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INVESTIGATION OF THE COLOUR REPRODUCTION QUALITY OF INKJET DIGITAL PRINTING MACHINES

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Abstract: *Industrial digital inkjet printing machines are increasingly entering commercial printing, label, packaging, etc. The quality of printing and the speed of inkjet printing machines are constantly increasing, but in a number of industries such as packaging, labels, etc. there are increased requirements for colour reproduction quality, which requires additional and in-depth research. The main purpose of this article is to study the different quality indicators of the most widely used digital inkjet systems. For the purposes of the experiment were used from the most commonly used in practice materials such as – regular matte and glossy coated paper, uncoated white paper, Jetcoat paper, photo paper - gloss, self-adhesive film - gloss, etc. with standard colour profiles FOGRA 39 and FOGRA 51 and offset uncoated paper with standard colour profiles FOGRA 29 and FOGRA 52. Several test forms with a large number of test charts and various control elements are printed on the aforementioned digital printing presses on different media. Colour gamut (2D and 3D), colour volumes, colour differences, etc. were studied. ICC profiles for the specific printing systems and materials have been generated and 2D visualization and comparison of the colour gamut of the studied media at different values of L and 3D visualization and comparison of the colour gamut of the studied media with standard ICC profile FOGRA.*

Key words: colour reproduction quality, Inkjet printing, ICC profiles, digital printing, substrate, colour gamut

1. INTRODUCTION

The past few years ought to be considered as booming for digital printing. In these novel times every user demands his items delivered in the shortest time conceivable. This, naturally, introduced the need to provide printing on demand. Manufacturing brochures, books, posters, labels, some types of flexible packaging, personalized items, security printing etc. is also flourishing (Bozhkova, Spiridonov & Shterev, 2017). Besides all that, from the users' perspective, there is an ever growing and active demand to provide for ecologically sustainable options. Digital printing is a perfect candidate to tackle this problem as it produces less emissions and waste. Furthermore, digital technologies rely on more robust materials, which could in turn be more beneficial for the end user. Digital technology allows for greater flexibility when compared to conventional techniques, which is a must if one aims to provide high-quality production, which could be customized or delivered within the briefest timeframe without the addition of unnecessary expenditures. Therefore, it is impossible to find a contemporary printing house to stray away from complementing its traditional printing techniques with industrial-grade digital inkjet printers. Inkjet printing systems represent one of the most popular solutions for industrial printing. In theory (even though this is not true for each model) they use contactless deposition method, which is relatively universal, and allows to apply inks of various chemical composure (most of them are water-based) over almost any kind of surface in a wide variety of scales. Practice has shown that customers come in bearing high expectations with regard to digital printing, anticipating it to be on par with conventional techniques as far as standard colour reproduction accuracy factors, the lack of colour variation in a printing run, the reproduction of Pantone colours, colour proof etc. are concerned (Spiridonov & Shopova, 2013). Judging by the technical specifications, originating from the wide variety of top-tier inkjet printing systems, one must conclude that that these products are bound to satisfy the aforementioned criteria. However, reality is different and shows that this is not true and that many such industrial grade systems display significant deviations and problems regarding several quality parameters. This article is a part of a series, offering a purely objective scientific approach and proprietary methodology, based on the measurement and analysis of a range of factors, used to determine print quality. The methodology offered is based on unbiased measurement and assessment of densitometric and colorimetric factors, as well as their quantitative binding to the particularities of human perception and the fundamentals of print quality, as set by the graphic technology ISO standards suite (TC 130).

The original methodology, suggested by authors and described herein is based on the measurement, analysis, and assessment of:

1. Assessment and analysis of the volume in 3D and 2D colour gamut of the tested digital printing machine during printing over different media. Comparison of the obtained ranges against the FOGRA standards.
2. Generating of ICC for the digital printing system over different media and assessment of the complete reproduction specifications, comparison over standard profiles, investigation og icc profiles quality, research of colour stability over time, etc.
3. Complete accuracy analysis of colour and tone reproduction from a particular digital inkjet printing machine.
4. Research and assessment of colour variation during printing run, as well as analysis of colour variance as function of time – printing the same image (complete edition) over a predefined time period, reparability in different printing runs.
5. Analysis and comparison of the capabilities to obtain similar colour parameters between the tested digital printing system and conventional presses – an item of particular importance when the first edition is in offset, for example, and is then supplemented using digital printing machines. Analysis of the capacity of investigated inkjet printing systems to simulate PANTONE colours and determination of colour differences.
6. Colorimetric parameters analysis in the case of single, double, triple, etc. ink overlays. Calculation of colour differences, compared to reference values and international standards, characteristization data, etc.
7. Analysis of densitometrical parameters in digitally printed images – optical densities of solids, reproduction accuracy of tone values, simulation of tone value increase, etc.

2. EXPERIMENTAL

For the purposes of the experiment we have modelled special test forms with specialized scales and control elements for:

a) Colourimetric tests and assessment of colour characteristics of simulated PANTONE colours on inkjet digital printing presses.
b) Test charts to generate ICC profiles.
c) Charts for colourimetric analysis of colour characteristics for a digitally printed image (Kašiković et al., 2015).
d) Images with distinct colours.
e) Precision control scales for estimation of colour reproduction accuracy, gradient precision, etc.
f) Densitometric analysis patches – for estimating of density of solids, TVI (Tone Value Increase), Print Contrast etc.

To complete the test, we have used a premium inkjet printing system, as offered by one of the segment-leading brands. The fundamental task in building a colour profile is the at-most precise reproduction of the digital original. The derived ICC profiles, on the basis of which we have tested the Fogra 51, Fogra 52, Fogra 29 and Fogra 39 ranges are rooted on the characterization data, as published on the FOGRA website (Fogra, 2022). The profiles are generated with optimal colour separation conditions as per ISO 12647-2/2004/2013 (International Organization for Standardization, 2013).
Part of the scales used are presented in figure 1. The testing forms are printed with settings for different resulting ICC profiles. Before printing the test editions all machines are calibrated according to manufacturer’s instructions with the aid of spectrophotometer.

