Sustainability of Printing Techniques: Potentials and Incomparable Aspects

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Abstract

CEWE uses digital printing and photographic techniques to produce photos, CEWE PHOTOBOOKS and further highly valued photo products. Whereas advantages in quality, efficiency and minimum cost of ownership are well communicated, the full picture on the sustainability aspects of a printing technology is learned during operation. Only recently have sustainability aspects been addressed more prominently by printing technology providers, often for the purpose of gaining competitive advantage.

This paper concentrates on sustainability aspects of printing techniques from the point of view of a print service provider (PSP) and displays data measured by CEWE. Each printing technique we regard offers potentials to improve. The complexity of the evaluation is further increased by the product properties, which puts certain sustainability aspects into perspective. So for instance recyclability plays a more important role for an advertising mail than for a personalized photo book.

Thus, sustainability is not seen as an absolute measure but means to assume responsibility for the whole life cycle of products overcoming the boundaries of companies and the limitations to single aspects like carbon footprint or water footprint.

Open and transparent communication of sustainability aspects is the silver bullet for continuous improvement. Eager competitiveness and advertising of single advantages by ignoring the whole picture is obstructive and does not help to continuously improve sustainability of printed products.

1. Introduction

1.1 Objective of this Paper

Different printing technologies compete for quality, efficiency and minimum cost of ownership. Recently more sustainability aspects are of increased interest. Many printing technology providers (PTP) are now addressing these issues, in part to gain a competitive advantage. As a print service provider (PSP) we see an increasing number of customers actively seeking more sustainable products and choosing from a variety of offers.

At CEWE different products are produced with different printing techniques. Among them are digital printing with liquid toner, solid toner, inkjet, standard offset printing, as well as silver halide photographic printing. The obvious questions for us as a PSP are: what is the right product, the right technique and how shall quality – cost – sustainability aspects be evaluated.

This paper concentrates on sustainability aspects of printing techniques as they are used for photographic application, currently, as in the past, the main business of CEWE. The paper covers the above mentioned printing techniques, photographic AgX as well as digital printing, but omits the standard offset printing process.

In a previous paper sustainability issues from the point of view of a PSP were addressed referring to a specific product, in that case our brand product, the CEWE PHOTOBOOK [1]. This paper shall address more generally sustainability aspects of those printing technologies that are used by CEWE as a PSP. With experiences and measurements in our production sites we want to contribute to the discussion about sustainability aspects and their improvement.

1.2 Sustainability as an improvement process

Sustainability embraces ecological, social, and economical responsibilities. Quality and cost are economical dimensions of the three-dimensional sustainability framework. Broken down to printing technologies further sustainability aspects comprise social responsibilities such as work place safety (OHS, occupational health and safety), product safety, and ecological responsibilities such as waste and recyclability, energy consumption, carbon footprint, VOC, ozone, and dust emissions, water usage and quality of water effluent.

The PSP has to choose not only the printing technique with appropriate chemicals and colorants, but also adequate media, mainly adequate paper. On top of that, finishing of different print products determines further processing and chemical options. Quality and cost considerations are more or less straightforward to determine for printing techniques. Much more complicated is the evaluation of further sustainability aspects, and more often than not, these are considered only after the printing technique has been established in the manufacturing process. Furthermore, the different longevity of products produced at the PSP puts aspects into perspective. So for instance recyclability plays a more important role for an advertising mail than for a personalized photo book.

One conclusion of this paper is that, no matter which printing technique is used, there is always potential to improve sustainability aspects. While one aspect may be better than with the competing technique, another aspect might require further improvement. Thus, sustainability is not seen as an absolute measure but rather as a trigger to the improvement process for aspects other and more than just cost or quality. Sustainability means to assume responsibility for the whole life cycle of products, overcoming the boundaries of companies and the limitations to single aspects like carbon footprint or water footprint.

1.3 Current Trends of Sustainability in Printing

In the recent past, a lot of research papers, overviews, company communication, and even advertisements, have addressed sustainability issues of printing. It is not the intention of this paper to give an overview of these. Whereas PTP company advertisements often communicate strengths of techniques only, and whereas PTP research often concentrates on the improvement of a single issue, the PSP has to see the whole picture and needs to know weaknesses and problems of technologies and materials in order to make decisions. However, weaknesses and problems are very rarely addressed and only reluctantly communicated.

Furthermore, I review critically the competitiveness of sustainability, which has become common place in the digital printing industry. Comparisons of single aspects that do not embrace all sustainability aspects are too constricted to base decisions upon. Going public with such comparisons can thus be misleading. The limitation to an arbitrarily chosen aspect alone does not help to improve a products' life cycle. Efforts should be made to advance sustainability of printed products and to improve obvious weaknesses.

