbased adhesives. Trade journal articles and interviews with industry representatives show that the problems associated with the retrofit of equipment are slightly different for each facility. The original design of equipment, the end use for which the adhesive product is intended, and the mix of solvent-based and waterbased adhesive products that a facility wishes to process all influence the ability of a plant to effectively overcome the problems associated with retrofit plans. In some cases, retrofit involves little more than attention to the performance characteristics of the adhesive product, and adjustment of equipment within the parameters of its original design. In other instances, extensive engineering and installation work must be done before waterbased products can be processed.

For example, one company reports using the same laminator for solvent-based and waterbased products, however, thorough cleaning of the cylinders during product changeover must be ensured.⁸ Another manufacturer was able to identify waterbased adhesives which could be used with their current production equipment. This manufacturer uses adhesives for installing insulation on industrial and consumer heating and air conditioning units. The adhesive developed for this application used new high solids technology and ingredients that resulted in a high solids, low viscosity product.⁹ These examples show that with careful process control, waterbased adhesives can be easily introduced into some existing manufacturing processes.

Unfortunately, retrofit is not always so simple. One label and label stock manufacturer reported that all mixing tanks, holding tanks, filters, pumps, and piping had to be modified or replaced to prevent contamination of waterbased adhesive products by previously used solvent-based adhesives. The facility pre-coated its waterbased mixing and holding tanks with glass-fiber to allow for easier clean-up with high-pressure water. New pumps with lower horsepower and compression rates were necessary to transport waterbased adhesives due to the lower viscosity and higher surface tension of waterbased adhesives. The facility uses dedicated lines to transport waterbased adhesives from mixing tanks to process holding tanks. The coatings travelling through these lines are never exposed to air as exposure to air can cause some waterbased adhesives to conglomerate causing pumping problems. These lines are made of PVC, and are replaced rather than cleaned when they become clogged with adhesive residue.¹⁰

5.2.2 Application Equipment

Waterbased adhesives are available which can use existing solvent-based coating equipment with little or no modification.^{1,11} Some waterbased formulations have the tack needed for dispensing on today's high-speed labeling lines.⁷ With the addition of defoamers, surfactants, and rheology modifiers, as well as improved polymerization techniques, waterbased adhesives can be successfully transfer-coated and direct-coated with reverse roll, gravure, and other coating systems.¹¹

Many coating methods, especially gravure and reverse gravure, require low viscosity formulations (approximately 200 to 500 centipoise). Such coaters are well-suited for use with waterbased PSAs, however, they require formulations with high performance wetout agents to reduce dynamic surface tension and provide acceptable substrate coverage. Waterbased adhesives also require very clean surfaces relative to solvent-based applications to achieve sufficient wetout action.²

Wetout is improved by the addition of surfactants, which lower static surface tension of the acrylic adhesive. However, such wetout agents do not effectively reduce surface tension during dynamic, high-speed application. The conditions of typical PSA coating processes can also cause surfactants to foam, but the addition of defoaming chemicals further reduces the wetout effect of the surfactant.^{4,12} The optimum ratio of surfactant to defoamer in a particular adhesive formulation is dependent on the line speed and the type of coater with which the adhesive is to be used.⁴ In order to respond to emerging conditions on the production line, this problem may require that the retrofit plan include some means of adjusting the surfactant/defoamer formulation prior to delivery to the coating head. Acetylenic diol surfactants have been tested and provide good wetout (especially under dynamic conditions) with minimal foam generation and minimal effect on final adhesive performance.¹²

As with other issues, the anecdotal evidence indicates that although general classes of problems can be anticipated, the manifestations of these phenomena, along with the appropriate corrective actions, are facility dependent. One facility that switched from a solvent-based to a waterbased acrylic laminating adhesive for polyester-to-paper bonding noted that foaming was a problem, however, with experience, operators were able to develop effective responses, and the overall benefits of the transition to waterbased were greater than the problems.⁸

