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Adhesives for the Paper Packaging Industry: An Overview

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Abstract

Today, packaging plays a crucial role in maintaining the quality of products during uses by providing safeguarding against physical, chemical and environmental challenges. While polymer-based packaging material has been very extensively used, there has been a recent move to paper-based packaging products because of their economic and environmentally-friendly nature. Currently, Paper and paper-based board materials have been used as packaging material for food products, and e-commerce business. Adhesives in packaging industries are critical to the structure of most paper and paper board packaging, whether applied during the process of conversion and on the packaging line. From a production point of view, adhesive choice can significantly affect process line efficiency and production performance. Adhesive types used in paper industries are water-based adhesives both synthetic and bio-polymer based (starch, cellulose, protein and itaconic acid), Solvent-based adhesives (polyurethane and acrylic-based) and 100% solids adhesives like heat sealing adhesive and hot melts. More recently, water-based heat-expandable adhesive having thermally insulative and cushion-like properties has been provided for use in protective packages and wrap. Here, we aim to present an overview of the research trend of adhesives in the paper packaging industry. The overview summarizes the different adhesives for paper packaging industries.

Keywords

Paper, Packaging, Bio-Based, Adhesive, Expandable

1. Paper Packaging

Packaging covers and protects after manufacturing of goods, guard its integrity through handling, transportation, warehouse and distributing, and ensure its wholesomeness during uses. The packaging is also used for physical protection, which includes enhancing shock shielding, internal product safeguarding and reducing shock damage caused by snagging, friction, vibration and impact. This protection can be as simple as preventing damage of the product to providing barriers to moisture, oxygen, carbon dioxide, and other gases. Packaging can act as a stoppage for light to protect color of a product from deteriorating. In addition to providing non-resistant protection, many packages today play an active role in the quality of a product by helping to maintain the desired conditions around the product [1] [2].

Polymer's characteristic makes plastic packaging ideally suited for protecting products during shipment and delivery to customers. However, despite its advantages, plastic is made of a petroleum resource, whereas paper and pulps are made of trees. Furthermore, plastic can be recycled and reused but it is currently difficult to achieve high levels of post-consumer recycled content in plastics due to post-consumer waste contamination and like many other major plastics applications, plastics used in flexible packaging have come under deep scrutiny in recent years as sustainability concerns rise and spread globally. Historically, papers have been used in flexible packaging for many applications, including confectionery, pet food and dried food [3]. Paper is far more biodegradable than plastic and very easily recycled. Additionally, paper-based flexible packaging is often laminated with plastic/aluminium or coated with resin, therefore becoming non-recyclable. Many companies are switching to paper packaging instead of plastic packaging to become more sustainable, especially with the new plastic tax coming into force in 2022. However, switching to paper also has its environmental issues [4].

Currently developing, pulp and paper industries are one of the major sectors in every country of the globe contributing not only to gross domestic product but surprisingly to ecological pollution and health hazards also [5]. In India, there are around 700 pulp and paper mills producing about 7.0 million tonnes of paper and paper board. Every tonne of pulp produces 1.25 tonnes of black liquor solids as waste [6] [7] [8] [9]. Paper and paper-based board materials are one of the earliest and largest used packaging forms for e-commerce business and food products like beverages, dry powders, confectionary, bakery products, etc. owing to their eco-friendly nature [10]. We have needed adhesive systems for such growing and sustainable paper industries. Here, we reviewed the research trend of adhesives in the growing paper packaging industries.

2. Manufacture of Paper

Paper is made from cellulose fibers, which are obtained from trees, recovered papers and annual plant fibers like cereal straws. Today about 97% of the world's paper and board is made from wood-pulp, and about 85% of the wood-pulp used is from hardwoods and softwoods. Hardwoods are used as an ideal raw material for corrugated cases as well as printing and writing papers. Paper is produced by pressing together fibres of cellulose pulp which is obtained from rags or grasses, wood and dehumidifying them into flexile sheets. It is an adaptable material with many uses like writing, packing, printing, etc. [11] [12].

Manufacturing of paper and pulp industry involves the following steps:

1) Pulping processes;
2) Refining procedure;
3) To form a thin fibre mixture;
4) Fibre formation on a thin screen;
5) Enhance the material density pressurization;
6) A suitable surface finishing procedure.

