CHAPTER 9

The use of digital systems in textile printing

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9.1 INTRODUCTION

During the last 20 years a digital revolution has occurred that has touched everyone's life. We are now surrounded by digital telephones, audio equipment, cameras, camcorders, TV, laser barcode readers, etc., and many homes possess a computer with access to the Internet. Digital technology has greatly affected many industries including the textile printing market, not only by the introduction of full-width jet printing machines but also in every aspect of conventional print production, from the design stage, through coloration and recipe formulation, screen manufacture and print paste preparation to the final electromechanical control of the printing machine itself.

Ink-jet printers have become very well established in both offices and homes for printing alphanumeric and graphical data (particularly following the widespread adoption of digital cameras) and indeed the quality of the prints from such machines can now rival that of laser printers. The earliest use of jet printing machines on textile fibres occurred some 25 years ago but this was confined to the carpet industry owing to the relatively low pattern definition of which the machines were then capable (10 to 25 dots per inch (dpi)). These are described in Chapter 4 and all are based on the use of solenoid valves which cannot easily be upgraded so as to meet textile printing requirements [1]. More recently high-definition ink-jet printers, used in conjunction with computer-aided design (CAD) software, have become established for preparing pre-production sample prints on textiles. However, a number of wide-format, ink-jet printing machines, together with suitable inks, are now being marketed and these can yield prints of acceptable quality and fastness properties on most textile materials.

Jet printing may be defined as a process by which the desired pattern with its individual colours is built up by projecting tiny drops of 'ink' (special dye liquors) of different colours, in predetermined micro-arrays (pixels), onto the substrate surface.

In all true jet printing systems the ink is projected onto the surface of the substrate as a coherent and controlled series of drops; it is therefore inappropriate to use the phrase 'spray printing', as is sometimes done. Usually a set of inks is used consisting of at least three or four primary colours, namely cyan (turquoise), magenta, yellow and optionally black, the so-called CMYK inks. These colours are also employed in gravure and offset lithographic colour printing although in such applications the three primaries are either printed as dots of varying diameters (amplitude modulation) or as uniformly sized dots of various randomised density arrangements (frequency modulation). Less commonly so-called spot colours may be pre-mixed to match the specific shades in the pattern, as is done in conventional textile printing. As most ink-jet printers were originally designed for paper printing, the terms encountered in, for example, technical specifications are more related to those used in the reprographics industry than to those that a textile printer would normally employ. Thus reference is usually made to inks rather than dye solutions, pigment dispersions or print pastes. Similarly print resolution is usually defined as dots per inch (dpi) or lines per inch (lpi) rather than as mesh or raster.

Today 90% of all printed textiles are produced on rotary- or flat-screen machines [2], the choice of which system is used depending mainly on the length of fabric to be printed. Particularly in the field of rotary printing, machine design and operation continues to be refined so that, for example, setting up and pattern fitting can now be achieved quickly using laser light alignment devices and individually driven screens, whilst screen changing times can be reduced to as little as 10–15 min. So what are the attractions for a total change to a jet printing system?

The first reason for increased interest in digital printing processes lies in the very common use of CAD systems followed directly either by laser engraving or exposure of screens coated with suitable lacquers. Less commonly the digital data from the CAD system may also be used to jet-print a set of colour separation positives for subsequent conventional UV exposure of the screens. More recently ink-jet printing methods that operate directly on the pre-coated screens, followed by conventional light exposure, have been introduced.

It is even more attractive to eliminate the making of screens altogether, and such is the possibility offered by direct ink-jet printing of textile materials. The immediate benefits are:

(a) Very quick customer response for both strike-off and bulk prints and wastage on pre-production sampling minimised
(b) No capital tied up in the screens, with major savings in storage space (patterns now stored on CD-ROMs or on similar storage media) and damaged screens eliminated

(c) The number of colours and the size of the pattern are virtually unlimited enabling the production of very long repeats (e.g. fully bordered bed sheets) and full tonal (photorealistic) prints
(d) Instant fitting of patterns at start-up, thus minimising fabric and paste wastage
(e) Minimal downtime, because pattern changes and also colour changes, when using CMYK inks, are virtually instantaneous
(f) Only the ink required for the design is laid down, thus eliminating any waste of print paste
(g) The amount of ink applied to the substrate is far less than that used in a screen printing process.

In addition jet printing meets most of the foreseen market trends in which short production runs and waste minimisation in pattern sampling [3] has become increasingly common (Table 9.1). Under present market conditions rotary-screen printing of short run lengths means that machine efficiency (productive occupancy) is rarely more than 40–50%, whereas an ink-jet printer offers, say, 90% operating efficiency.

Table 9.1 Predicted trends in textile production and marketing (UK Department of Trade and Industry, Foresight Manufacturing Panel, 2000)

2000	2010
Mass production	Mass customisation
Long supply pipeline	Short supply chain
Sell from stock	Make to order
Sequential processing	Simultaneous processing

It is essential to appreciate that the technology of ink-jet printing is fundamentally different from that of all other textile printing techniques, not only because of the non-contact mechanics of the print head but also in the means by which the individual colours of a design are produced. A great deal of computation is necessary to produce each of the millions of pixels in a design and this continues for as long as the machine is printing the fabric. In the past printing machines were adjusted entirely by mechanical methods using the operator's experience and judgement, and although modern impact printing machines may be fitted with more refined electromechanical feedback devices, these are considerably less sophisticated when compared with the electronic control of jet printers.

9.2 IMAGE CAPTURE AND DISPLAY

9.2.1 Computer-aided design

The use of computer-aided design (CAD) systems for the generation of pattern and colourway display has become almost a standard procedure in printed textile production. These systems typically allow the capture of the designer's artwork using a flat bed (up to A3 size) scanner or, for larger patterns, a rotary scanning device. Image capture is also possible using colour cameras but this is less common. The data thus acquired represents the location and colour of each individual pixel (picture element) of the design and the number of these will depend on the definition at which the artwork is scanned (usually a few hundred dpi). When displayed on the computer monitor screen, the design may then be tidied up and edited. Thus the software allows the manipulation of the scanned image of the original artwork so as to define the number and precise shades of the design colours (usually a maximum of eight to 12, with several colourway combinations). The output data will also include details of the individual colour separations and the required design repeats, fall-ons, and optimum fitting (see section 9.2.6). However, with the widespread adoption of computer monitors or visual display units (VDUs) and digital methods of colour communication the need has arisen for some means of ensuring shade reproducibility from one VDU to another. Similar colour control is necessary with both the input device (usually a scanner) and the output device (e.g. a digital printer). To achieve this it is necessary to employ software known as a colour management system (CMS) [4].

The precise colours displayed on a conventional monitor are determined by voltages applied to the three 'guns' ejecting a stream of electrons that pass through a mask onto tiny groups (triads) of screen phosphors. Depending on the phosphor type these in turn emit red, green or blue light, the intensity of which is related to the voltages applied to the guns. The luminosity of the emitted light is controlled digitally in 256 levels (0 to 255, i.e. eight bits in binary notation). Theoretically this 24-bit system (eight bits for each R, G and B value) is capable of displaying 2^{24} (almost 16.8 million) colours but in reality the number of perceived colours is much smaller, particularly if the monitor is viewed under office lighting conditions [4]. Nevertheless a wide gamut of on-screen shades can be displayed by varying the relative luminosities of the light emitted by the red, green and blue (RGB) phosphors and this is termed additive mixing of colour. When the three values are all 255 the screen displays white and when all are zero the screen is blank, i.e. it is black. The range of shades which can be displayed by a VDU is very extensive, wider than can be achieved by any class of dye applied to a textile and also very much wider than is possible when printing with cyan, magenta and yellow jet inks. The colour characteristics of different makes of VDU do vary to some extent, mainly in the choice of the green phosphor and this is particularly the case with the proposed SMPTE-240M standard for high definition television (HDTV). Even standard monitors can display very much brighter shades than CMYK printers in the red and blue regions, yellows can be of similar brightness whilst in the cyan/bluish green region CMYK prints may be marginally brighter (Figure 9.1).