Another manufacturer of pressure-sensitive tape who replaced their heptane-based pre-coat with a waterbased acrylate for a short production-scale run encountered foamability problems. The firm reported that some of the foaming problems resulted from agitation caused by the gravure roller and could be eliminated with an alternative application method such as flow bar coating.¹³

A manufacturer of labels and label stock that is currently in the process of converting their adhesive operations from solvent-based to waterbased indicated that waterbased adhesives require a different configuration of rollers and a different gravure set-up for the coaters. The application roller must be designed to allow a greater deposit of waterbased adhesive to remain on the substrate because waterbased adhesives do not penetrate substrate surfaces as well as solvent-based formulations.¹⁰

5.2.3 Drying Ovens

The same oven drying line is frequently used to handle both solvent-based and waterbased adhesives.¹⁴ Hot air ovens are the most common type of dryer, although such mechanisms may be supplemented by infrared (IR) heating. Unless grandfathered from environmental regulations, most solvent-based adhesive coating facilities employ some type of pollution abatement system on their ovens. Most of these ovens either incinerate the exhausted solvents for fuel value (heat recovery), or capture the solvent vapors by condensation or adsorption on activated charcoal.

References differ on the energy requirements for drying solvent-based adhesives versus those for drying waterbased adhesives. One source stated that the energy requirements for drying waterbased are less than for solvent-based adhesives, since it is not necessary to heat large volumes of air to keep solvent concentrations low. When drying solvent-based adhesives, the air volume and air speed must be large enough to avoid an explosive concentration.¹⁴ This concentration limit is usually in parts per million (ppm) and is termed the LEL.

Numerous other sources conclude that waterbased adhesives require more energy to dry, because water evaporates more slowly than many solvents and therefore requires additional drying time.² The heat needed to vaporize water is 540 cal/g while the requirement for typical adhesive solvents such as MEK and toluene is 100 to 200 cal/g. This difference translates into the need for higher temperatures, or longer required residence times, with resulting higher utility

costs.⁷ Since many adhesive-coated substrates are temperature sensitive, increasing temperature in the oven is not always an option. Longer residence times are achieved with longer ovens or slower operating line speeds. The former solution requires capital expenditure and increased floor space, while the latter can result in reductions in output, productivity, and profit.^{7,15}

There are several ways of reducing the additional oven residence time required to dry waterbased formulations. Among them are preheating the substrate prior to adhesive application, increasing air flow in the drying oven, and preheating the coated substrate with an IR lamp before entry into the oven.² Although each of these options will increase energy requirements, they can generally result in a net energy savings by reducing oven energy consumption. One solution that may offset some of the energy increases required by waterbased is the recirculation of oven exhaust. With sufficient make-up air to avoid saturation, recirculated air can reduce the volume of air that must be heated from ambient temperatures while still evaporating and removing water from the coated layer. Recirculation is not usually an option with solvent-laden exhaust because of explosion hazards.

5.2.4 Other Manufacturing Issues

One issue involved in retrofitting solvent-based coating equipment to apply waterbased adhesives is clean-up requirements associated with waterbased adhesives. While still wet, some waterbased PSAs can be cleaned with warm water or a soap solution.² However, once the water has evaporated from these waterbased adhesives, the remaining solids portion forms a nearly impenetrable layer which can be difficult to remove. In some cases, solvents are required to "cut" through the dried solids from the waterbased adhesives in order to remove them from coating line equipment.

An advantage of waterbased conversions, particularly for coaters who provide converting services, is the potential for improved die cutting and guillotine cutting operations. Generally, these cutting operations require a less viscous and more rigid polymer response. A more viscous response will result adhesive oozing during cutting operations (characterized by bleeding of the adhesive around the product's edge or knife fouling).¹⁶ Waterbased adhesives are ideally suited for these converting operations since the dried adhesive forms a rigid polymer coating which can be readily cut.

