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Environmental aspects of waste paper recycling

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Nowadays, production and use of recycled paper is well established and widely accepted. The necessary technologies are available and it is possible to produce all types and qualities of paper using former waste paper as raw material. The recycling of waste paper has a number of advantageous environmental aspects:

- *it saves natural resources like wood, energy and fresh water*
- *it minimizes water pollution and saves space on landfill sites and incinerator capacity.*

Recycled paper can be used for the same purposes as paper from primary sources. There are no indications that recycled paper creates any harm to human beings resulting from contamination by:

- *germs and pathogens*
- *chemicals, e.g. formaldehyde*
- *dioxins and furanes*
- *heavy metals, e.g. lead*

The de-inking sludge is waste of normal category that can be landfilled or incinerated together with municipal solid waste.

Short introduction to paper manufacture

The basic raw material for the production of any kind of paper is vegetable cellulose fibre. These fibres are present in the cell walls of all plants. Cellulose comprises approximately 40-50 per cent of the dry weight of woody as well as non-woody plants. The cellulose fibres are bound together by lignin. There is a great variety of raw materials available for paper production, e.g. leaves, rice husks, bark, bamboo, grass, wood, flax, straw, banana leaves, etc. Apart from these primary raw materials, waste paper and old rags can be used as well. Industrialized paper manufacturers use wood as their major source for cellulose fibres.

The first step in paper manufacture is pulping, wherein the cellulose fibres are separated from the bonding material, lignin. There are basically two methods for converting raw fibre material into pulp: mechanical pulping and chemical pulping (or a mixture of both). Mechanical pulping is used mainly for coniferous woods (soft wood). It aims at a high yield rather than a pure pulp. The product is called wood pulp and is used for low quality paper.

The chemical pulping method dissolves the bonding lignin by chemical reaction and separates the cellulose fibres with a minimum of degradation. The chemical method can be either a sulphate or a sulphite pulping process. The respective sulphate or sulphite waste liquor (black liquor) in addition with the liquid residue of the subsequent bleaching step are the major sources of water pollution resulting from paper manufacture. Because of the gentler method of separation, the fibres of the chemical digestion retain most of their characteristic intrinsic strength. The

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obtained kraft pulp is therefore used to produce high quality paper.

To remove remaining impurities from the pulp and to enhance the brightness of the final paper different bleaching processes are used. They can be divided into two major groups - the chlorine bleaching methods and the chlorine-free bleaching methods. The chlorine bleaching methods utilize elemental chlorine as well as chlorine containing compounds while the chlorine-free bleaching processes use chemicals like hydrogen peroxide, elemental oxygen, ozone, hyposulphite, etc. The bleaching process normally consists of several steps with an intermediate washing of the pulp. This results in a high consumption of water and due to the chemicals involved, a major amount of contaminated liquid residue.

The transformation of the pulp into paper or board is carried out through four main operations: formation and drainage, pressing, drying, and reeling, winding and sheeting. During formation and drainage the fibre and water suspension is distributed over a wiremesh so that the water drains through the mesh. A wet sheet of paper is retained. Machine-made papers are formed continuously on a moving wire. Before reeling the water content of the fresh paper must be reduced. The necessary press comprises two rolls revolving in contact with pressure applied between them. After pressing the paper still contains 50 to 60% moisture, most of which must be removed before reeling. The most common drying method makes use of rotating cast-iron cylinders that are steam-heated internally. Drying normally takes place on a series of such cylinders. After drying, the paper is reeled for subsequent finishing. Smooth surfaces are obtained by passing the paper through the rollers of a callender. Due to the different types of paper and respective quality requirements the described basic process is modified in various ways leading to the great variety of paper products known in modern life.

Waste paper recycling technologies

Cellulose fibre has the special property of forming fibre to fibre bonds by the exchange of hydrogen ions as the water is removed. As a result the stability and strength of paper is achieved. This process is reversible. By adding water the strength of the fibre bond is diminished.