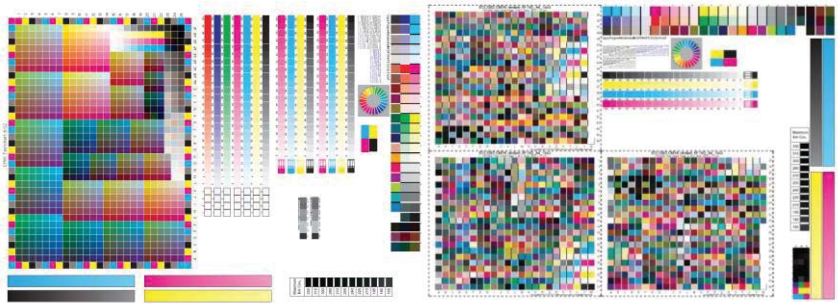


Figure 1 (part 1): Part of the testing forms used during experiments

Figure 1 (part 2): Part of the testing forms used during experiments

2.1 Test materials

We have used two basic types of printing media – different brands of coated papers and uncoated papers. They are one of the most common stocks in printing houses and come with good printing specifications (whiteness, opacity, mechanical properties, etc.), as well as with great price/quality ratio (Ozcan et al., 2020). In this case the main goal we set is to observe the colour gamut of used inkjet systems while working with the used printing stocks. In order to perform a comparison of the colour gamut for the used materials in the used inkjet digital machines, it is necessary to get both 2D and 3D visualization with a standard ICC profile FOGRA 29 and FOGRA 52 for uncoated papers and FOGRA 39 and FOGRA 51 for coated papers, so that one can gain visual idea of available colour gamut. To get the 2D and 3D visualizations of the ICC colour profiles we have used the PROFILE MAKER5.0 and ColorThink Pro 3.0.3 software products.
For the purpose of testing a total of three inkjet printing systems (from the mid and high price tier) have been used on different printing media. This article is based on machines, used in different areas of polygraphy as core digital printing systems. Other articles of this series offer insights investigation of the rest of printing quality parameters of suggested methodology, also another printing systems from this class, electrophotographical systems and others.

2.2 The test completion comprehends the following parameters:

1. Testing and comparing the 2D cross sections of colour gammuts Durst TAU RSC 330, Gallus Labelfire 340 и HP DesignJet Z6800 against FOGRA standards.
2. Testing and comparing the volume and shape of 3D colour gamut of Durst TAU RSC 330, Gallus Labelfire 340 и HP DesignJet Z6800 against FOGRA standards.
3. Calculation and comparison of the colour gamut volume ΔE^3.

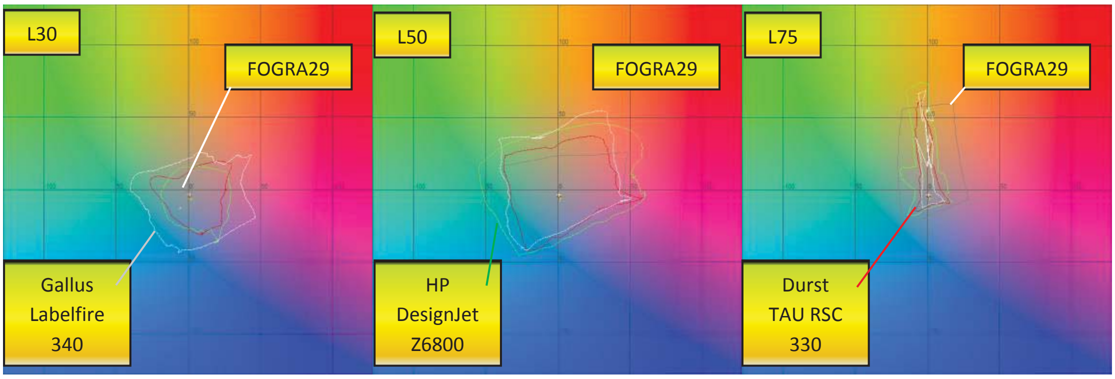
3. RESULTS AND DISCUSSION

To test and compare the volume of colour gamut we have combined several specialized ΔE^3 software products, which yielded generally more accurate result representation. Please note that this is the maximal colour ranges, which is reproducible by the digital printing systems Durst TAU RSC 330, Gallus Labelfire 340 and HP DesignJet Z6800. This is why colour volume is one of the cornerstone specifications.

With the aid of the different software products, we were able to calculate the colour volumes from the printing results for the used substrate and to compare them against the reference values for the corresponding FOGRA standard. This research and graphic representation of 2D cross-sections and 3D volumes of colour gamut is aided by these specialized software products: X-Rite Profile Editor 5.0 and ColorThink Pro 3.0.3.

3.1 Investigation of colour gamut volumes and comparison of 2D and 3D colour gammuts of different digital inkjet printing systems

One important function, which is used to visualise the colours, as reproduced by any given machine, is the 2D and 3D representation of the respective colour gammuts. This paper also uses 2D and 3D representations. The 2D representation of colour gammuts with different cross-sections along the L-axis of the CIE Lab colour space allows for good visual comparison of colours in light, mid and dark tones, as well as comparison of a large number of colour gammuts at once. The 3D representation of colour gammuts allows a complex visual assessment for the 3D body of the colour gammut. It is appropriate for the visualisation and comparison of ore or two colour gammuts.
In order to perform the comparison for the colour gammut of the examined prints from the corresponding digital printing presses – Durst TAU RSC 330, Gallus Labelfire 340 and HP DesignJet Z6800 it is necessary to provide a 3D visualisation with a standard ICC profile FOGRA 29 and FOGRA 52 for uncoated papers and FOGRA 39 and Fogra51 for coated papers with the ultimate goal to achieve visual representation for the colour gammuts.
The visualization of 2D cross-sections with different values of L yields a rich fact set on how the colour gamut varies, with the media used, against the reference values as per the corresponding FOGRA standard. This allows for a deeper insight into the colour volume and also aids tracking the corresponding values of L, which can be in the range 0 to 100.
The next figures show the comparison of 2D cross-sections across different media, as printed with Durst TAU RSC 330, Gallus Labelfire 340 and HP DesignJet Z6800, compared with the corresponding FOGRA standard.
Figures 2 to 5 show 2D visualization of colour ranges over tested media with the use of Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330.