The paper-making process involves four inputs which are source of chemicals, fibre, water and energy [13]. The primary source of fiber is wood. The three main components of any wood are cellulose, hemicellulose and lignin. The concentration of each component varies according to type of species [14].

2.1. Pulp Manufacturing

Manufacturing of paper and pulp starts with raw material preparation by debarking, chipping, and other processes. It can be physical or chemical pulping or else combination of both. Cellulosic pulp is manufactured from the raw materials, using chemical and physical *i.e.*, mechanical means [15] [16].

2.1.1. Mechanical Pulping

Mechanical pulping separates fibers from each other by mechanical means applied to the wood or wood matrix causing the moderate break of the bonds between the wood fibers. In mechanical pulping, the objective is to maintain the main part of the lignin in order to achieve high yield with acceptable strength properties and brightness causing a low resistance to aging. The main processes are Groundwood Pulping by pressing wood chips against a rotating surface to grind off small pieces, Thermo-Mechanical Pulping, by using high-temperature steaming before refining [17] [18].

2.1.2. Chemical Pulping

Chemical pulps are made by digesting the raw materials, using the kraft and sulfite processes. In the kraft pulp process, the active cooking chemicals are sodium hydroxide and sodium sulfide. Kraft pulp possesses superior pulp strength properties in comparison to sulphite pulp. Kraft processes produce a variety of pulps used mainly for packaging and high-strength papers and board. In the sulfite process Acid bi-sulphite, Bisulphite, Neutral sulphite, and Alkaline sulphite are mainly used to attack and remove lignin. Mechanical pulps are weaker than chemical pulps, but cheaper to produce and are generally obtained in the yield range of 85% - 95%. Chemical pulping yields approximately 50% but offers higher strength properties and the fibers are more easily breached because the mechanical pulping process does not remove lignin.

2.2. Pulp Washing and Screening

Fresh water may only be introduced to the washing stage after bleaching in a closed system. After washing and screening the pulp is sent to the bleach plant or paper mill.

2.3. Bleaching

Bleaching is any process that chemically modifies pulp to increase its brightness. The principal pulp bleaching agents are chlorine dioxide, hypochlorite, peroxide, chlorite, oxygen and ozone.

2.4. Stock Preparation

Stock preparation is conducted to convert raw stock into finished stock for the paper machine. The pulp is prepared for the paper machine including the blending of different pulps, dilution, and the addition of chemicals [19] [20].

2.5. The Wet-end Operation

The pulp is pumped into the headbox of the paper machine at this point. The slurry consists of approximately 99.5% water and approximately 0.5% pulp fiber. The exit point for the slurry is the "slice" or head box opening. As the wire moves along the machine path, water drains through the mesh [21].

2.6. Pressing and Drying

As the paper enters the press section, it undergoes compression between two rotating rolls to squeeze out more water. Then it continues its way through the steam heated dryers losing moisture each step of the way. About 90% of the cost of removing water from the sheet occurs during the pressing and drying operations [22].

2.7. Coating

Coating is the treatment of the paper surface with clay or other pigments and/or adhesives to enhance printing quality, color, smoothness, opacity, or other surface characteristics. There is a great demand for paper with a very smooth printing surface [23] [24].

2.8. Finishing

At the end of the drying process, the sheet is smoothed using an "ironing" method, which consists of hot polished iron rollers mounted in pairs with synthetic material rollers, one above the other.

2.9. Shipping

The paper comes off the machine ready for reeling up into large reels, which can be cut or slit into smaller ones, according to customer requirements.

2.10. Quality Control

To ensure that the paper or board is of consistently high quality. Moreover, for food contact applications, microbiological and chemical controls have to be carried out [25] [26].

3. Types of Paper

Paper can be classified into the following categories based on numerous parameters. Paper is divided into two broad categories: fine papers, generally made of bleached pulp, and typically used for writing paper, bond, ledger, book and cover papers, and coarse papers, generally made of unbleached kraft softwood pulps and used for packaging [27].

