The Influence of Adhesives and Adhesive Applications on the Recyclability of Paper Products

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ABSTRACT

The finiteness of many resources made it necessary to think about how to save them by developing resource-saving technologies, eg, to recycle materials. An especially successful example for this concept is the recycling of used paper. To execute the idea of recycling it is necessary to think about a material recycling of the used products when designing them. This means that all additives of the process have to be designed in the way they do not disturb the later material recycling. Today adhesives play a decisive role in the production of almost all paper products, especially for mass-produced articles and therefore it is important to choose adhesives and adhesive applications that do not disturb the recycling of paper products. While in recycling processes which take place at high temperatures (eg, glass or metal recycling), the influence of the adhesives usually formed by organic polymers can be ignored, in the field of low temperature recycling technologies, the question whether an adhesive is recycling-friendly or not can only be answered by knowing its application and the recycling process. If the recycling processes are known it is easy to chose suitable adhesives and adhesives applications. For paper recycling there are a lots of adhesives and adhesive applications today that fulfill the requirements of recyclers.

INTRODUCTION

While at the beginning of the industrial revolution nobody much thought about the finiteness of natural resources, during the last decades of the twentieth century the call for processes which carefully treat resources became louder and louder. The finiteness of many natural resources made it necessary to think about how to save them by developing resource-saving technologies, eg, to recycle materials. To execute this recycling successfully, it is necessary to consider this early during the construction and production of goods, and this leads to the idea of “sustainable development”. Sustainable development was introduced at the environmental summit in Rio de Janeiro in 1992 as a model for future action. The idea is that people living today should be able to satisfy all their needs without leaving a heritage of pollution, climate problems, and used-up resources for future generations. Legal requirements show this trend in our society. For instance, the introduction of the Packaging Directive in Germany in 1991 was an important step into this direction. The recycling rates and collecting systems predetermined in it have had a strong influence on the recycling of packaging material. On a European level this thought was legally established in the European Packaging Directive (Directive 94/62/EC) dated 20 December 1994. The objective of this directive was to reduce the amount of packaging waste in Europe by 50% by 2001. At the end of 2001, as a new aim, a recycling rate of 55-70% by the year 2006 was proposed. The Directive 2004/12/EC of the European parliament and of the council amending Directive 94/62/EC on packaging and packaging waste has set further targets. In order to comply with the objectives of this directive,

member states shall take the necessary measures to attain the following targets covering the whole of their territory (Article 6 b), d), e)): No later than 31 December 2008 60% as a minimum by weight of packaging waste will be recovered or incinerated at waste incineration plants with energy recovery. No later than 31 December 2008 between 55% as a minimum and 80% as a maximum by weight of packaging waste will be recycled. No later than 31 December 2008 the following minimum recycling targets for materials contained in packaging waste will be attained: 60% by weight for glass; 60% by weight for paper and board; 50% by weight for metals; 22,5% by weight for plastics, counting exclusively material that is recycled back into plastics; 15% by weight for wood.

To execute the idea of the recycling law it is necessary to think about a material recycling of the used products when designing them. This means that all additives of the process have to be designed in the way they do not disturb the later material recycling.

RECYCLING OF MATERIALS

Material recycling has been carried out with many product types successfully for decades. Products which consume a lot of energy in production have been manufactured from secondary raw materials for a long time. Proven examples are the reuse of metal and glass, both of which are recycled at high temperatures and then processed to new materials with a quality that cannot be distinguished from the original raw material. This use of secondary raw materials allows considerable energy savings, as high as 60-95% when recycling metals, depending upon the kind of metal. Energy savings in glass recycling are still at about the 20% level. Total energy saving of course also depends upon the collecting and sorting system. In recent years there have been increased efforts to improve the quality of secondary raw materials. Products that are composed of several materials are divided before recycling so that each material can be recycled separately. Dismantling costs can be reduced from the start by properly considering product design, marking of product ingredients, and attention to recycling-related industry norms and regulations.

Today adhesives play a decisive role in the production of almost every good, especially for mass-produced articles. Since recycling is so important today, it is not surprising, that the variety of different recycling processes for primary materials influences the development of modern adhesive technology. For many recycling processes today there are optimized adhesive systems and adhesives applications available. In this connection recycling is of special importance regarding products with a short lifecycle. Products that have a lifecycle that lasts for only several days or weeks, such as packaging or magazines, have to be designed so that they can be taken back into the resources loop immediately. Adhesives in the paper and packaging field are expected to be especially recycling-friendly.

