Digital printing technologies and possibilities for recycling of printed papers: (a comprehensive overview)

Rossitza Sardjeva, Enitsa Koeva

Keywords: digital printing, paper, recycling, de-inking

Paper plays an important role in digital printing, especially towards quality requirements for this printing process. Digital printing is the hot topic among papermakers in respect with paper recyclability. Paper recyclability depends on inks systems used in digital printing, like toners and liquid inks and its setting mode on the different substrates as well. Possibilities for de-inking are accepted as a part of the whole quality of digital printing technologies. The basic process in paper recycling is the removal of the ink from the printed paper surface. This process is called de-inking. Generally, the de-inking process is based on the separation between hydrophobic inks and hydrophilic paper fibers. When there is a mix of papers, printed by conventional and digital printing systems, the de-inking process does not work properly. Evidentely in this case one must have a very important criterion for graphic papers products - their ability for recycling. Nowadays there is an increased interest in this subject and a huge demand in the digital printing market and towards papers producers. Generally, in every printing process, the interaction between paper (or substrate) surface and colorant is an important factor in determining print quality. This factor also arises the question connected with paper's recycling and utilizing paper waste after printing. Print and paper waste is now valuable and sought as a resource and is in high market demand.

1. Introduction

Nowadays the printing industry is shaped by digital printing technology and evidently this will be the main trend in the near future. Digital printing is the most talked about topic in the printing industry. According to Smithers Pira forecast digital commercial printing and in particular electrophotography (EP) and inkjet are most popular digital printing technologies and they have a strong potential for the future. For the years 2013 - 2018 inkjet will increase by 2/3 and electrophotography will reach 23% [18, 23]. The share of inkjet is set to double by 2020 [5].

Digital printing has helped print service providers better to cope with a changing print market. The value of digital printing today lies not only in replicating offset work on a smaller scale or at a shorter run length, but it lies in developing unique, high-value products and applications [13].

The great advantage of digital printing is the possibility to change the printed information after every cycle of the process and to print variable data of information (VDP). Variable data printing will reach a relative share of all digital printing market from 28% in 2012 up to 34% in 2017 [18]. Also digital printing has made inroads into the packaging markets, where offset and flexography have long been dominant [13].

2. Waste papers in recycling process

In 2013 paper was recycled at the impressive rate of 71.7% in Europe. Paper consumption has dropped by 14% whereas collection and recycling volumes have been retained at a very high level [8]. In Europe two tones of paper are recycled every second [9].

The basic process in recycling is the ink removal from the printed paper surface. This process is known as the *de-inking process*. Traditional de-inking technology predominantely depends on classical ink compositions with hydrophobic properties which tend to remove from the paper with the help of *floatation procedure*. For this purpose first of all printed papers have to be dispersed in special pulpers, making a strong dissolved suspension (~ 1% fibers and 99% water). To this mixture alkaline chemicals, soap, surfactanst and other additives have to added. Afterwards the suspension must be saturated with air.

The general technological scheme of de-inking includes different stages which describe the whole conventional recycling process, as [21]:

- separating the fibers in a water suspension, mechanically;
- removing of impurities using special sieves;

- centrifuging the suspension;
- ink floatation, by air using;
- inks removing on the surface (mechanical effect);
- rinsing out the pulp;
- bleaching with peroxide and then moving bleached pulp to regular paper production;
- recycling of waste water in a closed-loop process.

Floatation is the most usable method for the selection of the mixture on the base of water surface tension and different abilities of the particles to moisturize in water suspension. In this stage fibers have absorbed some

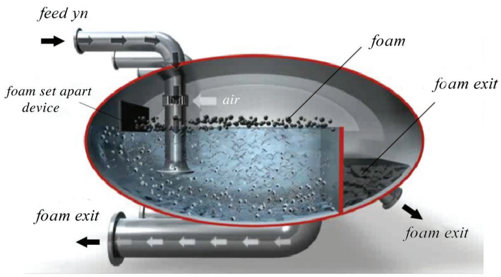


Figure 1: Floatation cell for deinking [21]

water while inks, being water-repelant, move to the surface. The air bubbles take the hydrophobic particles and transfer them in the foam (on the surface). Afterwards they can be easily removed (Figure 1).

The flow of "loaded" bubbles transfers up through the whole pulp. All this is repeated several times in order to achieve better ink separation and therefore to achieve acceptable pulp brightness.

Floatation is an effective process for the size of ink particles between 20 to 100 μm [21]. On the surface of floatation cell there is a field of brown foam, consisted of ink, paper fibers, fillers, white pigments coming from coated papers (if there is such type of paper in the mixture). When there are particles out of these dimensions, the floatation effect tends to decrease.