Since the fibres in waste paper have already been pre-treated, slushing or defibring, with a minimum amount of cutting, is all that is required in pulping of waste paper. It is essential to choose equipment and processes that minimize fibre shrinkage and cause as little damage to the fibre as possible. Nevertheless, a certain loss in quality has to be accepted when reprocessing fibrous material. Depending on the quality and cleanliness of the waste paper, approximately 75 to 95% of the waste paper can be converted into new paper products.

Apart from the fibrous material waste paper carries a number of impurities into the pulp the most important of which is ink. Without the removal of the ink, the final recycled paper shows a brownish or greyish colour. Modern paper recycling processes therefore incorporate de-inking steps that remove a maximum of 70% of the ink. Two types of de-inking processes are used - washing processes and flotation processes. The latter is most common in Europe since the amount of contaminated wastewater and losses of fibrous material is minimized. During washing or flotation the major amount of the filler materials are also removed.

Other impurities in waste paper pulps are string wires, rags, plastics or heavy material like pins, chips, metal pieces, stones and dirt, etc. These are removed by certain devices like deragger robes, bucket elevators or sieves. More serious are remainders that stick to the fibre itself such as lacquer, coatings or glue. These may later on interfere with the

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sophisticated printing processes of high quality papers.
To enhance the brightness, waste paper pulp is also bleached, but only by chlorine-free technologies. The further steps making the final paper follow the same process line like pulp from primary sources.

Environmental impacts of paper manufacture from primary and secondary sources

To assess the environmental impacts of paper production and consumption a number of aspects are of importance. The figures given in this chapter are taken from a publication of the German Federal Office of Environment /1/:

- **consumption of wood**

The amount of wood needed as a raw material for paper manufacture depends on the type of wood, the applied technology and the quality requirements for fibres and paper. The production of wood pulp in general consumes less wood (1.02 to 1.12 t of wood per t of paper) than the production of kraft pulp (1.65 to 2.25 t of wood per t of paper). The production of recycled paper from 100% waste paper requires no wood. The environmental impacts of the extensive utilisation of wood due to an increasing paper consumption depends on many factors (e.g. exploitation of natural forests, spread of monocultures, availability of wood residues from timber and furniture production, sustainability of forestry, etc.). Since sustainable methods of forestry are not common everywhere, the increasing consumption of paper results in deforestation and related negative impacts for the environment.

- **use of energy**

When looking at the energy consumption of paper manufacture, it is important to carry out a `life cycle analysis´ that includes all steps of paper production and utilization (e.g. production of wood, manufacture of paper, transport of wood and paper, utilization of paper, etc.). For the three main types of paper (wood pulp, kraft pulp, waste paper pulp) the energy required for the production of one ton of paper is given.

	Paper production	**Pulp production only**
Wood pulp	30-37 GJ/t	15-25 GJ/t
Kraft pulp	35-54 GJ/t	26-45 GJ/t
Waste paper pulp	13-17 GJ/t	5 GJ/t

Tab. 1: Required energy for production

Taking into consideration that the use of energy has a strong influence on the consumption of natural resources (coal, mineral oil and gas), the generation of air pollutants (particulates, SO_2, NOx, greenhouse gases) and consumption of water, a reduction of the overall energy balance for paper manufacture is advisable.

- **fresh water demand**

Depending on the technology applied for the production of wood or kraft pulp the consumption of fresh water varies over a wide range. While older technologies consume up to 400 m^3 water per ton of paper, modern processes with more or less closed water circuits need only 20 to 50 m^3 water per ton of paper. Compared with approximately 5 m^3 water per ton of paper, the production of recycled paper requires the smallest amount of fresh water.

- **amount and contamination of waste water**

The utilization of large amounts of fresh water during paper production leads to large amounts of wastewater with a great variety of contaminants. The process steps of debarking the wood, separation of

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the bonding substances like lignin, removal of ink and other impurities from waste paper pulp and bleaching of the pulp from both, primary and secondary sources are relevant for the generation of wastewater.

Some ten different contaminants of the wastewater from paper mills are recognized to be hazardous under German environmental law. Most important are the organic chlorine compounds that come from the chlorine bleaching processes (e.g. chloroform, tetrachloroethane, chlorobenzen, chloro-phenol, chloracetic acid, dioxines and furanes, postchlorinated biphenylene). These are often highly toxic, stable over a long period and accumulate in the biomass.