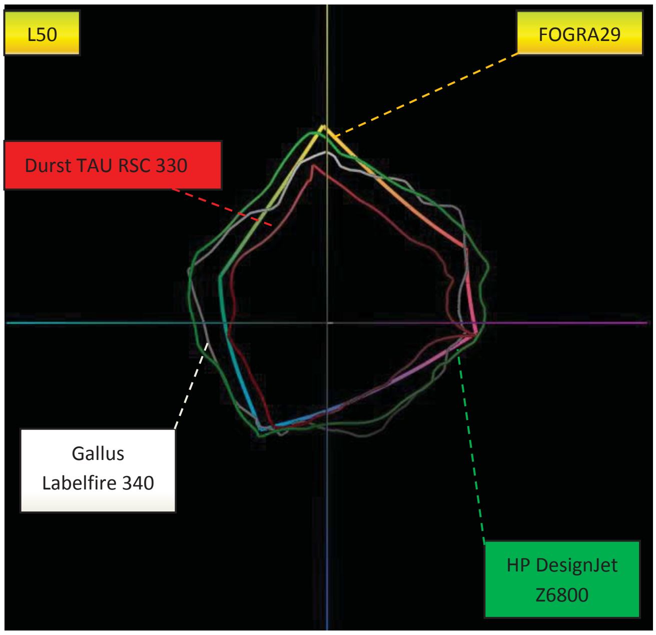
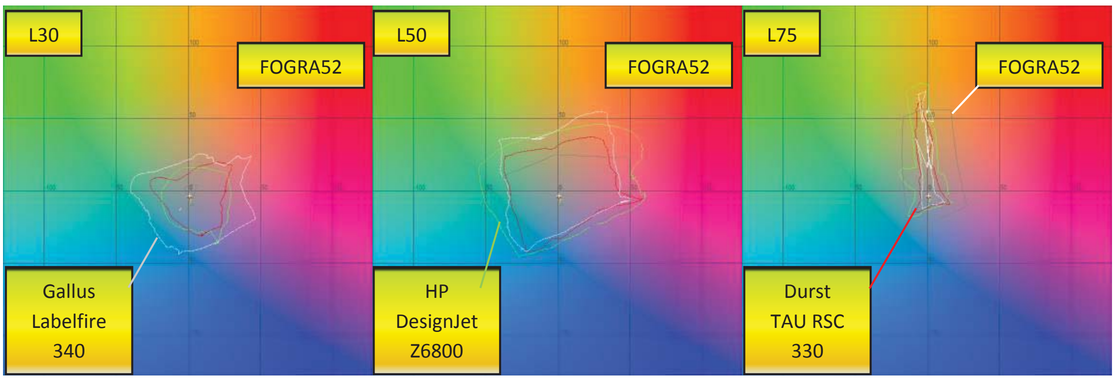


Figure 2: Graphic representation and comparison of 2D colour gamut with different values of L over uncoated paper, as printed with Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with reference values as per FOGRA29

Data shows that the most accurate reproduction of tone and hue, as compared to FOGRA standards, is observed with coated (matte or glossy) and uncoated (offset) papers in mid tones for L=50. With dark tones L=30 (FOGRA29, FOGRA52) for uncoated papers and L=10 (FOGRA39), respectively L=15(FOGRA51) for coated papers, the colour range derived from the test is comparatively larger, than FOGRA standards. In light tones for L=75 the colour range of tested papers, as printed with the corresponding inkjet digital machines is considerably smaller in comparison to the FOGRA standards.
To compare the colour gamut on offset uncoated paper, a standard ICC profile was used FOGRA 29 and FOGRA 52.



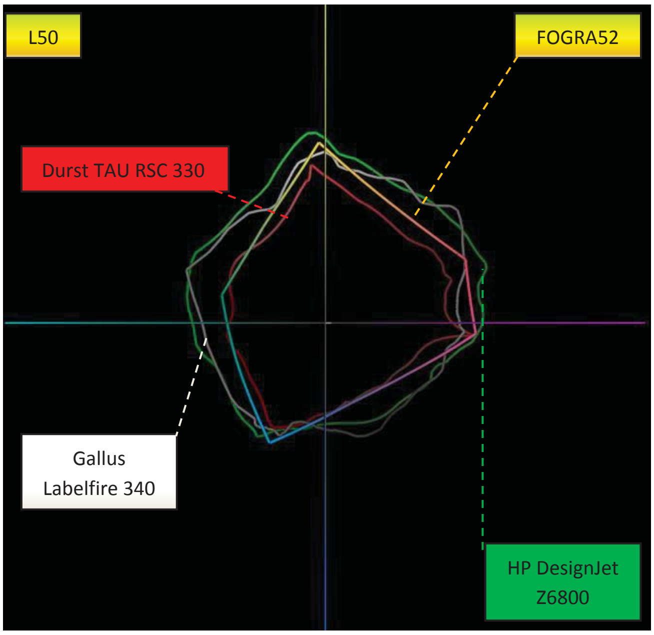


Figure 3: Graphic representation and comparison of 2D colour gamut with different values of L over uncoated paper, as printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with reference values as per FOGRA52

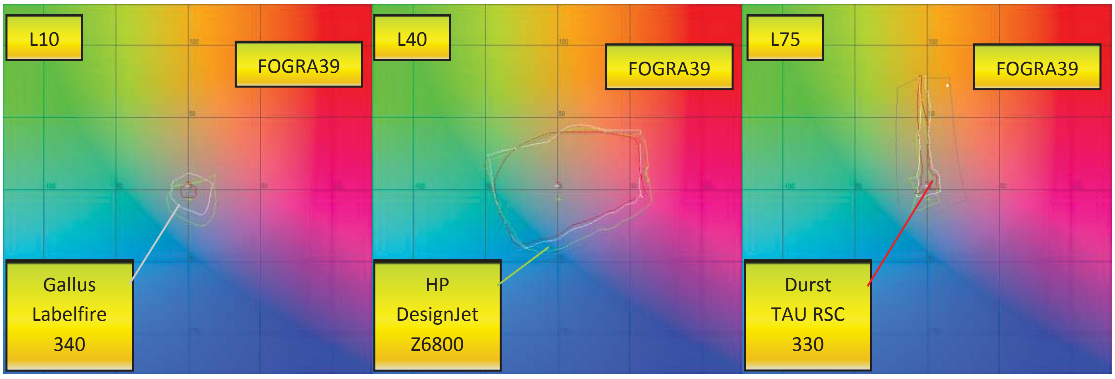


Figure 4 (part 1): Graphic representation and comparison of 2D colour gamut with different values of L over coated paper, as printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with reference values as per FOGRA39

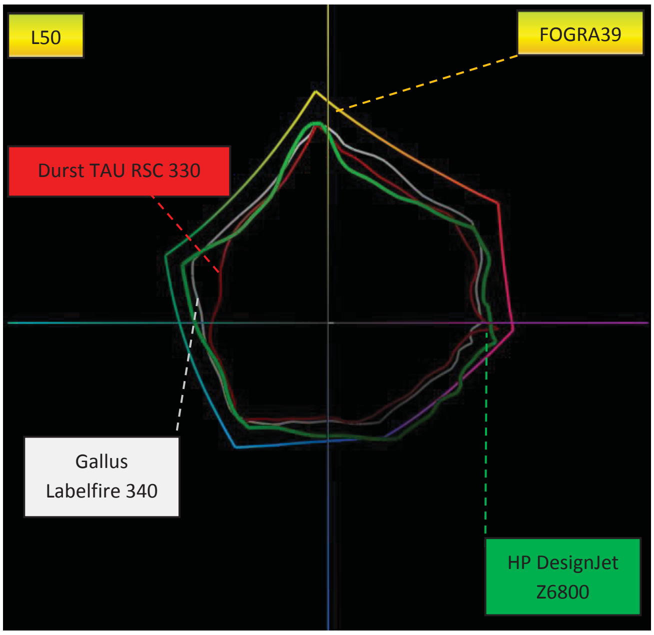


Figure 4 (part 2): Graphic representation and comparison of 2D colour gamut with different values of L over coated paper, as printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with reference values as per FOGRA39