3.1. Kraft Paper

This is typically a coarse paper with exceptional strength, often made on a machine and then either machine-glazed on a dryer or machine-finished on a calendar. It is sometimes made with no calendaring so that when it is converted into bags, the rough surface will prevent them from sliding over one another when stacked on pallets [28].

3.2. Bleached Paper

These are manufactured from pulps which are relatively white, bright and soft and receptive to the special chemicals necessary to develop many functional properties. They are generally more expensive and weaker than unbleached papers. Their aesthetic appeal is frequently improved by clay coating on one or both sides [29].

3.3. Greaseproof Paper

This is a translucent, machine-finished paper which has been hydrated to give oil and grease resistance. Prolonged beating or mechanical refining is used to fibrillate and break the cellulose fibers which absorb so much water that they become superficially gelatinized and sticky and thus create a sheet with very low porosity [30].

3.4. Glassine Paper

Glassine paper derives its name from its glassy, smooth surface, high density and transparency. It is produced by treating greaseproof paper in a supercalender where it is carefully dampened with water and run through a set of steam-heated rollers resulting in very few pores or other fiber/air interfaces existing for scattering light or allowing liquid penetration [31].

3.5. Vegetable Parchment

The process for producing parchment paper was developed by passing a web of high-quality chemical pulp through a bath of concentrated sulphuric acid. The cellulosic fibers partially dissolve, filling the spaces between the fibers and resulting in extensive hydrogen bonding. Thorough washing in water, followed by drying, causes re-precipitation and consolidation of the network, resulting in a paper with excellent wet strength, even in boiling water and resistant to grease. Labels and inserts in products with high oil or grease content are frequently made from parchment. It can be treated with mold inhibitors and used to wrap foods such as cheese [32].

3.6. Waxed Paper

Waxed papers provide a barrier against penetration of liquids and vapors. Many base papers are suitable for waxing, including greaseproof and glassine papers. The major types are wet-waxed, dry-waxed and wax-laminated. Wax-sized papers, in which the wax is added at the beater during the paper-making process, have the least amount of wax and therefore give the least amount of protection. Wet-waxed papers have a continuous surface film on one or both sides, achieved by shock-chilling the waxed web immediately after application of the wax. This also imparts a high degree of gloss on the coated surface. Dry-waxed papers are produced using heated rolls and do not have a continuous film on the surfaces [33].

4. Adhesives for paper

Adhesive bonding is a process that adheres two surfaces permanently together by application of an adhesive material. While this process is well understood for compact materials it gets more complicated for porous fibre-based materials like paper and paper board [34]. The strength of an adhesive bonding depends on various physical properties of both, paper and glue [35]. Adhesives come in many forms and types and choice will be determined by the substrates being bonded, the machinery in use in the process and other factors, for example, the potential requirement for food-safe materials. Most adhesives are applied via specially designed machinery, adding another layer of complexity to the selection process and requiring adhesives with specific properties to match the operating parameters of the equipment. In some cases, adhesives are designed specifically for a particular machine type or model. Examples of adhesive use by the packaging industries include:

- Case and carton manufacture;
- Paper bag making;
- Paper tube winding;
- Flexible packaging lamination;
- Remoistenable gummed tapes and labels [35].

5. Bio-Based Adhesives

Bio-based adhesives are manufactured from naturally occurring materials such as animal or agricultural products like starch, cellulose, protein, casein, animal glue-gelatin, natural rubber, etc. [36].

Adhesive types used in paper industries:

- Water-based adhesives, both natural and synthetic: include starch and its derivatives, casein, latex and synthetic emulsion systems such as polyvinyl acetate, acrylics and polyurethanes dispersions.
- Solvent-based adhesives, in which the carrier is an organic solvent rather than water; these include polyurethanes and acrylics.
- 100% solids adhesives which have no carrier solvent; these include heat sealing adhesives and hot melt adhesives [37].