9.2.2 Digital colour management systems and colour communication

An understanding of instrument standardisation and of the colour management and communication systems available requires some knowledge of colour physics, a wider explanation of which is not possible here. Suffice it to say that any colour may be specified by three coordinates that locate its position in a three-dimensional colour space. Although three-dimensional, these spaces are often represented graphically in two dimensions or as planar projections. There are a number of standard CIE (Commission Internationale de l'Eclairage) colour spaces, each varying in its overall uniformity and each having its own coordinates [5,6]. The commonest colour spaces are:

CIE *xy* (as in Figure 9.1):	colour coordinates *XYZ* or *xyY*
CIELAB:	colour coordinates $L^*a^*b^*$
CIELCH:	colour coordinates *LCH* (lightness, chroma and hue)

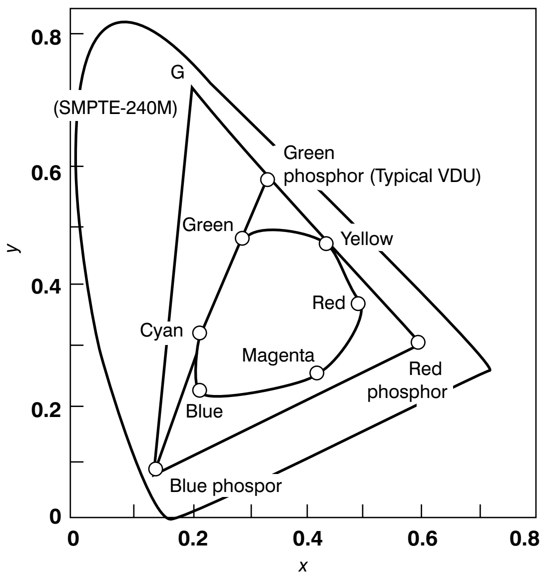

Figure 9.1 VDU and printer colour gamuts

The need for colour management systems (CMS), which ensure colour consistency between input devices, monitor displays and the final printed output, has long been recognised in the reprographics industry and there are many commercially available software packages that allow standardisation of equipment used to acquire, display and print coloured images. These use a widely accepted standard form of ICC Color Profile, as defined by the International Color Consortium [7], to ensure that colour consistency can be achieved and communicated from one device to another and also from one user to another. Colour management systems are provided by the vendors of the ink-jet printing systems now offered for textiles, as part of a multi-purpose package that may selectively include:

(a) A textile design (CAD) system, e.g. TreePaint (BTree/Duagraphics), Inspiration (Sophis), Image 4000 and ImageBox (Stork) and Vision Studios (Nedgraphics).
(b) A colour physics system for device calibration, display of colour gamuts, etc., e.g. Harmony (Sophis), PrintMaster (Duagraphics) and Vision Easy Coloring Pro (Nedgraphics).
(c) A raster image processing (RIP) system which translates pattern (RGB) data into printer (CMYK) data and then drives the jet print head causing each of its jets to fire at the appropriate times.
(d) Software that allows recipe predictions with different dye/fibre systems to produce the desired colours by conventional screen printing. Accurate recipe match prediction is usually based on spectrophotometric measurements of the target shades and suppliers of such equipment market the necessary software (e.g. DCIMatch/SmartMatch (DCI) and ProPalette/ExpertMatch (Gretag-Macbeth)). All the major dye vendors also offer such systems (e.g. Ciba's COLPOCA software). To be fully effective these systems still require calibration using the customer's own particular substrates and application methods.
(e) Additional software that allows a VDU display of selected designs applied to various end uses, e.g. patterned furnishings in a room setting or fabric designs draped on mannequins. This is clearly a useful marketing tool.

9.2.3 Calibration of input and output devices

The need for the design computer's monitor to display exactly the desired colours varies from one user to another. Some firms employ colour communication software which ensures that their customers can specify shades purely from on-screen appearance (using systems such as GretagMacbeth's ColourTalk or Datacolor International's (DCI) ImageMaster) [8], but many people appear to be happy that the display is only reasonably representative of the end result. A less precise form of control is usually available from the use of generic ICC profiles for the type of monitor being used or by employing special calibration software that allows the monitor's display to be adjusted. Such adjustments to colour display on a particular monitor can be made using a CAD editing suite such as Adobe Photoshop or by employing the software provided by the computer manufacturer (e.g. Apple's ColorSync and IBM's ICM software).

However, for the closest control of on-screen colour it is necessary to make external measurements of displayed colour patches using a suitable spectrophotometer (e.g. Minolta's CRT calibrator, the Color Vision Spyder and GretagMacbeth's Spectrolino) or a monitor that has such a built-in standardisation system installed. A fully integrated colour management and recipe prediction system can even be downloaded from the World Wide Web (www.ewarna.com). Such a system has a particular advantage over the provision of individual software packages in that new product data and software updates can be instantly transmitted to customers.

For the standardisation of scanners and printers the provision of a standard test card, on which are printed graduated colour patches, is the first requirement and in practice the 240 shade, IT8.7/2 reflective colour targets (produced by Kodak, Fuji and Agfa to the ANSI standards) are commonly used. The CIE colour coordinates (e.g. XYZ or $L^*a^*b^*$ values) of each colour patch are known so that when calibrating a scanner the software compares these values with those calculated from the data recorded by the scanner and can thus build a device profile. With some colour management software the data may then be sent to a jet printer and if the resulting print is re-scanned a printer profile can be produced. However, as with the calibration of monitors, the most accurate shade reproduction is achieved only when the printed test patterns are measured using some type of spectrophotometer. These may be hand-held devices, e.g. the Colortron (X-Rite), Spectrolino (GretagMacbeth), Microflash45 (DCI) or, for large numbers of measurements, automated instruments such as the AutoScan (X-Rite) or SpectroScan (GretagMacbeth) units can be employed.

Once a system is standardised the various colour management packages available can provide additional manipulation of colour data, not only between input and output devices, but can also allow for differences in type of illumination, viewing conditions, substrate, etc. This requires a reliable colour appearance modelling system.

The CIECAM97s model has already been incorporated into some CMS software, although an improved version has recently been proposed [9]. All mathematical conversion of colour data between any two devices is carried out via an intermediate, device-independent, colour space. Thus cameras and scanners usually output data in terms of RGB values and the software will convert the data to a CIE, device-independent, colour space ($L^*a^*b^*$, LCH or XYZ). These results will then be modified using the appropriate colour modelling computation and the data finally transformed into CMYK output for the printer (Figure 9.2).

