Inkjet Inline Printing – Identification and Analysis of Critical Production Related Parameters

Magnus Viström*, M.Sc

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ABSTRACT

Inline printing on packaging is becoming an important factor due to market demands for shorter product series and flexibility in production. Print speed, set-up time and print quality are examples of important parameters to consider assuring high productivity in the printing process. This paper will identify and analyze production-related factors that characterize productivity in inkjet printing through studies on high-speed inkjet printing. Typical production lines are studied in parallel to characterize demands from the packing machines as well as other related factors. This paper discusses whether the characteristics of the identified factors for inkjet printing work in conjunction with the current production lines. The results indicate that inkjet is an interesting alternative for inline printing, but that the reliability of the inkjet unit is of crucial importance.

BACKGROUND

Inline printing of barcodes, best-before dates and batch numbers on packaging has been available for several years while more sophisticated printing of text information, logos and pictures in four colors is just now starting to catch producers' interests. Industries that today order and use packaging solely produced by conventional printing technologies are getting more interested in digital printing solutions. Driving factors are the potential to gain marketing and logistical advantages. According to Morgavi (2003), the driving force comes from customers that are demanding adapted products to an increasing extent.

Many product variants, different languages and legislation make it a complex task to satisfy all packaging requirements. However integrating digital printing in existing production workflows can realize benefits and savings (Birkenshaw, 2003). Stock reduction, shortening of lead time, change-over time reduction and higher flexibility are possible to obtain through the introduction of a hybrid printing solution where a digital print is made on pre-printed packaging (Viström, 2003b).

* STFI-Packforsk AB (magnus.viström@stfi.se) and
Royal Institute of Technology (KTH), Sweden

An inline printing solution can also improve marketing. Information on packaging could, for example, on the fly be tailored to fit specific consumers or customer segments. It has been shown within the food and pharmaceutical industries that customized information on packaging has the potential to give products higher market value and increased customer satisfaction (Viström, 2003a). According to a study of companies within the corrugated packaging market, 70% desired better methods to handle different languages, designs and stock keeping; 83% desired a better correlation between marketing activities and the packaging (Fredriksen, 2002).

Digital printing gives the unique opportunity to customize information on every printed copy, which means that the technology is applicable for on-demand production (Birkenshaw, 2003). Inkjet which is considered as a viable digital printing technology for customization of information inline, has the advantage to keep the printing unit from coming into contact with the substrate. Due to this non-impact process, an inkjet printer head can print on any substrate regardless of thickness (Moncarey, 2003), which also means that it is possible to print on packaging material even after folding it into a three-dimensional package. Smith (2003) further strengthens that inkjet technology is very promising for future packaging applications because it can be relatively fast and print on a wide variety of substrates with different ink types. Another big advantage of inkjet printing is the high consistency of color density compared with xerography (Daming, 2003). Since specific colors are often closely associated with a brand product (Holger, 2002), color reproduction is of major importance.

To profit from a digital printing solution integrated into an existing workflow, it must work satisfactorily in industrial environments and be reliable in critical situations, not creating a bottleneck. In addition, the vendor should be able to guarantee 24-hour service if the equipment should fail (Veresh, 2003). Hence it is of crucial importance to uphold a high productivity, which can be defined as "the ratio of output of a production process to the input" (Evans, 1993). Even if the system performs well, it is of crucial importance that costs are not too high compared with potential gains (Veresh, 2003). The cost per printed unit is still high compared with conventional printing for large quantities but by printing "On demand" savings of administration, distribution, waste, warehousing and production costs can be realized, offsetting the higher production costs (Birkenshaw, 2003).

It is evident that digital printing integrated inline has the potential to create both savings and benefits, but there are challenges to overcome in order to achieve satisfactory productivity. The purpose of this paper is to:

Identify productivity related factors in high speed inkjet printing and investigate whether these factors work well in conjunction with current production lines.

This paper will focus on the opportunities of inline printing solutions even though offline printing might be advantageous in some situations. Aspects on investments and variable costs for printing systems are not included in the study; neither are aspects on the information workflow necessary for variable data printing.

CHARACTERISTICS OF HIGH SPEED INKJET PRINTING

High-speed inkjet applications are characterized by having fixed "single pass" printer heads that cover the whole print width (Stowe, 2003). Single pass systems have a separate printing unit for each color (Kipphan, 2002), which means that the substrate only has to pass under the printer heads once.

The achieved print quality is dependent upon whether the ink and printer head are adapted to work together. Variations in drop velocity, frequency and volume, as well as air bubbles and blocked nozzles can give variation in the print quality in single pass systems (Smith, 2003). If a printer head meets with nozzle blocking, this means that one or more nozzles are obstructed and not able to jet the ink. There is also a risk for side shooters, which means that one or more jets are pointing in the wrong direction. A way to increase print quality is to use "gray scale" printer heads building-up every single pixel by one or several droplets. This technology gives a higher perceived resolution and can reduce the sensitivity to some of the variations mentioned above (Smith, 2003).