I would like to give two examples to illustrate that simplification and limitation to an arbitrarily chosen sustainability aspect may give rise to misinterpretations and can lead to false conclusions.

Recently, a PTP company advertised the better environmental friendliness of LEP (liquid electro photography) versus AgX (silver halide photographic printing), and hereby referred to the fact that water is needed for AgX processing [2]. The fact that LEP shows VOC emissions of a substance which is to be classified "H304: May be fatal if swallowed and enters airways" was not addressed in the same publication [2]. Neither were carbon footprints or end of life criteria like deinking addressed.

A DEP (dry toner) company lately advertised their better deinkability as compared to LEP [3]. On the other hand, subsequent lamination of DEP prints, in order to overcome weaknesses of heat resistance, make it undeinkable. So it is often a question of the chosen product's properties that determines a sustainability aspect.

PSP in this case do appreciate that an LEP company is trying to improve on the obvious weakness of deinkability [4, 5]. It would be ideal if a technology's weakness was communicated simultaneously with their installation to avoid damages in a deinking plant for instance [1].

Sustainability does mean accepting the onus of responsibility and to seek solutions to improve on the weaknesses in the life cycle of products.

Finally, the proposal of sustainability evaluation models [6], in which a simple factorial model combines eutrophication of water, waste production, eco-toxicity, etc. with aspects as work place safety and toxicity to human, is misleading. In the extreme, this might balance human life to that of bacteria, and is thus of moral and ethical dubiousity.

PSPs need the disclosure of issues regarding work place safety, product safety, and environmental impacts and PSPs should be enabled to base their decisions upon these.

2. Sustainability Aspects of Printing Technologies

2.1 Silver Halide Photographic Printing (AgX)

AgX is an old technique that centers around the heavy metal silver (Ag) as its halide salts are light sensitive. But silver is an environmental hazard (H400: very toxic to aquatic life and H410: very toxic to aquatic life with long lasting effects). Photographic paper is double-sided PE laminated white fresh fibered paper with the light sensitive emulsion above the PE layer. It consists of AgX crystals sensitized with sensitizing dyes and dye-precursors (couplers) in gelatin. During processing, silver, AgX, sensitizing dyes, and more water soluble additives are taken off the paper. Combined with the chemicals used for photographic processing a mix of effluent results which has been an environmental pollutant for a long time. However, due to the combined effort of the AgX producers and the processing laboratories, the pollution has decreased considerably. AgX can now be taken as an example of sustainability as improvement process.

At CEWE, all processing solutions are recycled to their physical maximum. Due to dry paper entering the colour developer (CD) solution, a certain amount of water is needed with CD recycling. With an average recycling ratio of 90 %, about 10 g/m^2 of chemical concentrates are needed as fresh dosage and 20 g/m^2 have to be disposed of. In central Europe, photographic waste chemicals are all used in the concrete industry for nitric oxide reduction. The main water usage is for the final wash of paper after processing. Of the 2.2 L/m^2 water usage that we publish in our sustainability report [7] only about 1.2 L/m^2 are used for paper processing, and we have installed machines working with as little as 0.4 L/m^2.

Independent of the amount of water used, the extent of pollution is determined by the carry-over from the last processing bath. On a regular basis, the water effluent is controlled by chemical analysis in our central lab; the main pollutants are

ammonia (NH_4^+): 450 (± 150) mg/m^2,
sulfate (SO_4^{2-}): 600 (± 200) mg/m^2, and
silver: (Ag): 3.0 (± 1.5) mg/m^2.

The State limits are met at all times, the one for silver being 30 mg/m^2. All waste water of photographic processing is cleaned at the waste water treatment plant. The effluent ingredients are a minor hazard. Sulfate and halides lead to salting of the waters, ammonia and organic ingredients including gelatin lead to eutrophication. Silver in processing effluents exists as an Ag-thiosulfate complex that degrades to passive silver sulfide - comparatively passive and non-hazardous due to the extremely low solubility and very low resulting silver ion concentration [8, 9].

A further water hazard is EDTA (Ethylenediaminetetraacetic acid), a non-biodegradable complexing agent used to stabilize ferric as the bleaching agent. The water immission of EDTA was reduced by more than 50 % in the German photographic industry between 1995 and 2002. At CEWE, the immission of EDTA today is 0.7 (± 0.1) g/m^2. However, the final fate of EDTA is assumed to be the degradation of ferric EDTA [10, 11, 12]. As only ferric EDTA is emitted by the photographic processing site, the EDTA immission does not contribute to heavy metal displacement.

