ISSN: 0974-5823 Vol. 7 No. 3 March, 2022

International Journal of Mechanical Engineering

Comparative Study & Critical Analysis of Different Inkjet Printheads in Relation to their Print Performance Parameters

Sanjeev Kumar[1], Prof. (Dr.) Anjan Kumar Baral[2]

[1]Research Scholar & Assistant Professor, Department of Printing Technology, GJUST, Hisar, India

[2]Professor, Department of Printing Technology, GJUST, Hisar, India

ABSTRACT

Digital printing is relatively a new technology in printing industry. Inkjet technology in digital printing segment is the future technology to be considered for producing colour jobs. Growth of inkjet is very significant because of its application in various printing sector especially publishing segment. The inkjet printhead is the heart of any inkjet printing press. There are various inkjet technologies which are used as per the need of application and job. Different printheads is having working principle with its advantage and disadvantage. The main aim of this research paper is to study the specification of different printheads with its performance, advantages and disadvantages. Also, it is discussed about the printing standard in digital to achieve consistent colour.

Keywords: Inkjet, printheads, performance, digital print standard, droplets, nozzle, continuous inkjet, thermal inkjet, piezoelectric inkjet.

INTRODUCTION

Inkjet is a new way to print a colour document. Inkjet is a process in which very small drops of liquid inks injected through nozzles to print the substrate. This technology is able to print on substrate without requirement of intermediate image carrier. The key point of inkjet technology is to print on substrate directly. Inkjet printing is widely used in variable data printing, print on demand and customised printing in India and abroad. In the 17th century, the development of inkjet technology was begun. The first fundamental inkjet concept was introduced in the 19th century by Joseph Plateau (Belgian physicist), and Lord Rayleigh (English physicist). In 1865, Plateau explained the relation between the jet diameter and the drop size (Wijshoff, 2010). The mechanism of droplets by the liquid stream of Lord Rayleigh is fundamental concepts (Rayleigh, 1878). In 1861 and 1865, Maxwell's derived very significant electromagnetic equation which has very significant influence in the development of inkjet technology (Maxwell, 1861). This evolution leads to Pierre and Jacques Curie applying the piezoelectric effect in inkjet technology in 1880 (Wijshoff, 2010).

REVIEW OF LITERATURE

Inkjet has gone through lot of research and development during 17th century to till now. According the mechanism of drop generation, inkjet technologies can be classified in two categories; i) Continuous inkjet (CIJ), ii) Drop-On-Demand inkjet (DoD).

- **Continuous Inkjet: History and Development**

The theoretical concept of Lord Rayleigh was first practical demonstrated by Elmqvist (Seimens-Elema) in 1951 (Elmqvist, 1949). This invention opened the door of first commercial inkjet chart recorder named Mingograph. This record the analog voltage signals having frequency upto 1.25 kHz. In 1960s, it is demonstrated further by Dr. R. G. Sweet from Stanford University by the application of pressure, the size and spacing of the droplets can be controlled (Sweet, 1965). With the application of electric charge selected droplet, these charged droplets when passing through the magnetic field could change its path. The charged droplets will deflect towards the magnetic field and the pass through the gutter for further recirculation. The uncharged droplets will remain go ahead and come in contact with media surface to produce an image (Sweet, 1971). This is known as continuous inkjet technology (CIJ). CIJ can be classified as; i) Airflow deflection; ii) Charge deflection. The charge deflection can be further divided into binary deflection, multiple deflection, hertz deflection and microdot.

In 1964, character printing was enabled with the extension of Dr. Sweet’s invention and Lewis-Brown patented (US 3298030) by A.B. Dick Company (Arther M Lewis, Shaker Heights, 1967; Wijshoff, 2010). This leads the first commercial continuous inkjet device named Videojet 9600 in 1968. This is known as multiple charged deflection continuous inkjet (fig 1). Elmjet, Scitex and Image are few manufacturers of such types of printheads. The company Sharp also launched similar product Jetpoint printer in 1973 after research on multiple drop deflection.

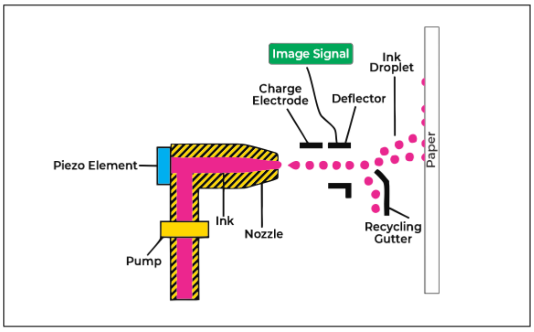

Fig 1: Multi deflection Continuous inkjet technology (Lau & Shrestha, 2017)

Later, Dr. Sweet and Cumming patented the technique in which individual droplets were charged selectively and other remains unchanged. This is known as binary deflection continuous inkjet technology (fig 2). IBM in 1970s boosted the inkjet technology with number of researches (Buehner et al., 1977). In 1970s, during its development, Professor Hertz and his team at Lund Institute of Technology, Sweden developed few technologies in continuous inkjet that were able to print different shades of gray successfully (Carl Hellmuth Hertz, Skolbanksvagen, 1966). By controlling the density of droplets at each location, different shades of gray could be achieved. This is known as Hertz deflection continuous inkjet.

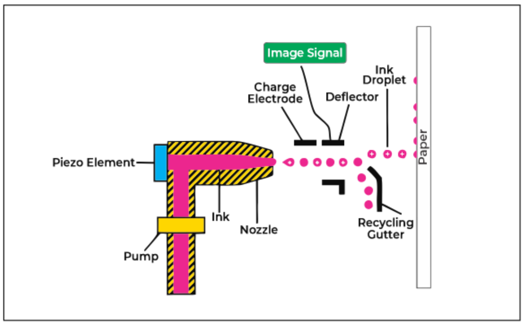

Fig 2: Binary deflection continuous inkjet technology (Lau & Shrestha, 2017)

On the basis of Hertz's principle, Iris Graphics and Stork (1977) made a colour inkjet printer which was able to produce high quality colour image. In1988, Microdot Continuous inkjet printhead was invented by Hitachi in which variable droplets generates from the same nozzles. It was never commercialized (Askeland, 2015; Le, 1998).

Airflow Deflection CIJ, Piezoelectric transducer was used to apply pressure. Due to pressure wave at nozzle opening the ink stream breaks into uniform size of droplets. The droplets are selectively charged to deflect by electrostatic field to produced desired output. Air stream is applied to deflect small droplets and recycled (Askeland, 2015). Kodak (Versamark, Ultrastream), Domino, Scitex Iris, Stork, Imaje, VideoJet are some players in continuous inkjet technology.