5.1. Starch

Starch is a complex polysaccharide which occurs naturally in plant matter. Commercially, the plants used are corn, wheat and potato, with some use of rice, tapioca and sago. Starch composition that is amylose: amylopectin ratio and particle size vary with source and adhesive manufacturers adjust their processes to suit [38] [39] [40]. One of the most common uses of starch adhesive is in the production of corrugated board. Dextrin adhesives are derivatives of starch. The starch is depolymerised by acid and/or heat treatment and the molecules are then repolymerised to produce highly branched structures which are soluble in water, the extent of their solubility being determined by the acid/heat treatment. A wide range of dextrin adhesives is available, with different viscosities and applications, and modifications are possible using the additives mentioned above. Borated dextrin's contain borax to increase tack. Dextrin's generally have higher solids than starch adhesives, *i.e.*, less water, which means they dry faster and thus support higher line speeds. As well as being suitable for bonding paper-based materials, e.g., bags/sacks and tube winding, dextrin's can also be used in high-speed paper labelling of cans and bottles [41]. To enhance the performance of adhesive starch is blended with polyvinyl alcohol. The blends between starch and polyvinyl alcohol would improve blending properties like the tensile strength becoming higher and the presence of hydroxyl groups tend to form strong hydrogen bonding among molecules [42] [43].

The nanoparticle latex-based starch adhesives can be applied as replacement for Synthetic latex adhesives for a variety of applications to porous and non-porous Substrates. One example is in the preparation of improved tissue papers or for making multi-ply tissues, napkins, paper towels, etc. [44]. A starch-based corrugating adhesive provides a controlled rate of viscosity increase and green bond formation comprising water, starch, caustic alkali, an active boron source, and polyvinyl alcohol having an 88% - 90% degree of hydrolysis, wherein the polyvinyl alcohol constituent imparts a definite increase in the rate of viscosity building of the adhesive, the rate of viscosity increase being controlled to provide an effective green bond and final adhesive bond on a corrugated board surface [45]-[50]. The invented adhesive starch with boric acid has the advantages of high stability and water resistance, low price, environmental protection, improved sizing speed, small amount of adhesive, and strong adhesion force [51] [52]. The starch adhesive for cigarette paper is good in environmental protection performance and bonding performance [53] [54]. The modified glutinous rice flour is prepared from glutinous rice flour, sodium bicarbonate, bentonite, and polyacrylamide. This adhesive provides a method for preparing the corrugated paper adhesive with good bonding strength and water resistance [55] [56] [57] [58]. The nano-modified starch adhesive for corrugated paper box can be applied and it has improved bonding effect [59]. A new starch-based adhesive with high solid content, high binding force, and low viscosity was prepared via hydrolysis of cassava starch with α-amylase using glycerol as a plasticizer and Ammonium Zirconium Carbonate as a crosslinker. The adhesive was applied to coated paper as a partial substitute for styrene butadiene rubber latex [60] [61].

5.2. Cellulose

Cellulose is the most abundant biopolymer, and its ability to adhere makes it an ideal biomaterial for developing green adhesives and coatings [62] [63] [64]. Sources of cellulose are mainly softwood and hardwood, agricultural sources such as corn, jute, and sugarcane bagasse [65] [66] [67] [68]. From these sources, cellulose is extracted, isolated, and then modified for a specific application. Based on extraction, and treatments, it can be in micro size, micro fibrillated cellulose, microcrystalline cellulose [69], and nano size [70] [71] [72]. Nanocellulose, classified as nanofibers, nanowhiskers, and cellulose nanocrystals, is one among the cellulosic material with one dimension in the nano range [70]. Cellulose is widely used as a reinforcing agent in various adhesive systems [73] [74] [75] [76] [77]. The waste corrugated carton, waste office paper and waste packaging cardboard were used as materials to make nano-cellulose with the sulfuric acid method. The oxidized starch adhesives were prepared and modified by adding different amounts of nano-cellulose. The addition of nano-cellulose improved the properties of the oxidized starch adhesive [78]. The paper adhesive with cellulose like sodium carboxy methyl cellulose, hydroxymethyl cellulose has the advantages of high fluidity, high penetrability, good fiber affinity, high adhesive strength, good water resistance, no toxicity, and no harm, and can form adhesive film with good toughness and uneasy adhesive-water separation phenomenon. Paper sheet using the adhesive has high compression resistance and high puncture resistance [79] [80] [81].