Since it is quite complicated to measure and control the individual compounds that contaminate the wastewater of paper mills, certain sum factors are used to describe the water pollution:

a) Biological Oxygen Demand (BOD)

The BOD factor describes the amount of in-water dissolved oxygen that is necessary to degradate the organic contaminants. Normally the BOD_5 is used. This factor gives the amount of oxygen in mg/l that bacteria and other mircro-organism require in five days in order to decompose the polluting organics. BOD_5 is a measurement for easily biodegradable contaminants.

b) Chemical Oxygen Demand (COD)

The CODfactor describes the amount of oxygen dissolved in water that is needed for the total oxidation and degradation of all contaminants. This factor also takes into account those substances that are not easily biodegradable and that therefore can enter natural water resources and might create problems when extracting drinking water from surface water reservoirs.

c) Adsorbable Organic Halogenide (AOX)

The AOX factor describes the amount of organic compounds in wastewater that contain at least one halogen atom and that are adsorbable on activated carbon. These substances are recognized to be hazardous because of their toxicity, long retention time and ability to accumulate in the biomass. The AOX factor is suitable to describe the pollution of water by substances most relevant to the environment.

Over the last few years the paper manufacturing industry has put a lot of effort into wastewater treatment plants in order to meet the requirements of environmental legislation. Depending on the type and age of technology, the efficiency of the wastewater treatment and the type of pulping material, the respective pollution factors vary over a wide range.

Table 2 indicates that wastewater contamination strongly depends on the type of pulping and bleaching. The production of pulp from waste paper shows very low water pollution factors compared to the other processes.

- **influence on municipal solid waste generation**

Waste paper is a major component of the municipal solid waste. If it is not recycled it must be landfilled or incinerated together with the other waste fractions. This will consume space in landfill sites and will occupy capacity of municipal solid waste incinerators. Although waste paper is not recognized to be a hazardous waste, it will create air pollution when burnt or will contribute to the production of leachates and methane gas during the anaerobic digestion process at landfill sites.

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factor	kraft pulp				wood pulp	waste paper pulp
	sulphite pulping		sulphate pulping			
	conventional bleaching	chlorine-free bleaching	conventional bleaching	chlorine-free bleaching		
BOD_5 (kg/t)	26-81	2-25	20-30	1-8	2-50	0.1-1.5
COD (kg/t)	70-290	20-35	72-120	22-65	3-90	0.8-5
AOX (kg/t)	3.7-7	0	3.7-10	0.22-1.2	< 0.02	0.012-0.2

Table 2: Wastewater contamination according to different types of paper production technologies

In many countries the recycling of waste paper already has a long tradition and is supported by a well established collection and processing structure. In Germany approximately 50% of the raw material for paper production is waste paper. This saves a lot of space at landfill sites or incinerator capacity. If the recycling of paper had not taken place, 50 additional major landfill sites or 29 additional incinerators would had have to be installed in the last 40 years to cope with the huge amount of waste paper. Although the incineration of paper generates energy, the energy saved by using waste paper as raw material for the pulp production is higher.

During the pulping process solid residues are generated. This is true for pulp from primary and secondary raw materials. Typical residues from the pulping of primary raw material like wood are bark, sludge of the washing operation, and ash from the generation of energy or chemicals. During the pulping of waste paper the major residues result from the sorting of the paper, the removal of impurities from the pulp and the de-inking process. On average some 0.19 m^3 of solid residue is generated per ton of recycled paper while the production of paper from primary sources produce 0.08 to 0.16 m^3 of solid waste per ton. These residues have to be landfilled. Some parts can also be used as incinerator fuel for energy production.

Use of recycled paper

From early times critical questions and objections have arisen against the use of recycled paper. Some critics had doubts about the acceptance of recycled paper by the customer because of its mean-looking greyish colour. Others feared that recycled paper would create damage to modern copying and printing machines or believed that there were health hazards for human beings resulting from the use of recycled paper. After many years of experience in using recycled paper, none of these objections have been proven.