- **Drop on Demand Inkjet: History and Development**

The basic concept of changing and controlling of droplets in continuous inkjet printheads is bit complex (Le, 1998). Therefore, at the similar time the work on drop-on-demand (DOD) inkjet technology came into existence. The drop-on-demand inkjet printhead ejects required size of droplets where it is expected to draw image on surface. This is the simplest form of inkjet technology. Drop-on demand inkjet heads opens the aperture of the nozzle when the drop is required to form an image (Le, 1998). DoD inkjet can be categorizing into Thermal, Piezoelectric, Electrostatic, Acoustic and Mechanical valve. Thermal inkjet is further divided into roof shooter and side shooter. Piezoelectric is also classified into bend mode, push mode, shear mode, squeeze mode (Askeland, 2015). Majorly, Thermal and Piezoelectric DOD inkjet printheads are widely used in the industry (Kim et al., 2008)

- **Piezoelectric DOD (PIJ)**

In 1940s, Hansell worked first towards this direction and invented first DOD device (Wijshoff, 2010). It was not much developed into a commercial product. The first Drop-on-demand process came out in 1960s. It was based on electrostatic pull inkjet. Basic working principle was patented by Winston in 1962 (Wijshoff, 2010). A conductive ink was used in nozzle by negative pressure. An electrode is located outer side of the nozzle. When high voltage is applied, pressure was generated which finally produce droplets from the nozzle (Li et al., 1994; Taylor, 1964).

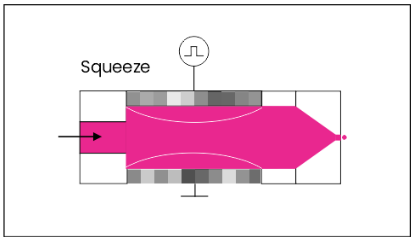

Fig 3: Squeeze mode (Wijshoff, 2010)

In 1972, S. L. Zolten, E.L. Kyser and S. B. Sears are those inventors who contributed to this drop-on-demand technology (Steven I. Zoltan, 2020). They purposed squeeze mode technique. A hollow tube of piezoelectric ceramic is used to collect ink. When electric current is applied then due to piezoelectric effect the tube squeezes and appropriate pressure is generated which ultimately form a droplet. This is known as squeeze mode (Bugdayci et al., 1983). Multiple nozzles in Squeeze mode printhead are not in use for graphical printing industry. In 1973, bend mode was introduced by Stemme, Chalmers University (Stemme & Larsson, 1973).

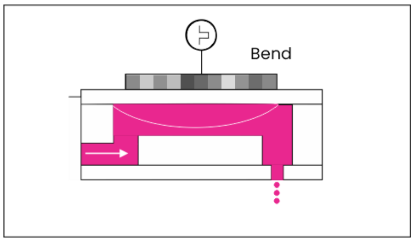

Fig 4: Bend Mode (Wijshoff, 2010)

In this piezoelectric ceramic bends when electric current is supplied which ultimately increase pressure by mechanical motion on the outer orifice of the nozzle to create desired form of droplet (Kyser & Sears, 1976). This is the bend mode piezoelectric DOD inkjet. Push mode of piezoelectric inkjet was invented by Stuart Howkins in 1984.

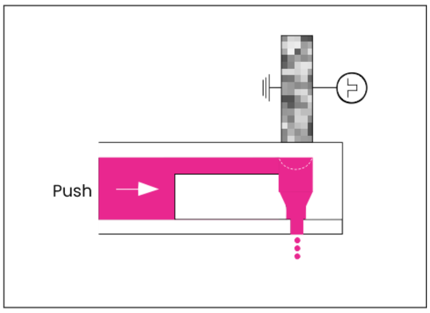

Fig 5: Push mode (Wijshoff, 2010)

In this technique, the piezoelectric ceramic push the ink chamber wall to create pressure on ink to come out from opening. Shear mode was invented by Fischbeck (US 4584590) in which electric field is arranged perpendicular to the effective polarization of piezo crystals.

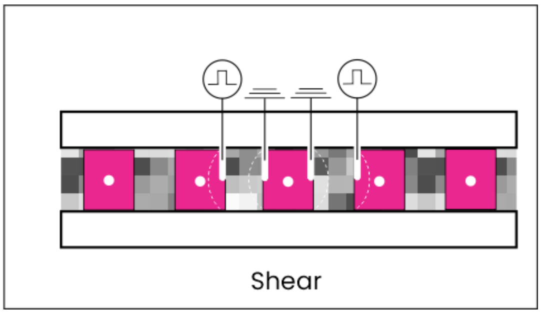

Fig 6: Shear Mode (Wijshoff, 2010)

This shear operation forces piezoplates towards ink to eject the tiny drop (Le, 1998). Epson, Ricoh, Trident, Fujifilm, Kyocera, Xaar, Toshiba, Panasonic, Seiko II, Konica Minolta, Samsung, Xerox (Tektronix), Brother, Domino, Sharp etc. are few major players in Piezoelectric inkjet printhead.

- **Thermal Inkjet (TIJ) -** As far as inkjet is concern, Thermal inkjet and piezoelectric inkjets are more popular among the printers. Epson played a major role in development of thermal inkjet. HP leads in the productivity while Canon is for high quality with small drop formation. Earlier thermal inkjet was more popular but now piezoelectric inkjet has wide range of utility in aspect of substrate. Piezoelectric can deposit a wide range of one material on the surface of other substrate in well-defined patterns. Now-a-days inkjet is also used in manufacturing of electronic display panels like LED display, solar cell etc (Dijksman et al., 2007).

The thermal inkjet is of two types; Roof-Shooter and Side-Shooter thermal inkjet. In Roof-shooter the heater is located just opposite to the orifice. Whereas, in Side-shooter thermal inkjet, the heater is located to the side of ink chamber (Wijshoff, 2010). Endo and Hara (Canon) invented (1979) a technique called “Bubble Jet” technology where drop-on-demand inkjet technique is used.

In this technique, water vapours are used to create a bubble which ultimately gives pressure to ink to come out through the orifice. This fabricated technology allows manufactures to produce printers at low cost with high density (Yano, 1982).

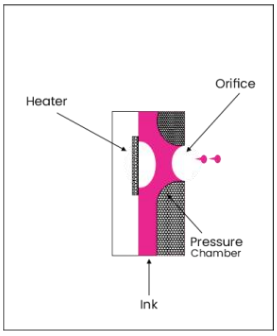

Fig 7: Roof Shooter (Askeland, 2015)

With the introduction of drop-on-demand inkjet technology, the inkjet technology becomes reliable. As it is more simple process which leads to open doors for further improving in the process. HP, Canon, Lexmark, Kodak, Silverbrook MEMS, Memjet, Kyocera, Jetinks etc are the major manufacturer in this area.