PAPER RECYCLING

In spite of synthetic packaging materials and electronic media internationally, paper and board consumption is increasing steadily. While in 1950 about 50 million tons of paper were produced world-wide, in 1998 approximately 300 million tons were produced. In the year 2010 four hundred million tons are projected. In Europe, Japan and the USA, where one fifth of the world population lives, more than two thirds of the paper is consumed. To make this increase in paper production possible and for saving resources at the same time paper recycling has been intensified steadily in the last decades and has now reached a high technical level.

Most of the products made of paper only have a life span of a few days (eg, newspapers) or a few weeks (eg, packaging). Therefore it is not striking that the thought of recycling has been a firm component of paper production for a long time. As early as the 13th century waste paper was reused. Not only the technical conditions have changed in the following centuries, but also the reasons for recycling. At the beginning, suitable raw material for producing writable material was scarce and the use of waste paper was largely determined by economic interest. Especially in countries with not much wood the consumption of wood could be reduced and the forests could be saved. Today the economic advantages are largely exploited. The increase of waste paper use in industrialized countries is determined by problems of disposal. In the sense of resource saving, the recycling of used cardboard packaging materials and other papers is a further example in accordance with the idea of sustainable development. It is a prime example for treating all resources including the renewable ones as carefully as possible. Paper recycling in Europe has increased markedly throughout the 1990s. The amount of paper collected and recycled at the end of the decade is roughly two thirds more than at the beginning. This means that the recycling rate (percentage of recovered paper use compared to total paper consumption) was 54,6% in 2005, compared to about 40% in 1990 [Fig. 1] according to the Special Recycling 2005 Statistic (September 2006) of CEPI. A total of 46.6 million tonnes of paper and board were recycled in Europe in 2005 and more than half of the paper used in Europe today is now made from recovered paper. Recycling of paper is a significant part of the paper manufacturing process in Europe but also a large industry in its own right, with links to a number of sectors in the global economy. Building on the success of the initial “European Declaration on Paper Recovery” launched in 2000, which was responsible for pushing Europe’s recycling rate to 54,6%, the new declaration launched in 2005 covers more European countries, more European organisations and has even greater ambition. The European sectors have now joined forces with the common goal of further increasing Europe’s recycling rate to 66% by 2010. The new target would mean that some two tonnes of paper is recycled in Europe every second. Twelve different sectors in the paper value chain have pledged their support for the declaration covering all paper and board products and aims to make sure that all of the correct systems are in place to push the European paper recycling rate even higher.

The prime objective of waste paper recycling is to utilize the fibers contained in pre-or post-consumed waste paper. Non-fibrous components, whether they derive from paper or are added during the processing or the use of paper, should be removed at the highest degree possible to avoid quality defects in the produced papers (specks, holes) and production process faults (eg, wet web breaking).If you take a closer look at paper and paper products, you notice that even simple papers and boards do not only consist solely of cellulose fibers. They contain many additives that guarantee the particular use properties of the papers. In the paper mill many papers are coated to improve the surface properties. In processing, most of the graphic and packaging papers are printed afterwards and then partly varnished or coated. Due to the large number of materials that get into contact with the paper during its life-cycle, there are very different impurities. Regarding disturbances in production especially thermoplastic impurities (stickies) must be mentioned. These impurities that occur at higher temperatures during paper production can get sticky and so lead to process disturbance. As many paper additives have thermoplastic characteristics, it is not striking that problems with stickies can occur in the paper machine drying sections. At these temperatures of 80°C to 120°C, many thermoplastic substances get soft and sticky. Thermoplastic deposits can also show sticky properties at or only slightly above room temperature, depending on their glass-transition temperature. In principle all non-paper components that can form sufficient adhesion and cohesion can be a source of sticky impurities (eg, resins from wood, coating binders,

inkbinders, coatings, impregnation, adhesives). To fulfil both these requirements, stickies have to be liquid or at least must be soft enough to form sufficient adhesion bonds. At the same time the particles must be big enough and must have enough cohesion to achieve noticeable effects. Thermoplastic particles (stickies) big enough to achieve noticeable effects (sufficient adhesion and cohesion) get into the paper machine principally in two ways. Particles come in from the waste paper to the drying section already big enough, or they agglomerate during the recycling process, forming large particles from small ones.

THE PAPER RECYCLING PROCESS

If we talk about the influence of adhesives in paper recycling, first it is necessary to make a distinction between external and internal paper recycling. External recycling (post-consumer waste) is the recycling of external accumulated paper waste. Whereas printing inks are removed by flotation, the most important removal process for most of the other impurities is sorting.

