JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

AN INFORMATION OF 3D PRINTING TECHNOLOGY IN PHARMACEUTICAL DEVELOPMENT AND APPLICATIONS: AN UPDATED REVIEW

1 Mr. Shaikh Naumaan Naeem *, 2 Dr. Mrs. Pradnya Palekar – Shanbhag, 3 Mr. Akshay Goraksh Yenare, 4 Mr. Akash Paramhans Tiwari, 5 Mr. Manishkumar Prajapati

1,3,4,5 Department of Pharmaceutics, 0riental College of Pharmacy, Sector 2, Behind Sanpada Railway Station, Sanpada West, Navi Mumbai-4000705, Maharashtra, India.

2 HOD Department of Pharmaceutics, 0riental College of Pharmacy, Sector 2, Behind Sanpada Railway Station, Sanpada West, Navi Mumbai-4000705, Maharashtra, India.

ABSTRACT: -With the introduction of three-dimensional (3D) printing technology, the pharmaceutical industry is joining the fourth industrial revolution. 3D printing technology is the most innovative and influential tool for building solid objects by applying several layers in a row under computer control. Three-dimensional (3D) printed medicines can be a potential tool for the realization of personalized therapies adapted to the exact needs of each individual patient, considering their age, body weight, comorbidities, and pharmacogenetic and pharmacokinetic characteristics. 3D technology offers an alternative to conventional techniques for new drug delivery systems and NDDS in the field 3D printing techniques can be used to produce new dosage forms such as microcapsules, complex drug release profiles, nanosuspensions and multilayered drug delivery devices. The various 3D printing technologies used include inkjet printers, thermal inkjet printers, fused deposition modelling, hot melt extrusion, etc. From lab-grown organs to drug delivery devices, anatomical models to personalized medicine, 3D printing applications are widespread in the pharmaceutical industry. on. 3D printing is now recognized as a valuable, efficient and economical tool that can change the future of pharmacy in general and pharmaceutical care in particular.

Keywords:-3-Dimensional Printing (3DP), Drug Delivery, Novel Drug Delivery System, Thermal Inkjet Printing, Personalized Medicine.

INTRODUCTION:-

The technology sector has experienced a major industrial revolution, as artificial intelligence and three-dimensional printing (3DP), once a figment of the imagination, have been understood and implemented. Three-dimensional printing (3DP) has found its versatile application in fields such as technology, chemical industry, military, fashion industry, architecture and medicine. 3DP technology has proven to be one of the most ingenious technologies to date, especially in the pharmaceutical industry. Research into 3D printing technology has grown dramatically and significantly only in the last decade following its availability since the late 1980s. 3D printing is a new technology for the rapid construction of 3D objects by placing or joining several successive layers one after the other. The International Organization for Standardization (ISO) defines 3DP as "the preparation of objects by coating material using a print head, nozzle or other printing technology". [1-3]

3D printing technology enables unprecedented versatility in the design and production of complex materials for use in customizable and programmable medicine. This is a great strategy to overcome some of the challenges of managing a routine medical unit. Charles Hull was the first to describe 3D printing technology for commercial use. [4-6]

Inits simplest form, a 3D object is produced by layering one by one on a platform using computer-aided drafting techniques and programming. The material is first pushed by the printer in the x-y plane and forms the base of the object. The printer then moves along the z-axis and the liquid binder is extruded from the bottom of the material to a certain thickness. This process is repeated, following

computer-aided sketching instructions, until the object is created layer by layer. After complete removal of the unbonded substrate, a 3D object is formed. This printing technique is also known as additive manufacturing, solid freeform manufacturing or rapid prototyping. In principle, structures can be built from a 3D digital file using imaging techniques such as magnetic resonance imaging (MRI) or computer-aided design (CAD) software to instantly create custom objects. [7,8] Various 3D technologies have been developed to create new solid drug delivery systems, making them one of the most popular and unique products. Their biodegradable nature, site specificity, and potential for drug delivery have made them favourable for bone tissue engineering. 3D bioprinters offer the possibility of creating very complex 3D structures from living cells. This advanced technology has become popular and can be applied in cancer treatment3DP technology offers many innovative approaches and strategies for NDDS, and thus is of increasing interest in the pharmaceutical industry. [9,10] Considering all the main points mentioned above, this review is designed to highlight the development of pharmaceutical application of 3D printing technology, including their positive perspectives compared to traditional approaches. This review should provide an overview of 3DP approaches and the likely challenges of such strategies. [1,11]