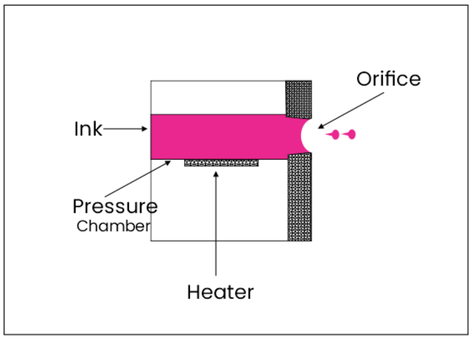

Fig 8: Side Shooter (Askeland, 2015)

- **Electrostatic Inkjet-** Winston submitted the first patent in 1962. (US 3060, 429). This is the fundamental working principle. Conductive ink is kept by a negative pressure in a bucket. A droplet of ink is pulled off by using a high voltage pulse on an electrode outside the nozzle. The droplet can be located on the substrate using the appropriate deflection fields (Wijshoff, 2010). Electrostatic jet is based on an orifice inducing an electric field, which forms a meniscus known as a Taylor cone. The drops are separated as fine droplets far lower than the diameter of the orifice. The ability to throw out fine droplets and the simplicity of its structure has greater advantage than piezoelectric inkjet and thermal inkjet (Lee et al., 2008). Under the voltages 2.5 kV and 10 µm in diameter, a stable micro-drip mode was observed.

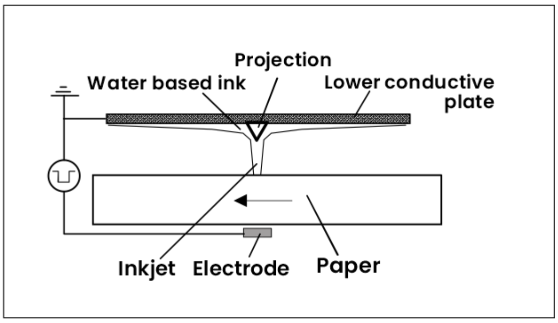

Fig 9: Electrostatic Inkjet (Sou et al., 2002)

With the increasing height of the micro dust the electric field strength increases linearly. The electric field on the periphery of the meniscus may be further concentrated as the dust diameter decreases (Kim et al., 2008). Continuous tone image can be produced by this principle. A fine jet flows out of the meniscus under appropriate conditions. The magnitude of electric fields needed for jetting is dictated by the electrical conductivity, dielectric constants, viscosity, surface tension and liquid density (D. H. Choi & Lee, 1993). To achieve the print quality, less sensitive hot melt ink was used to reduce the paper sensitivity.

Sou et al. (2002) investigated the control of ink transportation in electrostatic inkjet printer. The minimum ink volume and drop size of the ink droplet can be achieved by charging nearly 1.0kV voltage, decreasing the viscosity of ink, surface tension, and contact angle. High quality of print can be predicted by controlling above variables (Sou et al., 2002). In 2002, Yoshinobu FUKANO and their team developed multichannel electrostatic inkjet printer capable of printing four colour at 600 dpi resolution (Fukano, Y., Masuda, K., Okano, M., & Yonekura, 2002). A simulation study shows that the proposed mechanism allows a fine droplet of few picoliters to form and execute less than 100 volts of operating voltage (Lee et al., 2004).

A study was carried out to investigate the phenomenon of electrostatic inkjet in Pin-to plate discharge system. Between an isolated capillary tube with ion-conductive water and an electrode of metal plate, high voltage was applied. Under conditions of the appropriate voltage application and water level, a large drop was formed from the tube on the dark discharge. The drop was about a millimetre in diameter (Hiroyuki Kawamoto, 2005). This inkjet technology is used in display fabrication process (Son et al., 2006). An experimental investigation explores the micro dripping mode of electrostatic droplet ejection of various physical properties of liquid solvents, such as DI water, acetone, dioxanes. There is a focus on how the electrical conductivities of liquid solvents influence the stability of a drop-on-demand dripping mode. The optimal conductivity range from 10-6 to 10-6 S/cm for a stable droplet ejection in a mode of micro-dripping is discovered given the applied voltage and flow rate. It shows how physical properties of various liquid influence the jetting behaviour (Jung et al., 2006).

A study reveals the possibility of fluid flowing through fine micro-capillary nozzles for the jet printing of sub-micrometer resolutions patterns and functional devices. Key physics aspects of this approach, which have certain features in common with related but relatively inferior graphical arts techniques by a direct, high-speed imaging of droplet formation procedures (Park et al., 2007). The electric field induced drop formation was found at the beginning of the twentieth century, where ink injections can be made from a nozzles, Since discovery of electro-dynamic (EHD) technologies, micro-colloid thrusters, tin jet printing, crop pesticides and film deposition have become common in many different areas (J. Choi et al., 2008).

A new design of inkjet head requires lower driving voltage of 36V DC with drop velocity of 2.82 m/sec which enhance the rate of finished products and reduces the final cost (Lv et al., 2010). This type of inkjet heads are widely used in printed electronics and biotechnology applications (Rahman et al., 2010), printing of edible inks (Sun et al., 2013) and 3D printing (Schlatter et al., 2020).

Acoustic inkjet

The first report of drop ejection using the acoustic generator was in 1927 (Wood, 1927). If an ultrasound underwater wave concentrates on a free liquid area, its radiation pressure will eject liquid drop from the surface. This mechanism is used for the printing of acoustic inkjet. By using the ultrasonic wave of a tone burst the number and size can be controlled. Acoustic dropping generators use an acoustic beam to dispel drops on a free liquid surface. A variety of configuration can be used to focus the ultrasonic wave such as spherical lens, spherical transducers, Fresnel lens, phased array lens etc (HAMAZAKI & MORITA, 2009).

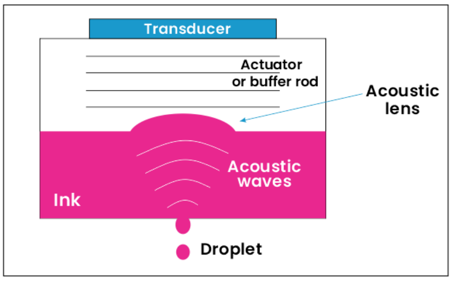

Fig 10: Acoustic Inkjet (Castrejón-Pita et al., 2013)

A burst of acoustic energy is concentrated with this technique on an area of a fluid that causes a drop to be thrown. This has the advantage that a nozzle is not needed. Various acoustic energy focusing methods, including acoustic shape lenses and Fresnel acoustic lenses can be used (Castrejón-Pita et al., 2013). However, such type of inkjet printhead is not commercialized hard copy printer.

OBJECTIVE OF THE STUDY

In the recent times, digital printing technologies are becoming popular & being accepted and adopted by the print buyers because of print quality, time of delivery, process standard and green aspects of the printing. Inkjet printing especially industrial application is growing day-by-day due to its speed of operation and cost factor coupled with wide range of technology under this inkjet printhead.