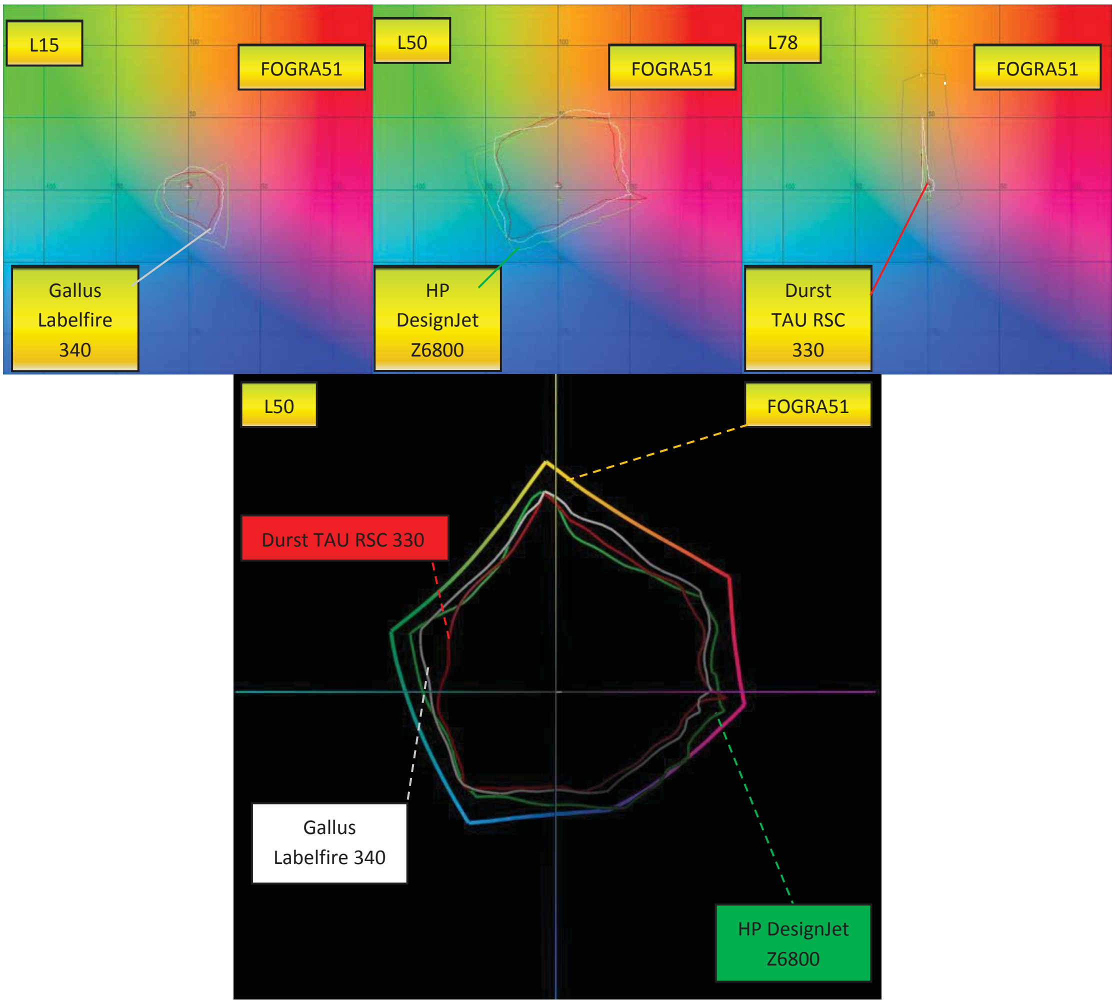


Figure 5: Graphic representation and comparison of 2D colour gamut with different values of L over coated paper, as printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with reference values as per FOGRA39

From figures 6, 7, 8 and 9 one can observe that the colour range of FOGRA29, as well as FOGRA52 is considerably larger in light tones compared to the offset paper printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330. It is also apparent that in certain regions the colour range of all tested printing systems, material can reproduce colours, which FOGRA29 and FOGRA52 cannot, but this is mostly limited to dark tones. In mid tones there is a large resemblance between the test print and the FOGRA29/52 prints.

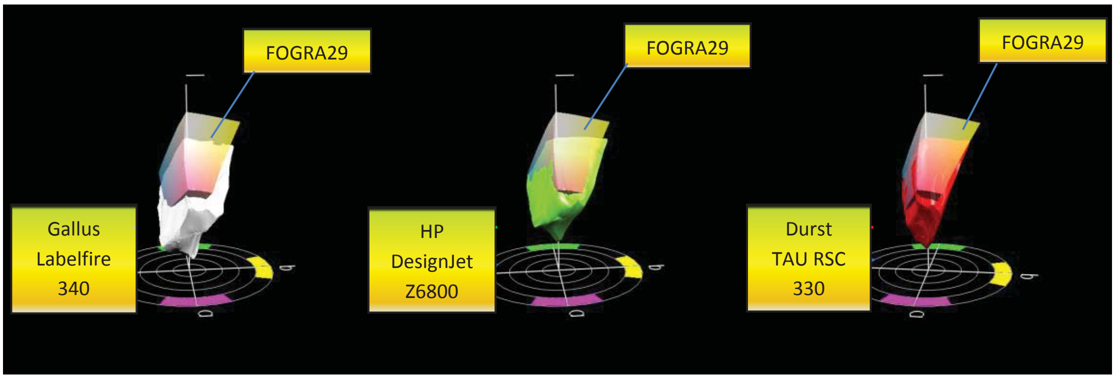


Figure 6: 3D visualisation (Lab system) of an ICC profile of offset paper printed through Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 and FOGRA29