Inkjet technology can be divided into "continuous" and "drop on demand." A constant flow of droplets is generated using continuous inkjet, but only part of the droplet flow is transferred to the substrate. Droplets not used for printing are deflected by an electrical field and transferred back into the system. Using "drop on demand," droplets are produced exclusively when they are needed for the print (Kipphan, 2001). Continuous inkjet is still the dominating technology in packaging and direct mail markets, but recent advancements in the Piezo drop on demand technology makes the latter technology also very interesting for future applications (Schwartz, 2002).

In Pira's report "The Future of Digital Color Printing," high speed continuous inkjet presses are described as the fastest color printing systems, illustrating the future potential of inkjet printing. These exist systems that are built on water-based continuous inkjet technology and can print variable information at a maximum 300x600 dpi at 150m/min using four colors. (Smith, 2003). Printer heads can be purchased separately in order to develop specific printing systems in-house.

The "drop on demand" high-speed inkjet segment is also described as very interesting. There exist printer heads using "gray scale" Piezo drop on demand technology that allows eight gray levels for each pixel (300 dpi). The output is claimed to have a visual resolution of more than 900 dpi and can reach a printing speed of 24m/min. UV-curing pigmented inks are typically used (Smith, 2003). When it is sufficient to have a lower resolution there exist other drop on demand printer heads that are somewhat faster (39 m /min) providing 200-300 dpi.

Piezo drop on demand inkjet printer heads are considerably less expensive than continuous inkjet printer heads, which reach much faster print speeds (Wilson, 2003). However, droplet frequencies of 100kHz are claimed to have been achieved on the laboratory scale for drop on demand technology. This drop frequency would correspond to a linear speed of 63m/min at 600 dpi (Smith, 2003).

Only two types of ink are typically suitable for continuous inkjet (water or solvent-based) (Schwartz, 2002), while there are several options for the drop on demand technology. One example is oil-based pigmentary inks, which compared to water based inks gives a rapid drying time, a high light fastness and less cockle on the substrate, implying that a high print speed could be achieved (Schofield, 1999). Another example is UV-curing ink that has an excellent reliability in single pass web printing systems (Niegel, 2003) and is used successfully in other conventional print technologies. Other advantages are high opacity, fast drying, good preservation of ink consistency, no drying of ink in printer heads and good scratch hardiness (Stowe, 2003). A major challenge when UV-curing inks are used, however, is to assure that undesirable substances do not migrate through the packaging walls causing food contamination (Niegel, 2003). The option to choose between different ink types is advantageous since there exist many different packaging substrates requiring different ink types to get a good ink adhesion. This paper is therefore focused on the drop on demand technology even though continuous inkjet also is of major interest.

GENERAL DESCRIPTION OF PACKAGING LINES

Packaging materials can be divided into flexible, semi-rigid and rigid. A flexible packaging material may consist of paper, plastic film, aluminum foil or combinations of these materials and are fed from a reel and formed directly in the production process. Carton packaging and cardboard packaging that are delivered flat belong to semi-rigid packaging, while glass packaging, tins, etc., are classified as rigid packaging (Andersson, 1997). This paper focuses on flexible and semi-rigid packaging since they seem more suitable for printing directly onto the package.

Three basic functions for packaging technology are forming, filling and sealing. When forming flexible and semi-rigid packaging, is it crucial to attain sufficient stability to manage subsequent filling and handling. When the carton packaging (semi-rigid) is filled and sealed, it obtains the stability needed for distribution and consumption (Andersson, 1997). There exist several ways to pack products and each packaging line normally has it's own specific solution. A rule of thumb, however, is to always have more capacity in a following machine (Begéli, 2004). Some machines use pre-folded packaging while other machines form, fill and seal the packaging. Besides these basic processes, there exist complementary functions, such as transportation, sterilization, marking, labeling and check weighing (Andersson, 1997).

Among carton machines, there exist systems that fill packaging from above (top-load) and from the side (side-load). Top-load machines are used for free-flowing products like rice, powder, frozen fish, vegetables, cereals, etc. If additional objects are to be added into the packaging (instructions, stickers, etc.), top-load machines are advantageous. Side-loaded machines are characterized as smaller and less complex than top-load machines. Blister packaging containing tablets are typically packed in cardboard boxed by side load machines. Another type of system inserts products into sleeves. Cartons are delivered as pre-glued or flat blanks. The latter is folded and glued inline while the former is erected inline by pressing two opposite corners. Pre-glued cartons require less complex packaging machines, but when the packaging is to be filled as a multi-pack box, it might be easier to use flat blanks since they are folded after the product has been put in position (Begéli, 2004).