To take case of wide application, number of inkjet printheads is available in the market place to cater a wide array of print jobs. Each of these printheads comes with a series of benefits and unique characteristics. Study of these unique characteristics of various printheads is the need of the hour. This will help to compare and indicate the jobs suitability and other related factors so that the selection and use of specific inkjet printhead can be pointed out for sustainable growth and use for particular printhead in the printing industry. The main objective of this study is: i) to compare the printhead find out the print quality factors of various inkjet printhead that are available in the market place. ii) to find out physical specifications of various inkjet printheads, iii) to find out the print performance of printheads, iv) to find out the limitations of the inkjet printheads, v) to study the digital print standard.

RESEARCH METHODOLOGY

To achieve above listed objectives, various parameters related to the inkjet printhead performances are identified. Data related to the various parameters is collected from the reliable resources. This collected data is complied, interpreted and represented in some informative manners.

DATA COLLECTION AND ANALYSIS

Data is collected from the various reliable sources. The authentic data is most important for any study. So, maximum data is collected from their parental websites and compiled.

- **Physical specification of various inkjet printheads**

A printhead in which the drop diameter is usually associated with the nozzle size (Castrejón-Pita et al., 2013). A chart below shows physical specification of different major inkjet printheads.

Table 1: Specification of printheads (data is collected from parent website)

Inkjet Technology	Company Name	Printhead Model	Nozzles	Swath	Resolution	Frequency	Speed
				mm	dpi	kHz	m/min
CIJ	Kodak	Ultrastream	2496	108	600	400	152 m/min
		Stream11	2560	108	600	450	300m/min
TIJ	HP	Thermal	25344	129	1200	20	300m/min
		HDNA	10560	108	2400	20	300m/min
	Memjet	DuraLink	70400	222.8	1600	15.5	74.5m/min
		DuraFlex	163840	324	1600	15.5	203m/min
		VersaPass	70400	222.8	1600	9.6	18.3m/min
	Canon	FINE	6000	-	1200	-	-
	Kyocera	KPJ-162-12SBE30-STG	1920	162.2	300	-	-
PIJ	Epson	PrecisionCore	3200	120.1	600	50	-
	Ricoh	MH5220	1280	54.1	600	30	-
		TH5241 (MEMS)	1280	27.1	1200	20-40	125m/min
	Fujifilm Dimatix	Samba G3L	2048	43	1200	100	200m/min
	Kyocera	KJ4B Series	2656	108.25/ 112.42	600	30/40/80	75-100m/min
		KJ4C Series	1584	102.66	360	50	50 m/min
	Xaar	502 GS150	500	70.5	180	7.2	200m/min
		2001+ GS12U	2000	70.3	720	6.0-27	60
		501 GS8	500	70.5	360	8	45m/min
	Toshiba-tec	CF3R	1278	53.9	600	45	35m/min
	Panasonic	UH-HA820	-	-	600	30	75-150m/min
	Seiko II	RC1536	1536	108.3	360	37	50m/min
	Konica Minolta	KM1024iMHE	1024	72	360	45	150m/min
	Xerox (Tektronix)	W series	5544	115	1200	80	300 ipm
	Brother	BitStar	1680	340	1200	-	-
Electrostatic	ToneJet	Tonejet	nozzle free	105	600	-	1 m/s

- **Nozzles:** There is a direct relation of number of nozzle in the print quality of inkjet printing. Therefore, nozzle is to be taken into consideration for printhead evaluation and data is reflected in table 2.

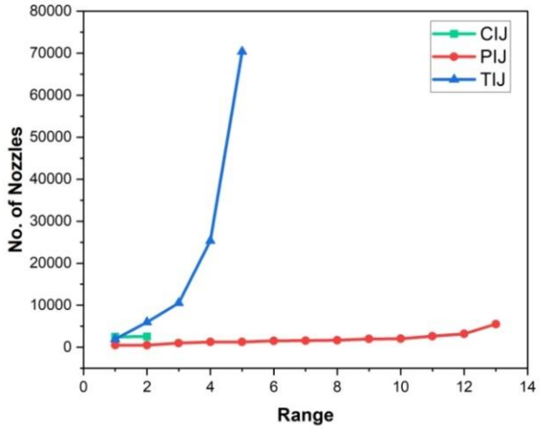

Chart 1: Range of nozzles

The chart 1 shows that the range nozzles of different inkjet printheads. CIJ has very limited range of nozzles. TIJ has high number of nozzles but less in range. PIJ has diversified in term of range of nozzles. This wide range of nozzles has advantage for PIJ to dominate in the inkjet market. Thermal inkjet printheads have highest number of nozzles but not in wide range. Continuous Inkjet printhead has specific range with very specific number of nozzles.

	CIJ	TIJ	PIJ	Electrostatic	Acoustic
Nozzles	2560	25344	3200	Nozzle free	No data
	2496	10560	1280	-	-
	-	70400	2048	-	-
	-	6000	2656	-	-
	-	1920	1584	-	-
	-	-	500	-	-
	-	-	2000	-	-
	-	-	500	-	-
	-	-	1278	-	-
	-	-	1536	-	-
	-	-	1024	-	-
	-	-	5544	-	-
	-	-	1680	-	-

Table 2: Number of Nozzles

Swath: Swath is the area that is covered by the inkjet printhead by one single move. The data is shown in tabular form in table 3. Swath is measured in mm.

	CIJ	TIJ	PIJ	Electrostatic	Acoustic
Max Swath (mm)	108	324	340	105	No Data found

Table 3: Values of maximum print swath

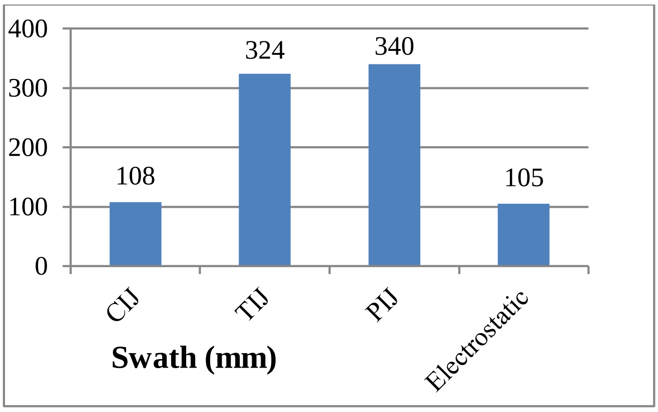

Chart 2: Values of maximum print swath.

The above shown Chart 2 shows the clear difference of various inkjet printhead swaths. This is also an important factor that is to be taken into consideration.

- **Resolution**: It is the key factor that directly relates to the print quality and performance. Data is shown in the below table 4. Resolution is measured in dot per inch (dpi).