ADVANTAGES:-

- Accurate and precise dosing of potent drugs.
- Production costs are reduced due to minimal wastage.
- Narrow therapeutic window.
- Individual and personal medicine.
- Large amount of medicine compared to traditional dosage forms.
- 3D printers are cheap and take up less space.
- Small batch production is possible.
- 3D enables controlled droplet size, complex drug release profiles, dose strength and repeated dosing. [12,13]

DISADVANTAGES: -

- Inkjet printers can only use ink with a high specific viscosity.
- The material in the ink compound must bond, but not bond to other parts of the printer.
- The rate of drug release is affected by how the ink binds to the printing materials.
- Printing of large objects is not possible.
- A limited number of raw materials can be used. [12,13]

POSSIBILITIES WITH THE 3D PRINTING TECHNIQUES:-

- 3D printing is applied in industries such as food, aerospace, automotive, jewelry, military, medical and dental.
- It is often used for rapid prototyping but within the aerospace industry it is used for actual production of final parts.
- The possibility to modify the design of a given part at will is a huge benefit for production.
- Within the pharmaceutical industry the ability to play with e.g. surface area and shape in general may provide interesting possibilities.
- 3D printing aka solid free-form technology, rapid prototyping and additive manufacturing.
- 1990 Fused deposition modeling was developed by Scott Crump at Stratasys.
- 1993 MIT Professors Emanuel Sachs and Michael Cima patented first device named ”3D printer” that could print plastic, metal and ceramic parts.
- 3D printing enables more flexible manufacturing. Thus, may also enable more flexible manufacturing of pharmaceuticals. Aprecia Pharmaceuticals have recently received FDA approval for a 3D printed orally disintegrating tablet and have started production.

3D PRINTING PROCEDURE:-

A) Material jetting

When the material is sprayed, droplets made of building materials or additives are selectively deposited in layers to build the object. This is a very similar process used in inkjet printers. The main difference is that these processes use additives or construction material instead of ink, and instead of paper, it is deposited and solidified directly on the surface of the construction plane, which changes the height and angles until the final product is obtained. This process uses elastomeric photopolymers, acrylic-based photopolymers, and wax materials as substrates in liquid form. These polymers are very attractive because of their long molecular chains related to them. The process of spraying the material is also known as Aerosol jet of Optomec Company [14-16] The basic process of spraying the material is as follows:

- The print head is located above the build platform.
- The building material is layered by a horizontally moving nozzle across the building plane.
- The layers that make up the building material are hardened and then cured with ultraviolet light.
- Drops of building material solidify and form the first layer.
- Construction platform land. v. The products are obtained with good precision and surface treatment.