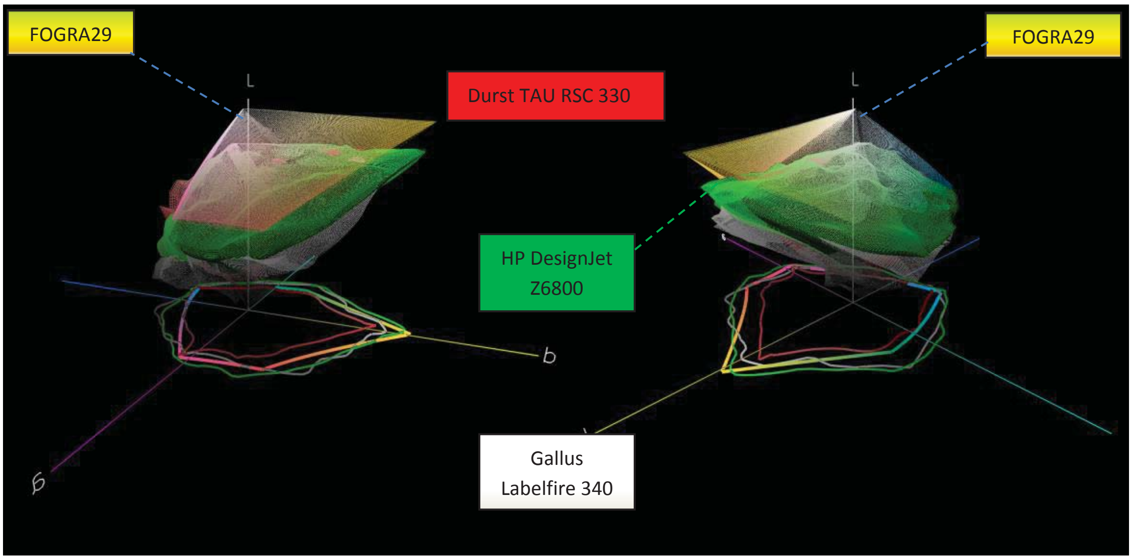


Figure 7: 3D visualization (lab system) of ICC profile of uncoated paper printed by all printing systems compared to FOGRA29

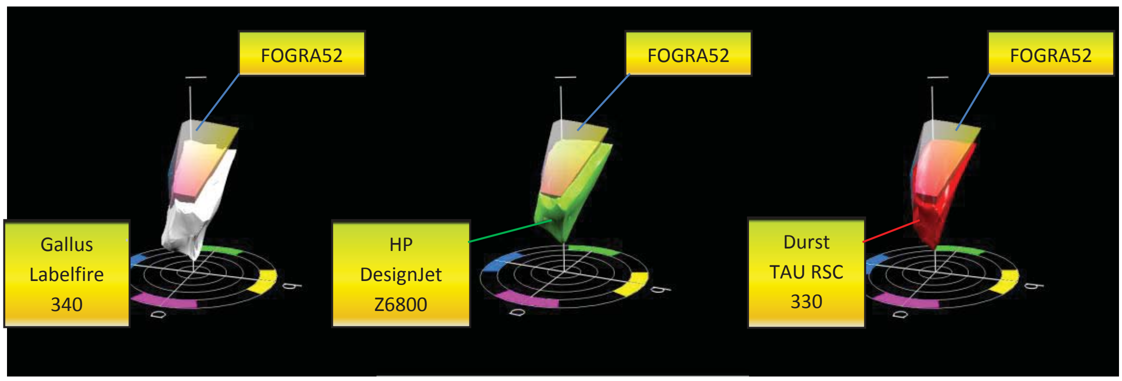


Figure 8: 3D visualisation (Lab system) of an ICC profile of uncoated paper printed through Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 and FOGRA52

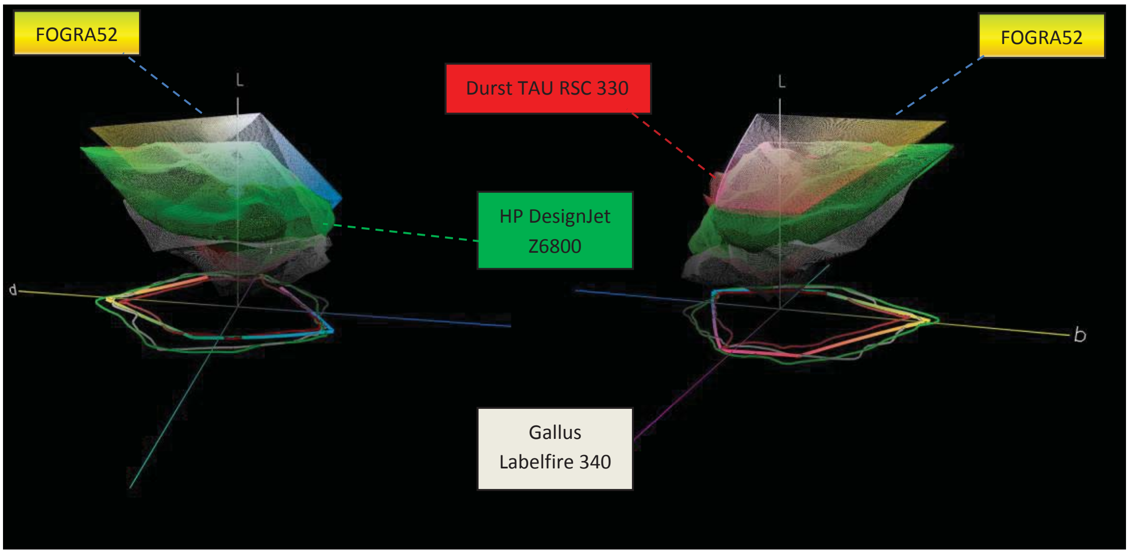


Figure 9: 3D visualization (lab system) of ICC profile of uncoated paper printed by all printing systems compared to FOGRA52

As a comparison platform for the colour gamut of coated paper the ICC FOGRA39 and FOGRA51 profile has been used:

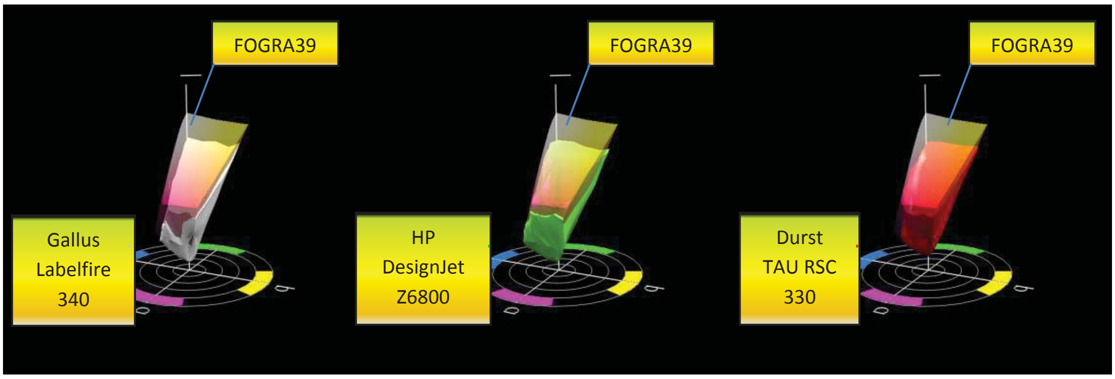


Figure 10: 3D visualisation (Lab system) of an ICC profile of coated paper printed through Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 and FOGRA39