	CIJ	TIJ	PIJ	Electrostatic	Acoustic
Max Resolution	600	2400	1200	600	No Data found

Table 4: Maximum range of resolution

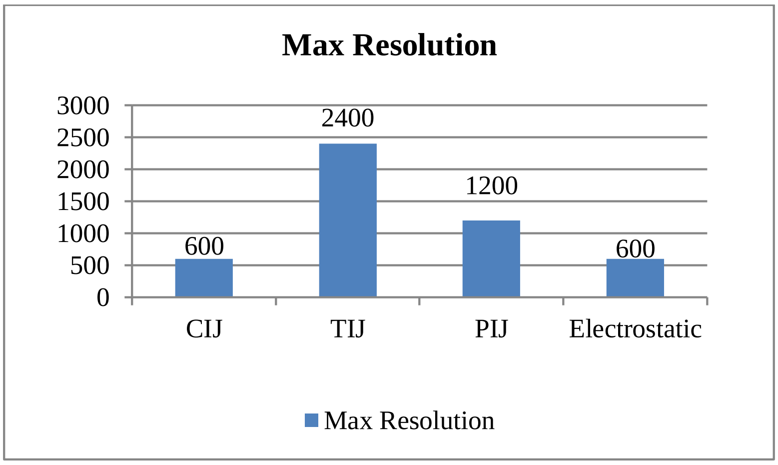

Chart 3: Maximum range of Resolution

- **Frequency**: This table 5 shows the data for frequency at which different inkjet works on. It is measured in kHz.

	Minimum Frequency (kHz)	Maximum Frequency (kHz)
CIJ	400	450
TIJ	9.6	20
PIJ	7.2	100
Electrostatic	No data	No data found
Acoustic	No data	No data found

Table 5: Frequency of printheads

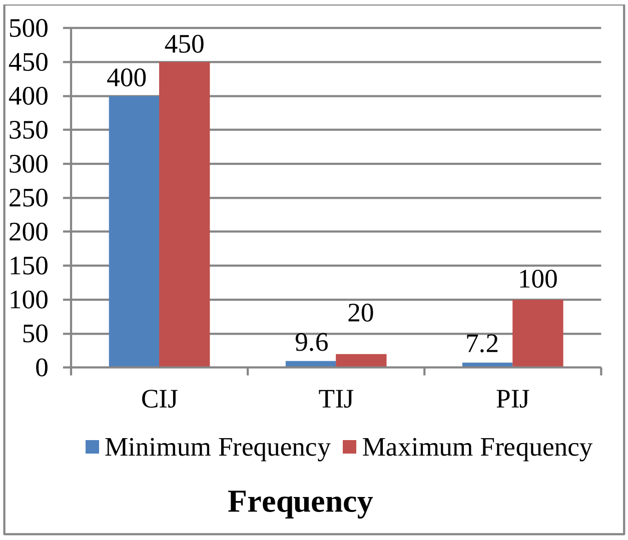

Chart 4: Frequency of printheads

- **Speed**: Speed of inkjet printhead denotes that how much area is to be printing in a given time. Speed of printhead is measured in meter per minute (m/min). Data for speed of printhead is shown below in table 6.

	CIJ	TIJ	PIJ	Electrostatic	Acoustic
Speed (m/min)	300	300	200	1	No data found

Table 6: Speed of inkjet printhead

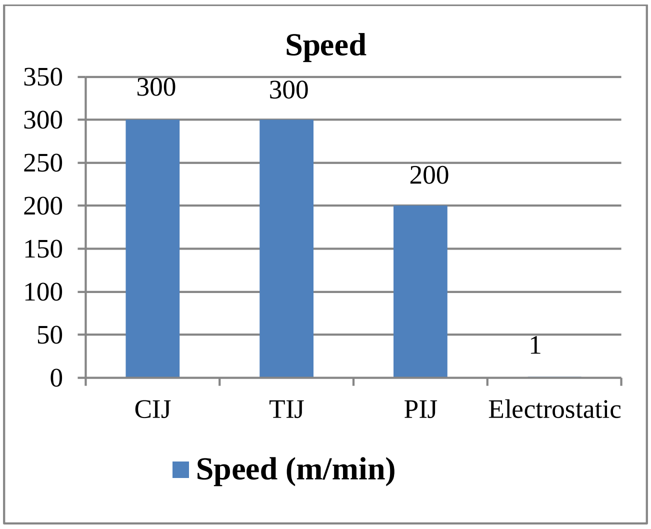

Chart 5: Speed of inkjet printhead

The above Chart 5 shows the speed of printhead in graphical view.

	Source	Desired	CIJ	PIJ	TIJ	Electrostatic	Acoustic
Drop Speed	(*Introduction to Industrial Inkjet Printing — IMI Europe - High Quality Inkjet Conferences and Courses*, n.d.)	4 to 5 m/s	Upto 50 m/s aprox	5-10 m/s	5 m/s	1 m/s (tonejet)	No data found
Drop Volume		2 to 32pL	3.8-9 pL	1.5-48 pL	1.2-9 pL	0.4-2 pL	No data
Drop Shape	(Martin et	Satellite free drop	Satellite Free drop	Having Satellite		Satellite free drop	No data

	al., 2008)			Drop			
Drop Size	(Castrejón-Pita et al., 2013)		80-100 µm	15-55 µm		~ 8 µm	No data
Ink layer			10-15 µm	1 µm	1 µm	0.5 µm	No data

Table 7: Performance of inkjet printhead

Performance of inkjet printheads

The performance of any inkjet printhead can be evaluated by drop speed, drop volume, drop shape, drop size, jet straightness any ink layer. Data is collected for above listed parameters in tabular format as shown in table 7.

- **Drop Speed**: It denotes the speed of droplet in meter per second coming out from nozzle. It is measured in meter per second (m/s).
- **Drop Shape**: in the table 7, generation of satellite drop is studied. This satellite droplet is also a considerable factor for selecting any inkjet printhead.
- **Drop Size**: Drop size is also studied in this paper. The range of droplet produced by the inkjet is studied and examined in table 7.

	CIJ	PIJ	TIJ	Electrostatic
Drop Speed (m/s)	50	10	5	1

Table 8: maximum drop speed produced by inkjet printhead

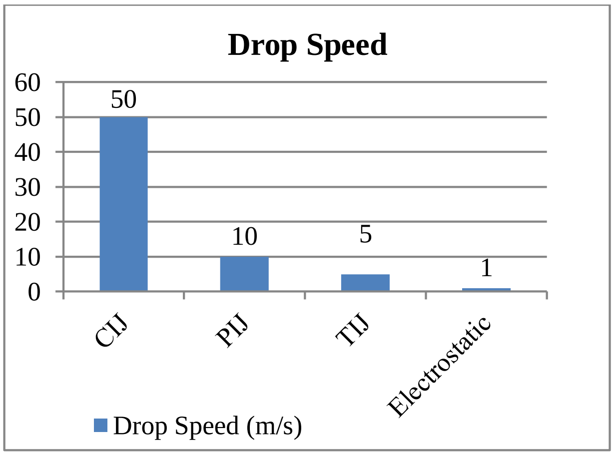

Chart 6: maximum drop speed produced by inkjet printhead

The above chart shows the maximum speed of droplet that can be produced by the inkjet printhead. This is also the deciding factor for the suitable application of various inkjet printhead

- **Drop Volume:** it is the volume of droplet departed from printhead nozzle. It is measured in picoliter (pL). Minimum and maximum values in pL is shown is table 9 below.