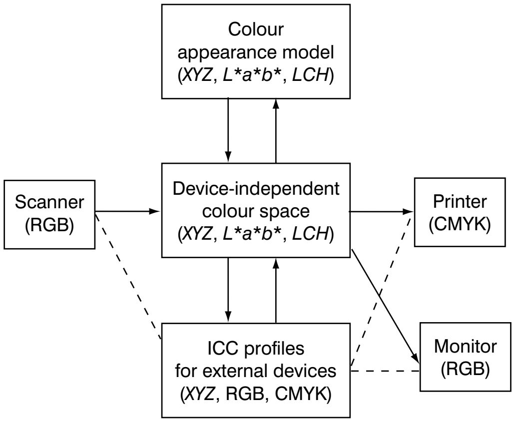

Figure 9.2 CMS transformations

9.3 SCREEN MAKING USING DIGITAL PATTERN DATA

9.3.1 Ink-jet printing systems for photo-masking of screens

Traditionally, separation positive films would have either been hand-made or produced photographically in order to make each screen. When digital pattern data became generally available around 1990 the making of the separation positives could then be achieved more rapidly using wide-format electro-photographic (laser) printers, or by applying molten, opaque black waxes to the film surface using a special type of piezo ink-jet printing system. These processes did not, however, overcome problems associated with the need to expose screens using a glass frame and applying a vacuum in order to attain good contact between the positive film and the screen surface.

In a later development the hot wax print system was also used to mask pre-coated screens directly, followed by UV light exposure. In Lüscher's piezo printing system (Figure 9.3) the molten black wax, which also contains a UV-absorbing chemical, is jetted onto the coated screen where it immediately solidifies. Very high pattern definition can be achieved (better than 300 dpi, corresponding to a line width of 40 μm). After exposure the wax can be easily removed using low-pressure water sprays. Because the wax is in intimate contact with the screen surface, fine pattern details are reproduced better and exposure times are shorter since no glass holding frame is required.

Figure 9.3 JetScreen (Lüscher)

More recently machines incorporating piezo-type jet print heads and using an aqueous, UV-opaque, black ink which is also applied directly onto lacquer coated, flat- or rotary-screens prior to conventional exposure to UV light, have been successfully introduced. These newer systems are claimed to produce a quality of engraving comparable to direct laser engraving (see below) whilst obviating many imperfections of earlier exposure methods, such as those produced by adventitious scratches on printed positive films or bubbles which could occur in wax-printed media. Some examples of both types of screen masking printers are listed in Table 9.2.

9.3.2 Laser engraving of screens

This method of preparing screens is now well established and probably accounts for at least 30% of screen production. For direct laser engraving the screen is pre-coated with a special lacquer which is first polymerised and then the pattern is burned out using a powerful carbon dioxide laser beam. Machines of this type are typified by the LEN-4000 series laser engravers (Stork) (Figure 9.5). Laser engravers, which were

Table 9.2 Screen-making machines using ink-jet technology

Manufacturer	For rotary screens	For flat screens
Stork	Max 4000 Mask engraver	(Mini) Jet screen
ZED Instruments	JetMaster (Figure 9.4)	
Perfecta Print	ScreenMaster R	ScreenMaster F
Lüscher		JetScreen

Figure 9.4 JetMaster (ZED Instruments)

Figure 9.5 LEN-4000 laser engraver (Stork)

initially considered expensive and rather slow, have been made more productive by the introduction of split-beam systems and a finished screen can now be made in as little as 30 min.

Because the power of laser beams can be modulated at high speed this technique of engraving is eminently suitable for the production of half-tone screens. In effect the modulated laser beam produces selected areas within the screen that vary in mesh size, which thereby enables half-tones to be printed. Very fine outlines can also be produced (typically from 5–80 lines per mm, equivalent to 130–2000 mesh) owing to the narrowness and coherence of the laser beam.

Laser technology has also been utilised as the means of exposing screens that have been coated with conventional, light-sensitised lacquers or for the exposure of galvano mandrels. This requires a specially developed lacquer and an argon ion laser beam. After exposure the screen is treated with an alkaline solution, dried and finally the lacquer is thermally polymerised. This technique is also suitable for the preparation of flat screens as the argon ion beam does not affect the polyester screen fabric.

9.4 DIGITAL CONTROL SYSTEMS IN THE SCREEN PRINTING INDUSTRY

As the installation of computerised records within the textile industry has become more common so has digital data been applied to all aspects of production. It is, for example, usual to be able to trace all production batches from the order book right from greige goods through to the despatch of the finished article. Software suppliers can provide textile management systems that may be integrated with recipe prediction and recorded, or autoweighing/dispensing units for both laboratory and bulk production, the data from which can then be used for stock control of chemicals and dyes. Recipe management systems allow records to be kept for all production batches with physical batch test results and this is particularly valuable for companies maintaining quality control accreditation (e.g. for ISO 9002). Applications of computer technology to all of these textile production operations are illustrations of systems known generically as computer-aided manufacture (CAM).

9.4.1 Automated print paste dispensing

Over the last two decades many firms have introduced digitally controlled systems for both volumetric and gravimetric dispensing of chemicals, dyes and print pastes [10]. In particular in the UK ICS-Texicon (later Datacolor International) was in the forefront of these developments and over 100 of its Autoweigh systems were installed in printworks and dyehouses. The dispensing of the print paste is controlled by special metering valves that allow the prepared stock colour pastes to flow into a tub placed on an electronic weighing platform, either before or after metered additions of the appropriate amounts of reduction paste, chemicals and auxiliaries. The Autoweigh unit is no longer manufactured but a wide variety of competing systems are presently available from other European sources, such as Bespoke Textile Computer Systems and Ozark Systems (UK), Stork GSE Dispensing (Figure 9.6) and Vanwyk Systems (Netherlands) and Termoelettronica (Italy). Although strictly speaking the electronic

Figure 9.6 GSE IPS print paste dispensing unit (Stork)

inputs from the weighing units are analogue, these are handled digitally by the control software, running either on an industrialised computer, which may be either a PC or a PLC (programmable logic controller). The stable performance of PLCs in industrial environments is well established but the use of a PC-based interface does, however, offer the benefit of the familiar graphical Windows display and touch-screen control if desired.

The software for these print paste dispensing units is usually integrated with the customer's CAD, recipe prediction and print machine management systems. Thus with a knowledge of approximate print paste usage for each colour in the design the appropriate amount can be dispensed to minimise wastage. However, this calculation must allow a certain degree of latitude so the system also allows mixing of pastes that remain at the end of the print run for subsequent recycling (usually for printing darker colours).

9.4.2 Digital control of rotary screen printing machines

In recent years many refinements have been incorporated into conventional printing units particularly rotary-screen machines. Laser beams may now be used for both screen alignment and pattern registration. Pattern fitting for repeat orders is greatly assisted by the use of computerised set-up data from previous runs. This is especially useful for machines fitted with electronically controlled motor drives on each screen (e.g. gear-coupled AC servo motors on Zimmer machines and a choice of pulsed stepper or stepless ring motors on Stork printers). These help to eliminate inaccuracies from play in gears or variable torsional twist in drive shafts. Other refinements offered by Stork include a means of ensuring blanket/screen synchronisation by using sensors installed near each print head that detect metal strips fixed at intervals in the blanket belt, the pulses so generated being used in an active control for finer adjustment of the individual screen drive motors [11]. The variations result from uneven stretching of the blanket, which may occur as the printing speed is ramped up or down, and for those who print mainly at constant speed a simpler and less costly system uses only two interlinked motors, one on the blanket and one for the screens.

9.5 PRINCIPLES OF INK-JET PRINTING SYSTEMS USED FOR TEXTILES

Jet printing systems used for textiles may be classified as being based on a selectively deflected charged-drop (continuous drop production) principle or a drop-on-demand (DOD) method, in which drops are produced as required by some impulse system. The aqueous print medium (i.e. the 'ink') used, is pressurised (3–5 MPa) for charged drop printers but is supplied at essentially atmospheric pressure to the most commonly used impulse print heads, namely the bubble jet and piezo-electric types. Each system has certain advantages, such as lower fabrication cost and faster printing speed, coupled with disadvantages such as inferior print definition or reliability [12].