3. Problems in recycling process caused by waste papers, coming from digital printing technologies

The real problems with digitally printed papers are coming from the different ink systems used in digital printing technologies. This is evident in the different compositions of the colorants used in electrophotography (EP). Electrophotography (EP) can use dry and liquited toners. Inkjet inks use liquid ink systems as well [20].

The de-inking process used nowadays in papers mills had been developed for the offset inks with hydrophobic ink systems and hydrophilic fountain solution in the printing process. In the same time flexographic inks for newspaper printing, which are water-based, the vehicles are soluble in the alkaline medium what causes problems. In this de-inking process there are particles less than < 1 μm in size, what is impossible for the floatation purpose. For example, if the amount of flexographic printed papers is more than 5% of the paper mix, it will be very difficult to successfully de-ink this mixture [12].

On the other hand, inkjet inks are predominantely water-based and the traditional de-inking process and floatation lead to obtain darkened fibers. Generally, requirements for paper recycling are having such a paper mix, that contains as little as possible components that are soluble in a light alkaline solution because of darkened tacky residues.

Many developments are in the process now in order to find a reliable de-inking technology, suitable for digitally printed papers. It must be universal process applicable to different ink systems, which involve different digital and conventional technologies without the need to pre-sort printed papers [12]. Today's situation shows that it is necessary for digitally printed papers to be taken out of the mixture of waste papers. In practice it is more acceptable to have a very small amount of digitally printed papers that are mixed with conventionally printed papers.

What are the main features of papers printed by different digital systems?

3.1 Electrophotography with dry toners

Printed papers with digital dry toners EP contain particles that have thermoplastically merged with the paper surface forming wide flakes. They cause black dots in the recycled papers which cannot be removed by de-inking and even by bleaching.

Recycling technology includes several stages. One of them is the dispersion as an enough diluted water dispersion (suspension). The toner particles are removed from the paper fibers, forming flakes with thickness of 10-30 μm and a width of 50-500 μm. They don't move through screen and centrifuges. Moreover, the thermoplastical resin in the toner is an obstacle for the oxidative bleaching process, especially in black toner. Even a very small amount of such printed paper creates a visible effect and decreases the de-inked pulp's quality. More problematic in this aspect are prints coming from low speed electrophotographic printers. Because of the low speed, the toner particles spend more time in the hot fusing stage, resulting in particles that adhere quite strong to the fibers, where from they cannot be removed. The higher the speed of the printer, the better are the results for de-inking [11].

Dry toners are devided into two types: conventional and polymeric. The last one is chemically synthesized (Figure 2). Nowadays the polymeric toners are used more frequently. The size of the polymeric toner particles is smaller (3-5 μm), and more uniform compared to those of conventionally made toner particles. They make a homogenious dispersion, which is better for the print quality and photodrum resistance. During the fusing process these toners are softening without melting like conventional-type toners [7]. The average toner composition can be seen in Table 1.

The de-inking process can be improved in three ways: dispersion, improved flotation and agglomeration.

Dispersion includes an additional stage where the toner particles are destroyed to smaller particles which can be removed in the deinking process. Decreasing the particle size can be achieved by intensive friction and heating in the suspension. For this it is necessary to use more electrical energy.

Components	Quantity [%]
Soot	6
Polymetylmetacrylat	90
Agent for electrical charge	2
Zn-stearat	1
Si-oil	1

Table 1: Average composition of toners [7]

Improved floatation was successfully introduced to de-inking process a decade ago. This method is well known for the separation of mixtures on the base of water surface tension and chemical properties of the particles. Fine solid particles have separated based on their ability to be wetted. For this water, air, low power and a small amount of surfactant must be added for having an impact on the surface tension properties of the particles. In order to prevent a large amount of foam depresors, other additives, including pH control chemicals can be added [21]. Hydrodynamic factors play a substantial role influencing the break-up process happening between particles and air bubles. Theoretically toner particles can be totally removed from the fibers if certain parameters are met:

- maintain a relative low temperature of the pulp;
- process continuation must be at least 60 minutes;
- add different components such as: 0,2% dispersion agent, 1,5% soap, 2% NaOH.

Practical experience shows that the effect of the processes depends on the type of toner, type of printer and many other specific terms. The real effectiveness here is about 75%.

