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METHODS FOR IMPROVING PROCESS CONTROL AND CORRECTION IN FLEXOGRAPHIC PRINTING

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Rezumat. *Testerul de imprimabilitate este definit ca fiind un dispozitiv care aplică uniform o cantitate reproductibilă de cerneală pe un suport, în condiții bine definite, folosind un control motorizat al funcției proces specifice aplicării filmului de cerneală. Această caracteristică repetabilă a procesului de trasare poate facilita și corelarea condiției de tipar curente definită prin parametrii primari de proces specificați prin procesul de tipar, suport, cerneală, ecran, ordinea imprimării etc. Prin creșterea utilizării și funcționalității testerului de imprimabilitate, tipografii au posibilitatea de a utiliza trasările de laborator pentru controlul și corecția procesului rezultând reduceri semnificative în costuri și timpi de producție.*

Abstract. *The printability tester is defined as a device for uniformly applying a reproducible amount of ink to a substrate under specified conditions using a motorized control of the ink transfer process specific function. This repeatable print operation characteristic may also facilitate the correlation of the actual printing condition set by the primary process parameters specified by printing process, substrate, ink, screening, printing order, etc. By extending the usage and functionality of the printability tester, printers have the possibility to use laboratory test prints as means of process control and correction at a fraction of cost and time.*

Keywords: flexographic printing, process Control, printability tester, laboratory preparation of test prints

1. Introduction

From different market requirements and expectations the need of reproduction quality is giving the motto "Printing the Expecting" a more meaningful relevance across production locations, printing technologies, substrate and production batches and even viewing environments. This need is pushing the flexographic printing process to become more consistent and predictable implying a higher level of the process standardization in order to ensure that the various parties involved in the flexographic printing production are able to control their part of the process in a meaningful and repeatable way. An essential component in this process is the specification of the ink set characteristics.

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To test various dry properties of the ink as e.g. colour, transparency, gloss, light fastness, chemical resistance to various agents and so on, a test print based on the actual printing condition set by the primary process parameters specified by printing process, substrate, ink, screening, printing order, etc. is necessary. While the appearance of the print from the commercial print process defines the visual characteristics of the printed product, the somewhat common practice to apply corrections directly during and on the printing process, typically leads to extra production setup time reducing productivity and increasing production costs. Alternatively using a printability tester with the appropriate settings, the flexographic printing condition may be tested in a consistent and predictable manner a priori of the actual process.

2. Requirements and recommendation

Printability tester

According to standard definition from ISO 2834-2 [4] the printability tester (**Fig. 1**) is a device for uniformly applying a reproducible amount of ink to a substrate under specified conditions. While any printability tester designed for the type of liquid inks to be tested (solvent, water or radiation cured) may be used, in order to ensure repeatable and reproducible printed ink films of uniform and at the required ink film thickness, the printability tester shall provide motorized control of the ink transfer function.

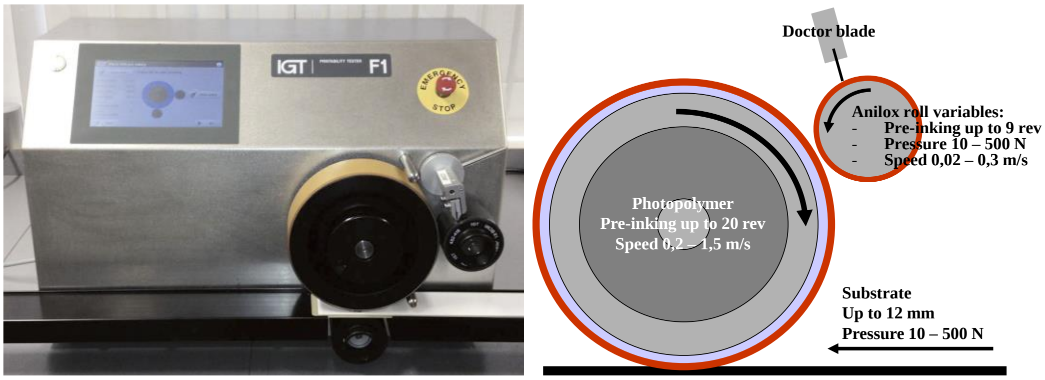

Fig. 1. IGT F1 Printability Tester Operation.