9.5.1 Charged-drop printers

In this system the ink is forced at high pressure through a very fine orifice (8–15 μm diameter) which produces a train of droplets whose uniformity is further controlled by vibrating the jet outlet at high frequency (0.5–1.0 MHz) with a piezo transducer. Because the droplets are produced in a continuous stream this is sometimes referred to as continuous ink-jet (CIJ) technology. An electrical charge is then selectively imparted to the individual droplets as they form by applying a voltage pulse between the jet orifice and a charging plate. The charged drops are then deflected as they pass between a pair of metal plates between which there is a high voltage potential, which may either be fixed (the Hertz principle) or varied (the Sweet principle) (Figure 9.7). Depending on the design of the printer, the uncharged drops may be allowed to fall on the substrate, which then carries corresponding printed ink spots, whilst the charged drops are deflected into a 'gutter' from which the liquid is recycled, or vice versa. In the simpler printers the drops may only be charged or uncharged and these are called binary charge systems. In a more sophisticated design the emerging droplets may be charged to varying levels (usually with eight to 16 stepped levels of charge) so that they may be selectively deflected to fall in the desired position on the surface of the substrate as it passes beneath the jets.

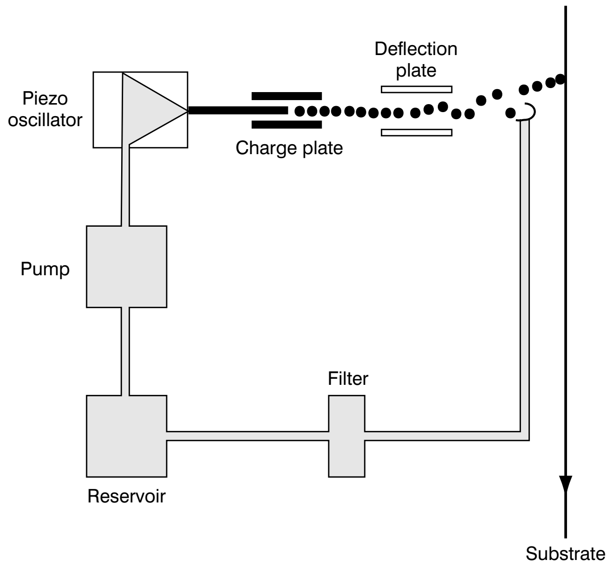

Figure 9.7 Charged drop printer (binary type)

Charged-drop printers require complex control systems. The first problem is to produce extremely uniform drops and then there is a need to control both electrostatic and aerodynamic interactions between neighbouring drops whilst in flight, as these affect both their velocity and path to the substrate surface. Furthermore, the charge ultimately carried by an individual drop depends not only on the composition of the ink but also on the mechanics of the drop-forming process. Complex modified charging programmes are used to control these interactions and careful initialisation procedures are required.

Textile sample printing machines using the charged-drop principle were introduced in about 1987. These operated on the binary principle with four print heads (CMYK) that scanned across the fabric sample attached to a rotating drum. Print production was, however, very slow (about 1 hour to produce a square metre). Thus the more recently introduced production printers employ a multi-level charge system and are fitted with a multiple array of print heads to increase output, as for example in the Stork and Scitex machines. Whatever the type of printer, the greater the number of jets and colours used the more chance there is for faults to occur, and the complexity of computation and data handling rates are increased.

9.5.2 Drop-on-demand printers

DOD printers depend on some means of imparting an electro-mechanical or thermal shock impulse to a printing ink, which is held at atmospheric pressure close to the jet orifice. Capillary forces prevent the ink from leaking out but when the jet is fired a pressure pulse passes through the liquid and a tiny droplet is ejected. Although various types of DOD printer have been developed over the years the market is now dominated by two systems, namely bubblejet types (e.g. Hewlett Packard, Canon, Lexmark, Xerox) and piezo types (e.g. Epson, Xaar, Spectra, Ichinose, Konica). The design of both types of print head is modular in concept and their fabrication is based on the construction of multi-layer/multi-channel silicon or ceramic wafers using essentially microchip fabrication techniques. This allows manufacturers to produce very compact, multi-jet arrays (100–500), the channels of which are connected to a low-voltage, pulse-generating system controlled by the downloaded pattern data. These channels lead to precision-oriented rows of jet orifices, having diameters (15–25 μm) rather larger than those of continuous ink-jet printers.

With piezo-actuated print heads the drive impulse is provided electro-mechanically. An applied pulse causes the individual piezo-ceramic walls forming the channels leading to the jet orifices to bulge, thus producing ink-drop ejection (Figure 9.8). With bubblejet printers ink-drop ejection follows the application of a very short voltage pulse to a tiny resistor etched within each channel of the print head. This pulse produces a local temperature of about 350 °C within a few microseconds and the coalescing micro-bubbles of steam formed displace a corresponding droplet of ink from the jet orifice, after which the bubble collapses (Figure 9.9). In general the microchannels in a bubblejet print head can be packed more closely than is possible in piezo devices. The

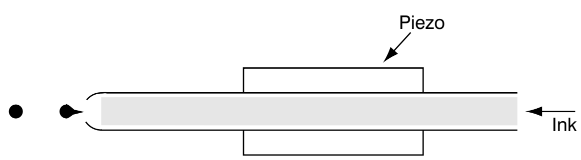

Figure 9.8 Tube type piezo jet

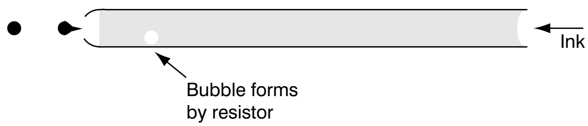

Figure 9.9 Bubblejet system

ejected droplets of ink usually have a volume of 100–200 pl (litres × 10^{-12}) and typically a diameter of about 40 µm (equivalent to a definition of 600 dpi).

Most bubblejet printers use mass-produced cartridges, very similar to the clip-on units used for computer jet printers. These cartridges comprise both the print head and the ink reservoir, which is replenished through a connecting fine bore tube to larger containers of ink fitting in the side of the printer. Thus if a defect occurs in one or more jets the whole print head can be easily unclipped and replaced. By contrast, in piezo-type printers the complete ink supply is remote from the print head, the replacement of which is more complex. Some cartridges contain the ink reservoir. This apparent disadvantage is compensated by the fact that, in general, piezo print heads have a considerably longer life than bubblejet units and can also handle a wider variety of inks.

With all machines the print head is made to scan across the substrate to produce a printed strip about 5–10 mm wide after which the fabric is indexed forward by a stepper motor before the next scan. Printing usually takes place bidirectionally, i.e. in both scanning directions. The speed of scanning is determined by the print definition required and the maximum frequency at which the jets can be made to fire (15–25 kHz). However, by using a number of staggered print heads it is possible to increase the width of the sequentially printed strips and thereby improve the overall printing speed.