5.3 CHEMISTRY ISSUES

Several of the raw materials used to formulate waterbased PSAs, such as polymers, antioxidants, or fillers, are similar to their solvent-based counterparts. However, waterbased formulations require additives that are either different from those used in solvent-based adhesives, or are unique to waterbased formulations. For instance, waterbased adhesives require surfactants and defoamers to achieve a balance between their wetout and foaming properties. In addition to these raw material differences, the polymerization process for waterbased is different than that for solvent-based adhesive coatings. This section discusses the differences between waterbased and solvent-based PSAs and their implications for an organization pursuing a retrofit of its equipment.

The addition of tackifiers normally serves to decrease the molecular weight of an adhesive as well as increase the glass transition temperature. However, other tackifier effects include lowering of viscosity, which must be considered when transferring and applying a waterbased adhesive. In waterbased acrylics, viscosity is virtually independent of molecular weight, allowing the successful coating and polymerization of high solids (low viscosity) products. Waterbased acrylic polymers are produced at viscosities around 100 to 500 centipoise and in order to be coatable on the variety of machines in use today, must be thickened.⁶

Although natural rubber is readily available as an aqueous latex, the dispersion of tackifier resins into the form of stable aqueous emulsions of consistent quality has presented problems. The most desirable tackifiers have melting points above 212°F and therefore cannot be readily emulsified by agitation with emulsifying agents at atmospheric pressure. Butyl rubber latexes do not require the addition of tackifiers and are used as tackifying agents themselves in higher strength adhesives. Acrylic waterbased PSAs are similar to NR-based PSAs in that they can be tackified by the addition of pre-emulsified tackifying resins.¹⁷ It is important that the dispersants be compatible with the surfactant in the waterbased adhesives.¹⁴

Other differences in solvent-based and waterbased acrylic PSAs include the following:

- solvent-based adhesive polymers are in a continuous phase, waterbased adhesive polymers are heterogeneous (*i.e.*, emulsified)
- solvent-based adhesives have low MW (to maintain coatable viscosities), waterbased adhesives can have high MW (viscosity independent of MW)

- solvent-based adhesives contain no anti-adhesive components, waterbased adhesives have surfactants, defoamers, fillers, etc.
- solvent-based adhesives have diffusion film formation, waterbased adhesives have coalescence

The high MW of waterbased aids cohesion without the need for crosslinking, however, this gain is often at the expense of peel and tack. For this reason waterbased acrylics require the addition of tackifiers and plasticizers. In solvent-based acrylics, maintaining a coatable viscosity limits the MW and thus solids content. Therefore, solvent-based acrylics require relatively more vehicle solvent (*i.e.*, VOC) than waterbased acrylics.

5.4 MARKETING AND OPERATIONAL CONCERNS

In addition to the equipment and chemistry issues that must be resolved before attempting a waterbased retrofit, companies must consider the operational implications of changing their manufacturing process. In particular, companies must recognize the limits of their ability to convert their marketing and managerial processes to handle waterbased products. The cost of planning and executing equipment and raw material conversions, the ability to satisfy the performance requirements of their customers, and the cost associated with a new operating regime are all factors that managers must consider when planning a retrofit of solvent-based processes.

5.4.1 Cost Issues

The cost of planning and executing a retrofit of coating equipment is very facility dependent. Among the issues that a facility must examine are the capital costs of retrofitting equipment, and the differences in raw material costs (*e.g.*, solvents vs. deionized water), energy consumption rates, waste stream costs including treatment and disposal, and research and development costs.²

Each of these categories of cost can be positively or negatively affected by the transition to waterbased formulations. Much of a facility's analysis of these costs will depend on the

quality of their estimations of cost factors for waterbased processes and products. While the historical cost of use for solvent-based products should be readily apparent to most organizations, the projected cost of use of waterbased adhesives is subject to some uncertainty. Current information on costs can be obtained from a variety of sources, including trade groups and adhesive manufacturers.