Due to the differences between a flexographic printing press and a laboratory printability tester, laboratory produced prints can be different in appearance and in ink film thickness from commercial prints. To match the same colour strength or print density, different settings from the actual press settings are generally required. The higher degree of settings customization, the better flexibility has the printability tester to match the press, especially by proper adjusting of the printing speed and impression pressure between the printing form and printing substrate.

Ideally but not necessary, the flexographic printing form should be in-house produced from the same the process as the printing form used for production. This will account for taking out one more variable from the process-lab matching, but will also speed up the replacement of worn out or scratched printing forms. It also makes its design easier in order to include the desired raster patches, lines, small sized text and other geometrical specific test elements.

As with the printing process, the choice of flexographic anilox rollers for the printability tester is based on their main characteristics: volume, screen ruling and screen angle. The typical anilox roller for the printability tester has either 3-4 bands of different characteristics to make the test print process more efficient or single band. The choice of chromium or ceramic plated is also non critical, because the workload in the lab is much smaller than the actual production, but typical higher volume anilox rollers are ceramic plated. While there is no definitive direct connection between the used production anilox rollers and the lab ones, one way to determine which ones are practical to be used is based on the lab to press direct correlation method described in 0.

Materials

Printing inks to be tested may be either concentrates with high viscosity used as basic inks during ink formulation process or print ready inks. Before testing a concentrate it needs to be mixed with an extender (varnish) resulting a dilution. Print ready inks are those printing inks of the appropriate composition and viscosity for the purpose of the printing process requirements. Rheological characteristics of either of the ink types have a decisive influence on the quality of the resulting test print and aim values shall be in the same aim range between lab and production [1]:

Dynamic viscosity η (tackiness) which can be termed as the inner resistance to the flow of the ink. The more viscous an ink, the less easily it flows and the more difficult it is for it to spread into a film. The viscosity has to be determined and adjusted with a solvent at a certain temperature. The initial viscosity plus the subsequent amount of solvent added to dilute the basic ink towards aim viscosity has to be recorded (viscosity curve - **Fig. 2**). The printing ink viscosity shall be determined in accordance with ISO 2431 [7], typically using a 4 mm fixed jet flow cup. Using a levellable stander with temperature control jacket and integrated thermometer will reduce the uncertainty of the flow time determination (Fig. 3). The printing viscosity aim is typically either the native of adjusted (by adding solvent) viscosity of the extender and this value shall be identical between lab and production. It is an absolute prerequisite that all the inks shall be printed with the same viscosity on the printability tester and production printing press. For practical reasons, it is recommended that all basic inks (not yet print ready) should first be adjusted to the same printing viscosity by adding solvent (as such becoming print ready) and only then mixed with the extender (varnish).

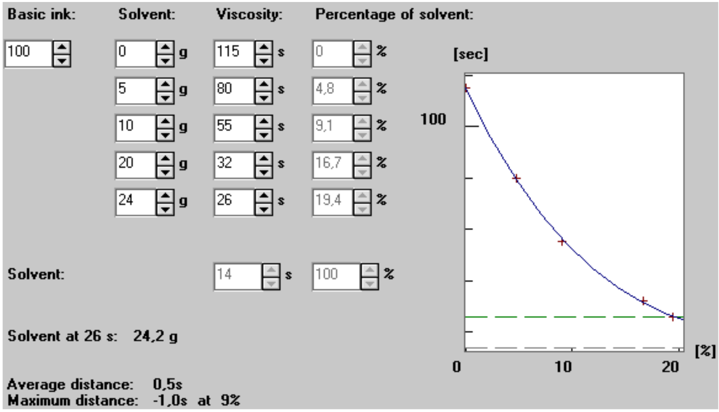

Fig. 2. Viscosity calibration curve for a 26 s flow time.

Thixotrophy is the characteristic of changing viscous inks from a high viscosity (in the case of nonmoving ink) into a significantly lower viscosity (when stirring). Since modern flexographic presses have an inking system that is continuously pumping the ink while maintaining the desired viscosity, it is relevant to address this characteristic of the ink in the lab by means of speed mixer (**Fig. 3**) usage before measuring viscosity or doing test prints. The stirring will also remove potential air bubbles from the ink.

