Section A-Research paper
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COMPARATIVE ANALYSIS OF DOT GAIN IN CONTINUOUS INKJET AND DROP-ON-DEMAND (PIEZOELECTRIC) PRINTING SYSTEMS ON UNCOATED, MATTE COATED AND GLOSS COATED PAPER STOCKS

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ABSTRACT

Inkjet printing is acquiring the market with a rapid pace and it is widely being used to produce the personalized prints on the web. It is available in two major forms; i.e. Continuous Inkjet (CIJ) and Drop-on-demand (Piezoelectric) form. At one hand CIJ presses give the high speed advantages, on the other PIJ presses have the tendency to impart higher resolution to the print. Objective of this paper is to compare the dot gain tendency in CIJ and DoD-PIJ presses on uncoated, matte coated and gloss coated paper stocks. For conducting the research, a master test chart was prepared, including presSIGN colour control bar solid patches for cyan, magenta, yellow and black solids and tint areas. This chart was then printed using both CIJ and DOD-PIJ presses under standard pressroom conditions on uncoated, matte coated and gloss coated paper stocks. Subsequently, the printed sheets were analyzed, focusing on dot gain of four primaries on cyan, magenta, yellow and black patches, using the X-rite e-Exact spectro-densitometer. The resulting dot gain data was analyzed on uncoated, matte coated and gloss coated papers using the correlation analysis.

KEYWORDS: - Dot Gain, Uncoated Paper, Matte Coated Paper, Gloss Coated Paper, Continuous Inkjet, Drop-on-Demand (Piezoelectric), Tint Patches, Surface Characteristics

INTRODUCTION

In the recent times, digital printing is finding its applications in production of personalized packaging. The demand for the personalized packaging is growing and it is expected to grow in coming years to take care of the varying needs of the packaging consumers. Some of the distinct advantages of digital printing over other available printing methods can be listed as, digital printing is fast and efficient. It has a very quick turn-around time, so the press set-up time is very low, allowing for the on-demand printing options (Swiftpak, 2021).

Inkjet printing is basically a type of additive manufacturing method/technology, which is basically aimed at possible reduction of production costs by using directly printed computer generated patterns instead of physical pattern masks. (Tekin et al., 2008). In the recent years, the industrial applications of inkjet printing have increased to many folds and it is going to certainly occupy a major portion of the whole printing market in future also. As per the current market trend, it is indicated that the applications of inkjet printing may have peaked. It indicates that the current focus in inkjet printing has been on uniformity and two-dimensional coverage of substrates. However, there is a lot of scope relating to the flow properties of interacting droplets with the substrate or previously deposited layers, is going to register further growth and applications of this technology in other allied applications in the coming time (Singh et al., 2010).

Conventional Inkjet printing technology is grouped under two distinct sub-headings; drop on demand (DoD) and continuous inkjet (CIJ). Both these technologies are used extensively in the graphic arts industries, and they are aimed at resulting into uniformly-sized droplets over the printing substrates. In drop-on-demand inkjet presses, the ink droplets are deposited on to the printing substrate as per the demand and requirement of the particular image to be reproduced, whereas in continuous inkjet presses, the ink droplets are ejected from the inkjet nozzles on a continuous basis irrespective of the formation of image onto the substrate (Castrejon-Pita et al., 2013).

Dot gain is one of the basic print quality factors, which needs special care and attention for reproducing faithful reproduction of the printing output. It is described as the effect of halftone dots growing in area between the original film and the printed sheet. Most of the printers look dot gain as one of the serious problems and that cannot be taken care. It should be kept in mind that, dot gain is inevitable and it is going to occur, but it can be managed and controlled within the tolerance limit to produce high quality printing output. Generally, dot gain is caused by the ink spreading around halftone dots (Lawler, 1997).

Some of the possible factors contributing to dot gain in a printing press can be; ink spreading out onto the paper, ink absorbing into the paper, and during the pre-press stage of image carrier preparations (Lawler, 1997). Basically, dot gain is resulted during the reproduction process. A typical ratio of C, M, and Y dot percentage is required to reproduce neutral gray. Some of the substrate characteristics that contribute to the dot gain can be summarized as; surface reflectance from paper, multiple internal reflectance from paper, absorption of ink from paper, and brightness and whiteness properties of paper (Chen, 2008).