METHODOLOGY

Two companies that use high-speed inkjet printing systems were the objects for case studies carried out during 2003-2004. In parallel, three companies within the food and pharmaceutical industry were studied to gain knowledge about the characteristics of typical production lines. Through the first case studies aimed at collecting users' experiences from inkjet equipment, productivity related factors in high-speed inkjet printing were identified. In the next step, these identified factors were compared with collected data from the studied production lines to conclude whether this printing technology works well in conjunction with the production lines or not.

Personnel responsible for or deeply involved with the build-up/installation of the printing system were the respondents in the first category of companies. Production managers were interviewed at the other companies.

CASE STUDY COMPANIES

User 1, U1. U1 is a printer working mainly in the labeling industry and was chosen for case study because they are the first company in the world to install a web-fed printing system consisting of the Dotrix SPICE inkjet engine mounted on a Mark Andy 2200 flexo press. (Currently SPICE is the only drop on demand single pass system (Smith, 2003).) More details about the configuration of the SPICE printer can be found in (Daming, 2003). This press makes it possible to produce short run color prints at a high speed assuring that the color density is stable. Customers' demand on print quality varies depending on their line of business. For some customers, a few misprints because of blocked nozzles are acceptable while others want impeccable print. Print quality is particularly important within the pharmaceutical industry since a misprint on dosage instructions can have serious consequences.

User2, U2. U2 produces industrial products sold primarily to business customers. U2 was chosen for the case study because it was one of the first companies in the world to install a four-color sheet-fed inline printing system in one of its packaging lines. Full print color is obtained by printing the four basis colors (cyan, magenta, yellow and black) over each other. The company's focus in August 2003 when they installed the equipment was to stabilize the printing process. It has now switched its focus to an improvement in print quality. An important advantage of having a full color printer inline is the flexibility gained when producing new commercial products. The company also no longer needs to keep stock of the tape containing commercial information that was found glued on the packaging. Furthermore, lead time has been reduced, which implies that time-to-market for new designs is shortened. This system (of which the printer is a part) makes it possible to produce gift boxes and special campaign designs on very short notice, which gives a higher flexibility and additional advantages, especially when considering that 10% of the products are co-branded.

As with all the other companies, print quality is important, but because U2 sells its products to business customers, print quality is not as important as if they were sold directly to consumers. A few misprints because of nozzle blockings are acceptable for this customer segment. As of today, this printing system does not have print quality sufficient enough to print on consumer packaging; however, steps are being taken to improve the quality of the prints to a level that is also acceptable for the consumer segment.

Case study companies (packaging lines)

Among the different packaging applications, food packaging in particular is attracting much interest. Short run printing, inventory reduction and customization are the main drivers for this activity (Nigel, 2003). The food and pharmaceutical industries are described as interesting to customise information on the packaging (Vistrom, 2003a). Two companies within the food industry and one within the pharmaceutical industry were chosen as case studies.

Producer1, P1. P1 is a typical company within the food industry that produces pasta, cereals and porridge oats. This study, however, is primarily based on data obtained from pasta production for the consumer segment. Top-load machines are used to pack 24 variants of pasta into carton-board packaging. Web-fed machines pack seven different types of spaghetti in plastic film (flexible packaging).

Producer 2, P2. P2 is one of the largest pharmaceutical companies in Sweden and sells pharmaceuticals worldwide. They believe it would be interesting to minimize the number of pre-printed packaging types using alternative printing methods. There are currently 240 packaging variants (30 markets times eight versions) for one of their typical products. Demands on print quality are extremely high since a misprint on dosage instruction could have serious consequences for a patient. Authorities in several countries would have to approve the use of a new print technology on substrates that come into direct contact with the pharmaceuticals. This approval could take several years. Therefore, it is important that the new technology is stable before it is introduced to the market. Regulations are less strict when printing on substrates that do not come into direct contact with the product.

Producer 3, P3. P3 produces all types of dairy products and 100,000 tons of milk in used in the production process each year, 45% of which is refined for regular milk. Milk cartons have information panels that frequently change. At the time of this study, the production plans for the next seven weeks included ten different panels. Hence, an inline printer system could provide more flexibility to update this information.

RESULTS (USERS OF PRINTER SYSTEMS)

Equipment /production data

U1. The printer system at U1 contains a hybrid solution that can both print specific PMS colors using flexo and variable data in four colors at 300 dpi (8 gray levels) by the SPICE inkjet engine. The print speed (maximum 24m/min) is variable and can be adjusted during production. However, if thick ink layers are applied, a speed of 20m/min has proven to give the best print quality. The distance between the printer head and the substrate shall be within the interval of 0.7 – 0.9 mm to obtain good print quality. UV curing ink is used and it dries immediately after it has passed under a set of UV lamps. In order to get a better print quality and ink adhesion a special coating is applied before the printing.