Fig. 3. Operation of analytical balance, ink speed mixer and flow cup.

For the test print of basic inks dilutions and leftover inks, a high quality contrast standardized printing substrate (**Fig. 4**), clear coated and sealed, containing no optical brightener and a preprinted black band area shall be used. For the test print of print ready inks the printing substrate is the actual substrate used in production.

Fig. 4. Reference Substrates – Leneta and APCO II/II (alternatiely IGT CT2846).

Typical lab activities are involving small quantities of inks, 100-200 g and due to the precision requirements of both mixing and leftover quantities, an analytical balance (**Fig. 3**) with 0.1 mg readability is essential part of the lab.

Climatic and handling recommendations [2]

All the tests shall be carried under standard climatic conditions as described by ISO 187 [8], standard atmosphere of 23 °C ± 1 °C / 50 % ± 2 % r.h. The ink and the printing substrate shall be kept in the lab for a period of time (typically at least 2 hours) to create temperature and humidity equilibrium. Some inks are more sensitive to environment and will require special handling conditions like keeping the ink in tightly sealed recipients, while uncoated substrates may require more time to reach equilibrium. Variations in temperature will significantly influence viscosity and its ongoing control remains as, arguably, the most significant variable in the flexographic reproduction process. If it is not controlled continuously and closely, uniform ink coverage and accurate color match cannot be achieved. Improper or high and low “spikes” in ink viscosity also results in ongoing color management issues, as one second shift can result in a change in color measurement of 1 ΔE^*_{ab} or greater. Viscosity affects not only the hue and strength of the printed color, but impacts other print quality attributes including ink lay down, TVI and trapping. Additionally, performance properties such as coating weight, drying speed and solvent retention are all effected by ink viscosity.

Use preferably non-powdered gloves and safety goggles during preparation and test. Thoroughly clean and dry the lab printability tester and all items that come in contact with ink or the printing substrate. Handle the printing substrate with care to avoid touching its printing surface preventing fingerprints or other contamination.

2.1. Measurement

The colour measurements and calculation of tristimulus values for reflective and transmissive samples shall be made in accordance with ISO 13655 [6], while measurement conditions should be M1, white backing. In graphic technology, the measurements are restricted to production print substrates that allows a meaningful interpretation of ISO 13655-compatible measuring instrument readings for front viewing conditions corresponding to reflectance response (0:45 or 45:0 geometry) and transmittance response (d:0 geometry). While for substrate fluorescence a M1 part 2 compliant device will suffice, for ink fluorescence a M1 part 1 compliant device is required, while older M0 compliant devices are not recommended at all for either of the two use cases.

Special metallic substrates and inks requires d:8 geometry measurement, typically SPI/SCI, in order to result in meaningful measurements based on the “measure as we see” principle. Such a setup, even if not common and covered by ISO 13655, it is the only practical choice.

When measuring half-tones, screen ruling is another factor that should be considered when selecting the instrument sampling aperture. If the area measured is made too small, the measurements become erratic and depend on the number of half-tone dots that happen to be measured. As such a 2 mm aperture is required for screens of 52 lines/cm and up, while 4 mm is required for 26 lines and up.

In order to reduce the homogeneity related uncertainty, when measuring test prints it is recommended to perform an averaged set of at least three readings. While ISO 2834-2 [4] quality requirements for printability testers specifies a normative equally spaced pattern adapted to the geometric form of the print area (minimum 9 measurement positions), in practice the daily lab activities are limiting averaged sets to 1/3 of the requirement. On IGT F1 printability tester two prints are made in succession. The second print is usually of better quality than the first, and is consequently used for evaluation. Correlated with IGT CT2846 reference substrate 40 mm black band convenient mid area location on this second print, it makes the ideal designated area for measurements applying the principle of 3 set reading lead – center – trail roughly 20 mm apart (**Fig. 5**). By analogy, a similar area can be designated on actual printing substrates.