Finally, at CEWE we developed a super-low-immission system, in which water immissions are reduced by 80 %. Measured values are

ammonia (NH_4^+): 100 (± 40) mg/m^2,
sulfate (SO_4^{2-}): 120 (± 40) mg/m^2, and
silver (Ag): 0.6 (± 0.3) mg/m^2.

The disadvantage is an increase of the carbon footprint by roughly 10 % due to increased energy usage of 0.01 kWh/m^2. As photographic water effluents - when emitted to a waste water treatment plant - do not pose a severe hazard, we only implement this super-low-immission system when local authorities request for further immission reduction.

A carbon footprint of photographic paper has not been published, but must be comparatively high. At manufacture, chemicals are mixed into gelatin and the AgX crystals undergo a ripening process. Paper has to be dried after coating, then cut, packed lightproof, and distributed. At photographic processing printing, processing, and drying consume appr. 0.1 kWh/m^2, resulting in 40 g CO_2e/m^2 when calculated with the German emission factor of 400 g/kWh. This represents about 10 % of an estimated minimum of 500 g CO_2e/m^2 for paper manufacturing.

Chemical processing of AgX at the PSP is the most critical sustainability aspect for AgX. At CEWE the processing machines are replenished automatically and there is neither contact nor are there discernible emissions in the production hall. The chemistry sector takes care of all desilvering, chemical treatment, and mixing of the process chemicals with trained personnel, protective gear and exhausts where necessary. The most critical component of processing chemicals is the developer agent which is highly sensitizing and as such a very harmful substance. Therefore it is mandatory to train personnel and provide appropriate equipment.

In regard of work place safety, the most important step in the history of photographic processing was the use of liquid concentrates, thereby holding the hazardous chemicals in a liquid matrix as opposed to using powders. Additionally, exposure is minimized with automatic mixing.

Since laminated layers are inseparable, the product and the production waste is finally disposed of by combustion or better: energy recovery, which represents the fourth of five levels of the European waste hierarchy. Impurities of photo prints in the waste paper collection from households will be screened at the deinking mill.

The quality of AgX is still the level pole for photographic printing. The consumer receives a safe and long-lasting product. Nevertheless, digital printing techniques have challenged this. Even better quality is available at remarkably higher costs or nearby qualities with slightly lower costs.

2.2 Liquid Electro Photography (LEP, Liquid Toner)

Due to small toner particle size LEP prints have a smooth, photographic appeal. In order to challenge AgX for quality, PE-laminated paper has been designed for LEP. In this case, neither the carbon footprint of the paper nor the fact that the paper is equally unrecyclable result in sustainability advantages over AgX.

But non-laminated paper can be used with LEP. Due to the heating of the intermediate transfer drum and an extensive cooling to limit the VOC emissions, the carbon footprint at the PSP operation is close to that of AgX. Taking make-ready time, machine up-time and wastage into account, we have calculated our energy usage of about 0.1 kWh/m^2 (i. e. 40 g CO_2e/m^2) of printed area. Information on the carbon footprint of the colorants and of the liquid carrier is not published.

The most critical sustainability aspect is the VOC emissions due to the carrier liquid. The emission rate is 200 mg/m^2 [1]. A possible carrier liquid could be Isopar L by Exxon Mobile, which is classified as “H304: May be fatal if swallowed and enters airways”. This calls for additional safety measures at PSP’s production, although the determined concentration of said VOC is below the legal limit [1]. Even though food safety approvals of printed samples were awarded to our supplier, we have found about 20 mg/m^2 of carrier liquid residues in printed samples. These might partly be bound in the colorant matrix due to the mutual solubility of toner and liquid. However, overall product safety as well as OHS issues could be much improved by a non-hazardous carrier liquid.

In cooperation with our supplier we initiated a project to replace isopropanol as a cleaning liquid with ethanol, usage of which is in the order of 10 mg/m^2. The result is an OHS risk reduction as we are replacing a substance with an additional H319 (causes serious eye irritation) and H336 (may cause drowsiness or dizziness) risk phrase to one that shares only the high flammability, H225.

Currently, a joint project has been started in order to reuse the overflow carrier liquid instead of delivering it to an external recycling operation, where it is downcycled to a cleaning liquid. The disposal volume of carrier liquid effluent at CEWE is approximately 3 g/m^2.

Another critical sustainability aspect of LEP is its difficulty with deinking. This is especially severe when standard paper is used and very short-lived products are produced. Deinking has achieved high publicity, see for example [3 - 6, 13, 14], and every printing technology meanwhile tries to comply with the requirements of deinking.