The printing system performs best at indoor temperatures (20°C), which is the prevailing condition at U1. Since the press is very precisely calibrated, there is a risk for problems if the press runs in a cold environment (8°C). Metal parts expand when the working temperature increases to 40-50°C and contracts when the press is turned off, whereby affecting calibration. It is also important to avoid condensation, which can appear due to temperature changes. There are otherwise no special humidity requirements to use the printing equipment.

U2 U2 uses oil-based printer heads (XJ126) to print on filled packaging (sleeves). The printer heads are based on drop on demand technology from Xaar, providing a resolution of 180 dpi. The same type of white corrugated board cut as flat blanks is used for all sleeves, but the quality of the purchased substrate varies. The consequences of the varying quality of the sleeve material is not known. There are three seconds between the time that the print is applied on the material and the material is handled again, which is more than enough time for the ink to dry, without any drying unit.

Printing is performed after the sleeves have been filled. (A sleeve is first folded around the product and then the sleeve is printed.) The choice to print after filling the packaging is based primarily on the desire to have the print positioned at an exact distance from the edge of the packaging. It would not have been possible to achieve this exactness before filling the package because of the design of the machine. Furthermore, it would have been necessary to have the printer head shoot from below the package or construct an additional device to turn the package material after printing.

Eight sleeves are printed in parallel, which means that theoretically 32 printer heads would be needed to print in four-color. However, in order to increase the print speed, two printer heads are positioned one after the other, printing every second pixel by turn. This solution implies a need for 64 printer heads and a maximum print speed of around 60m/min. This corresponds to a maximum of around 8400 products that can be printed per hour with the total machine set-up. The printing system is used at an indoor temperature (20°C) and 50% RH. The equipment has been exposed to temperatures of up to 43°C on hot summer days without a disturbance in performance. U2 has no experience using the equipment at lower temperatures.

The packaging machine operates 24 hours a day and is positioned inline with the manufacturing equipment. Products produced by the main line have to be manually cared for if the packaging line breaks down. However, the packaging machine is designed to have a higher capacity than the manufacturing machine so that it does not become a bottleneck. Typical changeover times between two different products on the main line can take between four and 50 minutes.

Reliability

U1. When the printer was new, nozzle blockings occurred every five seconds. Improvements have been made since then, which have led to the achievement of a stable process that fails less often. Today nozzle blockings appear around two times per hour. In 90% of the cases, it helps to slow down the speed or stop feeding for 30 seconds in order to repair the fault. In 10% of the cases, the heads are also in need of cleaning, which takes one additional minute. An operator has to inspect the printing process at least once a minute because of the risk for nozzle blocking or side shooters.

When the web is stopped, unhardened ink located in the area where the web is directed vertically starts to course and on the flat areas the print get blurred. Hence, this part of the substrate has to be removed in the converting stage.

When the operator notices a misprint, he stops the press and marks the web with a green label. The press is thereafter directly restarted or cleaned and restarted. Hopefully, the nozzle blocking has disappeared. If not, this process is repeated. When the failure is repaired, the operator marks the web with a red label. Thereafter printing and the rolling up on the end-reel is continued without removing the misprinted substrate. When the reel is converted later, the operator will notice the red label, whereby he will remove the substrate from the web until he sees the green label. If the operator does not notice the misprint when it first happened, a lot of defect substrate could be rolled up on the end reel. This means that only the red label would be attached and thereby more attention is required in the converting stage.

U2. Sleeves (folded packaging) mistakenly touch the printer heads around 20 times per day. This means that a printer head has to be exchanged once a week and the packaging line is stopped between 15 and 45 minutes (average 30 minutes). Operators check the printing process every 15-30 minutes. U2 currently has two operators that run the packaging machine, but aims to reduce this to one operator.

Nozzle blockings are common, but this does not stop the printing process. Cleaning of the printer heads is done on average once a day when the quality drops below a certain level.

Since the printing system is newly installed, different types of problems have arisen that can be characterized as teething pains. These have been fixed, however, they still occur to some extent. One specific problem is that it is difficult to remove air from the system, which can have an affect on printer head performance. Misprinted copies because of failures are thrown away manually. Spare parts are always stored at U2 in order to assure fast repairs should anything fail.

Start up /changeover time

U1. Water canals are used to heat the ink to the right viscosity. The water is always kept at 50°C, so it is just a matter of turning on a pump to get the right working temperature. This heating process, cleaning of the printer heads and a functionality check of the printer nozzles takes around 15-20 minutes when the press is started in the morning. Ten to 30 meters of substrate are wasted during this procedure because of nozzle blocking. When the press is warm and has already been in production, you can immediately re-start printing and achieve good print quality. One problem, however, is that the printer starts from the position where it stopped, which means that the first copy will be wasted. Changing from one job to another is very fast. There is no need for press adjustments since the density does not change. The system contains one liter of ink and has to be thoroughly cleaned before a change of color can be made, which makes it unrealistic to change colors in the printer heads. In order to use specific spot colors, the flexo section of this hybrid press is used.