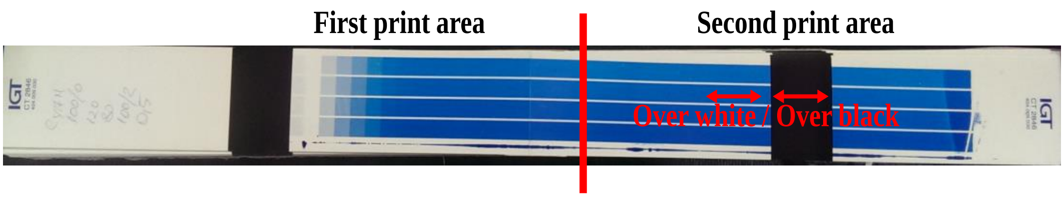

Fig. 5. Example of designated measurement set areas.

Viewing environment

Matching measurements for test prints need to be consistent with the visual judgement. This can reasonably be expected by using viewing cabinets complying with viewing condition P1 of ISO 3664 [3]. Based on metamerism and colour inconstancy check requirements, additional viewing conditions (CIE illuminats A, F11 – TL84, D65, etc.) may be used to appraise or compare test prints.

3. Test methods

Anilox roller lab to press direct correlation

The principle of this method is based on the flexibility of the settings customization that the IGT F1 printability tester has by fine tuning these settings in order to find the proper way to correlate lab and production for a given set of ink and anilox rollers. The helpers are coming here in form of the 4-band anilox rollers selection for F1 giving a wider range of ink volume transfer in one test print and the BestMatch (**Fig. 6**) spectral function developed and integrated into X-Rite eXact spectrophotometer family. BestMatch lets you know if you can get a close match to your reference color by adjusting the ink thickness (offset printing) or concentration (flexo and gravure printing).

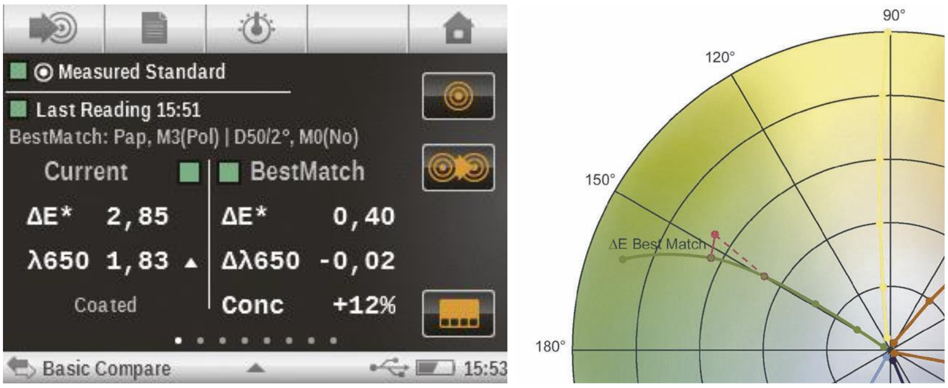

Fig. 6. BestMatch point - Best possible color (e.g. green) that can be achieved.

Preparation

Requirements: Printability tester, Materials – Print ready inks and printing substrate, Climatic and handling, Measurement.

IGT F1 printability tester with a selection of 4-bands and/or single anilox rollers.

A choice of print ready ink(s) and print substrate.

Production prints of the specified printing condition with combinations of all the available anilox rollers.

Measurements of each printing combination stored as job references inside the X-Rite eXact spectrophotometer memory for easy and fast access.

Execution

Set the correct printing speed and pressure in order to achieve the desired ink transfer for the same printing substrate to be tested on the printability tester. By increasing the print and/or anilox force and/or decrease the printing speed higher ink transfer is obtained. The opposite will give less ink transfer. Another aspect to be taken into account is the mottle effect, homogeneity of the transfer needs to be consistent with the one obtained into production (visual comparison using a camera based device). Higher print force and print speed may lead to mottle effects and/or poor ink transfer. Pre-inking function of the anilox roller may improve the uniformity of the ink transfer, but too many revolutions may dry the ink on it.

Using BestMatch function compare each of the bands of the chosen anilox roller and look for BestMatch possibility. A reasonable aim tolerance of 2.0 ΔE^*_{ab} is indicating that further tuning of the settings will match. The + or – sign of the BestMatch Concetrate correction is indicating also the direction of the settings change. If test print quality deteriorates without reaching the BestMatch point as the result of the change, it may indicate the need to switch to another printability tester anilox roller. In the practical scenario 8 press anilox rollers were tested against two printability tester anilox rollers, one 4-band and one single band. Results are presented in **Table 1**.