5.3. Protein-Based Adhesive

Soya protein

Proteins are composed of amino acids, the amino ($-NH_2$) and carboxyl ($-COOH$) groups form peptide bonds and tie the amino acids together. There are about 20 different amino acids that can be combined to form a protein. Proteins are divided into two major categories, fibrous proteins and globular proteins [82]. To describe and understand the structure of proteins it is necessary to study, at least four levels, the primary, the secondary, the tertiary and the quaternary level [83] [84]. Effects of ultrasonic on properties of modified soybean protein adhesives for duplex paper were studied. The results showed that the treatment temperature had the greatest impact on adhesion strength among all factors [85]. The adhesive was to formulate and evaluate a novel liquid paper glue based on a renewable material, polymerized whey proteins, and a synthetic polymer, polyvinylpyrrolidone (PVP-K90) [86] [87].

Casein

Casein is the protein present in milk, rendered soluble by the addition of alkali in water. Casein adhesives have an aggressive tack. They can also absorb significant amounts of water without significant change in viscosity, making them suitable for high-speed labelling of glass bottles and jars in cold or wet conditions, for example in beer bottle labelling. They have excellent resistance to ice water, which means that labels will not fall off the bottles in chilled conditions, but they can be removed when required, for example on returnable glass bottles, by soaking in an alkaline solution. However, casein is a high-cost raw material which is becoming more expensive, and alternative casein-free options are now available for the beverage sector [88].

5.4. Itaconic Acid

To solve problem with starch like poor durability of bond, many physical or chemical modifications of starch molecules have been considered, such as oxidation, grafting, crosslinking, esterification, and other complex modification [89]-[100]. There have been many reports about the synthesis, characterization, and properties of starch graft copolymers [101]-[106]. Itaconic acid (IA) is an unsaturated binary organic acid with one carboxyl group conjugated to the methylene group. It can easily copolymerize and provide polymer chains with carboxylic side groups, which are highly hydrophilic and are able to form hydrogen bonds with hydroxyl groups [107] [108] [109]. The main advantage of IA is that it can be produced from a variety of agricultural products rather than petrochemical sources [110] [111] [112].

6. Synthetic Adhesives

6.1. Polyvinyl Alcohol-Based Adhesives

Polyvinyl alcohol (PVA) is one of the most important commercial water-soluble polymers [113]-[120]. Due to its highly polar hydroxyl group, it also absorbs water readily, thereby joining the family of water-soluble polymers [121]. PVA is synthetic polymer with excellent film-forming property, emulsifying properties and outstanding resistance to oil, grease, and solvents [122]. It has excellent gas barrier properties, high strength, and flexibility [123] [124]. PVA is made by dissolving another polymer, polyvinyl acetate (PVAc), in an alcohol such as methanol, and treating it with an alkaline catalyst such as sodium hydroxide. Polyvinyl alcohol adheres particularly well to cellulosic substrates such as wood or paper. The main uses of PVA are in textile and paper sizing, adhesives, and emulsion polymerization. Based on the degree of hydrolysis, PVA is classified into grades of partially (85% - 89%) and fully (97% - 99%) hydrolyzed polymers

[125] [126].

6.2. Polyvinyl Acetate-Based Adhesives

Water-soluble polymers have attracted coating industries and adhesive market as the demand for solvent-free adhesives increased, which has the advantage of the absence of volatile organic compounds. Moreover, the use of PVA as a protective colloid for polyvinyl acetate (PVAc) adhesives has further created a demand for its use [127] [128] [129]. Paper Adhesive comprises polyvinyl alcohol, urea-formaldehyde resin, melamine modified resin, vinyl acetate, and water [130] [131]. Adhesive for paper comprises polyvinyl alcohol, polyvinyl acetate emulsion, cyclodextrin derivative, cellulase, modified glass fiber, and polystyrene latex with silane coupling agent. Adhesive has excellent adhesion, and promote various applications [132] [133] [134] [135].