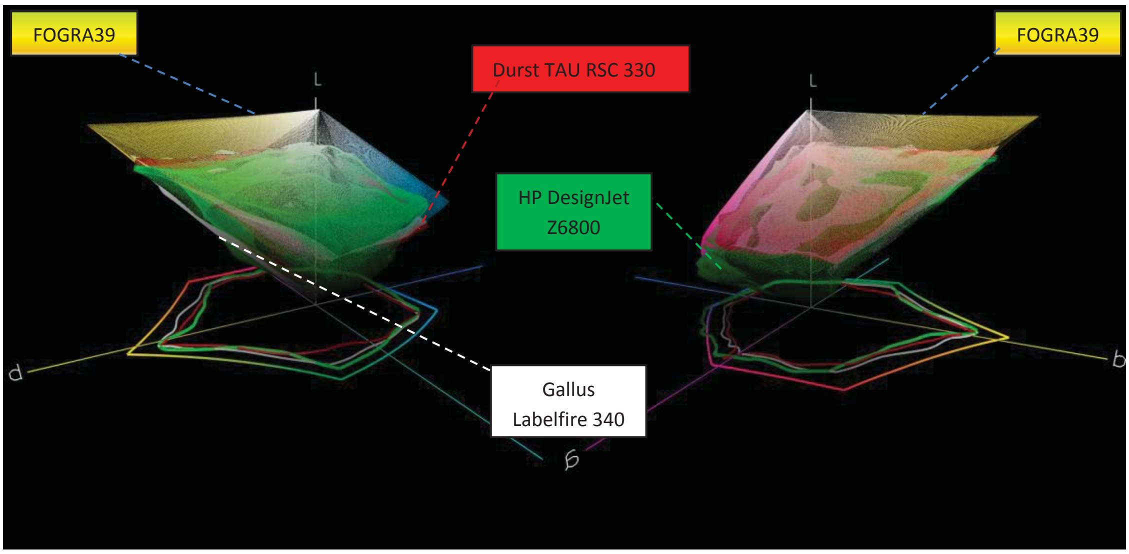


Figure 11: 3D visualization (lab system) of ICC profile of coated paper printed by all printing systems compared to FOGRA39

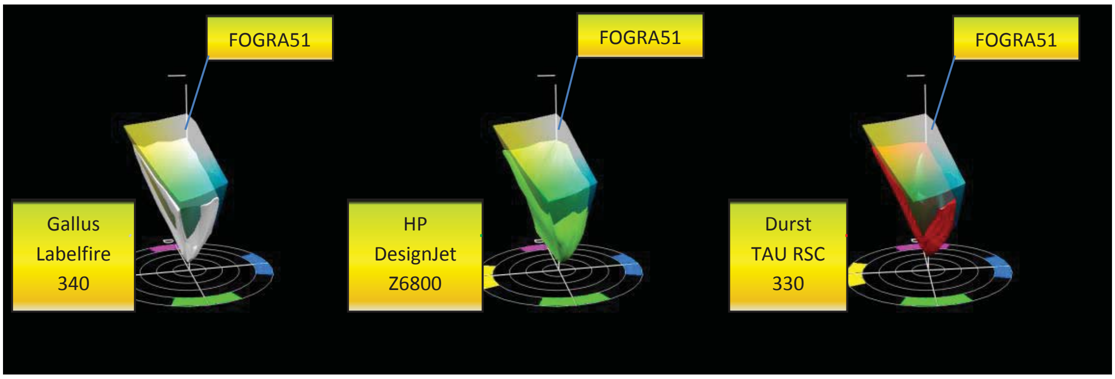


Figure 12: 3D visualisation (Lab system) of an ICC profile of coated paper printed through Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 and FOGRA51

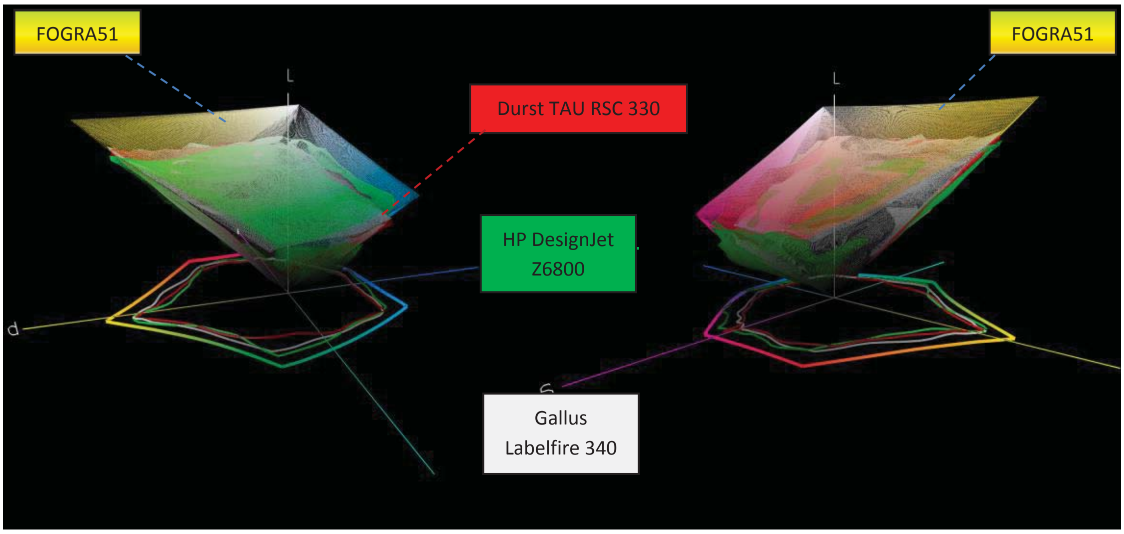


Figure 13: 3D visualization (lab system) of ICC profile of coated paper printed by all printing systems compared to FOGRA51

Figures 10, 11, 12 and 13 show that the colour range of FOGRA39 and FOGRA51 is considerably larger in yellow-green, blue-red and green-blue areas in light tones of coated paper, as printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330. Also it is visible that certain areas of the colour scale of tested printing machines, the material is able to reproduce colours mostly in the dark tones, which FOGRA39 and FOGRA51 can't. In mid tones we see good results for all tested machines and substrates, which come very close to FOGRA standards. With FOGRA39 and FOGRA 51, however, there is better colour reproduction in the lighter hues.
Tables 1 and 2 show the calculated values of the received ICC profiles for the media printed through Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with the reference values as per the corresponding FOGRA standard. Two specific software products have been used to calculate the volume of the colour range. Each of them has a proprietary algorithm to calculate ΔE^3, which accounts for the difference between the two software products.