Agglomeration happens at the start of the recycling process. The whole process can be described as follows: in the recycling pulper waste papers, hot water and al-

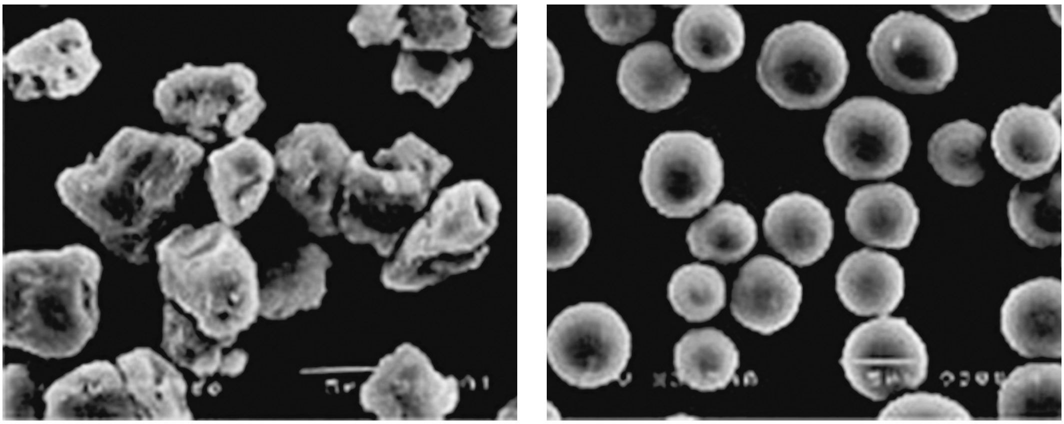


Figure 2: Classical (conventional) toner (left) and toner, produced by polymerisation (right)

kaline chemicals are subjected to intensive mixing. There fore paper is separated into fibers and toner particles are forcefully removed. The system converts in a water co-dispersion of hydrophilic fibers and hydrophobic toners and other additives like:

- filler – TiO_2 and $CaCO_3$;
- oil inks (from conventional printing papers);
- cation polymers like starch (in the solution)

For the purpose of separating the toner particles from the paper fibers their different surface tension and moisturizing ability are being utilized. Adding a small amount of petroleum oil, which is not water soluble, droplets will be formed which adsorb the hydrophobic toners particles and thus get covered with a film of oil. . The oiled particles stick to each other and form so-called liquid bridges (Figure 3). Particles sized less than 0,5 μm are subject to the Brownian Movement, together with the larger particles in the fluid. The formation of such bridges gives a strong result by descreasing the liquid capillary tension [21]. If we manage to select the right type of petroleum oil and increase the temperature we can have the right solution for thermoplastic resin in toners what makes it easier for the toners particles to stick together and increase the particle size. All this resulted as *agglomeration*.

After the agglomeration follows a conventional process of sieve and centrifugal treatment of the pulp leading to the removal of the larger sized particles. In this way the final product contains mostly clear paper fibers. In spite of all there are several problems here:

- The process requires a high temperature for heating very large volumes of water (50-70°C) and thus increase the energy consumption;

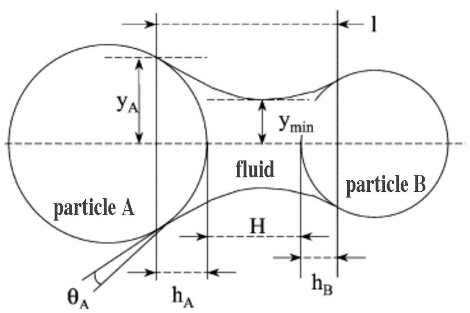


Figure 3: Particles merged by liquid bridge

- Also there are the problems with sticky particles, which adhere to the wall of the equipment as a residue, what causes clean-up problems.

On the other hand, the high temperature causes a softening of the toner resins.

In spite of these problems the process of agglomeration has real potential, because there is no need for additional equipment and expenses (<5% of the product price).

For the process of agglomeration, it is of great importance that the cation polymers in the papers' composition are moved to the pulp. One of these agents is modified starch, which have a negative influence on the process. This impact can be reduced by adding a surface active component (petroleum oil) and have the correct temperature (> 60°C). When only pure petroleum oil is used, without other surfactants, the influence of the cation modificator is not so important. In the whole temperature interval oil has a high effect on the agglomeration process. When the temperature is increased the toners agglomerate without any additives. This happens around a temperature of t ~ 65°C, where the toner particles are softened, thickened and are moving to each other.

Special attention has to be given to the *long and ultrashort pulsed laser methods* [1]. This is a relative new way using different types of lasers, with different wavelengths (λ), where, due to ablation process, toners can be removed from the paper surface. Ablation is an erosive process and by evaporation, toner particles are removed from the printed surface. There are different types of lasers - in the IR, visible and UV spectrum, with pulses in the nanosecond range. This method saves paper since the same waste paper is used directly, without the treatment with a special recycling process. Laser ablation of toners is a possible way to de-ink printed papers. This innovative method is now under further development and so far its importance is only theoretical.