6.3. VAE-Based Adhesives

Vinyl acetate ethylene (VAE) emulsions are based on the copolymerization of vinyl acetate (VAc) and ethylene, in which the VAc content can range between 60 and 95 percent, and the ethylene content ranges between 5 and 40 percent of the total formulation. VAE emulsions offer considerable performance advantages over PVAc homopolymers, due to the ability to alter the glass transition temperature (T_g) through the incorporation of the ethylene monomer. VAE-based adhesives are safe, non-toxic, and eco-friendly, and the adhesive is suitable for the bonding of paper box. The joint formed from the adhesive is hard to tear and crack, and the flexibility and toughness of the paper box are not influenced by the adhesive. The adhesive has the advantages of high oxidation resistance, no discoloration, good antimicrobial property, and good waterproof property [136] [137] [138] [139].

6.4. Acrylic-Based Adhesive

Using Butyl acrylate, vinyl acetate and styrene as the main raw materials, Butyl acrylate and vinyl acetate were first copolymerized, and then the graft polymerization was carried out with Butyl acrylate and styrene. The effects of monomers, polymerization process and emulsifiers on the polymerization and the properties of the water-based paper adhesive were studied [140] [141] [142]. For waterproof paper straw adhesive, acrylic copolymer emulsion blended with vinyl acetate emulsion along with water-soluble resin, corrosion inhibitors and anti-foaming agent [143] [144].

6.5. Chloroprene-Based Adhesives

In some of the studies, Poly chloroprene-based latex was used with zinc oxide to obtain the paper adhesive [145].

6.6. Polyurethane-Based Adhesive

Paper-plastic packaging materials have become important materials in the printing industry. Water-based adhesive for paper-plastic packaging is a new type of adhesive. The adhesive used for food and medical packaging materials asked for higher performance, such as stability, peel strength, and aging resistance, so there is a large necessity in developing an environment-friendly paper-plastic laminating adhesive with excellent performance. Wax emulsion, natural latex and waterborne polyurethane emulsion were mixed along with epoxy resin [146]. The dissolution of the non-ionic waterborne polyurethane is promoted through the surfactant and the bridging agent, so as to avoid the agglomeration of the non-ionic waterborne polyurethane. This adhesive for corrugated paper has strong adhesive bond and waterproof performance [147].

7. Heat Seal Paper Adhesives

The heat seal adhesive paper product comprises a paper substrate and a heat activatable adhesive. Heat seal adhesive paper is available that forms a bond to itself or another material as a result of application of heat. Heat seal adhesive paper can be referred to as dry bond paper. Heat seal adhesive paper is available having a coating that, when heated to a sufficient temperature, forms a bond with another substrate. The heat activatable adhesive comprises a result of applying an aqueous polymer dispersion to the paper substrate to form a coated paper substrate and drying the coated paper substrate. The aqueous polymer dispersion includes a polymer component having a melting temperature (T_m) greater than about 220˚F. and a glass transition temperature (T_g) greater than about 50˚F. A method for manufacturing a heat seal adhesive paper product is provided and a laminate product containing the heat seal adhesive paper product is provided. The coating can be applied by extrusion coating. Exemplary coatings include wax like paraffin wax, ethylene vinyl acetate, polyethylene, polypropylene, polyvinyl butyral, and cellulose derivatives. Exemplary products that include dry bond paper include sugar packets, tea bag packets, and various types of process food containing bags or pouches [148]. Heat sealing adhesive has good water resistance and water impermeability, keeps good weather resistance, deformation resistance, no softening, no toxicity, and no peculiar smell at high temperature, and has excellent performance [149].

8. Hot Melt Adhesives

As hot melt (HM) adhesive uses no solvent, it provides a solution to environmental concern. Hot melt adhesives were introduced to the market in the 1950s, and then have become increasingly important in the adhesive segment. HM adhesive covers 15% - 21% of the global volume of production and consumption of adhesives. More importantly, the total average annual growth rate of the consumption of HM adhesives is 1.5 - 2 times higher than that for other types of adhesives [150] [151] [152]. The HM adhesives are designed to be applied in consumer goods, packaging, construction, transportation, electronics, healthcare, and for other applications like bookbinding, furniture, etc. [153] [154]. The ability to modify the properties of the adhesive composition with the addition of various resins, oils, waxes and other additives makes HM adhesives commercially useful in a wide variety of applications [155]. Last but not the least, they are clean and easy to handle. Currently, almost all the base/major polymers for HM adhesives on the market are primarily derived from petroleum resources, such as ethylene vinyl acetate (EVA), block copolymers of styrene and butadiene or isoprene, polyesters, polyamides, polyurethanes and polyolefin's [156] [157] [158]. Recently, there has been an increase in research on fatty acid-derived dimers and different diamines-based HM adhesives. Overall, the basic resin highly affects adhesion strength and cohesion strength is the most important desirable property of the HM adhesive [159]. The application area of HM adhesives is vast, including for example carton and case sealing, paper industry, and bookbinding [160] [161] [162] [163]. The hot melt pressure-sensitive adhesive has improved normal-temperature bonding strength, cold resistance and performance [164] [165] [166]. In a basic hot melt formulation consisting of EVA base resin, wax, tackifying resin and antioxidant, various mol. weight grades of polybutene were used to partially replace the tackifying resin. This resulted in lower blend densities and improved hot melt removal efficiencies in laboratory tests which simulate the repulping process [167]-[174].