9.5.3 Formation of coloured patterns using ink-jet printers

Irrespective of the particular type of DOD jet printing machine being considered, the genesis of the individual droplets at the jet outlets follows a remarkably similar sequence [13], and they form approximately circular spots when they land on the substrate. As the jetted liquid leaves the jet orifice it forms a tail. If the conditions are ideal, the tail eventually collapses into the head of the drop, which becomes spherical before hitting the substrate surface. In practice there is a tendency, particularly with bubblejet systems, for the long tail of the drop to form small satellite droplets but this does not necessarily affect the printed design. The volume of the individual drops can vary considerably depending on the type of machine and the duration and voltage of the drive pulse. As the depth of shade increases so the coloured spots increasingly intermingle on the surface of the substrate. Each printed pixel of a design, when examined under a microscope, can be seen to be composed of individual drops of the coloured inks. The overall shade observed is dependent on the proportion of each of the primary colours applied (usually at least yellow, cyan, magenta and possibly black), the nature of the substrate and its pretreatment. Within the printer lies both hardware and software that interprets the pattern data downloaded to it (typically from a workstation or PC). Each individual pixel element of the original design is printed as a number of coloured spots arranged in a super-pixel, usually forming either a 4 × 4 or 8 × 8 matrix [13]. The number of colours which can be obtained using super-pixels formed with cyan, magenta and yellow ink spots increases with the size of this matrix. If the matrix is increased from 4 × 4 to 6 × 6 or 8 × 8 the number of possible shades increases by a factor of ten and fifty times respectively. The number of possible shades can be increased still further by either using more than the three primary shade inks or by modulating the size of the ink droplets.

Most jet printers used for textiles print at a definition of either 300/360 or 600/720 dpi. Higher definition printers, giving 1200 dpi or greater and often capable of printing with very small-volume drops (5–10 pl) are used more in the reprographics industry. It should, however, be remembered that it is the number of pixels per inch (ppi) that determines the design definition. For example, a printer that uses a 4 × 4 matrix at 360 dpi will give exactly the same contour definition (90 ppi) as another that uses an 8 × 8 matrix at 720 dpi, despite the greater number of individual drops of ink projected by the latter onto the substrate for any particular depth of shade. Not only does the larger matrix yield a much larger shade gamut, with finer shade gradations possible, but also the higher the dot density the more ink is applied per unit area (useful when printing heavier textiles). The printer software does, in fact, allow the user to adjust the volume of ink applied (i.e. the wet pick-up) to suit different substrates.

Another function of the printer software is to dither the placement of the individual ink drops from pixel to pixel so as to avoid undesirable mottled, moiré or chevron patterning effects [13]. Figure 9.10 shows a magnified image of a sequence of printed 4 × 4 super-pixels, representing three depths of shade, each pixel being separated by blank spaces for clarity; this illustrates dithering of both the placement and the number of ink spots for a given depth of shade. Some printers (particularly charged-drop devices) modulate the quantity of ink placed into each location in the pixel by firing groups of microdrops with volumes of 10 pl or less, thus giving finer control of the colours produced (Figure 9.11). Thus whilst a typical DOD printer using CMY inks and an 8 × 8 pixel matrix can reproduce about 275 000 shades, a multi-level charge-drop printer can attain a theoretical gamut of 16.7 million. This may appear a complex process but much additional computation has already been imposed on the original design data by the colour management systems in the host computer.

One effect that arises from the use of super-pixels is that the wet pick-up of ink in different areas of the printed fabric will vary depending on the depth of shade (Figure 9.12). This is observed as a difference in fabric penetration by the ink. The following

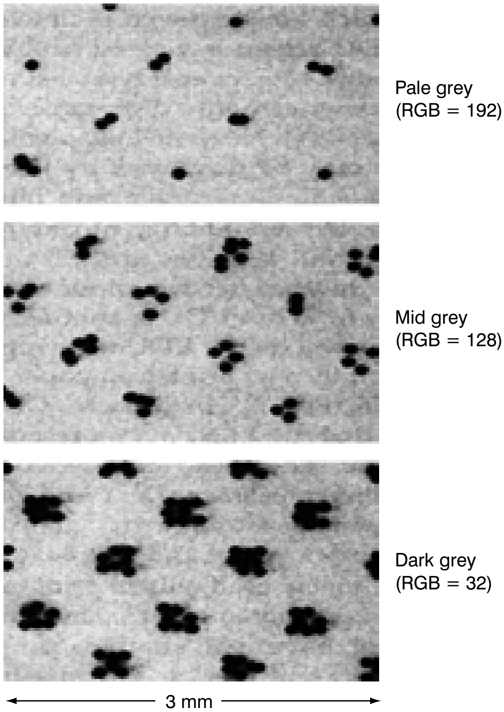

Figure 9.10 Photomicrograph of spot dithering

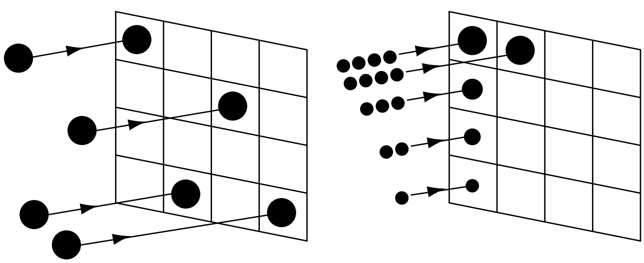

Figure 9.11 4 × 4 super-pixel half-tone matrices

typical figures illustrate this point. If the individual ink droplets have a volume of, say, 120 pl and assuming a medium depth shade, there will be about 30 drops per pixel, i.e. 3.6 nl of ink per pixel. If the printer definition is 600 dpi and the pixel matrix is 8 × 8 there will be 7.0×10^6 pixels per m^2 of fabric and this equates to an application rate of

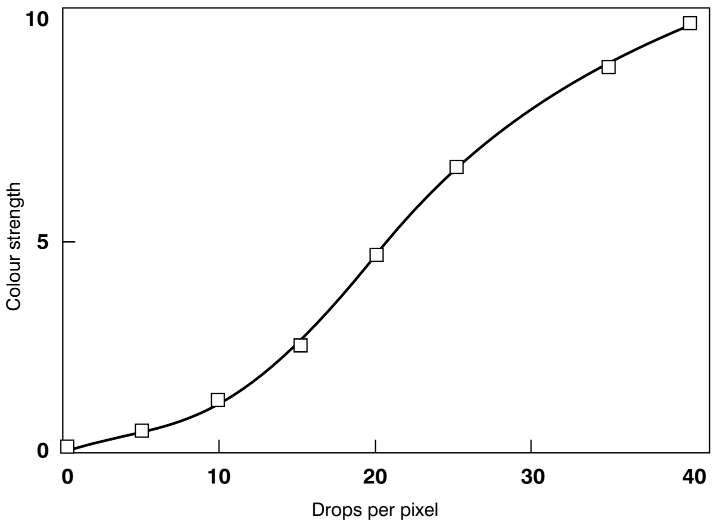

Figure 9.12 Relationship between drops per pixel and colour strength

about 32 ml/m^2. For a typical fabric of 150 g/m^2 this gives a wet pick-up of 21%, which is normal for ink-jet printing and in total contrast to conventional screen printing where the pick-up would be about 100%, irrespective of the depth of shade. Thus in jet applications the wet pick-up may vary in the range 5–40% as between pale and heavy depths or heavy and lightweight fabrics. Problems may arise after deposition of an ink droplet in terms of its wetting and possible wicking through the textile substrate. This is particularly true with ultra-fine pigment dispersions.

9.6 LARGE-FORMAT PRINTING MACHINES FOR TEXTILES

9.6.1 Direct ink application methods

In the past few years a bewildering array of wide-format (1 to 5 m), ink-jet printers have become available for the production of artwork on different types of substrate and for very diverse applications, ranging from very large advertisements on buildings and vehicles to the logos on the tail-fins of aircraft. Since many of these printers operate with a roll-to-roll feed of substrate they can, at least in theory and with a suitable choice of ink medium, be used to print textiles (Figure 9.13). Those that have been marketed usually print at about 1.6 m wide and use one of three main technologies:

Figure 9.13 Encad printer

(a) Piezo DOD systems (e.g. Vutek, Innotech, Mimaki, Epson, Stork Sapphire Ichinose, Reggiani)
(b) Thermal ink-jet (bubblejet) DOD devices (e.g. Encad, Canon, ColorSpan)
(c) Continuous ink-jet (CIJ), charged-drop printers using either a binary-charge system (Stork Truprint) or a multilevel-charge drive (Stork Amethyst and Zimmer Chromatex).