REVIEW OF LITERATURE

Dot gain is simply made-up of two parts; physical dot gain and optical dot gain. Physical dot gain generally occurs when the ink transferred onto the printing substrate, is widely spread causing a growth in the size of the printed dots, or it may cause due to the situation where the when the surface energy of the printing substrate is higher than the surface tension of the ink itself (Zjakić et al., 2011).

On the other hand, optical dot gain is related to light scattering in the substrate interacting with the printed image on the paper surface. Some of the light rays that hits to the surface of the printing paper, are then scattered laterally in the paper far enough to make them emerge under a halftone dot causing a decrease in overall reflectance of the print, which finally leads into the term dot gain, on the printed sheets (Wedin and Kruse, 1995). The very occurrences of dot gain can be the combined result of both the physical dot gain and the optical dot gain (Chang, 2001).

As per Chen, 2008, there is a relationship between the three printing quality factors; solid ink density, dot gain and print contrast, the higher the solid ink density, there will be higher dot gain and lower the print contrast on the printed output. This situation leads to poor image quality and everything on the printed sheet looks darker. It is highly demanded to monitor and control the solid ink density during the printing cycle. If all the four primaries cyan, magenta, yellow, and black are not controlled as per the standard reference values, then it would lead into poor colour balance and poor image quality. By controlling solid ink density during the print production cycle, it can result in balanced neutral gray.

As per Wedin and Kruse, 1995, physical dot gain is the result of the case where the halftone dots on the printed substrate actually are larger than they should be and it is affected by number of factors. One of the possible factors could be the viscosity of the printing ink, how the ink is going to spread on the surface of the substrate, once it is printed. At the same time, optical dot gain is entirely depending upon the surface morphology and characteristics of the paper to be printed. The printing paper having a larger scattering effect, the distance is relatively small, and the optical density will be more.

As per Chang, 2001, print quality is highly dependent upon the dot area on the printed sheets, because both the situation of higher dot gain and lower dot gain can lead into number of serious print defects. Higher dot gain is the results of the printed ink being spread over the printed paper, than the required. Ink-spreading, which is termed as dot gain can seriously affect the final print quality, different printed colour inks are overlapped with each other, resulting in color misrepresentation and in loss of image details. Higher dot gain value than the standard reference value, indicates the printed output with a decreased print quality and the sharpness of the print decreased considerably.

As per Vallat-Evrard, 2019, in inkjet presses, the physical dot gain is basically by the factors including; variations of the print head like, nozzle size, ejection speed, ejection volume, etc. or by variations of the printing substrate like, variation of the physicochemical parameters such as energy tension or capillarity. When the printed ink layer is deposited onto the printing substrate, the setting phase of the ink drying starts immediately. During the ink setting phase, the ink can penetrate into paper or alternatively spread on the surface. Ink setting is highly influenced by; capillarity, surface tension of the ink and surface energy of the paper, roughness, permeability, diffusivity.

RESEARCH OBJECTIVES

Inkjet printing technology is getting wider acceptance in the printing industry due to the number of potential benefits it offers in comparison to the convention printing processes. Future of inkjet printing lies on the speed of production, cost effectiveness, enhanced print quality and environmental sustainability. Among these potential factors, print quality is highly important, so to cater the specific needs and demands of the potential print consumers. Continuous inkjet and piezoelectric DoD inkjet presses are very common in the printing marketplace because of their quality and cost effectiveness, especially in long run printing and packaging printing applications. Dot gain is one of the key print quality attributes which decides the final quality output of the print. Objective of this paper is to compare the dot gain tendency in CIJ and DoD-PIJ presses on uncoated, matte coated and gloss coated paper stocks.

RESEARCH METHODOLOGY

In the local market, various types of papers were examined, and those that closely matched ISO specifications were considered. Ultimately, GSM 130 paper was chosen for further evaluation. Three paper varieties were selected for the study: uncoated, matte coated, and gloss coated. These are the main categories of paper substrates commonly find their applications in printing industry for taking care of wide range of printing jobs with different quality level and end uses.