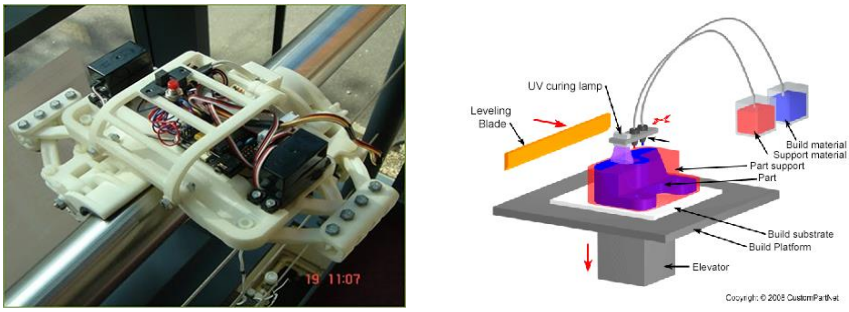


Figure 1: Material jetting

B) Binder Jetting

It is a prototype process for 3D printing technology that uses a binder in liquid form to agglomerate powder into layers to produce a solid 3D print. This technique was first invented in 1993 at MIT by Sachs et al. (1993). Ceramics such as MgO dipped alumina Metal such as cobalt, copper Metal oxide such as iron oxide, nickel oxide, cobalt oxide Polymers such as polyglycolic acid (PGA), polylactic acid (PLA), polycaprolactone (PCL), polyethylene oxide (PEO), biomaterial such as poly-L-lactic acid, calcium phosphates, calcium silicate was usually used as a binder. The ideal binder should be a low-viscosity material that can quickly absorb drops and easily falls from the nozzle. In general, the binder is moderately dried out after each printed layer. This will help improve the spread to the next layer, removing surface moisture and can also reduce immersion. The process of sprinkling the binder can also be felt Zip M print, S print, etc. The basic processes of the binder spray method are as follows with sprayed binder

- First, the binder is sprayed onto the print head of the inkjet printer.
- A new layer of powder is then applied with a roller on top of the existing layer.
- Subsequent layers are printed and glued to the previous layer
- Finally, the residual powder from the lower strings reaches above the structures. [17-19]

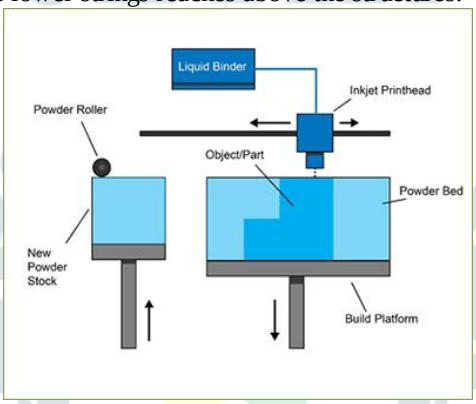


Figure 2: Binder Jetting

C) Direct energy deposition

DED, or Direct Energy Deposition, is a laser-focused material melting technique that uses focused heat power or a laser beam directed at the nozzle and build platform of the 3D printable object to melt the material. Unlike other techniques, this process uses a motion-controlled nozzle that can rotate on multiple axes. Instead of polymers and ceramics, metals and Stainless steel, copper, cobalt, nickel, aluminium, and titanium metalloids are preferred for DED printing. Laser Coating, Laser Engineered Net Formation, electron beam plasma, arc melting are prominently displayed An example of the DED technique The main processes related to direct energy coating technology are as follows:

- A four- or five-axis pointed arm moves around a stationary object.
- Building material is deposited on the surface of the object from the nozzle
- The building material is supplied as either powder or wire and is melted by laser, electron beam or plasma arc during deposition.
- More material is added, and it solidifies layer by layer and produces [16,19,20]

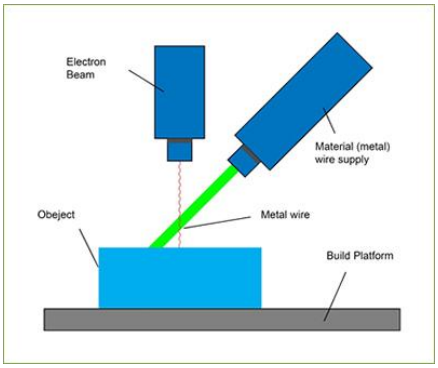


Figure 3: Direct energy deposition

D) Sheet Lamination

Sheet materials are bonded together to build an object based on the principle of sheet lamination technology. This is also known as a laminated item manufacturing, which was first invented by a company called Helisys in 1991, later revised by Mcor-Technologies in 2012. Together with LOM the construction material plate (which is equipped with glue or covered with glue during the construction phase) is moved to the construction phase. A the pre-planned and realized structure is then laser cut a page during platform movement; the cycle is constantly renewed until the climax of the design. Non-metals, polymers and ceramics can too be used for this purpose. Ultrasonic consolidation / Ultrasonic addition Manufacturing is an example of this technology The basic process involved in the Sheet Lamination technique are as follows:-