In order to improve the perceptual quality of an LEP print it can either be coated or laminated. In the latter case this leads to complete undeinkability as with photographic print. In the case of coating, the most recent technology of UV-coating gives rise to several questions, some of which are addressed in chapter 2.5.

2.3 Dry Electro Photography (DEP, Dry Toner)

Although DEP is the most commonly used digital printing technology and offers a competitive cost of ownership, CEWE has not made wide use of it so far. The bigger toner size compared to LEP reduces the appeal to the photographically trained eye. Improvements on quality are continuously developed by the PTPs and are tested in our laboratories.

Another drawback is the low melting point of the toner, which also restricts the use of DEP. Overcoming the weakness with lamination or UV-coating reduces a major sustainability advantage: it renders the DEP product undeinkable.

Because of the fusing in DEP, energy consumption is as high as with LEP, about 0.1 kWh/m^2 (i. e. 40 g CO_2e/m^2). Information on the carbon footprint of the colorants as well as of the toner polymer is not published.

From PSP’s point of view, there are two major sustainability concerns, one applies to the polymer material the toner is made of, the second to the control of airborne particles.

Depending on the supplier, polyester resins may contain residues of tin organic compounds used as polymerization catalysts. Resin material may also have residues of monomers, and if these are on the basis of Bisphenol A (BPA), they are subject of a serious discussion in the US and Europe.

Ideally, the toner material would be a biodegradable polymer, so that prints not entering an elaborate waste stream can biodegrade. This is most desirable for an advertising mail or another short-lived print item. Photo books, posters and similar long-term print products, on the other hand, should last a few decades before they start to biodegrade.

The second aspect is the particulate emission with dry toner techniques. Toxicological research showed that not only toner but also fine dust of silicon oil from the fuser unit can pose a health risk [15, 16]. Thus, the integration of wax into the toner polymer matrix instead of depending on fuser oil would be an advantageous sustainability development. This would also facilitate the finishing of the product as a lot of difficulties with coating, laminating and gluing result from silicon oil residues on the print.

Ozone emission is well controlled according to our measurements that showed 10 ppb, the limit being 100 ppb [17]. This is true for both, LEP and DEP machinery.

Cleaning fluids supported by the suppliers should be either water based or ethanol. We were often offered cleaning fluids which pose an unnecessary health risk to our employees. So far we have been suggested cleaner fluids containing terpenes which can cause allergies or which are based on mineral oils with potentially cancerogenic aromatic hydrocarbons and other hazard characteristics.

2.4 Inkjet, water based

CEWE uses water based inkjet printing for large format posters and canvas. Quality is very good, cost is very high. In order to deliver photographic quality the paper is PE-laminated and not applicable for the waste paper stream but has to be disposed of for energy recovery just as photographic paper. In order to accept water as the ink solvent, the photographic inkjet-paper is covered with one or more ink receiving layers. Thus, the inherent carbon footprint of the paper is about as high as photographic paper. Printing consumes only about 0.03 kWh/m^2 (i. e. 12 g CO_2e/m^2) because of the low speed. Information on the carbon footprint of the inks is not published.

Additional environmental drawbacks are the fact that a lot of water is transported and the fact that ink cartridges constitute a sophisticated high volume plastic waste, which should more effectively be reused. These contribute to the carbon footprint of this technology. Suppliers of water based ink must be careful not to use additives or solvent supplements that might become subject to authorization or restriction. 1-Methyl-2-pyrrolidone is a possible solvent additive and entered the SVHC list just recently [18].

Still, water based inkjet appears to be the technology with the lowest OHS risks used at CEWE. With water based inkjet safe products are manufactured and very promising developments are presently entering the market offering increased speed, reduced cost, and improved environmental performance, one of which is deinkability [14].

2.5 UV-Inkjet

Large format printing at CEWE is also done with UV-inkjet. With its superior substrate flexibility, UV-inkjet offers a wide variety of attractive photo products. We currently print on acrylic glass (PMMA), on PETG, on aluminum and on foam centered board.

Power consumption and the resulting carbon footprint of printing are mainly due to the UV lamp which initiates the polymerization of acrylates by decomposition of photoinitiators. Our results show about 0.5 kWh/m^2 (i. e. 200 g CO_2e/m^2). Information on the carbon footprint of the inks is not published.

The sustainability communication by many suppliers of UV-inkjet can be misleading. Organic solvents and thereby VOC emissions are reduced as compared to solvent inkjet. But this is balanced by high OHS risks and products, which are not safe to every standard. For instance, if a product needs to be food-contact safe, it is rather to be printed by solvent inkjet.