Table 1. ΔE^*_{ab} practical assessment lab to press anilox rollers correlation – reference ink

No.	*Press anilox rollers*			*IGT F1 4-band 402.228.412*				*IGT F1 402.212.412*
	Code	*Screen* l/inch	*Volume* ml/m²	*B1* 350/5.0	*B2* 250/6.8	*B3* 200/9.2	*B4* 150/12.3	*1-band* 150/16.0
1.	PFLEX420	420	3.6	1.6				
2.	PFLEX400	400	4.0					
3.	PFLEX340	340	5.0		0.9			
4.	PFLEX255	255	8.5			1.8		
5.	PFLEX220	220	6.0					
6.	PFLEX200	200	9.5				1.8	
7.	PFLEX140	140	12.3					
8.	PFLEX100	100	14.5					0.8

The process will require several iterations to understand the result of any setting change and the relation to the production desired aim. For an efficient lab operation one more aim for a multi-band printability tester anilox roller is to fine tune the settings in such a way that all bands may hit at the same time one of the actual press anilox rollers.

Once the proper settings and the anilox roller relation between lab and production are determined, additional inks and substrates combinations may be tested to check the consistency of the correlation (**Table 2**).

Table 2. ΔE_{ab}^{*} practical assessment lab to press anilox rollers correlation – additional combinations

No.	*Substrates*	*Average ΔE_{ab}^{*} correlation for all matches*			
		Ink 1	*Ink 2*	*Ink 3*	*Ink 4*
1	PS 1	1.6	1.2	0.9	1.1
2	PS 2	1.1	1.0	1.4	1.8

Assortments – preparing and defining, colorant calibration

An assortment is referred as being a selection of colorants (basic inks and/or leftover print ready inks) used for a recipe calculation related to the ink formulation process. Each assortment includes one or more transparent white (additionally opaque) and one substrate. A colorant calibration consists of a certain number of proportionately different mixtures of a basic ink with transparent (additionally opaque) white on white and black substrate. The absorption capacity of the ink can be determined from the different concentration grades on white substrate and the scattering capacity from the different concentration grades on black substrate.

One of the most practical limitations in the current lab ink formulation activities is the quality and performance of the assortments database used. A typical common practice is to rely on the assortments delivered by the supplier of the base inks. While convenient, the drawback is due to the way that particular database was created, the relevant parameters being not properly or at all communicated to the receiving lab.

Consequently, this leads to poor performance of the ink formulation process and inconsistency between ink reference aim, formulated recipe and print production results. Another typical common practice is to make the colorant calibration directly on the production substrate. While in some use cases it may be practical, several factors like the lack of black band, substrate inhomogeneity and dependency of colorant calibration on substrate characteristics, makes this setup not the most desirable choice in top of the question mark on how many production substrates should be included in the colorant calibration process. Additionally, the choice of anilox rollers to be used (lab and production) and their volume relation raises a lot of practical limitation for such a scenario.

This method is describing the necessary steps to be taken in order to create a consistent assortment that will provide reliable and predictable results into production.

Preparation

Requirements: Printability tester, Materials – Basic inks and reference substrate, Climatic and handling, Measurement.

IGT F1 printability tester with a selection of 4-bands and/or single anilox rollers.

A choice of reference substrate based on ISO 2846-X [9] requirements, e.g. IGT CT2846.

A choice of solvent and its associated parameters – viscosity, mass density.

A choice of basic inks (concentrates) and their associated parameters – viscosity calibration curve, mass density.

X-Rite Ink Formulation software and eXact spectrophotometer.

Execution

Define the reference thickness object of Cal 1.0 corresponding to the choice of the printability tester anilox roller band for entry based on the corresponding one from the most used into production. The rest will be correlated through the Thickness objects method described in 0.

Setup the assortment typically as shown in **Fig. 7** using the defined band of the printability tester anilox roller color layer entry.