3.2. Electrophotography with liquid toners

In digital electrophotography with liquid toners there are very serious problems in the de-inking process. A typical example here is the basic printer of HP Indigo, where the main process is described as an offset transfering (through an intermediate surface) of liquid toners to the substrate. Liquid toners are specific, usually named ElectroInks, which are characterised by very tiny particles (2-3 μm). This allows printing with small amounts of ink – the ink film thickness on the paper surface is about 1-3 µm. The liquid toners require a low temperature in the fusing and fixing processes which is favourable for the paper. The printed quality here is definetely higher compared to those with dry toners.

But on the other hand the smaller particles of liquid toners cause problems in flotation process, because they pass through the sieve. That is why the traditional de-inking process is not effective and in the pulp appear many dark dots which decrease the paper brightness afterwards. Instead of moving to the foam on the surface the colorants remain in the water and circulate several times through the closed loop circuit fluid. As a result, we have recycled pulp with low brightness. Bleaching is also not effective since black carbon pigment cannot be oxidized because of the toners thermoplastic resins.

The quality of this process depends on the ink systems and the type of printed paper as well. Coated papers are suitable and can easily be de-inked since there is no direct contact between paper fibers and toner particles – the toner layer is on the paper coating. When uncoated paper is used, due to direct connection between toner and paper fibers, fixed by heating and pressure, there is a very strong adhesion to the paper fibers what is a great problem for de-inking process.

In the practice there are many trials with electrophotographically printed papers with liquid toners. All these are on the based on different chemicals and physical systems in respect to the rheology of liquid carriers and their impact on the environment.

INGEDE had made tests papers printed with liquid toners and classified these tests as not successful [4]. (*INGEDE is an European Association of De-Inking, founded in 1989*).

Why are liquid toners so important for digital printing?

The basic advantage of EP with liquid toners is the possibility to have as high as possible print quality and high productivity as well. In the case of HP Indigo presses ElectroInks toner transfer in a *multipass* system, meaning that all colors are printed by one section. This is a great difference compared to the singlepass printers where we have four or more sections [14].
Liquid toners are suspensions with negative charged particles of pigmented resin dispersed in a liquid fluid (generally mineral oil) as a carrier. Mineral oil has a low volatility and its function is to make the particles tacky in order for them to adhere to the paper surface. As a result, fusing is accomplished at lower temperature and pressure, which means less energy consumption. Then the mineral oil (carrier) is removed in relatively long intervals by heating and evaporation. Setting time here depends on toner/substrate contact.
The main disadvantage of liquid toners especially of HP Indigo printers, despite their high printed quality, is that papers give very unsatisfactory results in the de-inking process. Trials were made by applying ultrasound in neutral fluid instead of an alkaline one, which is better towards the de-inking result. In spite of all this, so far there is not any method ensuring an acceptable enough result.
As the trend of electrophotography with liquid toners is growing permanentely in the next years, it means the amount of such printed papers will increase, therefore the negative impact on the recycling process will be very substantial.
The biggest difference between ElectroInks liquid toners compared to conventional inks is its content of charged particles in order to print using the electrophotographic mode. The right composition of such kind of toners is: pigment, dispersed in pured isoparafin, acting as a managing agent of the suspension. The pigments are the same as those used in offset inks, but the difference is that they act electrostatically and they have to be charged very fast and set as a solid layer on the substrate. Transferring to the intermediate offset surface, which is permanently heated in order to improve liquid evaporation, these electroinks form an elastic polymeric film, which adheres properly to the substrate and harden immediately. This results in something like a toner laminat on paper. There are several advantages compared to the conventional printing process:

- Liquid toner does not penetrate the paper, because the liquid part of the toner evaporates on the heated offset surface, before reaching the paper. That is why here there is no tone value increase what is happening in conventional printing;
- Every cycle the toner transfers almost in its full amount while in traditional offset printing process the ink film is splitting and only half of film thickness transfers to the substrate (in ideal case)

Nowadays there are two types of liquid toners: *low viscous isopar-based liquid toners and high viscosity liquid toners with non-volatile fluid as a carrier enabling a high content of solid. This kind of toners are known as a new generation of liquid toners.* New generation (HP Indigo, Océ, Xeikon-Trillium, Miyakoshi) solved the problems in the recycling aspect. At the 2012 drupa Xeikon has shown the Xeikon-Trillium system with a new generation of liquid toners. What's new in this new generation of liquid toners? Here there is a high viscous fluid (HVT, High Viscosity Toner), which is not volatile, instead of mineral oil. This is the essence of the Trillium technology of Xeikon. In fact, their liquid toners are the dispersion of toner particles in white pharmaceutical oil [17]. The toners particles are four times smaller than those of dry toners. The advantages of Xeikon Trillium compared to HP Indigo ElectroInks are:

- In this technology the toner carrier recycles without evaporation, because here there are no volatile organic compounds (VOC's);
- Toner particles don't get charged in their production process, it happens directly before printing.