- **Recycled paper for offices and printers**

In 1981 the German Federal Environmental Office commissioned a study in order to test the applicability of recycled paper in modern office use. These tests showed that there were no significant differences between paper from primary sources and recycled paper in respect to its use as writing paper, copying paper or printing paper. Similar to paper from primary sources, quality differences among recycled paper depend more on the selection of the raw material (quality of waste paper) the production process

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(pulping, washing, bleaching), the additives (fillers) and the finishing (coating, glazing). Only a few problems have been reported when using recycled paper for very high quality printing. For these special printing processes, very small remaining particles of former glue, lacquer or synthetics (so-called hotmelts) have effected the printing quality.

- **Health risks due to the use of recycled paper**

Waste paper is sometimes contaminated during its use and can contain germs and pathogens that might cause diseases. Therefore, there were some fears that recycled paper might be hygienically objectionable. But during the recycled paper production process the paper passes through process steps where it is heated to high temperatures (e.g. drying step) and thus it is practically sterilized. Investigations carried out in Germany proved that recycled paper is hygienically acceptable even for food packaging.

In 1990 there had been some rumors that recycled paper contained a higher amount of formaldehyde which degases during use. Formaldehyde can come from some special paper and board qualities, where it is used during the production process. But since these papers are very rare in Germany (the situation might be different in other countries) and mixed up with other formaldehyde-free papers during the recycling process, formaldehyde is hardly traceable in recycled paper. Its content is well below any limit set by the environmental legislation.

What seems more serious is the contamination of paper by dioxins and furanes. During the bleaching with chlorine a number of organic chlorine compounds are formed, among them dioxins and furanes. Apart from the bleaching, dioxins in paper can also originate from wood preservation chemicals or certain printing colours. Investigations proved that some chlorine bleached papers contain 30 to 50 ng TE/kg of dioxins and furanes (TE = toxicity equivalent). Chlorine-free bleached paper on the other hand often contains only < 1 ngTE/kg. During the recycling of paper chlorine bleached paper and chlorine-free bleached paper is mixed. Since no chlorine bleaching is applied during the recycled paper production, the intake of dioxins from chlorine bleached paper will be diluted by the other more or less dioxin-free papers. Nowadays, this results in a dioxin content of some 3-4 ng TE/kg for standard recycling paper, a figure well below any limit given by the environmental legislation.

These figures are the result of research and development and were not always like that. The dioxin and furane content in recycled paper has decreased steadily during the last few years since the paper industry has switched over more and more to chlorine-free bleaching processes. At the beginning of paper recycling sometimes 50 to 60 ng TE/kg have been measured in recycled paper. When investigations about the reasons for the contamination were carried out, certain sources of dioxins were identified. For example, carbon paper was identified as a major source of chloroparaffins, and some cardboard boxes for exotic fruits contained reasonable amounts of pentachlorophenol. Both substances are likely to form dioxins and furanes during the papermaking process.

The situation in developing countries may be different from industrialized countries. Depending on the development stage, the availability of technology and financial resources, the paper industry might still use older papermaking technologies that are based on chlorine bleaching processes. Additionally, environmental control regarding the use of certain chlorine (or dioxin) containing chemicals (herbicides, fungicides, wood protection chemicals, paper and cardboard impregnation, etc.) might not be as strict. Therefore, there are more possibilities for the intake of dioxins and furanes into the

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recycling paper production. Nevertheless, dioxin and furane contents in the vicinity of 60 ng TE/kg are not dangerous and meet the accepted environmental standards.

As regards the contamination of recycled paper, heavy metals, in particular lead have been discussed. During former printing processes that used printing types from lead, traces of lead were deposited together with the ink. There was the fear that during recycling, in particular, if paper was recycled several times, lead might accumulate in the recycled paper. Investigations have proven that the lead content of such recycled paper never exceeded any critical limit. At the same time, the de-inking technology was developed that removes the major amount of the lead together with the ink. Although enriched in the de-inking sludges, lead was never a problem. The concentration of lead was well below the limits of, for example, lead allowed in sewage sludge that is suitable as fertilizer on farmland. With the disappearance of old fashioned printing technologies, the "heavy metal problem" disappeared as well. Nowadays, de-inking sludges can be landfilled on normal landfill sites or can be incinerated in normal municipal solid waste incinerators without any special precaution.

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