- The building material or slab is placed on the cutting platform.
- The building material is glued to the previous layer with adhesives.
- The placed layer is then cut into the desired shape with a laser or a scraper.
- The next layer is added, and the same process is carried out. final object [16,17,19,21]

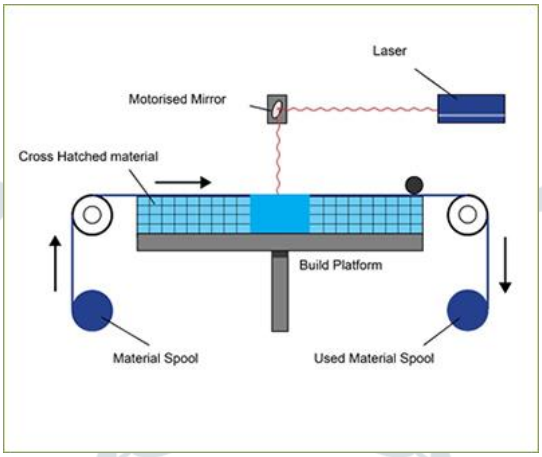


Figure 4: Sheet Lamination

E) Powder bed fusion

As the name suggests, it is based on additive manufacturing technology melting powders using thermal energy. Selective laser sintering (SLS), electron beam melting (EBM), direct metal laser Sintering (DMLS), selective hot sintering (SHS) are different powders bed fusion techniques with SLS being prominent and discovered by Carl Deckard 1987. Solid particles such as metals, polymers, ceramics can be used as an addition to this 3D printing technology. New improvements are being introduced with radio lasers to speed up the process The basic process involved in Powder bed fusion are as follows:

- Firstly, building material is spread over the build platform to form a layer, having a thickness of 0.1 mm.
- The SLS ((Selective Laser Sintering) machine warms up the powder material in the powder bed.
- A laser beam is used to fuse the first layer.
- Another new layer of powder is spread over the first layer.
- Subsequent layers with cross-sections are fused and added.
- This flow of process repeats till the final object is created.[16,17]

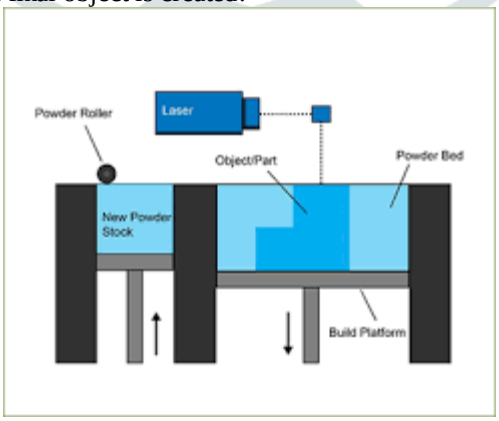


Figure 5: Powder bed fusion

TYPES OF 3D PRINTING TECHNOLOGIES [5,7]

A) Thermal Ink-Jet Printing [12,21]

Thermal inkjet printing involves the heating of ink fluid by a micro-resistor that converts the aqueous to vapor and expands to push the ink drop out of a nozzle. It is used in-

- preparation of drug-loaded biodegradable microspheres
- drug-loaded liposomes
- patterning microelectrode arrays coating and loading drug eluting stents
- producing biological films without compromising protein activity
- dispensing of extemporaneous preparation/solution of drug onto 3D scaffolds