The INGEDE tests have shown that high viscosity liquid toners of the Trillium system have good de-inkability results. Also, in an ecological aspect, this dispersion - toner particles/white oil - could be replaced from the paper surface by bioresins and vegetable oils [19].

New methods

For improving the recyclability of papers printed with liquid toners new methods are developed. One of them is using ultrasound in de-inking within a neutral fluid [24]. Ultrasound waves with a frequency of 20 kHz to 200 MHz are above the upper limit of human hearing. Ultrasound energy is a widely known way for particle separation. The process is very effective for improving flotation. The treatment with ultrasound can be applied 10 or 20 minutes before flotation. The longer the treatment, the better the result. The only disadvantage of this method is the relative low pulp brightness, because ultrasound waves impact not only toners but also paper fibers. That is why it is necessary to bleach using more concentrated bleaching chemicals. At Michigan University trials are made with an ultrasound frequency of 20 kHz in de-inking and thefinal results are tested according INGEDE's method 11 [2]. In these trials a comparions has been made of de-inking process in alkaline and in neutral fluids.

Assessment according INGEDE's method 11

This method works with six mandatory parameters to assess the de-inking ability:

- Y- brightness;
- a*- color, green-red, (CIELa*b*);
- A – purity: A50 – particles > 50 μm, A250 – particles > 250
- IE – removed ink;
- ΔY – darkness of the filtered water

Three of these parameters are connected to the quality of the deinked pulp – brightness, color and purity. The other two parameters - IE and ΔY depend on the process. That's why they are known as process parameters. In order to have a good de-inking ability the values of Y and IE must be higher, but those of A and ΔY – must be low. The evaluation of ability is made on the point base system according to the parameters values – brightness, color, purity, removed ink. The darkness of the filtered water is an important limit and desired values. The purity (A) is measured on the surface of impure particles devided in two classes according to their particles size.

Desired values depend on the paper type and the limit values are criteria for every type of printed papers. If the results reach desired values or better, the parameters obtain the maximum number of points (Table 2).

Parameters	**Y**	**a***	**A^{50}**	**A^{250}**	**IE**	**ΔY**	**Total**
Max points	35	20	15	10	10	10	100

Table 2: Max possible sum of points for different parameters

If the result is not satisfactory and does not meet the limit value for any parameter, the points are negative. With negative values of one or more parameters, the assessment is *"unsuitable for deinking"*. In order to form a final product assessment for the de-inking process, one has to sum up all six parameters points.

3.3 Deinking of papers printed by Inkjet technology

The problems coming from the Inkjet digital printing are mainly due to large differences of the ink systems used in this technology. Inkjet inks can be formulated in different ways: water- or solvent-based, with pigments or dyes, or hot melt type and others. Table 3 shows the average composition of water-based inkjet inks:

Components	Function	[%]
De-ionized water	Water carrier	60 – 90
Water-soluble solvent	Viscosity control	5 – 30
Pigment or dye	Colorant	1 – 10
Surface active substrate	Moisture, absorption	0,1 – 10
Biocid	Prevent appearance of microrganizms	0,05 – 1
Buffer	Keeping pH const.	0,1 – 0,5
Additives	Antifoams, chelate agent and etc.	>1

Table 3: The composition of water-based Inkjet inks [14]

For example, in black pigment inks there are numbers of fine distributed particles that can be replaced or eliminated by the de-inking process. But if there are more than 10% of inkjet printed papers in the mixture of waste papers the whole recycling will be unsuccessfully. Only a few pigment black inkjet inks can be de-inked effectively.

Today most of the paper printed on with inkjet inks is uncoated paper, including newsprint. With water-based inks (pigment or dye) the quality is not up to offset standards, but this situation is changing gradually. Figure 4 shows the process of ink setting - the absorption effect of water-based inks, with all components taken into the body of the paper through capillary action.

The penetration of the pigment is generally less than that of dye-based inks, as particles cannot travel easily past the paper fibers. Most of the papers used predominantely in inkjet are uncoated. Treating the paper surface with a fixative helps to quickly remove the colorants from the liquid phase of the ink, keeping a higher proportion on the paper surface. One mechanism is applying a cationic polymer and/or a multivalent metal ion such as calcium, magnesium, and others [20]. After