U2. Changing from one order to another takes three seconds if the size is similar to the previous order. Adjustments to change the packaging length take around 5-10 minutes. The height of the sleeves is always the same, which means that there is never a need to adjust the printer heads vertically. When an exchange of printer heads is made, a specific cone construction assures that it gets into the exact position. It unrealistic to change colors in the printer heads for a specific order, since it would take several hours to clean a printer.

Preventive maintenance

U1. It is advantageous to thoroughly clean all the color bars (bars supporting the printer heads) once a month, which takes 5-10 minutes. No other special preventive maintenance is necessary. An important remark, however, is that no printer head has been changed thus far because of the newness of the system. Since this press is a pioneer, head changes have been made so far mainly because of problems that can be characterized as teething pains.

U2. Print quality gradually changes during production because of dust from the substrate and air in the printing system. Heads are cleaned once a day for two minutes on average. A six-hour maintenance action is performed every week. The quality of the print is higher after the maintenance shift. It usually takes around two days for the quality of the print to drop to a consistently lower quality level.

Operators

U1. It is advantageous for the operator to have an education in graphic production to control the printing process. A traditional printer is well suited for the job. However, it is possible to learn how to operate the press without previous knowledge (training). An operator should have the basic knowledge necessary after a one-week training course. U1 has recently educated their operators in how to repair the printer equipment.

U2. After a one-day internal operator training course, the operator will be able to supervise and clean the equipment. Electrical engineers make repairs. It is not considered necessary for the operators to have a thorough education in graphic production.

RESULTS (PACKAGING LINES)

Equipment / production data

P1. Manufacturing and packaging are not directly linked at P1. The products are transported in tanks from the production units to the packaging lines. Employees work three shifts on the manufacturing machines and two on the packaging machines. Hence there is an over-capacity on the packaging machines. The sheet-fed machines reach a production speed of 35-48m/min (55-140 packages/min). The web-fed spaghetti machine reaches a speed of 35-45m/min (55-110 packages/min). P1 feels web-fed machines have fewer problems and are easier to supply with a new substrate. Sheet-fed machines must be attended to manually at certain intervals. Preventive maintenance is scheduled when the machine is not in production and an eight-hour cleaning is performed each month. The production hall is kept at a temperature of 21°C and 40-50% RH, however, these values can vary slightly between summer and winter.

One type of substrate is used for all carton packaging although the quality can vary. Bad quality carton increases the risk for production stoppage. Only one type of plastic film is used for the spaghetti production. The marketing department sometimes likes to introduce new substrates and this can have an impact on production and printability.

P2. Tablets are a typical product at P2 and can be packed in blister packaging. These are inserted by a side-load machine into pre-glued carton packaging together with "product packet inserts." Batch numbers are printed inline using a flexo cliché on the aluminum foil that covers the blister. Laser is used to mark the carton packaging with the date and batch number. The tablets are produced in different production lines and stored in large bulks. They are then transported and packed in a packaging line. The packaging machines are built to have an over-capacity in relation to manufacturing. Hence, packing is not performed inline directly after production. The speed of the particular packaging line described above is 170 products/min, which corresponds to around 14m/min. The average speed of a carton packaging line is around 200 packages/min, which corresponds to 25m/min. The temperature in the production hall is 20-22°C and the relative humidity is 8-10% in the printing area. A conditioning unit (which holds a RH of 30-40%) will soon be installed since there is a problem with the paper substrates curling. A major cleaning is performed every 30 days, which takes around eight hours. Because of long changeover times due to administrative requirements, there is a lot of time for maintenance between orders. The equipment is also serviced every month.

P2 would like to use the same type of carton for every order, but this is not always possible. Suppliers sometimes change the varnish on the packaging without informing the purchaser and some countries send their own packaging manufactured from different types of carton. This spread of different substrates affects print quality.

P3 packages milk in flexible packages on web-fed packaging lines at a rate of 4500 packages/h. This corresponds to around 12-15m/min. Reel changes are made automatically without stopping the machine. The speed is doubled for newer web-fed machines. P3 uses sheet-fed packaging machines (gable-top packaging) for their other liquid products. These machines reach the same speeds as the packaging lines for milk. Newer machines, however, are today reaching speeds of up to 12-15,000 packages/h. The packaging machines at P3 operate at an over-capacity in relation to the incoming primary products. The production hall is kept at an indoor temperature of 20°C and 50% RH. After the "best-before" date is printed on the packages with solvent-based ink they are moved to a cold-storage room (4°C), whereby condensation arises on the packaging surface

Production and packing of milk and similar products such as yoghurt, etc., are made inline, while butter and cheese products are stored in a buffer before packing. It is of crucial importance that these machines are kept running to ensure the stability of the desired composition of the ingredients. The same substrate is used for all packages in each production line, meaning that the same type of material is used for the outer packaging. Inside barriers can vary between different products. Machine operators perform the daily cleaning of the machines and an outside firm comes in twice a year to perform routine maintenance and service.