One factor that should not be overlooked when analyzing the cost of use of solvent-based formulations is the expected increase in the cost of releasing VOC emissions into the atmosphere. Under Title V of the Clean Air Act, many sources will begin to experience dramatically increasing emission fees scaled to their annual emissions. The net effect of these emission fees may serve to offset certain cost disadvantages associated with a transition to waterbased formulations. In addition, the costs of converting from solvent-based to waterbased adhesives may be offset in future expansion efforts due to the permitting requirements associated with increasing facility emissions (which requires emissions reduction elsewhere in the plant).

Another indirect cost of converting coating processes to the use of waterbased materials is the pure, applied, and problem-solving research and development (R&D) that must precede and follow such an action. Both product and equipment testing may cause production delays and result in engineering expenses as well as some lost production. It is important to note that, although not discussed in detail in this report, some amount of R&D will be required to identify the alternative materials for current applications, develop the processes to use those materials, and solve the inevitable manufacturing and marketing problems that will result from the transition.

5.4.1.1 Capital Costs

The adhesive coating process can be envisioned as the merging of four functions as discussed in Chapter 4: (1) web transport, (2) coating storage and distribution, (3) application of the coating to the substrate, and (4) drying or curing of the coating. The conversion of a process line from solvent-based to waterbased products will not usually require any engineering changes to the web transport apparatus, however, the equipment used to execute each of the three remaining functions will almost always require some modification, however minor. The cost of planning, designing, and installing such modifications are the capital costs of the retrofit.

Converting a coating storage and distribution system to use waterbased is likely to require that all mixing tanks, holding tanks, filters, pumps, and piping be retrofitted. This requirement is due to the inherently lower viscosity and higher surface tension of waterbased PSAs, and will also prevent contamination from previously used solvent-based adhesives.¹⁰ Storage and distribution equipment must also be constructed of a non-corrosive material (usually stainless steel) to prevent rust and other contaminants from becoming entrained in the coating.

One report examined during the preparation of this report stated that many current waterbased acrylic PSAs can be processed on conventional roll coaters with little or no mechanical modifications.¹ Other sources have indicated that a different configuration of rollers (particularly for gravure coating) is required for waterbased coating operations. Despite these differences, one certainty is that each particular combination of application equipment, coating material, and substrate will exhibit different characteristics, and therefore will require a different retrofit solution. One general rule of thumb is that the application roller must be designed to allow a greater thickness of waterbased adhesive to remain on the substrate.¹⁰

Oven drying lines represent large capital investments, usually several million dollars. The same line may frequently be used to handle both solvent-based and waterbased adhesives.¹⁴ However, some ovens may not be equipped to handle waterbased adhesives and must be retrofitted or replaced. Ovens may be increased in length, or line speeds may be reduced, to allow for the slower drying rates of waterbased products relative to their solvent-based counterparts.⁷ Oven panels may also have to be replaced with a water-resistant material (such as stainless steel) in order to process waterbased adhesives.

5.4.1.2 Annual Costs

The change in annual coating costs as a result of a waterbased conversion (primarily labor, materials, and energy consumption) will vary by facility. Cost impacts may be positive (decreases) or negative (increases) depending upon the efficiency of the current solvent-based process, and the particular characteristics of the intended waterbased process. Labor costs may increase in the short term, as with any major process change, but should stabilize at historical levels as experience is gained with the new process. Material and energy costs will, however, undergo a more permanent change.

Generally, the high material costs associated with solvent usage (\$1.50 to \$4.00 per gallon) will be dramatically reduced by the substitution of deionized water (approximately \$0.05 per gallon) as the primary dispersant for adhesive formulations.² However, because of the increased percentage of solid raw materials (by volume) in waterbased adhesive formulations, the cost of undiluted waterbased adhesive per gallon to the manufacturer is generally somewhat higher than corresponding volumes of solvent-based products. The required addition of surfactants and defoamers, generally higher solids content, and addition of fillers to raise viscosity usually cause the waterbased adhesive to cost more per dry pound than solvent-based. Although the unit cost of waterbased adhesives may be slightly higher than the unit cost of solvent-based adhesives, their relatively higher solids content usually offers greater coverage per gallon, resulting in inventory and shipping cost savings.²