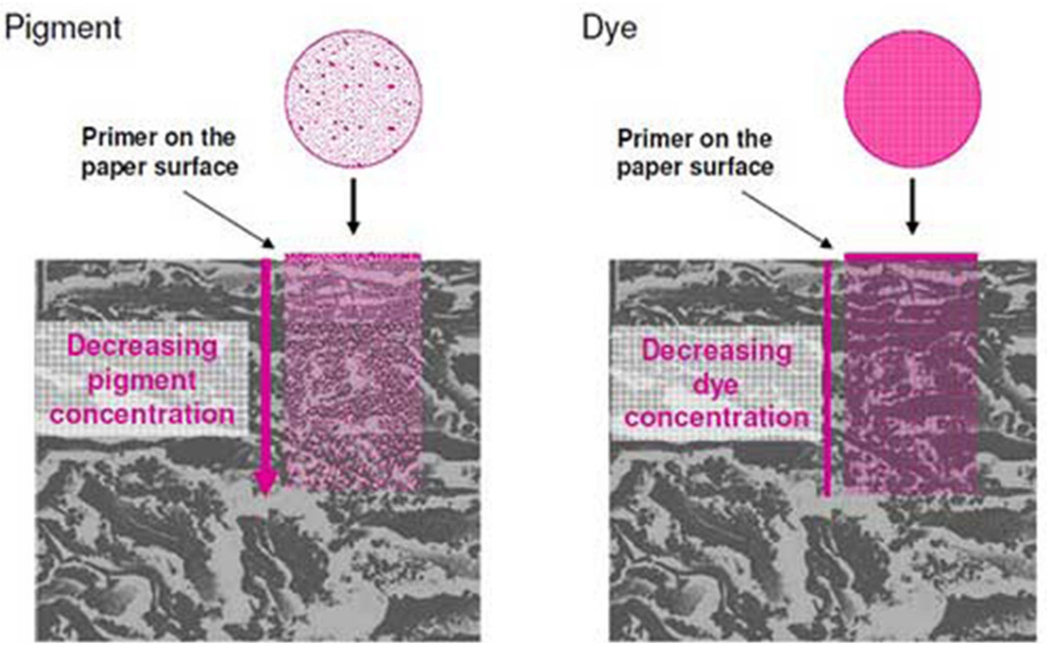


Figure 4: Schematic of inkjet print with water-based pigment and dye inks on treated (or primed) paper, source: Océ, [20]

printing, a small portion of the water carrier is absorbed and the ink viscosity then increases rapidly, becoming gel-like, which stops further penetration into the paper. This fast immobilising ink technology is becoming an integral part of the latest water-based inks.

Adding an absorbent pigment, such as silica, to the surface will absorb the water and stop the penetration into the body of the paper. This approach is seeing some very good results. Much more of the colorant is retained at the paper surface with a treated stock, as the pigment or dye is fixed.

Now there is a strong development in inkjet paper qualities. There are different paper types: the standard offset grades, newsprint, treated papers, pigmented grades and offset-like coated grade papers, with the photo-realistic expensive speciality coated grades offering the highest quality. This is another sign towards the maturity of inkjet becoming the mainstream printing technology in the future.

The current focus is on offset-like coated paper stocks:

Examples:

1. *Ziegler is a special Swiss mill, which provides a good range of inkjet papers for dye and pigment inks. They position their Z-Advance paper between a coated and a surface treated paper, suited for couponing, book printing, and direct mailing applications. Post-processing qualities are good for the bright sheet that is available in 70-135 g/m2.*
2. *Netherlands-based Crown van Gelder supplies Crown Digital HS, an uncoated stock designed for water-based pigment inks (ProInkjet Digital P). As for lightweight papers (LWC), there are lightweight matt grades for book publishing, and heavier weights in gloss and dull for commercial applications, including direct mail.*
3. *Mondi offers its DNS ranges, including a treated paper that helps retain ink that is optimised for quick water absorption for fast drying, no offsetting and increased productivity.*
4. *In North America, Appleton has introduced Utopia Inkjet, a coated product developed jointly with HP. For uncoated Appleton sells Utopia Uncoated Inkjet with ColourPro technology for enhanced print quality when compared to standard uncoated papers.*

In the December 2012 report FOGRA gives directions for solving problems in de-inking of papers printed with inkjet [15]. According to their research in de-inking process of papers printed with pigmented inkjet inks, the biggest impact comes from type of paper used. Based on these results FOGRA suggests de-inking tests and then issues certificates together with INGEDE. For receiving such document the product must satisfy criteria defined by European Council of recycled paper (ERPC).

In April 2008 on INGEDE's initiative a discussion of these problems was carried out0 with representatives from Kodak Versamark, HP Inkjet and Océ Inkjet. As a result formed an alliance was formed – the Digital Print Deinking Alliance (DPDA) and according to them the problems with the de-inking of inkjet papers tend to be solved soon.

Hewlett-Packard has done a trial in this aspect. At Drupa 2008 they presented their own roll-fed printing press, using an experimental pigmented ink system where a vehicle agent causes good ink setting and as a whole achieved good de-inking result. But this example is only a trial at present.

