Annals of
Reviews and Research

Mini Review
Volume 12 Issue 2 - October 2024
DOI: 10.19080/ARR.2024.12.555831

Ann Rev Resear

Paper Recycling

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Submission: October 04, 2024; **Published:** October 14, 2024

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Annotation

Paper recycling as a model example for assessing any recycling process. A brief description of the technological process of recycled paper production. Assessment in terms of energy intensity, relative costs, biodegradability, waste generation, and wastewater pollution. Calculations were made for the most common procedures, or average values of the respective technological operations were used.

Keywords: Paper recycling; Chemical treatment; Biodegradability; Social demand; Recycled packaging paper

Introduction

In 1979, the author of this article was the first in Czechoslovakia to deal systematically and professionally with the issue of the utilization of textile secondary raw materials. He conducted a survey of these materials in the entire Czechoslovak textile industry, focusing on the amount and type of waste generated. The then industry utilized much of it in the production of a range of products. In response, the author proposed a technology for the recovery of such secondary raw materials that could not be processed at that time. To solve this problem, the author became the European inventor of the technology of through-air bonding of non-woven fabrics and at the same time the first in the world to build a pilot plant for this technology.

Subsequently, he participated in the creation of a nanofibre production technology. In 1984, the author was a key figure in the founding of state-run biotechnology research in Czechoslovakia. The research resulted in the development of a technology for the production of bio-active wound dressings for surface tissue loss injuries. The definition of bio-polymer, which has been adopted into technical terminology, also comes from the author of this article from that period.

During his professional career, the author was engaged in research regarding paper, HDF, PE, and PET recycling. As a senior state researcher, he also developed numerous other products. And since it was a legal obligation at that time to start manufacturing every such developed product, the author always participated in the development of the respective industrial production technology and its commissioning. Thus, during his professional career as a scientist and manager, the author became acquainted with various technologies in detail, developed many of them himself, and eventually implemented all of them. Therefore, he is familiar with the entire process cycle in a comprehensive way, from research planning, through its implementation, subsequent development of the relevant technology, commissioning of the technology, to the launch of the developed product on the market.

In state research, it was a rule that before any product was approved by state authorities for development, a marketing analysis with economic analysis was required. The author thus well understands that the value of any product cannot be expressed in terms of its price, considering that any currency in the world is a very relative product that has a variable value in place and time due to many factors. Therefore, it is necessary to use measurable variables for any comparison that are independent of human factors. Any product value analysis also needs to include not only the costs of development, production, position, and market characteristics, but also a number of other parameters. Simply put, all products need to be viewed holistically if are to express their true value, which is never expressed merely by its price.

In a view of the above brief introduction, the author used paper recycling as a model example for this article. The same methodological approach, however, can be applied to any other product or technology, especially with regard to recycling.

Paper Production and Recycling Technology

In order to understand the below results and information, it is crucial to familiarize oneself with the entire production technology [1]. The basic raw material for the production of the most papers are cellulose fibers from wood. These are obtained by first cutting the wood into wood chips. Wood chips are then removed from lignin and other unwanted substances and formed into pulp. These processes can be chemical or just mechanical, but most often a combination of both is used. The pulp is then ground into individual cellulose fibers in water in refiners. The distribution curve of fiber length and fineness is very important in this grinding process, as it determines the subsequent mechanical properties of the resulting paper. For certain types of paper, the pulp is also chemically bleached.

But for paper to be paper and have the desired physical and mechanical properties, the pulp alone is not enough, and a binder must be added, which is most often modified starch, and also fillers, which are usually micro ground limestone or chalk, or both. The mixture is also added with optical brightening agents and titanium or zinc white (TiO_2 and ZnO). Alternatively, other fillers may be added to achieve certain desired properties. For this example, which regards recycling, however, this article will discuss office paper [2].

Office paper, if printed in black, poses no issues in the downstream processing or user chains. The basis of all black inks and dyes is carbon black (C). Some problems may arise in the case of color printing, where the inks contain chromophores [3] of certain metals. In such a case, it is advisable to utilize one of the chemical pulp isolation processes that degrades the contained dyes. Therefore, it is best to focus on paper products that are not used for hygienic applications. And this is ideally packaging paper. Old, used, or collected paper is shredded into smaller pieces. These are then again processed in a refiner, which grinds them into pulp fibers in water. This is where the first set of problems comes into play.