Reliability

P1. A production line has 5–10 stops per day (8h) on average, which corresponds to a total stop time of 30 minutes. There is a higher risk for more stops if the quality of the carton packaging is poor.

P2 has an average of two 15-second stops per hour because of packaging getting stuck in the machines. Stops can, however, become very time-consuming if something else goes wrong. These longer stops equate to two hours every 50 hours on average and can be due to human error if the wrong article number was entered at set-up.

P3. The efficiency of production is measured at 90% (all stops and changeovers are included). No statistics on stoppage because of failures exist because there are so few failures. The production facility has to operate at all times since there is a constant flow of milk, however, there are six productions lines so production can continue even if there is a failure on one line.

Start-up / Changeover time

P1. A changeover time of one hour including cleaning is needed to change the product. Changeovers are made every four hours on average. To start-up again takes a matter of seconds.

P2. The machines are normally cleaned and ready for a new product within one hour, but because of strict regulations, the previous order has to be recounted and checked-off before a new order can start. This procedure involves a lot of time-consuming administration and increases the total changeover time to four-five hours. The actual start-up time takes less than three seconds when the line is ready.

P3. A change from one product to another is often made while the line is running, for example, when changing from low-fat milk to standard milk. This procedure takes around 10-15 minutes. Other changeovers occur two-three times every 24 hours whereby the production line is stopped and cleaned for one hour. The actual start-up time afterwards is less than a minute.

Removal of defective products

P1. A certain number of controls for the packaged product are made inline: the bottom is sealed and the weight and content of metal (screws, etc.) is tested. The package is automatically removed from the line if a failure is detected.

P2. Removal of defective products is done inline by checking the readability of the printed information (batch number, dates) with cameras. If a product is identified as defective, a special device automatically removes the product from the packaging line. The tolerances for the cameras that check the print are set very tight, which means that 1% of the packages are mistakenly removed. Only a negligible part of the removed packages actually contain defects.

P3. A special device removes the product from the packaging line if it is identified as defective. Labels are scanned on a few products to ensure that the quality of the printed barcodes is satisfactory. However, barcodes are pre-printed on the packaging material for most products, which is the case for the milk for consumption.

Operators

P1. One operator supervises each production line and they sometimes help each other out if there is a problem at one of the lines. It is not a prerequisite for an operator to have a formal education since the company provides internal training. Operators make an hourly spot-check of the print quality of the "best-before" date printed inline by inkjet.

P2. Depending on the size of the order, two-four operators supervise the packaging lines. Some of them control the quality of product samples. One person would be enough to supervise the packaging line if such quality controls were not needed. An operator does not need a formal education since the company provides internal training.

P3. The operator's role is to supervise the production process and handle the changeovers. Operators today require more knowledge because of the more advanced technology although no formal education is required since the company offers internal education to operators. One operator supervises two packaging lines simultaneously for milk production. Each of the sheet-fed packaging lines requires one operator, because manual feeding of substrate is needed.

ANALYSIS AND DISCUSSION

A number of productivity-related factors were identified through result analysis. The paragraphs below describe and motivate these factors.

Speed

The maximum operating speed of the printing unit has to be equal to or higher than that of the packaging line so that it does not slow down the production rate. Hence, production speed is a critical factor for productivity. The results show that continuous inkjet speeds are far above those of the investigated packaging lines, while the drop on demand printer system at U1 providing a visual resolution of 900 dpi is still too slow for the fastest packaging lines. However, by lowering resolution demands, U2 has shown it is possible to print 180 dpi at 60m/min, which is a sufficient speed for all of the investigated packaging lines. As described in the "printer head" section, there are drop on demand printer heads in laboratory scales that are reaching linear speeds of 63m/min and providing 600 dpi. This indicates that increased print speed along with high print quality is on its way. One possible way to retain full speed on a fast sheet-fed packaging line would be to have two parallel lines in the first section of the machine merging into one line before the actual packaging machine is fed. The speed will thereby double and the risk for complete stops decrease since it would be possible to run the packaging line at half the speed should one printer fail.

Reliability

Integrating a printer system into a packaging line means that an additional device has to interplay with the existing packaging line. It is important to have a reliable printer system so that the production flow is not disturbed. Reliability demands are crucial when products are manufactured without using a buffer before entering the packaging line. One example is the milk production at P3. Moreover, if a new printing technology is to be introduced within the pharmaceutical industry, it is very important to assure that the technology is stable in the long term. An introduction of a new technology that might affect the products necessitates approval by authorities in numerous countries, which can take several years. Good reliability implies lower failure frequency and shorter stop times, which lead to higher productivity.