If you look at the post-consumer paper recycling process in detail, you will notice that it is primarily a mechanical process (supported by heat and alkali). In this process one tries to weaken the composite of the cellulose fibers by applying mechanical power, so that only single cellulose fibers remain. The mechanical power in a pulper or in refining drums is chosen so that it allows a fast but careful fiber isolation. These single fibers can be used for new paper. As early as 1998 the paper recyclers demanded for such materials in the guide to an optimum utilization of recovered graphic paper from the Bundesverband Druck: ‘Non-paper components should be dimensioned and mechanically stable in such a way that they survive as large particles, without being comminuted, in the conditions of pulping and allow mechanical separation by means of punched screens, slot screens and centrifugal purifiers. Relevant examples are cover foils, staples, thick adhesive layers, various product samples. Materials applied in very small dimensions or disintegrating into very small parts are unfavourable, because they can not be removed using today’s conventional sorting methods. Recovered paper components which dissolve in the process under standard conditions of deinking (pH 8 – 10) and reach the process water pose a risk of unintended spreading to all parts of the paper machine. This results in the requirement that recovered paper should contain as few components as possible which dissolve or disperse in a weakly alkaline medium and form sticky residues or cause discoloration’. To fulfill these requirements the paper mills that produce paper or cardboard out of waste paper have lavish cleaning systems (sorting machines and for graphic papers also deinking systems). After defibrating the suspension passes through several successive cleaning systems in which impurities are separated by their density, size or shape. Today slotted screens with a slot width up to 0.15 mm are considered most effective as far as sticky removal is concerned. The modern recycling processes in the paper recycling mills today allow the sorting of big and compact (> 0.2 mm) thermoplastic impurities. In spite of the most modern technology it is not possible to remove water-soluble, dispersed and very small particles from the water-loops by sorting. Although these particles are so small that you would not expect them to cause any harm, they may agglomerate during the process and so grow to bigger particles (the so-called secondary stickies) that then cause the well-known disturbances in the paper machine or the well-known quality flaws of the finished product.

Internal paper recycling (pre-consumer waste) describes the recycling of production waste within a paper mill with a processing line on site. An example is tissue and towel mills where paper goes directly from the paper machine to rewinders for the production of bathroom tissue or paper toweling. During this processing, adhesives are used for

laminating, for the pick-up of the first sheet on the tube, and for the end sheet tiedown, and the waste, or ‘broke’, created here must be returned to the paper mill. Here, in general, only a relatively small amount of rejects are moved back into the paper production process. In contrast to adhesives that get into paper mills by external recycling and have sources varied and unknown, in internal recycling there is only a relatively small amount of adhesive and the types used are known exactly. These mills normally do not have lavish sorting machines. As the additives added to the paper in production cannot be sorted out mechanically, most of the time the additives are required to be completely water-soluble or re-dispersible, even if this pollutes the process water with impurities. Adhesives that are used in this production are normally classified by the European Standard EN 1720 “Adhesives for Paper and Board Packaging and Disposal Sanitary Products Determination of Dispersibility” or by the American TAPPI standard UM 666 “Dispersibility Test for Adhesives”. Today there are many adhesives that fulfill the requirements.

PAPER AND PACKAGING ADHESIVES

Most products made of paper and paperboard, especially for mass-produced articles like bags or cartons made of paper, or graphic products like catalogues or magazines are manufactured with the help of adhesives to form complex finished products. Hence it is getting more important how adhesive applications influence the idea of the closed loop economy. Even though adhesives will not be recycled individually due to their small amount, it must be considered that they should not disturb the recycling of the paper. As adhesives play an important role in these products, it is not surprising that paper and packaging adhesives have a dominant share of the adhesive market [Fig. 2].

APPLICATION OF PAPER AND PACKAGING ADHESIVES

Next to the properties of the adhesives used to bond paper and packaging materials also the adhesive application and the adhesive application systems are important in paper recycling. In the packaging sector many kinds of application processes are used. Adhesives are applied by different rollers [Fig. 3], discs [Fig. 4], segments [Fig. 5], and nozzles [Fig. 6]. As this is a very heterogeneous market, the application processes are very different and adjusted to every production process. In spite of the variety there has been a clear, noticeable trend in recent years towards shifting the adhesive application from open systems to closed systems. Nozzle application from the closed system is advantageous compared to roller, wheel or segment application from open systems because the adhesive is only exposed to the environment during application. Early setting on parts of the application devices is not possible. By the use of closed systems maintenance and cleaning work can be reduced significantly, which results in cost saving because less time is needed for machine stops. These reductions of cleaning work and the reduced amount of waste and wastewater are also ecologically advantageous, and lead to further cost savings because the amount of adhesive residues that has to be disposed of is reduced.