The objective was to assess the dot gain behavior of both Continuous Inkjet (CIJ) and Drop-on-Demand (PIJ) forms of Inkjet printing. To conduct the experiment, a master test chart was designed using Corel Draw Graphics Suite 2020, incorporating different tint patches. The SID patches were created using a color control strip provided by presSIGN. Printing was carried out using three different presses: Canon VarioPrint i-series for CIJ, and Kodak Prosper 6000 for DOD-PIJ.

The printing work was conducted under standard pressroom conditions. A total of 500 sheets of various papers were printed, and for testing purposes, a sheet was extracted after every 20 printed sheets for each paper type. Objective measurements of dot gain were obtained using X-Rite (Exact) Spectro-densitometer available in the Quality Control Laboratory of the Department of Printing Technology, GJUS&T, Hisar.

DATA COLLECTION & ANALYSIS

To measure dot gain, Cofomegra dot gain values were used as a reference for the measurements, as shown in the table below. This comparison allowed for a thorough evaluation of the dot gain performance for each paper type and inkjet technology. Dot gain was collected on top side of the sheets only. Table 1, indicates the standard reference values of dot gain of the four primary colours.

Table.1. Cofomegra standard SID reference values

COLOUR	TYPES OF PAPER	40%	80%
CYAN	HAND USE	20 ± 4	15 ± 3
	OPAQUE COATED	16 ± 3	11 ± 2
	GLOSSY COATED	14 ± 3	9 ± 2
MAGENTA	HAND USE	20 ± 4	15 ± 3
	OPAQUE COATED	16 ± 3	11 ± 2
	GLOSSY COATED	14 ± 3	9 ± 2
YELLOW	HAND USE	20 ± 4	15 ± 3
	OPAQUE COATED	16 ± 3	11 ± 2
	GLOSSY COATED	14 ± 3	9 ± 2
BLACK	HAND USE	20 ± 4	15 ± 3
	OPAQUE COATED	18 ± 3	12 ± 2
	GLOSSY COATED	16 ± 3	10 ± 2

The dot gain was measured on 20 printed seats extracted after specific interval and further average was taken. Cofomegra dot gain values shown in the table.1 were taken as reference. The average dot gain measured values on uncoated paper, matte coated paper and gloss coated paper are shown in table 2 to table 4 respectively given below: -

Table 2, Dot Gain (40%) of CIJ Press

	Cyan	**Magenta**	**Yellow**	**Black**
UC	20.49	21.57	19.37	22.58
MC	14.47	15.55	13.35	16.56
GC	12.44	13.52	11.32	14.53

Table 2, shows the dot gain (40 %) of CIJ press, while printed on the uncoated, matte coated, and gloss coated papers. For all the primary colours, CMYK, the resulted values are well within the tolerance limit and the values of the standard reference values.

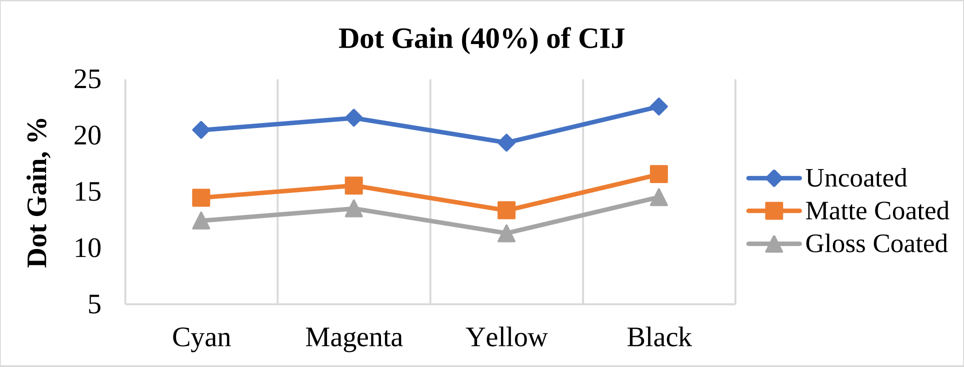

Figure 1, Dot Gain (40%) of CIJ Press

Figure 1, shows the dot gain (40 %) of CIJ press, while printed on the top side of uncoated, matte coated, and gloss coated papers. All the three papers; uncoated, matte, and gloss coated papers are showing the dot gain for all the four primary colours that are well within the standard reference values.