	CIJ	TIJ	PIJ	Electrostatic	Acoustic
Minimum Drop Volume	3.8	2	1.5	0.4	No Data
Maximum Drop Volume	9	40	84	2.0	No Data

Table 9: drop volume generated by different inkjet printheads

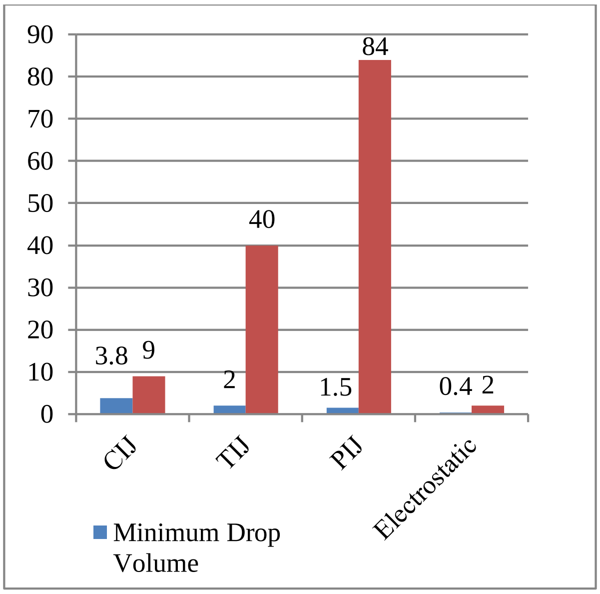

Chart 7: drop volume generated by different inkjet printheads

Drop volume is the size of the inkjet droplet. This is also the measureable factor.

- **Ink layer**: The thickness of layer produced by the inkjet printhead is also examined. The above data clearly shows the valuable information regarding this in table 7.

Limitation of the inkjet printhead technologies

Sr. No.	Parameter	Source	CIJ	PIJ	TIJ	Electrostatic	Acoustic
1	Drop formation technique		Transducer	Mechanical Drop Formation		Taylor Cone and Jet (Electric field Technique)	Ultrasonic Waves
2	Droplet size Formation		Limit to orifice	piezoelectric actuator is difficult to make droplet smaller than nozzle size	difficult to make droplet smaller than nozzle size	Can produce smaller droplets then opening of orifice	Can produce smaller droplets then opening of orifice
3	Structure of Printhead	(Kim et al., 2008)	Complex printhead structure			Simple printhead structure	
4	Heat		Cold process	Cold process	actuator has the heat problem	Cold process	Cold process

Table 3: Limitation of inkjet printheads

The above table 3 is showing data related to the limitation of inkjet printhead. To evaluate few factors are taken into consideration like mechanism of drop formation, droplet size formation, structure of inkjet printhead and heat produced or application of heat during functioning of the inkjet printhead. These above factors influence the overall performance of the printhead. Therefore, critical analysis is done on these factors.

DIGITAL PRINT STANDARD

A good printing is measured by its print quality. To measure print quality parameters, there are some device and equipments. To maintain print quality, we need some global standards. Printing sector also has some international standards which are adopted worldwide to achieve standard print quality. International Organization for Standard (ISO) has defined some print quality standards. ISO 12647-2, includes several parts which are more related to different conventional printing and digital proofing processes.

ISO 12647- Part 7 is for digital proofing but not for the digital printing (Trochoutsos et al., 2018). Process standard for offset and digital should be different due to some technical reasons. There are many factors which are not directly applicable in digital printing. Therefore, new digital printing standard ISO 15311 is being generated by Fogra's working group.

Digital Print Standardization –ISO 15311: PSD – Process Standardize Digital provides industrial guidance from data creation throughout printing and is delivered by Fogra for digital printing. "Graphic Technology - Requirements for printed matter for commercial and industrial production" is the ISO title. There is however some discussion in ISO TC130 WG3 whether or not digital printing should be the standard. ISO 15311 is a multi-part, representative application standard, contrary to ISO 12647-x. The present structure of this ISO is: i) ISO 15311-1 - Part 1 Parameters and measurement methods; ii) ISO 15311-2 - Part 2 Commercial production printing (almost published); iii) ISO 15311-3 - Part 3 Large format printing (draft will be published as Fogra specification); iv) ISO 15311-4 - Part 4 Additional parts based on use case (in discussion).

The Digital process standard has three main goals - i) Output process control; ii) Colour Fidelity; iii) PDF/X compliant workflow (Fogra, 2018). Fogra is continuously working on Process Standardize Digital.

RESULT AND DISCUSSION

- **Physical specification of various inkjet printheads**

Table 1 has compiled data of various inkjet printhead manufacturers. It is clearly shown that different inkjets are different in terms of their physical specifications. The above table includes most common factor of any inkjet printhead. Colour modes means whether particular inkjet technology is capable of producing multicolour print. Almost all inkjet technologies are capable of producing multicolour printing especially thermal and piezoelectric inkjet are widely used. However, Kodak is the only player who produces continuous inkjet in colour mode. CIJ is primarily used in coding and marking because of its suitability.

Nozzles are the opening from where tiny droplet comes out. More inkjet nozzle means more number of ink droplets in shorter period of time at large area. The chart 1 shows the range of nozzles for different inkjet printheads. PIJ are having wide range of nozzles may be the reason of its popularity followed by TIJ and CIJ respectively. Though, highest nozzles are available with TIJ. PIJ inkjet printheads are having maximum swath as shown in chart 2. It also relates with the speed of the machine. The chart 3 shows the comparative study of maximum resolution for CIJ, TIJ, PIJ and Electrostatic are 600, 2400, 1200 and 600 respectively.

Frequency is also an important factor as shown in chart 4. CIJ printheads are having maximum frequency i.e.450kHz which makes them suitable for bar coding and marking as well as for colour printing whereas; other printheads frequencies are less than 100 kHz. CIJ and TIJ printheads are having maximum speed i.e. 300m/min followed by PIJ and electrostatic inkjet printhead as shown in chart 5. Speed relates with the time saving factor in inkjet.

- **Performance of inkjet printheads**

Table 2 shows the data related to the inkjet printhead performance. The value of various parameters is collected and analysed. The printhead speed is different to the drop speed. Drop speed of CIJ is around 50 m/s comparatively more than others (shown in chart 6) which means the throw distance of droplets form printhead to substrate is more. The more distance between the substrate and printhead enables to print on wide variety of substrates including uneven surfaces as well. Other printheads like TIJ, PIJ and Electrostatic inkjet printhead are having drop speed 5 m/s, 5-10m/s and 1m/s respectively which mean the substrate surface need to be very close to the printhead. In case of Electrostatic inkjet printhead the speed is 1m/s due to application of effective electrostatic field. Small size of dot can be created by the small drop volume of the droplet. The chart 7 shows that PIJ is having larger drop volume than others i.e. 1.5-84 pL approximately whereas CIJ and TIJ are having intermittent drop volume ranging from 3.8-9pL and 1.2-9 pL respectively. The smallest drop volume is generated by Electrostatic inkjet printhead i.e. 0.4-2pL due to which almost continuous image can be printed (see chart 7).