Improvement potentials start with the UV lamp. Mercury vapor lamps are used widely, as LED technique is more expensive. With LED the formation of ozone can be effectively reduced – but many machine suppliers are still too reluctant to offer this option. Our workplace measurements showed 20 ppb of ozone at the UV-inkjet machine and up to 40 ppb ozone at the UV coater [17]. Working with the inks needs protective gear, as almost all acrylates in use are irritant (H315: Causes skin irritation, H319: Causes serious eye irritation) and many of them are sensitizing (H317: May cause an allergic skin reaction).

An unpleasant odor is often formed with UV curing which the worker is exposed to, and which in some cases stick to the product for a long time (up to months). As the photo product is mostly for indoor use, CEWE chose a supplier with a bearable product smell. A smell also lingers in the production area, even with increased aeration. When we initially started production of UV-inkjet and UV-coating without exhaust or aeration increase, workers complained about dry mouths, dry airways, and headaches. Preventive measurements of possible hazards conducted by an analysis institute had negative results for the reaction products. Substances causing the unpleasant odor are either unknown or those known were below the detection limits of gas sampling with subsequent GC/MS (0.02 mg/m^3). In order to assume product responsibility, all UV inkjet machines should be equipped with a built-in exhaust.

It is believed that benzophenones after photoinitiation cause unpleasant odors [19]. Many suppliers are therefore using triarylphosphinoxides instead. However, the latter are also toxic for reproduction (e.g. Trimethylbenzoyldiphenylphosphinoxide, R62: Possible risk of impaired fertility), and are not an ideal replacement for benzophenones.

The main concern with UV-inkjet and further UV techniques like UV-coating is however that the point of responsibility remains unclear. PTPs, machine producers and ink producers, deliver efficient machines and safely packed chemicals. At the PSP, a radical polymerization is initiated under uncontrolled conditions. Most of the PSPs are small companies with limited know-how. As the term “UV-drying” is widely used in the industry, a chemical reaction is often not anticipated. With optimal conditions, the polymerization efficiency is believed to be around and above 90 % [19]. As the status of the UV-lamp might not always be optimal and as speed and lamp power can be changed, nobody can confirm the efficiency of the polymerization.

Due to H-abstraction and disproportionation reactions side products are additionally formed. The resulting product is considered unsafe for food-contact due to migrating substances and is not suggested for toy application. Nevertheless, products we sent to the product test institute were regarded safe in the sense that they did not show forbidden substances above threshold limits.

Whereas PTPs deliver safe products to PSPs, the printed product might have safety deficiencies. Responsibility for product safety lies with the PSP. However, in order to fully assume their responsibility, the vendors of UV-inkjet as well as of other UV-colorant or UV-coating technologies should research the entire system, including side effects and including OHS risks, and bring the results to the knowledge of the PSPs.

3. Conclusion

As a conclusion, PTPs are to incorporate sustainability into their products and printing technologies. This should start at research level. Guidances are legislations and safety regulations as well as controversial discussions on chemicals as the ongoing discussions about nanomaterials or BPA (Bisphenol A) in Europe and the US.

The European Chemical legislation REACH [20] is restricting certain uses of chemicals (annex XVII) and authorizing others (annex XIV). The German GS sign conditions are met by applying read-across of chemicals restricted to other uses. Thus, by avoiding the chemicals listed in annex XVII although they are not restricted for the product in question, a safer product can be designed. The continuously increasing list of SVHC substances for which a duty of notification exists puts the PSP into a difficult situation [18]. But when PTPs avoid the chemicals of this list, safer products result and the need for notification ceases. All chemicals that are potentially carcinogenic, mutagenic, reprotoxic, represent vPvB or PBT substances, or have similar health and environmental concerns like endocrine disruptors or sensitizing substances will eventually appear on this list and must be avoided. Many of the substances are known and listed for instance on the SIN list of ChemSec, the international chemical secretariat, an NGO [21]. The SIN list comprises 626 substances compared to 144 on the current SVHC list as of June 2013 [18, 21].

Implementing safeguards into printing equipment helps to take care of OHS and product safety aspects. While research is busy replacing solvents, colorants or additives with safer solutions, application specialists of current products should address OHS and product safety issues to combine efforts of PTPs and PSPs for immediate improvement.

The waste stage of the printed products must be considered. The majority of printed products – books being an exception – have very short life spans, and thus recyclability and bio-degradability are important sustainability aspects. The PSPs are the ones customers turn to for answers and should be put in the position to have a qualified answer to their queries.

Open and transparent communication of sustainability aspects is the silver bullet for continuous improvement. Eager competitiveness and advertising of single advantages by ignoring the whole picture does not improve the sustainability of printed products.

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