9. Expandable Packaging Adhesive

In order to protect various items during handling, shipping or transportation, protective products such as padded wraps, envelopes, packages and containers are currently used. Such protective products may be placed in surrounding engagement with the product to protect the product from potentially damaging contact. Such protective products traditionally used closed cell extruded polystyrene foam to form a cushion or plastic "bubble wrap" material which relies on an air gap or bubble between the plastic layers, to form the protective cushion. The water-based heat expandable adhesives include a plurality of heat expandable microspheres having an initial expansion temperature range of from about 35˚C to about 110˚C and a maximum expandable temperature range of about 50˚C to about 150˚C. These microspheres may be made from a variety of materials, but generally have a polymeric shell and a hydrocarbon core. Adhesive provides dielectric heating, particularly RF heating, a foamable waterborne composition [175]-[190].

Consumers frequently purchase ready-made products, such as food and beverages, and other products, in containers made from packaging substrates in disposable containers. These containers can maintain the temperature of the liquid or food contents by reducing heat or cold transfer from the contents through the container to the consumer's hand. To help insulate the hand of the consumer from the heat of a hot beverage, or keep the desirable temperature of the contents of a food or beverage container longer, heat expandable adhesives and coatings have been developed by the inventors for use with packaging substrates, for example, with multilayer micro fluted board, paper or paperboard. Such expandable adhesives and coatings can expand upon being heated over a range of certain temperatures. The layer of insulating material may be at least a partial coating of the sidewall surface. The material may be adapted to be expanded to provide thermal insulation [191].

10. Conclusion

There has been increasing concern regarding environmental problems arising from the widespread use of petroleum-based plastic materials for packaging. Many efforts have been made to develop sustainable and biodegradable packaging materials to replace plastic products. There has been a recent shift to paper-based packaging because of environmentally-friendly nature. Adhesives in paper packaging industries play a critical role. Various types of adhesives are used such as water-based adhesives both synthetic like acrylic emulsion-based, polyvinyl acetate-based, polyvinyl alcohol-based and combination of polyvinyl acetate and acrylic emulsion depending upon the ultimate performance of packaging material. But increasing global energy issues due to shortage of petroleum resource focus of the industries have been shifted towards developing sustainable adhesives which are cost-effective and renewable. Currently, various biomaterials have been exploited as sustainable adhesives including starch, cellulose, soya, itaconic acid and chitosan. Bio-based adhesives are manufactured from naturally occurring materials such as animal or agricultural products like starch, cellulose, protein, casein, animal glue-gelatin, natural rubber, etc. 100% solids adhesives like heat sealing adhesive and hot melts were also used in paper industries which are eco-friendly. Just now, water-based heat-expandable adhesive having thermally insulative and cushion-like properties has been provided for use in protective packages and wrap. In a nutshell, the recent developments highlight biopolymers' immense potential for developing novel and high-performance materials in accordance with the new concept of sustainable development. In order to sustainable paper adhesive, bio-polymers, a green building block, revealed a new path and a new area for research.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Abbreviations

IA: Itaconic acid
PVA: Polyvinyl alcohol
PVAc: Polyvinyl acetate
VAE: Vinyl acetate ethylene
VAc: Vinyl acetate
T_g: Glass transition temperature
HM: Hot melt
EVA: Ethylene vinyl acetate