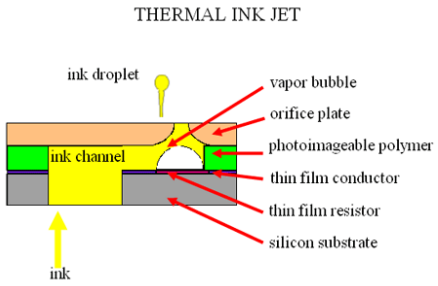


Figure 6: Thermal Inkjet Technique in 3D Printing

B) Inkjet printing [12,21,22,23] It is a powder-based 3D printing that uses powder as a substrate, on which various combinations of active ingredients and ink are sprayed layer by layer, which have different droplet sizes and finally solidify into a solid dosage form. The ink used for pharmaceutical purposes is replaced by pharmaceutical solutions containing drugs, and edible sheets called substrates are used instead of ordinary paper. Inkjet printing provides high-resolution printing by applying ink to a substrate in either Continuous Inkjet (CIJ) or Drop on Demand printing. Inkjet is additionally referred to as a "maskless" or "needleless" approach. The advantages of an inkjet printer include e.g.

- Low processing cost
- Rapid processing rates
- Generation of minimal waste
- It gives CAD information in a ‘direct write’ manner
- It processes material over large areas with minimal contamination [9]

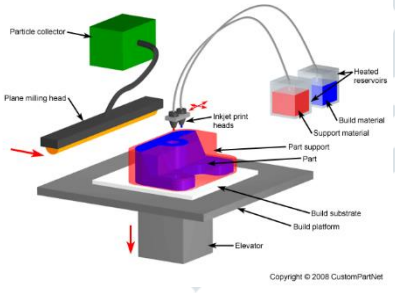


Figure 7: Inkjet Printing in 3D Printing

C) Selective Laser Sintering [12,22,23] Selective laser sintering is said to be a quick manufacturing process which works using powder coated metal additives, a process generally used for rapid prototyping. SLS uses a continuous laser beam as a heating source to bind together the powder particles from a powder bed. During the printing, the laser is directed to draw a selected pattern onto the surface of the powder bed thereby creating a 3D structure. Laser beam sinters the powder and binds it in layer-by-layer fashion.

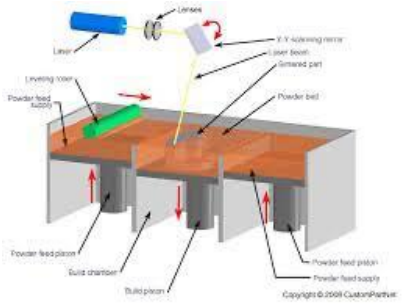


Figure 8: Selective Laser Sintering

D)Fused Deposition Modelling [23,24]

Fused Deposition Modelling Printers are common and more economic than the Selective Laser Sintering type. In Fused deposition modelling printer, beads of heated plastic are expelled from the print head in place of the ink, therefore, building the object in thin layers. Upon solidification, the polymer (laid down layer by layer) gives the precise shape as was designed by computer aided design models.

FDM 3D printing offers several limitations such as-

- lack of suitable polymers
- slow and sometimes incomplete drug release because the drug remains trapped in the polymers, and
- lack of evaluation of the miscibility of the drug and additives used with the polymers

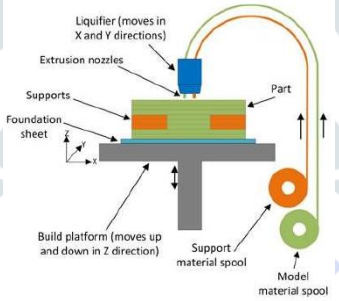


Figure 9: Fused Deposition Modelling

E) Stereo Lithography [25]

Stereolithography was discovered by Charles Hull in 1988. It involves the solidification of the liquid polymer or resin by a computer aided laser beam, creating a 3D structure. Highly accurate and detailed polymer parts are produced using this method.

F) Hot melt extrusion [25]

In this method of 3D printing, polymer and drug are melted at high temperature along with pressure for blending. It includes several operations like feeding, heating, mixing and shaping. By using hot melt extrusion technique, solubility and bioavailability of poorly soluble drugs are often improved.