Ideally, satellite drops are avoided. TIJ and PIJ produce satellite droplets while CIJ and electrostatic produce satellite free droplet. This can affect the final output of the print. CIJ is able to produce larger drop size upto 100 µm Electrostatic inkjet can produce approximately 8 µm. Whereas, TIJ and PIJ lies in between CIJ and electrostatic printhead. The ink thickness for Electrostatic printhead is minimum amongst these printheads i.e. less than 1 µm (table 7).

- **Limitation of the inkjet printhead technologies**

The above table 3 shows the limitations of the various inkjet technologies. Inkjet printheads are differentiated by the techniques by which drop is to be generated. On the basis of these inkjet printheads are categorized. In CIJ inkjet printhead piezo transducers are used to generate continuous stream is formed. These continuous streams of droplet are electrostatic charged which are deflected by opposite charge electrode or by airflow. Piezoelectric ceramic in PIJ and air bubble in TIJ generates drop mechanically.

Electrostatic field is responsible for form droplet in electrostatic inkjet printhead whereas ultrasonic waves are used to generate tiny drops in Acoustic inkjet printhead. Drop size is very important factor to decide the print quality. Generally, inkjet droplets are measured in picoliter (pL). CIJ, PIJ and TIJ produces drop size which are limited to the opening of the nozzles. These are unable to produce smaller droplet than nozzle opening. Electrostatic inkjet printhead has advantage that can produce smaller droplet than its opening. CIJ, TIJ and PIJ are relatively complex structure than electrostatic and Acoustic printheads. The complex structure of printhead may lead other difficulties like clogging, cleaning, accuracy etc. which may require more maintenance.

The thermal inkjet only uses heat application to make drop from nozzle. Due to which it cannot use solvent based ink which can explode in between the printhead. Other printheads have this advantage like PIJ is cold process of producing droplet which makes it enable to print wide range of inks with these technologies. Also CIJ has some limitations as there is application of electrostatic deflection to differentiate the selected droplet.

CONCLUSION

In summary, it is observed that every inkjet printheads are different in physical specifications. The mostly inkjet printheads are manufactured as per the end user requirements, whether it is process colour or monochrome. Every inkjet printheads has some limitations as well. Piezoelectric drop on demand inkjet printheads are much popular followed by Thermal inkjet printheads in colour printing segment. Continuous inkjet printheads are having much complicated structure; due to high droplet speed these are quite useful in coding and marking. Few companies like Kodak are producing multicolour continuous inkjet press. Moreover, print quality performance in inkjet depends on the resolutions of the printheads. Maximum resolutions for CIJ, TIJ, PIJ and Electrostatic are 600, 2400, 1200 and 600 respectively. Each technology has its own limitations. There are lot many other factors which are important and should be also taken into consideration. Process Standardize Digital (PSD) is under development. Fogra has great contribution for creating ISO 15311 for digital printing. However, there is still a lot of potential for additional investigation in this field.

REFERENCES:

1. Arther M Lewis, Shaker Heights, A. D. B. (1967). *Electrically Operated Character Printer*.
2. Askeland, R. A. (2015). Inkjet Print Engines. In *Handbook of Digital Imaging*. https://doi.org/10.1002/9781118798706.hdi026
3. Buehner, W. L., Hill, J. D., Williams, T. H., & Woods, J. W. (1977). Application of Ink Jet Technology To a Word Processing Output Printer. *IBM Journal of Research and Development*, *21*(1), 2–9. https://doi.org/10.1147/rd.211.0002
4. Bugdayci, N., Bogy, D. B., & Talke, F. E. (1983). Axisymmetric Motion of Radially Polarized Piezoelectric Cylinders Used in Ink Jet Printing. *IBM Journal of Research and Development*, *27*(2), 171–180. https://doi.org/10.1147/rd.272.0171
5. Carl Hellmuth Hertz, Skolbanksvagen, S. iuge S. (1966). *Ink jet recorder*. https://patents.google.com/patent/US3416153
6. Castrejón-Pita, J. R., Baxter, W. R. S., Morgan, J., Temple, S., Martin, G. D., & Hutchings, I. M. (2013). Future, opportunities and challenges of inkjet technologies. *Atomization and Sprays*, *23*(6), 571–595. https://doi.org/10.1615/AtomizSpr.2013007653
7. Choi, D. H., & Lee, F. C. (1993). Continuous-Tone Color Prints by the Electrohydrodynamic Ink-Jet Method. In *In Proceeding of IS&T's Ninth International Congress on Advances in Non-Impact Printing Technologies*.
8. Choi, J., Kim, Y. J., Lee, S., Son, S. U., Ko, H. S., Nguyen, V. D., & Byun, D. (2008). Drop-on-demand printing of conductive ink by electrostatic field induced inkjet head. *Applied Physics Letters*, *93*(19), 1–4. https://doi.org/10.1063/1.3020719
9. Dijksman, J. F., Duineveld, P. C., Hack, M. J. J., Pierik, A., Rensen, J., Rubingh, J. E., Schram, I., & Vernhout, M. M. (2007). Precision ink jet printing of polymer light emitting displays. *Journal of Materials Chemistry*, *17*(6), 511–522. https://doi.org/10.1039/b609204g
10. Elmqvist, R. (1949). *Measuring Instrument of the Recording Type*.
11. Fogra. (2018). *Process Standard Digital Handbook 2018*. 85609.
12. Fukano, Y., Masuda, K., Okano, M., & Yonekura, S. (2002). Development of Multi Channel print head for Electrostatic inkjet. *JOURNAL-IMAGING SOCIETY OF JAPAN*, *41*(2), 151–157.
13. HAMAZAKI, T., & MORITA, N. (2009). Ejection Characteristics and Drop Modulation of Acoustic Inkjet Printing Using Fresnel Lens. *Journal of Fluid Science and Technology*, *4*(1), 25–36. https://doi.org/10.1299/jfst.4.25
14. Hiroyuki Kawamoto, S. U. and R. K. (2005). Fundamental Investigation on Electrostatic Ink Jet Phenomena in Pin-to-Plate Discharge System. *JOURNAL OF IMAGING SCIENCE AND TECHNOLOGY*, *49*(1), 19–27.
15. *Introduction to industrial inkjet printing — IMI Europe - high quality inkjet conferences and courses*. (n.d.). Retrieved April 16, 2021, from https://imieurope.com/inkjet-blog/2016/2/8/industrial-inkjet-printing
16. Jung, D., Kim, Y., Byun, D., Ko, H. S., & Lee, S. (2006). Investigations of the mechanisms of the electrostatic droplet ejections. *Proceedings of 1st IEEE International Conference on Nano Micro Engineered and Molecular Systems, 1st IEEE-NEMS*, 1043–1046. https://doi.org/10.1109/NEMS.2006.334608
17. Kim, Y., Son, S., Choi, J., Byun, D., & Lee, S. (2008). Design and Fabrication of Electrostatic Inkjet Head using Silicon Micromachining Technology. *Journal of Semiconductor Technology and Science*, *8*(2), 121–127. https://doi.org/10.5573/JSTS.2008.8.2.121
18. Kyser, E. L., & Sears, S. B. (1976). Method and apparatus for recording with writing fluids and drop projection means therefor. In *U.S. Patent no. 3,946,398: Vol. Siliconics*. http://www.google.sh/patents/US4339763
19. Lau, G. K., & Shrestha, M. (2017). Ink-jet printing of micro-elelectro-mechanical systems (MEMS). *Micromachines*, *8*(6), 1–19. https://doi.org/10.3390/mi8060194
20. Le, H. P. (1998). Progress and Trends in Ink-jet Printing Technology. *Journal of Imaging Science and Technology*, *42*(1), 49–62.
21. Lee, S., Byun, D., Han, S. J., Son, S. U., Kim, Y., & Ko, H. S. (2004). Electrostatic droplet formation and ejection of colloid. *Proceedings of the 2004 International Symposium on Micro-NanoMechatronics and Human Science, MHS2004; The Fourth Symposium "Micro-NanoMechatronics for and Information-Based Society" The 21st Century*, 249–254. https://doi.org/10.1109/mhs.2004.1421312
22. Lee, S., Byun, D., Jung, D., Choi, J., Kim, Y., Yang, J. H., Son, S. U., Tran, S. B. Q., & Ko, H. S. (2008). Pole-type ground electrode in nozzle for electrostatic field induced drop-on-demand inkjet head. *Sensors and Actuators, A: Physical*, *141*(2), 506–514. https://doi.org/10.1016/j.sna.2007.08.019
23. Li, H., Halsey, T. C., & Lobkovsky, A. (1994). Singular shape of a fluid drop in an electric or magnetic field. *Europhysics Letters*, *27*(8), 575–580. https://doi.org/10.1209/0295-5075/27/8/004