While there is considerable debate over the net energy consumption changes due to a transition to waterbased, the following factors will influence the overall increase or decrease in energy use: (1) possible increase in oven size, (2) possible increase in oven residence time, (3) possible increase in use of recirculated oven exhaust, (4) possible reduction in building ventilation (due to less solvent air emissions) requirements, and (5) possible increase in energy requirements of storage (heat jacketing) and pumping equipment.² No conclusive evidence was found to substantiate either side of this argument during the preparation of this report.

Liquid waste disposal costs should be lower for waterbased adhesives since some companies reduce the volume of effluent by allowing partial evaporation of wastewater prior to discharge to treatment facilities.^{2,10} Annual costs for regulatory compliance should also be reduced with the reduction or elimination of solvent usage and hazardous waste generation.^{10,18} Insurance costs should also be reduced as users reduce their storage of hazardous solvents thereby lowering the risk of fires.²

5.4.2 End Product Market Issues

When considering the retrofit of adhesive coating equipment to handle waterbased formulations, it is essential to consider the end-use of the product to be manufactured. Waterbased adhesives have evolved to satisfy a wide variety of applications, but are not always applicable to a particular product or market niche. Coating system operators should evaluate the

ability to satisfy customer demands before committing to the retrofit of equipment. There are two essential issues to address: (1) whether the applications required by a facility's customers can be satisfied with waterbased products; and (2) whether waterbased products can be profitably manufactured and sold to satisfy those applications.

5.4.2.1 End Product Suitability

There are two broadly recognized categories of PSA applications: high performance and low performance. These categories are defined by the end-use of a particular product and the environmental and mechanical conditions to which it will be subjected. The major advances in waterbased PSAs have been in low performance applications, although research is continuing and progress towards the development of waterbased for high performance applications is steady.

Acrylic PSAs constitute the largest use of waterbased technology in the current market. In 1991, an estimated 78 million dry pounds of waterbased acrylic adhesives were consumed, compared with approximately 27 million dry pounds of solvent-based acrylic adhesives. The single largest user of waterbased acrylic PSAs was carton sealing tape, at about 30 million pounds. In addition, approximately 13 million dry pounds of tackified carboxylated styrene-butadiene latex and 2 million dry pounds of tackified natural rubber latex were consumed in 1991, mainly in the paper label market. Generally, rubber-based waterbased PSAs have enjoyed an economic rather than a performance-related advantage over waterbased acrylics.¹

The many new applications that have been realized for waterbased acrylic adhesives include plastic labels, porous medical tapes, packaging and office tapes, duct tapes, foam mounting tapes, carton sealing and splicing tapes, and protective masking sheets.^{1,11} Waterbased adhesives have also made inroads into the label and decal industry. Waterbased formulations which meet the adhesion requirements for low energy substrates (*i.e.*, high density polyethylene and polypropylene) are available as well. Recent product developments include waterbased PSAs that have service temperatures of -10° to 120°F. Current waterbased acrylic adhesives exhibit water and humidity resistance suitable of such demanding applications as shampoo-bottle labels.¹

Tackified acrylic waterbased adhesives have received considerable attention in recent years as a replacement for tackified SBR adhesives in low shear applications such as paper labels. With continuing improvements in shear performance of waterbased acrylics, many new

applications may also be able to use these adhesives. Newer tackified acrylic waterbased adhesives have been formulated to meet the performance requirements of mounting tapes such as double-coated films and foams, and high-temperature splicing tape. Other tackified acrylic waterbased adhesives have been successfully evaluated for applications such as exterior graphics vinyl, semi-permanent vinyl labels, and automotive decals.¹¹