Typical mid-range DOD printers cost £15 000 to £25 000 with a similar sum required for a full suite of associated CAD and colour management software. The control of jet printers resides in a programme running on a workstation or PC, which may be either dedicated to this task or also serve as a platform for the CAD system. All the present machines have reciprocating print heads, which tends to limit output (typically 0.1–0.2 m/min) but this is adequate for sampling or low-volume production for certain niche markets. With some printers it is possible to choose between at least two print definitions but if the definition is doubled the production speed is usually halved. However, there have been exceptions to the low productivity typical of most jet printers and some machines are now capable of producing printed fabric at 0.5–1.0 m/min.

Canon marketed its TPU0020 bubblejet printer, which achieved its relatively high production rate by printing a very wide strip (almost 100 mm at 360 dpi) of the fabric on each scan of a print head having 1360 jets. It has not enjoyed widespread success, however, since this printer requires a much higher capital investment compared with that of other machines. A lower-cost solution to higher productivity is offered by the Macdermid ColorSpan Fabrijet XII printer which prints at 600 dpi and can be set up to maximise print speed by using a staggered arrangement of up to 12 print cartridges (e.g. three each for the CMYK inks) to print a 25 mm strip of fabric at each scan.

Choice of inks is very flexible since the software provided can accommodate the use of additional spot colours (e.g. bright orange, red, blue and green) so that one can print with two heads each of CMYKOG, CMYKRB or CMYKOB to achieve wider colour gamuts (see section 9.7.2).

Piezo print heads are now being developed which are capable of higher printing speeds but, because development costs are extremely high, machine and print head manufacturers and software providers have formed strategic partnerships to develop second-generation jet printers with target running speeds nearer 1 m/min,. Higher speed piezo print heads have, for example, been developed by Aprion (Israel) and Spectra (USA). Stork markets the Sapphire printer with 16–jet print heads (2 × 8 colours) with 180 nozzles per head and a production speed of 0.1 to 0.3 m/min.

Zimmer, in conjunction with the Israeli firm, Jemtex, has developed the Chromatex charged-drop printer (Figure 9.14). The size of drop produced by this system is about ten times larger than that of most other jet printers and as the print definition is relatively low (100–120 dpi) the inks are pre-mixed to match the individual colours of each design, as in conventional printing. There is no super-pixel formation, so effectively the pattern definition is also 100–120 ppi.

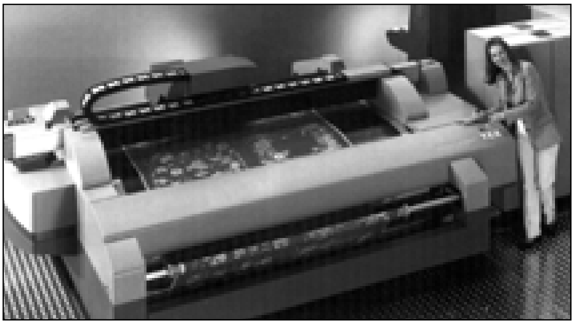

Figure 9.14 Chromatex printer

With all machines the manner in which the fabric is carried under the print head is critical. Not only must it be presented without bowing and with good edge-guiding but it must also be indexed forward precisely after each scan of the print head. To this end fabric tension must be controlled as it transfers from roll to roll. Tension control needs adjusting appropriately for each type of fabric, and knitted constructions are prone to give handling problems, particularly with variable stretching and edge curl. Some printer mechanisms incorporate a recording system for these settings to facilitate repeat orders on a particular fabric quality.

9.6.2 Indirect ink application methods

A completely different approach is offered by Xerox Engineering Systems with its 1.3 m wide, 8954DS electrostatic paper printer, which applies special CMYK inks containing disperse dyes suitable for dry-heat (sublimation) transfer printing of synthetic fibres, in particular polyester. The inks are supplied as concentrated dispersions that are diluted with a pre-mixed solution by the user. The transfer paper can be printed at 0.35 m/min at 400 dpi and it is suggested that this stage can be carried out with minimal supervision during a night shift, the subsequent printing of the fabric taking place under conventional transfer printing conditions using a heated flat-bed unit or drum machine (see Chapter 3). The NUR FabriGraph piezo-type printers are available in 1.5 and 3.2 m widths and they are offered for producing heat-transfer printing paper at up to 0.45 m/min. This system uses eight inks (CMYK, each at two strengths).

Transfer-paper jet printers require considerably more capital investment than other jet machines that print the fabric directly, but have certain attractions, not least in the fact that the flat, uniform surface of paper is easier to print than that of a textile fabric. Moreover, stock costs (i.e. for transfer paper) are lower than for fabric, which can then be printed and supplied at short notice. Thus the transfer route is often used for the printing of flags, burgees and banners, which are usually woven from spun polyester.

For those firms already operating bulk-scale transfer printing machines (using screen- or flexo-printed paper) the jet printing of transfer papers for sampling/approval purposes is obviously attractive and both stages of the process are simple to operate. In some cases, for example the printing of pile fabrics such as fleeces, transfer printing can yield superior results, particularly if the transfer process is vacuum-assisted. Transfer printing of made-up garments such as T-shirts on carousel-type machines is of particular interest but this is usually accomplished using screen-printed plastisol inks, which are ideal for cotton garments. The impact of heat-sublimation printing papers in this sector is therefore likely to remain low until such time as there is a commercially viable process for rendering cotton-rich fabrics printable with disperse dyes.

For certain end uses it is possible to employ a film-release type of transfer printing system in which the special release paper is first digitally printed and the design then heat transferred, for example onto cotton garments. This system, introduced by Xerox and Digital Screen Printing Technologies, is claimed to give prints with very good fastness even to severe washing conditions.

9.7 INK SYSTEMS FOR DIGITAL PRINTING

Specially purified ink solutions have been manufactured for many years to meet the requirements of paper printing for the office reprographics and domestic computer market. The main requirements were that the ink should be very stable to storage and not adversely affect the particular type of print head in which it was to be employed. Dye selection is based firstly on shade requirements, i.e. a bright yellow, magenta and cyan (turquoise) and for prints to have a limited degree of fastness to light and water. Accordingly a number of acid and direct dyes have been commonly used [14]; these are formulated as relatively low-concentration, aqueous solutions containing solubilising agents and humectants such as ethylene glycol. The viscosity of these inks needs to be low (3–10 mPa s) for satisfactory droplet formation, particularly for bubblejet print heads. Some piezo print heads can operate with somewhat higher viscosity inks (15–30 mPa s), making them better suited for the application of hot-melt and UV-curable type inks.

9.7.1 Inks for textile fibres

Following the introduction of digital printers for textiles, stable inks were needed that met the fastness properties associated with each type of fibre and end use. Water-soluble dyes are specially purified with respect to freedom from both particulates and electrolytes, and are controlled for viscosity, pH, surface tension, non-foaming characteristics and storage stability. Depending on the type of printer, inks are supplied either in pre-filled cassettes/cartridges or in bulk for user-filling of ink reservoirs. The ranges of special jet printing inks at present available are:

(a) For cellulosic fibres: reactive dyes (stable liquid formulations)
(b) For polyester fibres: disperse dyes (very fine dispersions)
(c) For wool, silk and nylon: acid dyes (stable liquid formulations).