Table 1: Colour gamut volume ΔE^3 for Uncoated Paper

Uncoated Paper ΔE^3					
	FOGRA 29	FOGRA 52	Gallus Labelfire 340	HP DesignJet Z6800	Durst TAU RSC 330
Color Think 3.0.3	181382	163565	207411	228134	141819
Gamut Vision 1.4	187079	162620	304569	395050	206122

Table 2: Colour gamut volume ΔE³ for Coated Paper

Coated Paper ΔE^3					
	FOGRA 39	FOGRA 51	Gallus Labelfire 340	HP DesignJet Z6800	Durst TAU RSC 330
Color Think 3.0.3	402279	386692	249767	298815	223135
Gamut Vision 1.4	444027	448088	477068	476522	393221

According these results, one can obtain the graphics as shown in Figures 14 and 15.

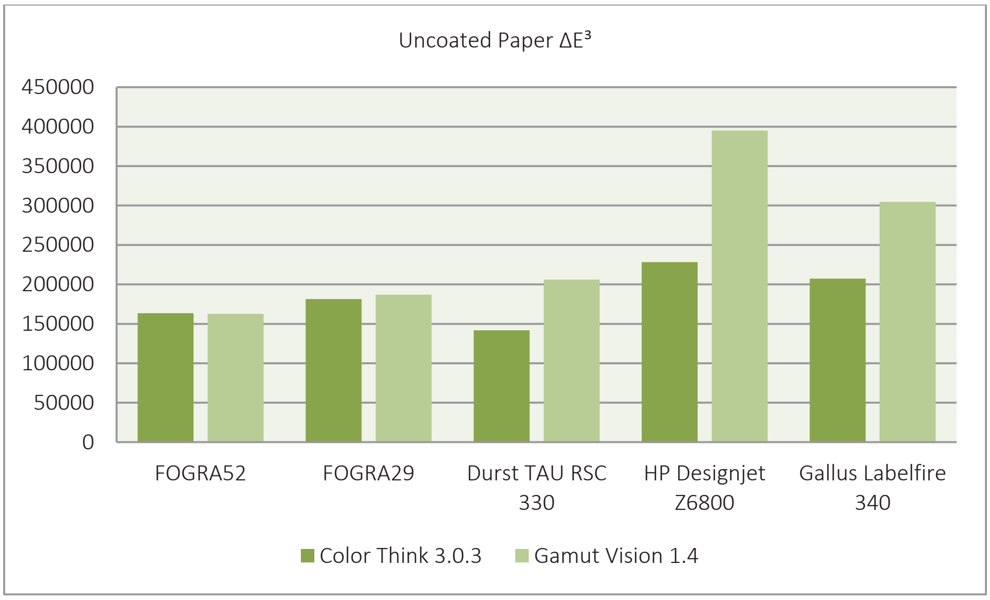


Figure 14: Graphic representation of the colour gamut ΔE³ for Uncoated Paper as printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with reference values as per FOGRA calculated with CHROMIX Color Think 3.0.3 and Gamut Vision 1.4

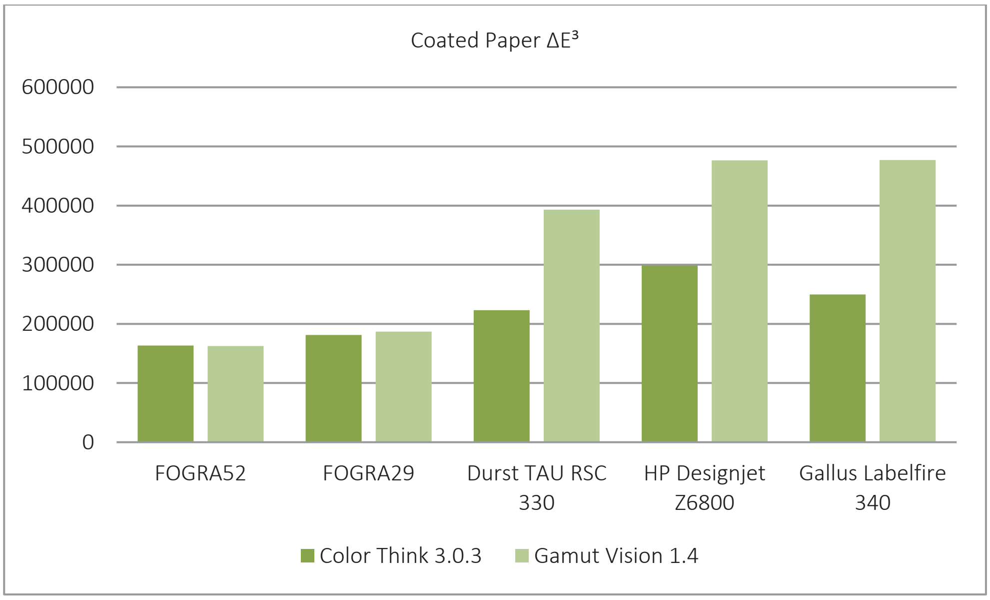


Figure 15: Graphic representation of the colour gamut ΔE³ for Coated Paper as printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with reference values as per FOGRA calculated with CHROMIX Color Think 3.0.3 and Gamut Vision 1.4

4. CONCLUSIONS

From the tests performed in relation to this article, we have arrived at the following conclusions:

1. This research is a part of complete method to evaluate digital print quality, based on scientific approach and unbiased analysis of a great number of colorimetric and densitometric parameters for the printed image such as: achieved colour differences in relation to the set / desired colours and ISO standards, accuracy of reproduction - colour and geometric, grey balance, TVI, Colour Gamut, etc.
2. In real conditions, over widely used media, we have examined some of the most used industrial grade inkjet digital printing systems as the results are compared against FOGRA standards.
3. All of obtained results for colour gamut volumes, 3D and 2D cross section surface analysis are valid for the studied printing conditions and used materials. The authors do not claim general evaluations of the investigated digital presses.
4. From the 2D visualization we have made cross-sections of colour ranges of tested media, with different values of L, we have observed that with L=30 over uncoated paper, the largest colour range belongs to Gallus Labelfire 340, followed by HP DesignJet Z6800 and Durst TAU RSC 330 with overlapping ranges. With these values of L=30 (dark tones), colour ranges of tested inkjet printing systems are considerably larger, compared to the FOGRA 29/52 standards. With L=50 all three systems tested show larger colour range in green-yellow and yellow-red areas, compared to the FOGRA 29 and FOGRA 52. With L=75 the smallest colour range is observed with Gallus Labelfire 340, as all three digital systems display circa two-fold smaller colour ranges, compared to FOGRA 29 and FOGRA 52. For coated paper (matte, glossy) with L=10 (FOGRA39) and L=15 (FOGRA52) HP DesignJet Z6800 and Gallus Labelfire 340 show larger colour ranges, compared to Durst TAU RSC 330 and the FOGRA 39 and FOGRA 51 standards. With L=40 (FOGRA39) colour ranges for all machines are comparable and almost cover the FOGRA39 standard. With L=75 (FOGRA39) and L=78 (FOGRA51) we have observed, yet again, circa two-fold smaller colour range as compared to the FOGRA standard.
5. From the 3D visualization with ICC colour profile generation and the comparison between the latter and FOGRA 29 and FOGRA 52 (for uncoated media) and FOGRA 39 and FOGRA 51 (for coated media) for the tested inkjet printing machines and the tested media, we have established that Gallus Labelfire 340 followed by HP DesignJet Z6800 and Durst TAU RSC 330, we have better colour reproduction in the dark and mid tones, compared to FOGRA 29 and FOGRA 52. In the dark tones, the colour profiles of all tested inkjet printing systems go beyond the scope of standard FOGRA 29 and FOGRA 52 profiles. Data shows that when using uncoated media, best results, compared with FOGRA 29 and FOGRA 52, belong to Durst TAU RSC 330 followed by Gallus Labelfire 340 and HP DesignJet Z6800. From the results obtained regarding the 3D volume range over coated paper (glossy, matte), printed via the tested digital printing machines, it is visible that the FOGRA 39 and FOGRA 51 standards have larger colour gammut in lighter hues, compared to the prints as produced by all tested machines. Better colour reproduction is observed with coated media, especially in colour reproduction over mid hues in blue-green, green-red and red-yellow areas.
6. We have made use of two specialized software solutions to obtain the colour volume. Each of them uses its own ΔE^3 algorithm, due to which one sees variance in the calculated values.
   Colour gamut's and their volume are of special significance when the print quality is defined. Calculating ΔE^3 using CHROMIX Color Think 3.0.3 showed the following result:
   - For uncoated paper the largest colour gamut was obtained with HP DesignJet Z6800 (ΔE^3 =228134), followed from Gallus Labelfire 340 (ΔE^3 =207411) and Durst TAU RSC 330 (ΔE^3 =141819). The standard colour gammuts of FOGRA29 (ΔE^3 =181382) and FOGRA52 (ΔE^3 =163565) were best met by the HP DesignJet Z6800 (26% > ΔE^3 FOGRA29 and 39% > ΔE^3 FOGRA52), followed by Gallus Labelfire 340 (14% > ΔE^3 FOGRA29 and 27% > ΔE^3 FOGRA52) Durst TAU RSC 330 (22% < ΔE^3 FOGRA29 and 13% < ΔE^3 FOGRA52).
   - For coated paper the largest colour gamut was obtained with HP DesignJet Z6800 (ΔE^3 =298815), followed from Gallus Labelfire 340 (ΔE^3 =249767) and Durst TAU RSC 330 (ΔE^3 =223135). The standard colour gammuts of FOGRA39 (ΔE^3 =402279) and FOGRA51 (ΔE^3 =386692) were best met by the HP DesignJet Z6800 (26% < ΔE^3

FOGRA39 and 23% < ΔE^3 FOGRA51), followed by Gallus Labelfire 340 (38% < ΔE^3 FOGRA39 and 35% < ΔE^3 FOGRA51) and Durst TAU RSC 330 (44% < ΔE^3 FOGRA39 and 42% < ΔE^3 FOGRA51).

Calculating ΔE^3 using Gamut Vision 1.4 showed the following result:

- For uncoated paper the largest colour gamut was obtained with HP DesignJet Z6800 (ΔE^3 =395050), followed from Gallus Labelfire 340 (ΔE^3 =304569) and Durst TAU RSC 330 (ΔE^3 =206122). The standard colour gammuts of FOGRA29 (ΔE^3 =187079) and FOGRA52 (ΔE^3 =162620) were best met by the HP DesignJet Z6800 (111% > ΔE^3 FOGRA29 and 143% > ΔE^3 FOGRA52), followed by Gallus Labelfire 340 (63% > ΔE^3 FOGRA29 and 87% > ΔE^3 FOGRA52) and Durst TAU RSC 330 (10% > ΔE^3 FOGRA29 and 27% > ΔE^3 FOGRA52).

- For coated paper the largest colour gamut was obtained with Gallus Labelfire 340 (ΔE^3 =477068), followed from HP DesignJet Z6800 (ΔE^3 =476522) and Durst TAU RSC 330 (ΔE^3 =393221). The standard colour gammuts of FOGRA39 (ΔE^3 =444027) and FOGRA51 (ΔE^3 =448088) were best met by the Gallus Labelfire 340 (7% > ΔE^3 FOGRA39 and 6% > ΔE^3 FOGRA51), followed by HP DesignJet Z6800 (7% > ΔE^3 FOGRA39 and 6% >ΔE^3 FOGRA51) and Durst TAU RSC 330 (11% < ΔE^3 FOGRA39 and 12% < ΔE^3 FOGRA51).

6. REFERENCES

Bozhkova, T., Spiridonov, I. & Shterev, K. (2017) Overview of security printing types and trends in its future development. *Bulgarian Chemical Communications.* 49, 195-201.

Fogra (2022) *Charakterisierungs-daten für den standardisierten Druck*. Available from: https://fogra.org/downloads/arbeitswerkzeuge/charakterisierungsdaten
[Accessed 20th September 2022]

International Organization for Standardization (2013) ISO 12647-2:2013. *Graphic technology — Process control for the production of half-tone colour separations, proof and production prints — Part 2: Offset lithographic processes*. Geneva, International Organization for Standardization.

Kašiković, N., Novaković, D., Milić, N., Vladić, G., Zeljković, Ž., Stančić, M. (2015) Thermovision and spectrophotometric analysis of ink volume and material characteristics influence on colour changes of heat treated printed substrates. *Tehnički vjesnik*. 22 (1), 33-41.
Available from: doi: 10.17559/TV-20130928115500

Ozcan, A., Kasikovic, N., Arman Kandirmaz, E., Durdevic, S., Petrovic, S. (2020) Highly flame retardant photocured paper coatings and printability behavior. *Polymers for Advanced Technologies.* 31 (11), 2647-2658. Available from: doi:10.1002/pat.4991

Spiridonov, I. & Shopova, M. (2013) Determination of the effect of gray component replacement level on colorimetric characteristics of color proof. *Journal of the University of Chemical Technology and Metallurgy.* 48 (3), 247 – 253.