Latex or emulsion hydrocarbon elastomers are still a relatively minor part of the current market and are generally restricted to styrene-butadiene emulsions and some natural rubber latex. Some performance goals not yet achieved, especially for high performance applications, include humidity and water resistance, film clarity, rheology, high temperature peel, adhesion to low surface energy surfaces, plasticizer resistance, and controlled removability.¹

One label and label stock manufacturer has been able to replace most of their solvent-based products with waterbased alternatives. However, some products do require characteristics of natural rubber that waterbased acrylics have been unable to provide such as extremely cold bonding, wet bonding, and peel and re-peel ability.¹⁰

5.4.2.2 End Product Cost

One company noted that although waterbased adhesives formulations cost more than solvent-based adhesives, the difference is not significant enough to truly drive the total product cost. The final product cost is normally determined by the cost of the product backing. For example, in the case of label stock manufacturing, the cost of raw paper is the driving factor in the end-product cost. The company noted that although the increased cost of undiluted adhesive is fairly substantial (up to double the cost of solvent-based for specialized applications), the relatively low percentage of total cost associated with the adhesive formulation will prevent an unacceptable increase in price to customers.¹⁰

5.4.3 Capacity Loading

In addition to considering the end use of its products, a company should consider its allocation of capacity to those products before making a commitment to coating with waterbased adhesives. Companies with limited product lines and a narrow range of product performance requirements may find that they can dedicate whole production lines to classes of products. In

some cases, such operations will handle adhesive formulations that are similar enough to be run consecutively on a production line with little or no modification of the line between jobs. The ability of such firms to plan and execute a waterbased retrofit is limited more by their ability to find suitable replacement formulations than by the need to retain production process flexibility.

Firms that manufacture a broad range of products, or that batch-process custom coating jobs, may find it necessary to run vastly different products on the same machinery within short periods of time. For such operations, the engineering that precedes a retrofit of equipment may be complicated by the need to retain the capability to coat solvent-based products on the same equipment. Retrofit planning should take into account the degree of process flexibility required by market orientation, production and inventory control methods, and the cost of transitioning equipment between various jobs.

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CHAPTER 6

ENVIRONMENTAL MULTI-MEDIA ANALYSIS

6.1 GENERAL

The growth in waterbased versus solvent-based PSAs since the early 1970s is the result of upgraded performance properties, including improved environmental performance.¹ The main environmental advantages of waterbased PSAs are the reduction in VOC emissions and hazardous wastes. This chapter will discuss some of the issues that continue to cause disagreement among the scientific, environmental, and industrial communities about the net effect on the environment of converting from solvent-based to waterbased adhesive coatings.

6.2 PRELIMINARY ENVIRONMENTAL MULTI-MEDIA ANALYSIS

The modification of a manufacturing process to enable the use of waterbased coating materials has an impact on the facility's multi-media emissions and discharges. The evaluation of multi-media waste generated in all phases of a manufacturing process, from raw material extraction to end product use, is called environmental multi-media analysis. Such a process is normally conducted using either historical material, process, and emissions data from an existing plant, or data that are projected for a model plant. The completion of an environmental multi-media analysis is beyond the scope of this report, however, the issues that would be examined and resolved by such an analysis are reviewed in the following sections.

6.2.1 Air Emissions

The retrofit of solvent-based adhesive coating equipment to process waterbased materials can reduce both the number and size of VOC emissions points in a manufacturing facility.^{2,3} First, by replacing current solvent-based PSAs with waterbased, the level of VOCs emitted from the coating operation may be reduced. In plants with fully enclosed coating equipment (relatively rare), this reduction can be very accurately measured. In the majority of plants, this component of reduced VOC emissions can be estimated using emissions factors and mass balance

calculations. Solvent-based adhesives range from 20 to 70 percent solids (median of 40 percent) and may range in density from 7.0 to 7.5 lb/gal.