The main producers of these products are Ciba, BASF, Dystar, Avecia (mainly for OEM suppliers) and DuPont, although there are many smaller, custom ink producers. Some manufacturers have more recently introduced pigment printing inks, namely Irgaphor TBI (Ciba), Helizarin (BASF), Teno-Jet (Brookline Chemical), Artistri (DuPont) and Jetex P (Dystar) inks. For ink-jet applications the pigment particles are milled much more finely (to around 0.1 μm diameter) than those used for conventional pigment printing. With some systems the pigment binder is incorporated in the ink and with others the polymer must be applied as a secondary treatment. These developments represent an important landmark in the further development of ink-jet printing for we now have available a process that is said to require neither special fabric pretreatment nor after-washing and so is very environmentally attractive. For inks containing pigments, particularly where an organic binder is present, it is preferable to use jet printers of the piezo type. The high temperature that is reached by the tiny bubble-producing elements in the print head may in time produce a charring effect on the binder in the ink, known as kogation.

Currently most research into inks for jet printing of textiles is concerned with pigments, owing to their good fastness properties and versatility, i.e. can be printed on any textile with no pretreatment.

9.7.2 Shade gamuts attainable with jet printing inks

The range of shades that any three primary colours will produce is often represented by a colour triangle displayed on a CIE chromaticity diagram. If CMY printing inks were always present on the surface of the substrate as tiny individual dots with no intermingling, as is the case with gravure and offset printing (producing what is termed 'partitive mixtures'), the shades would all lie within a triangle formed by joining the *xy* coordinates of the C, M and Y components in Figure 9.1. This is, however, not the case in all but pale shades, as can be seen from the coordinates of binary mixture shades produced by cyan/yellow (green), magenta/yellow (red) and cyan/magenta (blue). Within each pixel the blending of the spots of the C, M and Y inks corresponds more closely to subtractive colour mixing with which designers, dyers and printers are more familiar. The colour triangle therefore acquires extended boundaries indicating an extension to the gamut of shades achievable. Because of the extreme non-uniformity of the CIE *xy* colour space it is often unclear where major differences between different colour combinations of inks may lie. In such cases it is better to transform the colour data into the corresponding colour coordinates of the CIELAB colour space, in which the vertical *L* axis defines the lightness (white at the top, black at the bottom) and around which the full colour circle is more uniformly arranged. Simplified colour gamuts may then be represented as a two-dimensional display on an *ab* diagram.

Figure 9.15 illustrates, in CIELAB colour space, the gamut of shades that can be achieved by a typical CMY ink combination whilst the outer gamut boundary shows by how much the range of shades attainable can be extended by using additional spot colours. Printed colours obtained with standard CMY combinations are particularly lacking in the bright orange/red region. Many wide-format jet printing machines now offer the possibility of operating with seven or eight inks, there being at least an orange and bright green added to the standard primary shades. Manufacturers of inks for each textile fibre therefore provide additionally a golden yellow and bright shades of orange, mid-red, reddish-blue and green to the standard CMYK products. There are, however, variations in colour gamut between different classes of ink. For example, disperse dyes in the cyan shade region are not as bright as those based on acid or reactive dyes.

Mention should be made of the availability of additional so-called photo-inks, which are weaker solutions of the three primaries. As the name suggests these are

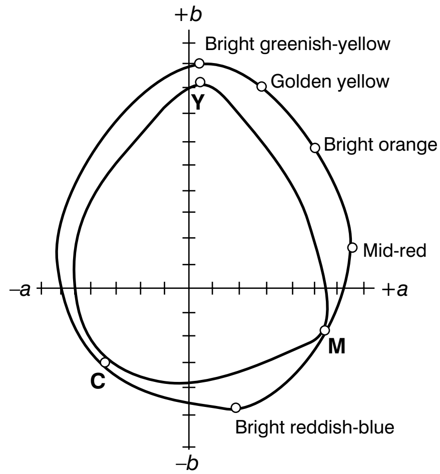

Figure 9.15 CIELAB extended gamuts

used mainly for paper printing where they enable finer gradations of hue and better rendering of skin tones. The use of such inks (and indeed the use of the black ink) can increase the number of individual shades attainable within the gamut but does not extend the boundaries of the CMY shade gamut; photo inks are not normally used for textile printing. The black ink is employed mainly for producing full black shades and neutral greys rather than as a dulling component for CMY combination shades.

With the exception of the abovementioned pigment printing systems, all fabrics to be jet printed require a pretreatment in addition to normal cloth preparation and this normally involves padding with a solution of the required products followed by drying. The first requirement is to attain a balance between the ease with which the fibre surface is wetted by the ink drops and the natural tendency for the coloured spots to spread laterally along individual fibre bundles. For this purpose a suitable textile thickening agent (typically medium-viscosity sodium alginate) is used. Depending on the dye and fibre type various auxiliary products and fixation agents are also incorporated. Thus to assist solubilisation and fixation of reactive dyes the pad liquor contains urea and sodium carbonate whilst for acid dyes applied to silk or nylon fibres a solubilising auxiliary agent and ammonium sulphate are added for similar reasons.

After printing and drying it is then necessary to fix the dyes using either steam or dry heat. Reactive dyes may be fixed by atmospheric pressure steam for 10 min at 102 °C or for correspondingly shorter periods if high-temperature steaming equipment is available. As with the fixation of conventionally printed fabrics it is also possible to use thermofixation conditions (5 min at 140 °C) although ink-jet prints thus produced tend to appear rather weaker and duller compared with steam-fixed prints. Disperse dye prints may similarly be either steamed at high temperatures (10 min at 175 °C) or, more usually, baked at 180–200 °C for 90–120 s. The fixation of acid dyes on nylon and silk is always by atmospheric steaming (typically 15 min at 102 °C). Equipment manufacturers now produce batch steaming/thermofixation units specially designed to handle the short lengths of fabric that are typical of much jet-printed production.

Finally the goods must be rinsed, washed-off and sometimes after-treated, if the very highest wet-fastness properties must be attained, and then dried.

9.8 VARIABLES AFFECTING SHADE REPRODUCIBILITY

In the textile printing trade jet printers are used either for sample approval prior to printing the pattern conventionally or directly for small-scale production prints. How reproducible such prints can be will depend on a number of factors but principally will involve possible variations in:

(a) Substrate and how it is prepared
(b) Inks (including their stability) and the consistency with which the jet system delivers them to the fabric surface
(c) Absorbtion/fixation characteristics of the dyes used in the inks
(d) Reliability of all the jets in the print head to remain functioning (i.e. not become blocked).

9.8.1 Effect of substrate variations

Even when using the many grades of paper that are available for ink-jet printing it is immediately evident that the substrate has a marked effect and, depending on the type of pretreatment given to a fabric, the colour yield can vary by 50–100% [13]. Nearly all textiles that are to be jet-printed are given a pretreatment with thickener containing *inter alia* humectants, alkali or acid, and surface-active agents, depending on the dye/fibre system. Such pretreatment can have a major effect on the colour yield of the print, particularly in heavy shades. For optimum colour yield the tiny spots of ink within each super-pixel must remain clearly defined on the fibre surface (when viewed under a microscope) because once the white fibre surface is completely covered by ink spots, leaving no uncoloured fibres on the surface, there is no further appreciable increase in the depth of colour of the print. Thus it is not desirable for the ink droplets, once they land on the fibre surface, to spread (by capillary wetting along the weft and warp yarns of the fabric) but at the same time the inks must be absorbed sufficiently on the fibre surface and then allowed to dry so as not to cause smearing or marking-off faults. Once the printed fabric dries (this usually occurs without assistance since the wet pick-up from jet printing is considerably lower than that of a screen printed fabric and production speeds are slow) the dyes are fixed in a conventional manner, i.e. either by steaming or thermofixation.