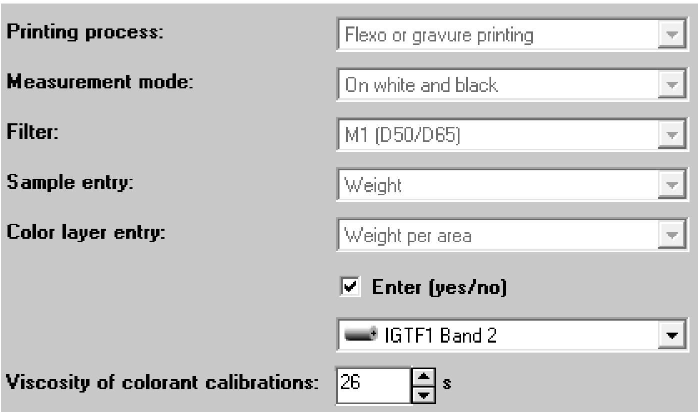

Fig. 7. X-Rite Ink Formulation software assortment setup.

Define used solvent by its designation, mass density and viscosity.

Define assortment Paper by its CT2846 code, and carry on the measurements over its white area and black bland using eXact with M1 measurement condition.

Define basic inks by their designation, mass density and viscosity calibration curve.

Carefully prepare dilutions of each basic inks mixed with the transparent extender typically using a series where next one is using double of the basic ink from current one, e.g. 0.5%/95.5% - 1.0%/99.0% - …- 64.0%/36.0% - 0.0%/100,0% as shown in **Fig. 8**. Each dilution must be print ready having its viscosity aligned with designated value of the printing process as set in the previous step. Opaque white extender will be treated as any other basic ink in terms of the mixture series with transparent white. The typical entry in the database is starting with Transparent white, Opaque White, Black and then the rest of the other basic inks. Additionally, sample points for Basic Ink/Opaque white and Basic Ink/Black should be added in the higher concentration area (**Fig. 8**).

	FXX300L	TCN029S
0,5 %	99,5	0,500
1,0 %	99,0	1,00
2,0 %	98,0	2,00
4,0 %	96,0	4,00
8,0 %	92,0	8,00
16,0 %	84,0	16,0
32,0 %	68,0	32,0
48,0 %	52,0	48,0
64,0 %	36,0	64,0
80,0 %	20,0	80,0
100% FXX300L	100,0	
100,0 %		100,0

	XR Red	XR Extender 1	XR Op.White	XR Black
50XR_50XR	50,0		50,0	
90XR_10XR	90,0			10,0

	XR Extender 1	XR Op.White	XR Black
95XR_05XR		95,0	5,00
80XR_20XR		80,0	20,0
60XR_40XR		60,0	40,0

Fig. 8. Colorant calibration series.

Using the settings found as result of method 3.1 and the selected anilox roller band for colorant calibration, make test prints for each dilution.

				Color distance dE:	
	TCN026B	FXX300L	TCN029S	On white	On black
0,5 %	0,5%	99,5%	-	0,6	0,8
1,0 %	1,0%	99,0%	-	1,1	1,1
2,0 %	2,0%	98,0%	-	1,1	1,2
4,0 %	4,0%	96,0%	-	1,0	1,8
8,0 %	8,0%	92,0%	-	1,2	3,5
16,0 %	16,0%	84,0%	-	0,7	6,5
32,0 %	32,0%	68,0%	-	0,7	8,8
64,0 %	64,0%	36,0%	-	2,3	6,2
100,0 %	100,0%	-	-	2,4	4,8
90,0 % 10,0	90,0%	-	10,0%	5,9	4,2

Maximum color distance: dE = 5,9 (On white), 8,8 (On black)
Average color distance: dE = 1,7 (On white), 3,9 (On black)

Fig. 9. Performance of colorant calibration.

Measure and record each test print with the corresponding field of the assortment database. After completing the recording process for each basic ink, the ink formulation software will report the performance in terms of the actual measurement relation to the calculated prediction as a ΔE^*_{ab} difference. If some of the reported values seems odd (**Fig. 9**), remake and measure the test print for the corresponding value, but keep in mind that colorant absorption capacity is not linear nor is its scattering capacity.

Thickness objects calibration

This step is required to fully capture the anilox rollers relation from lab to production by establishing a mathematical relation between all printability tester and production anilox rollers to be used by ink formulation software ability to perform many complicated algorithms, such as computing many-flux calculations and spectral matching routines.