Also, since waterbased adhesives may generally be cleaned with less volatile (*i.e.* lower vapor pressure) solvents or even water, the fugitive emissions from equipment cleaning processes may be decreased. Again, such reductions can be broadly estimated, although not precisely measured. Sources have identified that emissions from cleaning operations result in less than 10 percent of the total facility's emissions.⁴

The largest source of emissions from solvent-based adhesive coating processes, drying oven solvent emissions, can be dramatically reduced, or even eliminated, by a transition to waterbased coating materials. This emissions reduction can generally be accurately measured, either through stack testing for large facilities, or through engineering calculations in smaller shops. The elimination of drying oven solvent vapor emissions would, in turn, eliminate the need for costly recovery or incineration equipment on oven exhaust stacks. Finally, miscellaneous sources of solvent emissions such as solvent storage, handling, and transfer; adhesive mixing; and fugitive equipment leaks will be eliminated or reduced.

These air emission reductions are generally acknowledged to be possible in any conversion from solvent-based to waterbased products. However, the true net reductions are equipment, material, and facility dependent, and will be affected by the volume of products converted, the current capture and destruction efficiencies for solvent vapor emissions, and any solvent content in waterbased coating materials.

6.2.2 Wastewater Treatment Considerations

Information sources provide conflicting reports of the net effect of a waterbased retrofit on wastewater generation. One approach maintains that the wastewater volume generated from waterbased adhesives may be comparatively lower than for solvent-based adhesives since the volume of wastewater is often reduced by evaporation before disposal.⁵ However, another source stated that the volume of wastes generated from waterbased operations was no different than solvent-based operations.⁶ Also, any facility engaged in formulating their own water-based adhesives onsite will likely generate an additional wastewater stream during the water de-ionization process.

One company questioned during the preparation of this report noted that a waterbased retrofit resulted in an increased waste stream due to higher water usage for mixing and cleaning adhesives. They did state, however, that the overall effect should be a reduction in total waste generated.³

6.2.3 Solid Waste

Solid wastes generated from adhesive coating processes (both waterbased and solvent-based) are comprised of make-ready, slitting excesses, and some reject materials. Each of these materials may contain some residual vehicle (solvent or water) from the adhesive coating. Facilities which operate solvent-based processes usually assume for emissions calculations purposes that 100 percent of the carrier solvent is evaporated during the drying/curing stage. However, a confidential source stated that approximately 0.5 to 1.0 percent solvent remains in the solvent-based adhesive-coated product after drying. Since some of this material is shipped off site as solid waste, it is possible that some solvent is introduced to the landfill.

The overall affect of converting solvent-based coating lines to waterbased on solid waste generation is unclear. One reasonable conclusion is that non-hazardous solid waste generation may increase due to the fact that wastes which were previously classified as hazardous (due to contamination with solvents) would be re-classified as non-hazardous (no solvent contamination). It should be noted, however, that these uncontaminated materials may have an increased potential to be recycled, thus reducing total solid waste generation.

6.2.4 Hazardous Waste

Waterbased adhesives can significantly reduce the hazards and hazardous wastes involved with the use of solvent-based adhesives. Disagreeable odors, harmful vapors, flammability hazards, and hazardous wastes associated with solvent-based adhesives will be reduced, and may be eliminated, by the use of waterbased materials.⁵ These reduced or eliminated hazardous wastes may include solid waste (no longer contaminated with solvents), wastewater, recovered solvent from the drying ovens, and equipment cleaning wastes.

Cleaning wastes may still be considered hazardous, although contaminated with a less hazardous material (*i.e.*, toluene-soaked versus mineral oil-soaked rags). Where it is possible to replace a hazardous cleaning solvent with water, hazardous cleaning waste may be eliminated completely. Usually while still wet, waterbased adhesives can be cleaned with warm water or a soap solution.^{5,7} While this characteristic can dramatically decrease cleaning solvent usage, one facility (which is currently conducting cleaning solution tests using water, citrus-based cleaners, mineral oil, and mineral spirits) noted that they found soap and water solutions unable to effectively clean all coating equipment on their waterbased adhesive lines.³

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