Stop times correspond to an average of 30 seconds twice an hour for U1 and 30 minutes once every 168 hours for the printer systems at U2. Start-up times for the packaging lines are in general very short, but since an operator needs to be in place and set the machine running, the procedure may take a longer time.

It is possible to make the following calculations using the above facts and the prediction of 30 seconds for start-up time:

- Stop time per hour using the printer system at U1: [2*0.5 minutes (cleaning) plus 2*0.5 minutes (start up)] = 2 minutes

- Stop time per hour using the printer system at U2: [1/(24*7)*30 minutes (repairing) plus 1/(24*7)*0.5 minutes (start up)] = 0.2 minutes.

The calculations show the importance of having short start-up times if the printer system fails frequently.

The corresponding figures for the packaging lines are 3.8 (30/8) and 1.2 minutes/hour [120/(6*2*8)] for P1 and P2. Data is missing for P3. According to this simple analysis, the stop time because of failures could increase by 170% if the drop on demand printer system at U1 is used and 30 seconds are needed to start the packaging line. This is, however, not a complete analysis since a stop because of a failing printer head may also result in additional disturbances in the production line. For example, the results show that a stop in the printer system implies a disturbance in print quality. It is likely that even more time will pass for disposal of the misprinted items.

Other failures in the printing equipment occur besides those originating from nozzle failures, etc. Problems that have been identified as teething pains have occurred mainly because the case study printing systems were installed relatively recently. It is difficult right now to know whether these problems will completely disappear or if there is a weak link increasing average stop times per hour. It would be interesting to compare the stop times for these other failures with the nozzle failure stops but that is out of reach for this study.

Operator qualifications

The results show that it is important to have spare parts and the necessary competence in-house to assure fast repairs when striving for high productivity. As has been done at U2, a technician/engineer could be assigned to make the repairs, or the packaging line operator could take on the role of repairperson, which is the case at U1. The latter alternative would mean that an operator's qualifications would need improvement.

Improving an operator's qualifications would be advantageous to properly operate the printing equipment and assure a high print quality. U1says it is beneficial to have a proper graphic arts education to completely control the printer equipment. They mean however that it is possible to get the knowledge necessary to operate the printer system after a one week course. Operators currently do not possess any special graphic arts knowledge at U2, but since more focus will be put on improving print quality, an improvement in the operator's qualifications might be advantageous. Hence, if high quality inline printing starts to spread, more knowledge in graphic arts production would likely be demanded from operators.

Supervision

The printing process must be carefully supervised to quickly detect misprints when print quality is a priority. Fast detection means that operators can maintain the best possible productivity should a failure appear. The printing process has to be supervised at all times when products are sold to consumers with high print quality demands (U1), while products for the business-to-business segment require less frequent supervision (U2). Since the packaging line is always supervised, it would be possible to introduce this additional task without the need for additional resources. However, when one operator supervises two packaging lines simultaneously, as in the case of the web-fed lines at P3, more personnel might be needed. An alternative or complement to operators supervising the process is to install a vision system, such as the one P2 uses to scan batch numbers. Print quality demands determine tolerance levels. However, scanning larger, more sophisticated color prints would demand more advanced systems and a thorough investigation of what is available on the market would be needed. The results show that the vision system that scans batch numbers at P3 is mistakenly wasting 1% of their packages. Therefore, it might be advantageous to have a combination of a vision system with manual checks of rejected packaging.

Start-up time / Changeover time

The time required to change from one job to another on the printing equipment is negligible compared with the changeover time on the production lines. Hence, printer-related activities on changeovers do not affect the productivity of the production lines. At U1, the printer system needs to be turned on before the packing line is started since it takes 10-20 minutes to get the system running after it has been turned off. The printer system at U2 starts directly.

Climate

The results show that the printer system works well at indoor temperatures and 50% RH. Higher temperatures (40°C) do not seem to affect performance, but the equipment should not be run in colder temperatures, such as in a cold-storage room, since the equipment calibration can decay. Low-temperature inkjet inks that may eliminate these problems are in development (www.labelsandlabeling.com). There is no need to print in a cold-storage room at the investigated production lines, but it is important to assure a fast ink drying time since packages are packed together at the end of the production line or stored in a cold storage room (P3) where condensation can appear on the packaging.

Print quality aspects

The result shows that production stops vary depending on the print quality demands. Between U1 and U2, there is a factor difference of five-six in stop times because of failures. Print quality demands are lower at U2 where products are sold business-to-business, which means that many small stops due to nozzle blocking are avoided. Hence, print quality demands affect productivity.