For any paper to have the basic mechanical tensile strengths and the required flexibility, it must contain at least 5% fibers longer than 20 mm. Otherwise it would be brittle and break easily. To this end, the fiber distribution curve is checked during the first grinding in refiners. However, the second grinding in refiners shortens the fibers by about 60-80%. This causes that paper cannot reach the necessary mechanical strength for more demanding applications after a second grinding, even when using binders other than modified starch. Therefore, it is usually necessary to add 50% of virgin fibers to the secondary pulp [2]. (Note: This is an average value as the amount of virgin fibers varies according to the type of paper recycled and the technology used.) Due to the composition of the recycled material, modified starches as binders are no longer sufficient as the content of fillers increases with the recycled paper content, so acrylate dispersions are added to the paper pulp as auxiliary binders [4]. As a rule of thumb, the lower the proportion of virgin fibers in the recycled pulp, the more powerful binders need to be added. For some types of packaging paper, it is possible to use 100% recycled pulp, but this is uncommon and the resulting product has poor mechanical properties. In terms of balance, 100 kg of primary raw material (used office paper) usually can be used to produce around 200 kg of recycled packaging paper.

This packaging paper can then also be recycled, which is a common practice. Packaging paper would again be shredded and ground in a refiner. In that process, however, fibers of the virgin office paper have already been shortened to about 1 mm, while the fibers of the virgin pulp added during the production of the packaging paper in the first recycling are again shortened by 60-80%. This has two consequences. Approximately 50% of additional virgin fiber has to be added again, but even so the fibers are already so short that acrylic binders have to be used to achieve the required mechanical properties. And if this new packaging material is to be mechanically stressed, it needs to be laminated with PE. If we consider that 100 kg of primary office paper can be used in the first recycling to produce 200 kg of packaging paper, this quantity would generate 400 kg of secondary packaging paper in the second recycling. The resulting paper can usually no longer be recycled, although some literature states the possibility of recycling up to 6 times. However, these are such exceptional cases that cannot be taken as an applicable general benchmark.

Each processing stage also raises the question of biodegradability. Primary office paper has a biodegradability of about 3 weeks in nature due to the modified starches used as binders [4]. It then breaks down into individual cellulose fibers. These fibers have a longer biodegradability that depends on climatic conditions. In the first recycling, when acrylic binders are used, the bio-degradation time is extended to 1 year before the packaging paper breaks down into cellulose fibers. After a second recycling into a packaging material laminated with PE, the bio-degradation time in nature raises to 40 years [5]. (Note: Biodegradability depends on climatic conditions, environmental contamination, and whether the process is aerobic or anaerobic).

Energy intensity is another factor to be taken into account. A chipper has roughly the same power input as a grinder, and cutter has. The production of pulp and its grinding in a refiner at any stage have the same energy intensity, as well as paper pulp flotation, paper forming, and drying. It can therefore be concluded that each processing stage of paper production and recycling has the same energy consumption per 1 kg of paper produced. But for recycling, however, the energy balance must also include the cost of collecting the paper and transporting it to a processing facility, whereas for virgin paper, it involves only transporting wood to a mill. These costs make each recycling stage approximately 20% more energy intensive than the production of virgin paper. And if PE lamination is applied in the second recycling, the energy intensity of producing such packaging paper increases by about 40%.

How to cite this article: Peter S. Paper Recycling Ann Rev Resear. 2024; 12(2): 555831. DOI: 10.19080/ARR.2024.12.555831

Various literature states substantial energy savings in the production of recycled paper in the range of 40-60%. However, these calculations use some marginal conditions and items for virgin paper, but exclude similar ones in the recycling process. For example, the energy and transport costs of collection of recycled paper are not included in the calculations, yet they include the transport of tree logs over long distances. Also not included in these calculations are the increased energy costs of capturing and disposing of wastewater pollution from recycling processes. These claimed savings may occur for certain technologies and types of paper under certain conditions, but these are specific cases [6].