Table 3, Dot Gain (40%) of PIJ Press

	Cyan	Magenta	Yellow	Black
UC	18.46	19.54	17.34	20.55
MC	12.44	13.52	11.32	14.53
GC	10.95	12.03	9.83	13.04

Table 3, shows the dot gain (40 %) of PIJ press, while printed on the uncoated, matte coated, and gloss coated papers. For all the primary colours, CMYK, the resulted values are well within the tolerance limit and the values of the standard reference values.

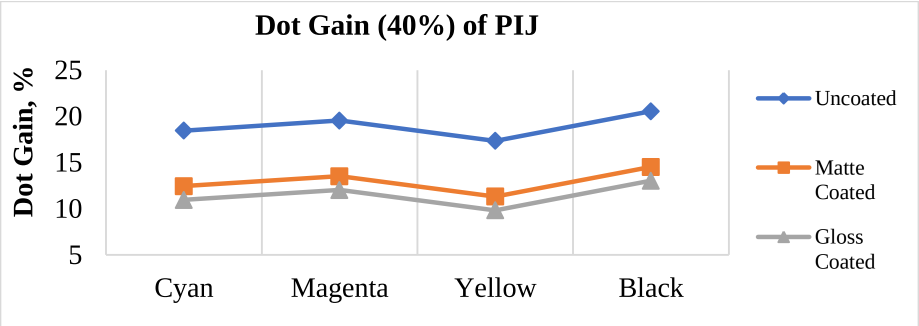

Figure 2, Dot Gain (40%) of PIJ Press

Figure 2, shows the dot gain (40 %) of PIJ press, while printed on the top side of uncoated, matte coated, and gloss coated papers. All the papers; uncoated, gloss coated, and matte coated papers, the dot gain is within the reference values and the same is true for all the four primary colours.

Table 4, Dot Gain (80%) of CIJ Press

	Cyan	Magenta	Yellow	Black
UC	13.93	15.01	12.81	16.02

MC	13.01	14.09	11.89	15.1
GC	11.67	12.75	10.55	13.76

Table 4, shows the dot gain (80 %) of CIJ press, while printed on the top side of the uncoated, matte coated, and gloss coated papers. For the primary colours, CMY, the resulted values are well within the tolerance limit and the values of the standard reference values, and black colour for the matte coated and gloss coated papers are slightly higher than the standard reference.

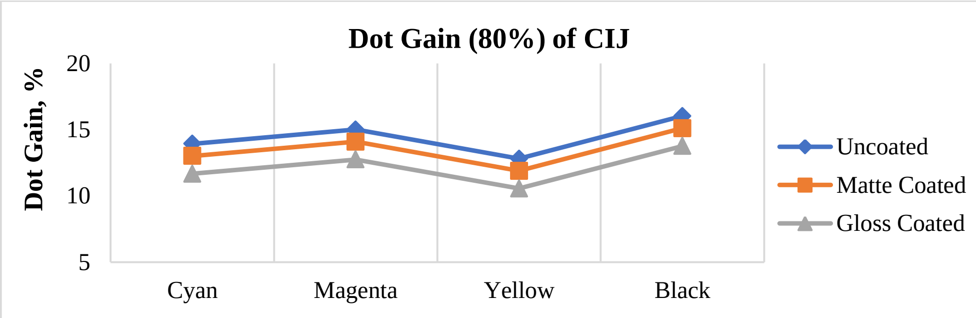

Figure 3, Dot Gain (80%) of CIJ Press

Figure 3, shows the dot gain (80 %) of CIJ press, while printed on the top side of the uncoated, matte coated, and gloss coated papers. Black colour for the matte coated and gloss coated papers are slightly higher than the standard reference, other three primary colours CMY are showing dot gain which are well accepted.

Table 5, Dot Gain (80%) of PIJ Press

	Cyan	Magenta	Yellow	Black
UC	11.97	13.05	10.85	14.06
MC	11.54	12.62	10.42	13.63
GC	10.43	11.51	9.31	12.52

Table 5, shows the dot gain (80 %) of PIJ press, while printed on the uncoated, matte coated, and gloss coated papers. For all the three papers and four primary colours, the values are well within the standard reference values. PIJ presses are showing better results than the CIJ presses.