The results indicate that pharmaceutical packaging has the highest demands on print quality while other consumer packaging (within the food industry for example) is in second place. Products sold business-to-business have the lowest quality demands.

The studied producers are generally running the same type of substrates on their packaging lines to keep to a standard. However, the difference in substrate quality between suppliers may have an impact on print quality. Customers sometimes deliver their own substrate to be used in the packaging line at P2, which affects the print quality. Therefore it is advantageous if the printer equipment can print on different types of substrates. A special coating is applied on the substrate at U1 before printing which implies that it is less important to have a uniform substrate quality. However, since UV-curing inks are used, migration problems have to be considered if food or pharmaceuticals are to be packaged.

The results show that it is not realistic to change colors in the printer heads to meet the demands for specific spot colors. U1, who uses a hybrid printing solution, finds it is possible to print spot colors by using one or more flexo clichés. This is also possible at P2, who uses a cliché to print on blister packaging. However, flexibility would decrease with a static printing form and the advantages of having a non-impact printing method would disappear.

Preventive maintenance

Preventive maintenance is important for productivity and assures that the printing equipment will work properly. This activity can easily be coordinated with preventive maintenance activities performed at the packaging lines.

Adapting production lines

It is important that the printing unit can be integrated into existing production lines, since the investment cost of packaging machines is high (Andersson, 1997). Because there is a higher risk of failure when a printing process is added to an existing packaging line, it is important to assure that there is sufficient over-capacity to catch-up with the production schedule when printer failures appear. All investigated companies (U2-P3) have over-capacity in their packaging lines in relation with manufacturing.

Since stops in the packaging line imply disturbances in print quality, there is a need for a device in the packaging line that can remove misprints. This can be carried out before or after the package is filled (assuming printing is done before filling). As the results show, P1, P2 and P3 already have such a device in place, after the filling. Removing misprinted packaging after filling would therefore not demand any major extension of the packaging line other than a control of which products are waste. This means that packaging can be removed without stopping the packaging line, which is a prerequisite to avoid additional disturbances in print quality. According to U1, these appear when UV-curing ink is used and the web is stopped. U2, who prints with oil-based inks without any drying unit, has no such problems. The substrate can be removed before filling without disturbing the feeding process in sheet-fed machines, while in web-fed machines, misprinted parts need to be cut away somewhere in the middle of the web, which can be difficult. However, it is cheaper to discard empty packages rather than those already filled. Because 10-30m of the substrate needs to be removed when the printer system is started at U1, many filled packages would be removed unless it is possible to remove misprints before filling.

Considering that a filled package is three-dimensional, it would be easier to print on the packaging before it is formed and filled in the packaging machine. Unlike pre-glued cartons, flat blanks or flexible packaging material make it possible to print over the entire package using printer heads directed to shoot droplets in one direction. Printing before filling would not require any extra adjustments of printer heads to adapt to different packaging heights.

Because printing is performed on the package after filling at U2, there is a risk of it opening up and touching the printer head. The distance between the printer head and substrate has a small tolerance to ensure good print quality. Therefore, it might be advantageous to print before filling since it is more likely that a flat substrate will keep within the tolerances better than a filled and sealed package.

It is important to have the print positioned an exact distance from the edge of the package at U2. Since the machine sets the limits on exactness, printing has to be made after filling to achieve this exactness. Furthermore, an additional device would be necessary so that printing from below would not be necessary, which is not suitable for drop on demand technology. Hence, the design of the existing packaging line can be the deciding factor on whether to apply the print before or after filling.

There is a need to keep track of individual packages if the printed information is customized for a very short series or for individual packages. For example, if a package is rejected because of a misprint or incorrect assembly, this particular package has to be reproduced. New market demands at P2 make it necessary to keep track of individual packaging. A thorough inspection of rejected packages could assure that all individual packages are produced.

Open questions

This paper focuses on the opportunities using inline printing even though offline printing might be advantageous in different situations. A comparison between the printing types would accordingly be interesting for future research. Since costs are the deciding factor in most cases, a comprehensive overview of costs would also be interesting.

There is a chance that some data was not reported in this investigation since some of the companies have developed special processes and technical details that they want to keep to themselves. Only two users are included in this study even though leading technology has been investigated. Furthermore, the technology is developing quickly. According to Veresh (2003), the evolutionary process is driven by technology improvements that imply better quality, higher speeds and reliability.

CONCLUSIONS

The analysis shows that the following factors should be considered to achieve high productivity when a high-speed inkjet printer system is to be integrated into a packaging line.

Productivity related factors in high-speed inkjet printing:

- Print speed
- Reliability
- Print quality demands
- Operator qualifications
- Preventive maintenance
- Right climate
- Supervision

Critical factors in packaging lines

- Start-up time
- Reliability
- Sufficient over-capacity
- Operator qualifications
- System for removal of misprints
- Number of different substrates

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