ADHESIVES IN PAPER RECYCLING

Whether an adhesive film is mechanically stable enough to withstand undamaged the paper recycling process, so it is not torn into small pieces which pass all sorting facilities, depends on its inherent strength and on its geometry. Furthermore it has to be considered that the cohesion of all materials decreases as temperature rises. The same adhesive will behave completely different when the adhesive film shows different geometry or the recycling process takes place at different temperatures. Thick, compact adhesive films will normally not be broken at moderate temperatures. However the wish for thick adhesive

layers during processing of paper and board often conflicts with the wishes of the paper converter. In general one tries to apply as little adhesive as possible, if only for cost reasons. In addition, modern computer-controlled nozzle systems can optimize the adhesive application. There are today many adhesive application systems that apply single points (up to several hundred separate adhesive points per second) and therefore lead to an extreme cost-saving and clean application of adhesive [Fig. 7]. Next to the saving of adhesive and efficient production, such systems also have ecological advantages. Closed systems need considerably less cleaning expenditure, and in the case of water-borne adhesives very little waste or waste water is produced. Even with mechanically stable, non-water-soluble adhesives, there is the danger that these films created out of small droplets are so thin that they can not be sorted out in the screening machines of the paper recycling mills. Moreover, very thin films and high temperatures reduce the power that can be absorbed by the adhesive film, and it is easily torn into very small parts.

The best classification for the adhesives regarding their influence on paper recycling is the general view of the adhesive film properties, as in waste paper the adhesive exists as set or cured film [Fig. 8]. In general an adhesive film should have a higher inherent strength than the substrates to be bonded, for example a much higher inherent strength than paper, cardboard or carton or composites (fiber tear) and is requested to have properties which do not disturb the recycling: that is, it should be easily separable. Non-water-soluble adhesives which are characterized by a high glass transition temperature show enough cohesion in a sufficient layer thickness to survive the pulping process without damage. The problem is getting more complex regarding water-soluble or re-dispersible adhesives, as the environment in the recycling process contributes to the weakening of the mechanical stability of the adhesive film. At the predominant pH-values and temperatures of the aqueous environment in the waste paper mills, considerable stress is put on films that contain hydrophilic groups. This can lead to the complete destruction of these films, as the cohesion gets lost completely. By a good choice of raw materials, however, water-borne adhesives can be formulated in the way they are not torn into such tiny particles in the recycling process, that they remain mechanically sortable [Fig. 9]. Figure 10 shows the adhesive particle distribution of two water-borne pressure sensitive adhesives (PSA) coatings after the repulping of labels. As you can see clearly, adhesive film A is torn into much smaller particles than adhesive film B. The large particles of adhesive film B can be removed from the cellulose suspension nearly completely by mechanical sorting, as tests have shown. The particle sizes given in Fig. 10 are not the real size of the three-dimensional adhesive residues, but sizes that were found in a picture-analytical method. These are two-dimensional measurements that were converted into circles of the same size. From these circles the diameters were calculated.

For internal paper recycling (pre-consumer waste) adhesives based on polymers like polyvinyl alcohol, polyvinyl pyrrolidone and its copolymers, polyethyloxazoline, copolyesters containing sulphonated material, hydrophilic polyurethane and polyethyleneoxide, but also adhesives based on starch, dextrin and cellulose show a good water-solubility or re-dispersibility. In this connection one has to emphasize that dissolving or re-dispersing additives in paper mills can lead to two problems: a contamination of the process waters that leads to more waste water pollution; and future agglomeration of dissolved or re-dispersed additives. If they are thermoplastic materials, so-called secondary stickies can be formed.

SUMMARY

Recycling of materials will be increasingly important. Since many materials are bonded, it is important to choose adhesives that do not disturb the recycling of the primary materials. In recycling processes which take place at high temperatures, the influence of the adhesives usually formed by organic polymers can be ignored. In the field of low temperature recycling technologies like in paper recycling, the question whether an adhesive is recycling-friendly or not can only be answered by knowing its application and the recycling process. If the recycling processes are known it is easy to chose suitable adhesives. For paper recycling there are a lot of adhesives today that fulfill the requirements of recyclers.

In paper recycling a lot of adhesives can be sorted out easily. But the ability to sort an adhesive film in the recycling process is not only defined by the properties of the adhesive, especially its cohesion, but also by its geometry, and it also depends on the application. Another influential factor is the fixing of the adhesive film to the substrates. Furthermore, the characteristics of an adhesive film are influenced enormously by the pH-value and the temperature of the water in which the recycling process takes place. To be able to draw a really useful conclusion, the only way is to test the finished paper product. In the finished paper product the adhesive film is what it will be like when the product is later recycled. The influences of geometry and substrates can be tested exactly. Only tests on finished products can indicate whether the finished product or components of the product (eg, adhesives, but also coatings, inks or other additives) influence recycling or not.