Difficulties with the de-inking process are especially strong with dye-based inkjet inks. The DPDA alliance hopes to have results in the near future. According to FOGRA, in this case the type of paper and the type of press are important factors. With dye-based inks, flotation and other mechanical methods for inks removal don't work and INGEDE's method 11 cannot be applied. The great difference between dye-based inks and pigment-based inks is that dyes are water-soluble and they cannot adhere to the air bubles in the flotation process. This is the reason that they don't move to the foam surface. Dye inks can be removed by floatation if coated papers are used – here the dye molecules adhere to the components of the paper coating. In the other cases dye inks don't move in floatation and lead to undesired shades of the circuit water and pulp. That is why it is necessary to add a bleaching process in order to increase the brightness to the right level [6]. FOGRA intents to issue certificates similar to those for products printed with pigment inks.

3.4 Deinking of papers printed by new Inkjet printing technologies

The newest digital printing technology is nanographic printing. This technology is developed based-on piezo inkjet and uses low viscous water-based pigment inks. The pigments are very fine, tiny particles, in nanometers what is the reason for name of this technology. The ink layer is about 500 nm thick, what is less than half of that of traditional offset printing [22]. The small sized particles cause difficulties in the mechanical removal process in de-inking. So far is not known whether the pigments in these inks can be bleached successfully and at the same time there is not enough information about the de-inking ability of nanographic printed material.

Meanwhile Xerox and Fujifilm suggest a different way for achieving good results in de-inking with their new digital printing systems. Xerox developed a waterless inkjet technology – called CiPress, with specially patented dry grained, dye- and resin-based inks [16]. Dry grained inks change their physical state during printing. The inkjet process begins with solid inks granules that are fed from drums. Then they forced to melt by heating in the printing head and the molten ink is jetted through nozzles directly to a cleaned and warmed substrate (~106°C), where it hardens instantly. Then the web is cooled.

Generally, in traditional inkjet where water-based inks are used, first a paper treatment with hydrophobic coating can be applied, in order to achieve proper ink setting. Then energy can be applied to ensure efficient drying through water evaporation from the paper. On the contrary Xerox's inkjet technology does not need any paper treatment because there is no water or absorption, the setting process is effective enough. All this is due to the heating of ink and paper and the melted ink adheres properly to the paper surface. This is an advantage enlarging the possible types of papers used for inkjet printing. In addition, any deformation of the paper is not happening and also high ink gloss can be achieved without varnishes. Xerox's waterless grained inks are non-toxic and don't contain volatile organic compounds [16]. The only disadvantage of this technology is, that it is not suitable for gloss coated papers. The CiPress supports plain paper, uncoated, including offset, newsprint, calendared, ground wood, mechanical fibers, with media weight from 50 to 160 g/m2.

Fujifilm's JetPress 720 uses a specific technology of rapid pigment coagulation – RPC. Components of the RCP solution react instantaneously with the ink, promoting rapid coagulation of the pigment. This prevents running of the ink without changing the texture of the paper [10]. In this method, before jetting ink onto the paper, it is necessary to apply a special kind of primer, causing ink's coagulation. When ink comes in contact with the primer a reaction happens, due to pigment's coagulation, without changing the paper surface and preventing any ink slik and flow.

Generally, when printing on standard coated paper by water-based inkjetting, the water and solvent are not absorbed at the ink deposit, allowing the pigment to flow freely. Then, upon the placement of the next ink, the inks merge, causing blurring.

On the Jet Press 720, an RCP solution is applied to the paper before inkjetting. The inkjet system of the Jet Press 720 uses easy-to-de-ink water-based pigment inks. INGEDE made a trial with these printed papers (JetPress 720, Fujifilm) and the results are very optimistic, unknown for an inkjet method so far. According to INGEDE these results are comparable to those of classic offset inks. UPM (a paper producer from Finland) also makes tests using INGEDE's method 11 and obtained very good results, assessed as a "good de-inkability" of sheets printed with the Jet Press 720. All quality requirements were met and four out of six mandatory parameters even fulfilled the target of 100% [3].

Result (points)	Assessment
71 - 100	Good de-inking
51 - 70	Acceptable
0 - 50	Poor
Negative	Not sufficient de-inking process

Table 4: INGEDE scale for de-inking assessment

Also there are trials with prints from the new roll-based inkjet printer like the *KBA RotaJET-76 (in the beginning of 2014) organized by* INGEDE using newsprint. The results are very satisfactory and have been evaluated as "good". RotaJET technology uses water-based polymeric pigmented inks, where the polymer component impedes the pigment particles distributing through the paper fibers. Further trials have to improve the optical pulp quality applying a more effective way of pigment removal.