24. Lv, W., Liu, Y., Chen, D., Wang, L., & Sun, D. (2010). Design and simulation of electrostatic inkjet head. *2010 IEEE 5th International Conference on Nano/Micro Engineered and Molecular Systems, NEMS 2010*, 532–536. https://doi.org/10.1109/NEMS.2010.5592454
25. Martin, G. D., Hoath, S. D., & Hutchings, I. M. (2008). Inkjet printing - The physics of manipulating liquid jets and drops. *Journal of Physics: Conference Series*, *105. 01200*, 1–14. https://doi.org/10.1088/1742-6596/105/1/012001
26. Maxwell, J. C. (1861). On the physical lines of magnetic force. In *Journal of the Franklin Institute* (Vol. 55, Issue 3, pp. 161–175). https://doi.org/10.1016/0016-0032(53)91101-6
27. Park, J. U., Hardy, M., Kang, S. J., Barton, K., Adair, K., Mukhopadhyay, D. K., Lee, C. Y., Strano, M. S., Alleyne, A. G., Georgiadis, J. G., Ferreira, P. M., & Rogers, J. A. (2007). High-resolution electrohydrodynamic jet printing. *Nature Materials*, *6*(10), 782–789. https://doi.org/10.1038/nmat1974
28. Rahman, K., Ko, J. B., Khan, S., Kim, D. S., & Choi, K. H. (2010). Simulation of droplet generation through electrostatic forces. *Journal of Mechanical Science and Technology*, *24*(1), 307–310. https://doi.org/10.1007/s12206-009-1149-y
29. Rayleigh, Lord. (1878). On the instability of jets. *Proceedings of the London Mathematical Society*, *s1-10*(1), 4–13. https://doi.org/10.1112/plms/s1-10.1.4
30. Schlatter, S., Grasso, G., Rosset, S., & Shea, H. (2020). Inkjet Printing of Complex Soft Machines with Densely Integrated Electrostatic Actuators. *Advanced Intelligent Systems*, *2*(11), 2000136. https://doi.org/10.1002/aisy.202000136
31. Son, S. U., Choi, J. Y., Lee, S., Kim, Y., Ko, H. S., Kim, H. C., & Byun, D. (2006). Development of an electrostatic drop-on-demand inkjet device for display fabrication process. *Proceedings of International Meeting on Information Display*, *2006*, 655–659.
32. Sou, A., Sasai, K., & Nakajima, T. (2002). Control of ink transportation in electrostatic inkjet printer. *American Society of Mechanical Engineers, Fluids Engineering Division (Publication) FED*, *257*(1 B), 837–842. https://doi.org/10.1115/FEDSM2002-31145
33. Stemme, E., & Larsson, S. G. (1973). The Piezoelectric Capillary Injector-A New Hydrodynamic Method for Dot Pattern Generation. *IEEE Transactions on Electron Devices*, *20*(1), 14–19. https://doi.org/10.1109/T-ED.1973.17603
34. Steven I. Zoltan, S. H. (2020). Pulsed Droplet Ejecting System. In *United State patent*. https://patentimages.storage.googleapis.com/30/f4/62/e9b75605352fb0/US10679987.pdf
35. Sun, J., Wei, X., & Huang, B. (2013). Research on the influencing factors to printing quality of edible ink-jet printing ink. *Applied Mechanics and Materials*, *262*, 282–286. https://doi.org/10.4028/www.scientific.net/AMM.262.282
36. Sweet, R. G. (1965). High frequency recording with electrostatically deflected ink jets. *Review of Scientific Instruments*, *36*(2), 131–136. https://doi.org/10.1063/1.1719502
37. Sweet, R. G. (1971). *Fluid Droplet Recorder*. https://patents.google.com/patent/US3596275A/en
38. Taylor, G. (1964). Disintegration of water drops in an electric field. *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*, *280*(1382), 383–397. https://doi.org/10.1098/rspa.1964.0151
39. Trochoutsos, C., Politis, A., & Engineers, M. T. (2018). Developments in digital print standardization. *9th International Symposium on Graphic Engineering and Design*, 475–487. https://doi.org/10.24867/GRID-2018-p58
40. Wijshoff, H. (2010). The dynamics of the piezo inkjet printhead operation. *Physics Reports*, *491*(4–5), 77–177. https://doi.org/10.1016/j.physrep.2010.03.003
41. Wood, E. W. (1927). The physical and biological effects of high- frequency sound-waves of great intensity. *Philosophical Magazine and Journal of Science Series 7 XXXVIII .*, *4*(22), 417–136.
42. Yano, Y. (1982). *Liquid Jet Recording Process*.