9.8.2 Print consistency and shade reproducibility

Using a standard test pattern, repeatability and reproducibility trials have been made on different types of textile jet printers [4]. In addition to repeating the print test on the same day and on different days over a period of several weeks, printed samples were also taken from different positions across the fabric width; these were also assessed spectrophotometrically for shade variations. The results obtained with five printers showed that the day-to-day reproducibility of all machines was very good (the calculated colour difference ($\Delta E = 1.0$) being the level accepted in the dyeing trade. However, despite the use of the suppliers' colour management software, shade reproduction (i.e. the colour fidelity) was not so good ($\Delta E = 7$–11). Unfortunately no similar tests have been published for conventional prints so, in contrast with the textile dyeing industry, there are no generally accepted levels of acceptability for shade reproduction for printed designs.

A further feature of the test pattern used enabled the sharpness of printed outlines to be assessed. In all cases print definition across the weft (i.e. the print head scanning direction) was at best only 50–75 ppi whereas that in the warp direction was at least 100 ppi, irrespective of the dye/fibre system involved. This may be caused by the tendency for the formation of tails or satellites from the drops.

9.8.3 Print head reliability

In practice the durability and reliability of jets play a major role in the economics of each system. It is also important whether print heads can be cleaned readily and also easily be replaced by the user. Some manufacturers give their print heads a guaranteed minimum life (e.g. Stork guarantees the jets in their Amber and Zircon printers for 3000 hours (typically 6 to 12 months) although head replacement requires a technician, whilst Encad print cartridges are guaranteed to use at least a 500 ml container of ink before replacement). When changing from one ink type to another, piezo print heads can be flushed and the ink supply bottles changed quickly, whilst on bubblejet printers each print head cartridge/reservoir system is unclipped and changed.

All printers have software that allows a cleaning cycle for the jets and indeed this is deliberately interposed at intervals during printing (another factor that reduces output).

Common causes of temporary jet failure are because of air entrapment in the ink supply, and jet orifice contamination from airborne fibres or surface evaporation of the ink. Test patterns can be printed that identify any blocked jets and this also needs to be done at intervals between production runs. One advantage of using, say, a 600/720 dpi printer rather than a 300/360 dpi one is that the presence of a few blocked jets has a less marked effect on print quality with the higher definition printers. Recognising this problem some bubblejet printers such as the Encad Pro700 and the ColorSpan FabriJetXII printers incorporate an automatic detection system for malfunctioning jets. However, the overall durability of piezo print heads is recognised as being considerably better than that of bubblejets in which there is a tendency for the tiny resistor elements to burn out, a fault that can only be cured by changing the print head

9.9 MARKETS FOR JET-PRINTED TEXTILES

It is estimated that some 60% of initial designs never go into bulk production and even when they do design life is becoming shorter than was formerly the case [3]. Jet printing of samples not only allows quick response to customers but cuts costs since the making of screens for the initial strike-offs is obviated. The combined use of CAD, modern colour communication systems and ink-jet sample printing has revolutionised the whole cycle of design and colourway approval by customers, for what used to take weeks can now be accomplished in days.

For bulk production, because of the low productivity of presently available jet printers, it might at first sight seem that they could not possibly compete economically with screen printing machines. This is indeed true if more than a few hundred metres of fabric are to be printed. However, there is an increasing trend to short run lengths, which is now well below 1000 m per colourway in Western Europe compared with three times this elsewhere. This is one reason why flat-screen printing, which has lower printing costs for short runs compared with rotary printing, has actually tended to increase its market share to around 35% [2]. Moreover the present culture for minimum stockholding and right-on-time delivery means that for successful patterns repeat orders may be frequent but are for short fabric lengths. One approach to the limited production rate of jet printers is to install large numbers of machines, the total capital investment for which will still be less than that required for a high-productivity screen printer.

Jet printing really comes into its own, however, where one finds new market niches for which this technology is ideally suited. In this area advertising and sales promotion initially led the way, for the large printed fibre meshes that are jet printed for display on vehicles, particularly buses, and even large buildings can be considered to be a textile application. However, for these outlets it is resin-bonded pigments rather than dyes that are jet printed and these have also been used for mattress cover printing in the Legget and Platt wide-format printer in the USA. In the home furnishing design field some firms, purely for trade fair exhibitions, will print 'concept' designs using unfixed aqueous inks! Jet application to large areas of textile material has also been extended to the production of backdrops for theatres and TV studios, thus saving many hours of manual painting or spraying. Similarly, temporary, one-off prints allow the making up of garments that can be modelled and photographed for sales catalogues (e.g. for mail order firms). This is a particular advantage, for catalogues are commonly prepared three to six months ahead of bulk production.

Even more specialised outlets are for the printing of fabrics used for making yacht sails, flags and banners, umbrellas and even for hot-air balloons. In the textile apparel field digital printing of emblems and logos on T-shirts and other promotional sportswear has been long established whilst jet printing is ideal for one-off designs such as club ties, league football shirts, horse jockey vests and for the so-called mass customisation market.

Thus particularly in the USA there are now a number of Internet firms offering bespoke garments manufactured to an individual customer's specifications and then jet printed as 'cut and sew' panels. The same technique can be applied to certain *haute couture* designs that can be difficult to produce by conventional printing techniques, for example those requiring photorealistic, multi-tonal effects or where precise matching of a design is required across the sewn panels of the made-up garment. A degree of customisation is also possible for prestige automotives (for both the polyester upholstery and headlining fabrics) although this development has been so far confined to Japan and the USA.

Where garments or furnishings are sold over the Internet it is clearly desirable that colour representation on VDUs should correspond reasonably closely to reality. To this end GretagMacbeth's WebSync system (websync@gretagmacbeth.com) allows a degree of calibration using a simple set of colour filters that can be placed on the screen whilst the user makes adjustments to panels displayed on the monitor. However, colour images on the Web are often encoded as GIF images which are limited to 256 shades and of these only 216 shades are 'web safe' (i.e. will be displayed similarly on all web browsers).

9.10 CONCLUSION

Ink-jet printing of textiles has already established itself for initial sample production since this offers very fast customer response, versatility and economy. The integrated systems now available are capable of yielding repeatable sample prints that are sufficiently reproducible to be used for initial customer selection/acceptance followed either by:

(a) Small scale production (for rapid response, niche markets) using a jet printer, or
(b) Larger scale, laser-engraved screen printing based on an integrated recipe prediction system, with pre-production approval of conventional strike-off sample prints.

Limitations to the shade gamut that could be attained on early jet printers using only CMYK inks have been resolved. Additional spot colours are now available although not all of the printers on the market can yet accommodate these. Equally there are no longer technical limitations as to which fibres can be printed, particularly following the advent of special pigment printing inks. Economic limitations do still exist, however, as a result of relatively high ink costs and low productivity. However, for certain types of jet printer production speeds have in fact been forecast to increase at 30–50% per annum. At present jet printing of textiles holds no more than 0.2% of the market and a major expansion must await the advent of printers that operate at speeds in excess of 1 m/min, and preferably in a truly continuous manner.

The introduction in 2003 of the Reggiani printer using Aprion's piezo print heads said to be capable of printing at up to 1.5 m/min may well mark the beginning of a new era in ink-jet printing of textiles.

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