In addition, the cost of wastewater has to be factored into the overall balance. Although its quantity is roughly the same at each technological stage, each round of recycling increased pollution and reduces biodegradability. When wood is converted into pulp with cellulose fibers separated from lignin and other unwanted substances, water pollution is comparable to that caused by chemical treatment of recycled pulp, since this process releases binders and fillers used. Grinding in refiners shortens the cellulose fibers, so the amount of very short fibers in the pulp that are not captured during the floating and forming processes increases sharply with each round of recycling. These then pass into wastewater, since only a fraction of them are captured by filters, and eventually reach wastewater treatment plants, similarly to previously used fillers. Unfortunately, wastewater treatment plants utilize aerobic microbial technologies that cannot deal with cellulose fibers in a reasonable amount of time, not speaking of fillers which pass through unnoticed.

Note: Since there are a number of specific papermaking processes, the numerical values used here are presented as those most common, or as average values, for the respective application (Figure 1 & Table 1).

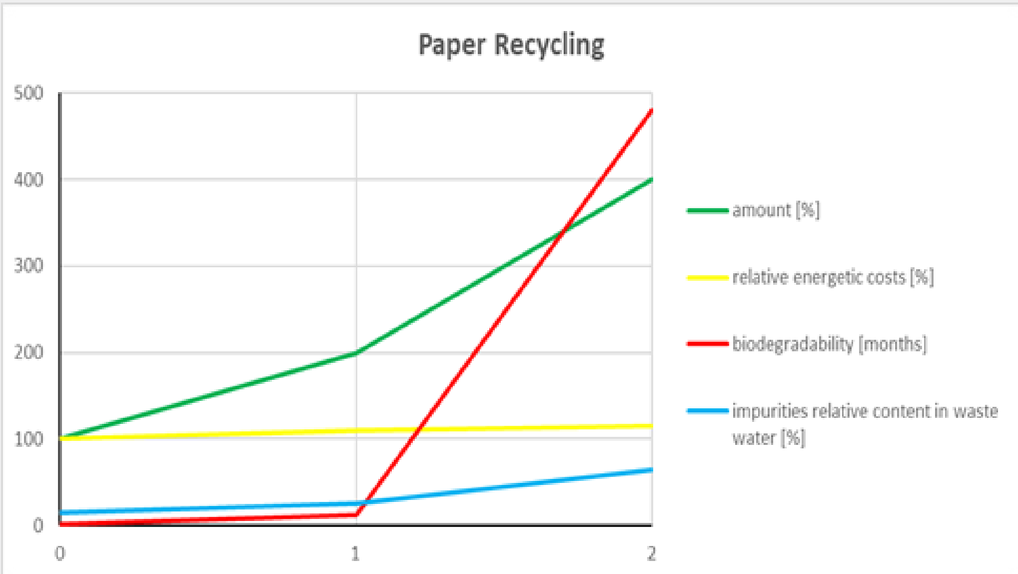

Figure 1: Summarizes the curves for the amount of paper produced in the different stages, the biodegradability, the energy intensity, and the pollution content in wastewater.

Table 1: Presents the data used to create the charts.

Paper Recycling			
Parameter/Value			
Paper production steps	**Primer paper**	**First recycling**	**Second recycling**
steps of recycling	0	1	2
amount [%]	100	200	400
relative energetic costs [%]	100	110	115
biodegradability [months]	1	12	480
impurities relative content in waste water [%]	15	25	65

Conclusions

When producing twice recycled paper, approximately 25% of the primary raw material (virgin fibers) is saved. When recycling is done correctly, the amount of virgin paper originally produced only moves up the timeline. It only delays its utilization further into future. But at the cost of significantly reducing its biodegradability. This is only up to the point where burning such recycled paper becomes the only practical way to dispose of it. Along with this, recycling increases the energy and production requirements for the production of such paper. Each recycling process also generates more wastewater pollution than the production of virgin paper and decreases biodegradability of this wastewater.

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Although some literature indicates the possibility to recycle paper up to 6 times, at some point, it will reach a state where it can no longer be recycled. For each recycling stage, the above balance applies, including that waste is just moving along the timeline and growing in volume. All the increased costs of recycling are paid for by people's taxes, since recycling is funded by subsidies. Thus, in general, the production of recycled paper is economically more expensive than the production of virgin paper. Even though recycling saves trees, it comes at the cost of other negative effects.

This article is intended to present what methodology should be used when evaluating recycling processes, yet it leaves out some parameters that relate to local conditions, which however, must be taken into account in other cases. These include, above all, the availability of raw materials and their supplies, transport distances, and, last but not least, market conditions, social demand, and other marketing factors.

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DOI:10.19080/ARR.2024.12.555831