While the method 0 can be used regardless of the ink formulation software and is the basic step for lab to production correlation (direct calibration), the thickness object calibration is the best and only way to actually port any recipe of a print ready ink from one anilox roller to another streamlining the ink formulation process. The relation is determined by applying several definite volumes (by anilox roller designation) of known recipes of print ready inks and measuring their spectral fingerprint.

Preparation

Requirements: Printability tester, Materials – Print ready inks and printing substrate, Climatic and handling, Measurement.

IGT F1 printability tester with a selection of 4-bands and/or single anilox rollers.

A choice of up to 5 print ready inks automatically generated or manually selected from the ink formulation and a print substrate.

Production prints of the specified printing condition with combinations of all the available anilox rollers.

Printability tester prints of the specified printing condition with combinations of all the available anilox rollers.

X-Rite Ink Formulation software and eXact spectrophotometer.

Execution

Setup the designation of the thickness object, choose the print process type as flexo/gravure and start the Calibration process by selecting the appropriate assortment from database.

Measurement of each individual recipe will result in a % ratio and their average will uniquely define the relation between the current thickness object describing the intended anilox roller and reference thickness object used to entry the colorant calibration. In the formulation process the recipes will be checked using the appropriate anilox roller of the printability tester and then ported to the actual anilox roller to be used into production.

The % thickness object calibration will be also consistent with the direct calibration of lab to production from 0 for the corresponding anilox rollers.

Conclusions

Conclusion (1).

By fine tuning the settings of the printability tester (pressure, speed, choice of anilox roller) it is possible to closely replicate the ink volume transfer for any given printing condition used in flexographic printing production. Going upstream it sets the possibility to further calibrate the ink volume relation between both lab and production anilox rollers useful for the ink formulation process, improving both the formulation accuracy but also the approval of the print ready inks based on objective and consistent measurement protocol. Other evaluations may also be carried in the lab without the need to actually go into production, improving productivity and reducing production costs.

Conclusion (2).

Failing to observe and follow the requirements and recommendation will increase the level of uncertainty for any involved method and process, reducing their effectiveness in providing reliable results.

Conclusion (3).

While the current project data shows the possibility to calculate TVI relation based on the anilox roller calibrated ink volume relation, the major constructive differences between the flexographic press and the printability tester, makes the TVI correlation tricky. One possible way ahead may be the research of printing forme polymers on printability tester with various hardness in order to make TVI reproduction possible in a reliable and consistent manner. Combined with the possibility to actually compensate TVI reproduction from tester to match the same production printing condition, it may be possible to correlate both solid color and its TVI gradation between lab and production.

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Notations and/or **Abbreviations**

Fogra – Graphic Technology Research Association (ger. Forschungsgesellschaft Druck e.V.)

FOGRA39 – reference printing condition used as exchange colour space in digital printing

TVI – Tone Value Increase

M0 – Standard ISO 13655 measurement condition using CIE illuminant A spectral power distribution of the measurement source at the sample plane

M1 – Standard ISO 13655 measurement condition using CIE illuminant D50 spectral power distribution of the measurement source at the sample plane

P1 – Standard ISO 3664 viewing condition using CIE illuminant D50

CIE – Commission internationale de l'éclairage (French), the International Commission on Illumination

SPI/SCI – Specular Port Included/Specular Component Included measurement specific to d:8 sphere optic geometry using closed black trap port

R E F E R E N C E S

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[4] ISO 2834-2:2015 Graphic technology -- Laboratory preparation test prints -- Part 2: Liquid printing inks.

[5] ISO 12647-6:2012/Amd 1:2015 Graphic technology -- Process control for the production of half-tone colour separations, proof and production prints -- Part 6: Flexographic printing.

[6] ISO 13655:2009 Graphic technology -- Spectral measurement and colorimetric computation for graphic arts images.

[7] ISO 2431:2011 Paints and varnishes -- Determination of flow time by use of flow cups.

[8] ISO 187:1990 Paper, board and pulps -- Standard atmosphere for conditioning and testing and procedure for monitoring the atmosphere and conditioning of samples.

[9] ISO 2846-X Graphic technology -- Colour and transparency of printing ink sets for four-colour printing.