4. Conclusion

All above said show that de-inking or the removal of inks from the paper fibers is the key problem in the whole paper recycling technology, especially towards papers printed by different digital methods. This conclusion is valid for most of all of electrophotographic digital printing with liquid toners as well as to some inkjet printing systems. They are now the most rapid distributed digital printing technology methods.
Without a doubt dry toners and dry inkjet inks (Xerox

CiPress) are compatible with the convential process of de-inking and recycling technology. So called „solid inks" are evaluated as reliable, cheap, perfect in the operation, stable on the substrates and tend to be easily removed in the de-inking process. With althogether 40 certificates towards paper recycling INGEDE sees dry toners and dry inkjet inks as suitable systems for de-inking without special attention to the paper type used. But in the case of electrophotography with liquid toners and all liquid inks for inkjet printing, there are substantial problems in recycling. As a consequence, liquid toner printed material should be avoided for recovered paper from de-inking and should be directed towards corrugated board production only. In this respect there is a urgent necessity for the development of new methods for de-inking.

References

[1] Ayala, L., Ricardo, D., Allwood, J.M., Schmidt, M. and Alexeev I. (2012): Toner-print removal from paper by long and ultrashort pulsed lasers, University of Cambridge, Cambridge

[2] INGEDE Assessment of Print Product Recyclability - Deinkability Test, July 2012, http://www.ingede.com/

[3] INGEDE sees incredible deinking results with the Jet Press 720, Press release from issuing company, May 20, 2010, http://whattheythink.com/news/company/fujifilm

[4] INGEDE, Accidental Deinking Trial: Liquid Toner Print cause Significant Damage in German Paper Mill, Press Release 3, 11 November, 2010, http://ingede.com

[5] Intergraf European Book Market Report (by consultancy of Smithers Pira), INTERGRAF Newsflash, 2015

[6] Le, H.P. (1998): Progress and Trends in Ink-Jet Printing Technology, Journal of Imaging Science and Technology, vol.42, No 1, http://www.imaging.org/ist/resources/tutorials/inkjet.cfm

[7] Nelson, P.E. (2001): What the Printer Should Know about Ink, GATF Press, NPES-2004, p.328

[8] Paper Recycling, Monitoring Report 2013, European Recovered Paper Counscil, European Declaration on Paper Recycling 2011 -2015

[9] Print and Paper Myths and Facts, INTERGRAF, Two sides, version 8, 2014

[10] Rapid Pigment Coagulation Technology (RAPIC), Press Release, Fujifilm, Products, Graphic Systems, Digital Press, JetPress 720, #features, 2014, http://www.fujifilm.com

[11] Romano F. (2005): Print-Media Business, Technologies of Graphic Arts Publishing, XANTE, NPES, p.500

[12] Romano, R (2011): Inkjet De-Inking a Topic to Dye For,Technical Conference on Deinking of Digital Prints in Grenoble and IMI's 19th European Ink Jet Printing Conference, Lisbon

[13] Romano, R. (2015): Trend and New Applications for Digital Communications, White Paper, part 1,p. 6

[14] Sardjeva, R. (2012): INKS, Materials for graphic arts, ISBN 978-954-28-1383-5, Siela, Sofia, p. 260

[15] Schiller,A.; Rauh, W.; Kuën, T. (2012): Deinking of Inkjet Prints, FOGRA Research report 45.001, Munich

[16] Sherbune, C. (2013): Production Inkjet: Making the Right Choice, A White Paper, p.7, http://whattheythink.com/sponsored by Xerox Corp

[17] Sherburne C. (2013): A Printing Technology Breakthrough, Xeikon Trillium

[18] Smithers Pira Releases VDP Forecast 2012-2017, Romano Richard, , 17.01.2013

[19] Smyth, C. (2012): More Details on Xeikon Liquid Toner web-fed press, http://whattheythink.com/articles/57645

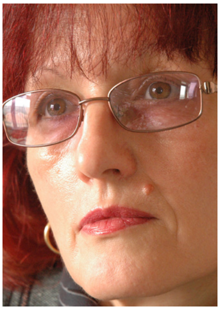
[20] Smyth, S. (2013): Sizing Up Inkjet's Paper Requirements, www.whattheythink.com

[21] Snyder, B. A. (1996): De-Inking Toner-Printed Paper, University of Washington

[22] The Nanographic Printing Process, White Paper, Landa Corporation Ltd., 12, 2012

[23] Wolf, P: Beyond traditional print, Production inkjet: a growth opportunity, www.drupa.com

[24] Zheng, W. (2013): Improved Deinkability of LEP (Liquid Electrophotography) Digital Prints (2013) Master's Theses, Paper 173



Rossitza Sardjeva

Associate Professor
Plovdiv branch,
Technical University of Sofia
Bulgaria

rsardjeva@tu-plovdiv.bg

Enitsa Koeva

Technical University of Sofia
Bulgaria

ennykoeva@gmail.com