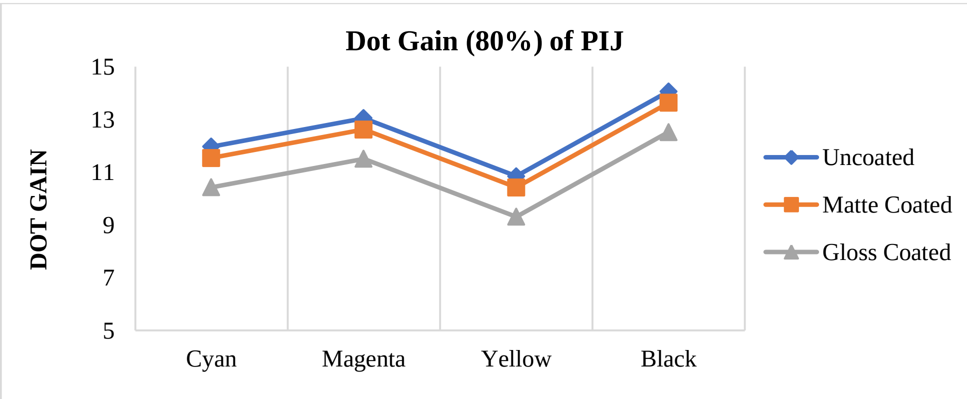

Figure 4, Dot Gain (80%) of PIJ Press

Figure 4, shows the dot gain (80 %) of PIJ press, while printed on the top side of the uncoated, matte coated, and gloss coated papers. All the four primaries with the three papers are showing the dot gain which are acceptable and within the tolerance limits with PIJ presses are showing better results than the CIJ presses.

RESULTS AND DISCUSSION

Porous substrates tend to absorb more ink, and hence dot gain. Absorption rate is highly dependent upon; coating, ink formulation, and paper quality. Ink characteristics such as, viscosity and surface tension, along with the absorption properties of the paper are the factors which decides the spreading of the ink on the substrate during printing operation. Appropriate formulation of inkjet inks may certainly help to overcome the above problems. Factors like nozzle size, printhead technology, and printing speed controls the accuracy of dot placement in production inkjet presses. Controlling these factors will help to control dot gain effectively. Dot gain in production CIJ and PIJ presses can affect the final print quality in various ways; loss of fine details in printed images, altering the colour appearance of the printed image, reducing the contrast between adjacent image elements,

The reference dot gain in 40 percent on uncoated paper, for all the four primary colours CMYK is 20 with a tolerance of plus, minus 4. In CIJ press, results on the top side of the uncoated paper dot gain of the four primary colours ranges from: cyan ink 19.08 to 22.35, magenta ink 20.16 to 23.43, yellow ink 17.96 to 21.23, and black ink 21.17 to 24.44. This indicates the dot gain is very much in the acceptable range and within the reference values.

The reference dot gain in 40 percent on matte coated paper, for all the three primary colours CMY is 16 and black is 18 with a tolerance of plus, minus 3. In CIJ press, results on the top side of the matte coated paper dot gain (40 %) of the four primary colours ranges from: cyan ink 13.06 to 16.33, magenta ink 14.14 to 17.41, yellow ink 11.94 to 15.21, and black ink 15.15 to 18.42. This indicates the dot gain is very much in the acceptable range and within the reference values.

The reference dot gain in 40 percent on gloss coated paper, for all the three primary colours CMY is 14 and black is 16 with a tolerance of plus, minus 3. In CIJ press, results on the top side of the gloss coated paper dot gain (40 %) of the four primary colours ranges from: cyan ink 11.03 to 14.30, magenta ink 12.11 to 15.38, yellow ink 9.91 to 13.18, and black ink 13.12 to 16.39. This indicates the dot gain is very much in the acceptable range and within the reference values.

Dot gain in 40 %, in CIJ press, on uncoated, matte coated, and gloss coated papers, for all the four primary colours, CMYK are well within the reference values, and hence the resulted dot gain is acceptable for all the three types of paper. Result shows gloss coated papers are having lowest level of dot gain, followed by matte coated paper, and uncoated paper with highest level of dot gain, when they are compared with each other. This is mainly due to the surface porosity and roughness of the paper and ink & paper interaction. With suitable coating layer, paper can be manufactured to have dot gain within the acceptable range as per the standard reference values.

The reference dot gain in 40 percent on uncoated paper, for all the four primary colours CMYK is 20 with a tolerance of plus, minus 4. In PIJ press, results on the top side of the uncoated paper dot gain of the four primary colours ranges from: cyan ink 17.05 to 20.32, magenta ink 18.13 to 21.40, yellow ink 15.93 to 19.20, and black ink 19.14 to 22.41. This indicates the dot gain is very much in the acceptable range and within the reference values.

The reference dot gain in 40 percent on matte coated paper, for all the three primary colours CMY is 16 and black is 18 with a tolerance of plus, minus 3. In PIJ press, results on the top side of the matte coated paper dot gain (40 %) of the four primary colours ranges from: cyan ink 11.03 to 14.30, magenta ink 12.11 to 15.38, yellow ink 9.91 to 13.18, and black ink 13.12 to 16.39. This indicates the dot gain is very much in the acceptable range and within the reference values.

The reference dot gain in 40 percent on gloss coated paper, for all the three primary colours CMY is 14 and black is 16 with a tolerance of plus, minus 3. In PIJ press, results on the top side of the gloss coated paper dot gain (40 %) of the four primary colours ranges from: cyan ink 9.54 to 12.81, magenta ink 10.62 to 13.89, yellow ink 8.42 to 11.69, and black ink 11.63 to 14.90. This indicates the dot gain is very much in the acceptable range and within the reference values.

Dot gain in 40 %, in PIJ press, on uncoated, matte coated, and gloss coated papers, for all the four primary colours, CMYK are well within the reference values, and hence the resulted dot gain is acceptable for all the three types of paper. Result shows gloss coated papers are having lowest level of dot gain, followed by matte coated paper, and uncoated paper with highest level of dot gain, when they are compared with each other. Comparing with CIJ press, PIJ is showing better results in the dot gain aspects, this is mainly due to the ink jetting techniques being incorporated in the inkjet head. PIJ has a better control over the deposition of ink droplets over the substrate, irrespective of the type of the paper being used for printing. Better dot gain results into better dot reproducibility and hence enhanced printing quality.

The reference dot gain in 80 percent on uncoated paper, for all the four primary colours CMYK is 15 with a tolerance of plus, minus 3. In CIJ press, results on the top side of the uncoated paper dot gain of the four primary colours ranges from: cyan ink 12.52 to 15.79, magenta ink 13.60 to 16.87, yellow ink 11.40 to 14.67, and black ink 14.61 to 17.88. This indicates the dot gain is very much in the acceptable range and within the reference values.

The reference dot gain in 80 percent on matte coated paper, for all the three primary colours CMY is 11 and black is 12 with a tolerance of plus, minus 2. In CIJ press, results on the top side of the matte coated paper dot gain (40 %) of the four primary colours ranges from: cyan ink 11.60 to 14.87, magenta ink 12.68 to 15.95, yellow ink 10.48 to 13.75, and black ink 13.69 to 16.96. This indicates the dot gain is very much in the acceptable range and within the reference values.

The reference dot gain in 80 percent on gloss coated paper, for all the three primary colours CMY is 9 and black is 10 with a tolerance of plus, minus 2. In CIJ press, results on the top side of the gloss coated paper dot gain (40 %) of the four primary colours ranges from: cyan ink 10.26 to 13.53, magenta ink 11.34 to 14.61, yellow ink 9.14 to 12.41, and black ink 12.35 to 15.62. This indicates the dot gain is very much in the acceptable range and within the reference values.

Dot gain in 80 %, in CIJ press, on uncoated, matte coated, and gloss coated papers, for all the four primary colours, CMYK are well within the reference values, and hence the resulted dot gain is acceptable for all the three types of paper. Result shows gloss coated papers are having lowest level of dot gain, followed by matte coated paper, and uncoated paper with highest level of dot gain, when they are compared with each other. Coated papers are manufactured with suitable weight of coated layers to seal the base paper, so that a smooth and low porous can be resulted to suit the setting of printed ink layers onto it.

The reference dot gain in 80 percent on uncoated paper, for all the four primary colours CMYK is 15 with a tolerance of plus, minus 3. In PIJ press, results on the top side of the uncoated paper dot gain of the four primary colours ranges from: cyan ink 10.56 to 13.83, magenta ink 11.64 to 14.91, yellow ink 9.44 to 12.71, and black ink 12.65 to 15.92This indicates the dot gain is very much in the acceptable range and within the reference values.

The reference dot gain in 80 percent on matte coated paper, for all the three primary colours CMY is 11 and black is 12 with a tolerance of plus, minus 2. In PIJ press, results on the top side of the matte coated paper dot gain (40 %) of the four primary colours ranges from: cyan ink 10.13 to 13.40, magenta ink 11.21 to 14.48, yellow ink 9.01 to 12.28, and black ink 11.96 to 15.49. This indicates the dot gain is very much in the acceptable range and within the reference values.

The reference dot gain in 80 percent on gloss coated paper, for all the three primary colours CMY is 9 and black is 10 with a tolerance of plus, minus 2. In PIJ press, results on the top side of the gloss coated paper dot gain (40 %) of the four primary colours ranges from: cyan ink 9.02 to 12.29, magenta ink 10.10 to 13.37, yellow ink 7.90 to 11.17, and black ink 11.11 to 14.38. This indicates the dot gain is very much in the acceptable range and within the reference values.

Further the correlation analysis was held for the dot gain in CIJ and PIJ presses to find out the relationship of paper properties with the dot gain of presses on different paper varieties. The Pierson Coefficient of Correlation (r) was used to find out the relationship of paper surface properties with the dot gain in the presses. This correlation analysis can help in finding the role of different surface characteristics of the paper with the dot gain happening in CIJ and PIJ forms of inkjet presses.

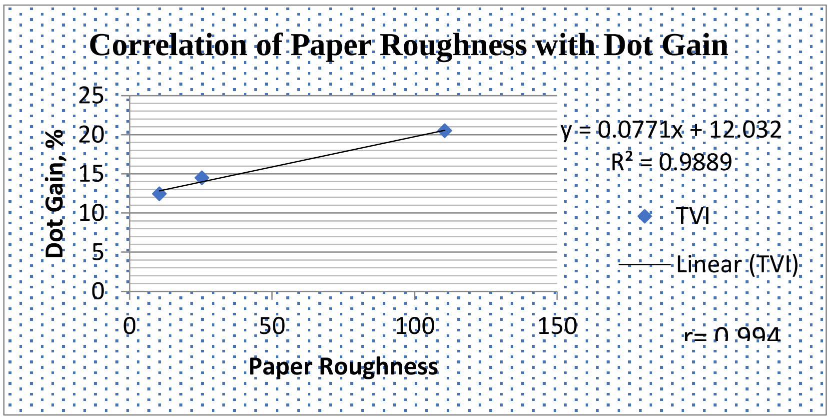

Fig. 5 Correlation of Paper Roughness with Dot Gain

Figure.5, indicates that the value of coefficient of correlation "r" was found 0.994 which shows that the value of TVI increases with the increase in paper roughness. Dot gain in 80 %, in PIJ press, on uncoated, matte coated, and gloss coated papers, for all the four primary colours, CMYK are well within the reference values, and hence the resulted dot gain is acceptable for all the three types of paper. Result shows gloss coated papers are having lowest level of dot gain, followed by matte coated paper, and uncoated paper with highest level of dot gain, when they are compared with each other.

CONCLUSION

Dot gain or tonal value increase is highly important in terms of faithful reproduction of tones and colours in inkjet presses. Though dot gain cannot be avoided, but it can be controlled for achieving better quality printing output. It is established for this research work, that the surface characteristics of the printing substrate and the quality of the printing ink essentially controls the dot gain on different types of paper. From the 40 percent and 80 percent dot values of all the four primary colours, CMYK, it is seen that, uncoated papers are prone to higher dot gain than the coated papers.

Due to the porosity and the rough surface of the uncoated papers, the ink may find it easily to either penetrate or absorbed into the uncoated paper, so is the unwanted dot gain during printing. Whereas, in gloss and matte coated papers, due the suitable coating layers, this possible absorption/penetration of inkjet ink into the paper surface is sealed, which essentially controls the final dot gain. Gloss papers are much better than the uncoated and matte coated papers in terms of tonal value increase and hence are suitable for high quality graphics printing. PIJ presses are highly successful and results into better dot gain values than the CIJ presses, as because of better control of inkjet droplets onto the substrate.

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