G) Extrusion 3D Printing [24]

Only the ablets containing Guaifenesin as expectorant can be formulated by extrusion 3D printing. The material is extruded from the automated nozzle on to the substrate and no higher support material is needed. Molten polymers, suspensions, semisolids, pastes are the kind of materials that are extruded.

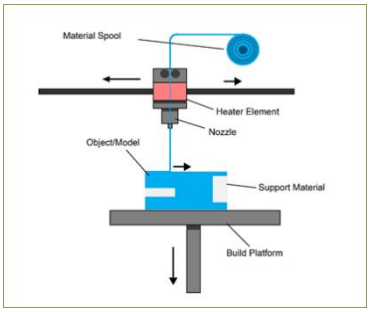


Figure 10: Extrusion 3D Printing

H) Zip dose [24,25]

Zip dose

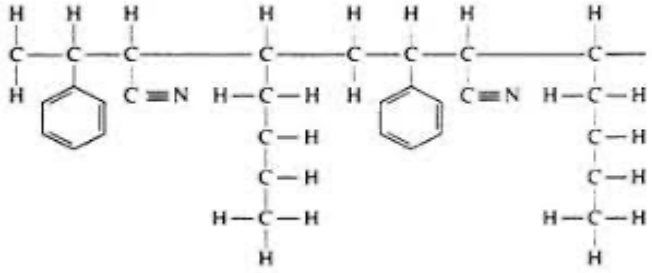
3D printing technology is said to be the world's first and only FDA-validated, commercial-scale 3DP for drug manufacturers. For formulating a tablet with high dose and rapid disintegration, this method offers a specific and digitally coded layering and zero-

compression processes. Hence it helps in overcoming a issue in swallowing. Example-Spritam® is an Oro dispersible tablet, which is used to treat epilepsy, is marketed by Aprecia Pharmaceuticals.

Materials used in 3D printing for pharmaceutical purposes are [26]

1. Acrylonitrile butadiene styrene

It is one of the most used materials in 3D printing. It is very durable, slightly flexible and light and easy to compress, making it suitable for 3D printing. The high temperature requirement is the only limitation of Acrylonitrile Butadiene Styrene. This materials are usually printed at 210˚ to 250℃ and have a glass transition temperature of about 105℃.



2. Polylactic acid

Polylactic acid is a biodegradable thermoplastic derived from corn and is therefore more environmentally friendly than other plastic materials. Polylactic acid is very biologically compatible with the human body. Polylactic acid structure is harder than acrylonitrile butadiene styrene material and melts at 180-220℃, which is lower than acrylonitrile butadiene styrene. The glass transition temperature of polylactic acid is between 60-65℃.

3. Impact-resistant polystyrene

High Performance polystyrene filament is biodegradable and has no harmful effect in contact with the human or animal body. Warp and sticking problems of High Impact polystyrene filaments can be reduced by using a heated pad when printing.

APPLICATIONS [27-34]

3D printing has been used in medicine for a long time, from the manufacture of dental implants to prosthetics adapted for its use. Today, this technology is used in a wide range of fields, from tissue and organ production to various medical research related to drug discovery, delivery and dosage forms.

1. Bioprinting of tissues and organs

Organ and tissue failure due to accidents, aging or birth defects remains one of the greatest unsolved medical problems worldwide. There are very few organ transplants because it is very expensive, and the number of donors is also limited. The solution to the current problem is to make the necessary tissue or organ from the patient's own body cells, which greatly reduces the problem of tissue or organ rejection. 3D printers can be used to make heart valves, spinal discs, knee menisci, other types of bone and cartilage, ear prostheses and more unique dosage forms.

2. Inkjet-based or inkjet-powered 3D printing technologies are two technologies that are mostly used in the pharmaceutical industry. Novel dosage forms such as nanosuspensions, microcapsules, mesoporous bioactive glass scaffolds, hyaluronan-based synthetic extracellular matrices, multilayer drug delivery devices, and antibiotic-printed micropatterns are often produced using 3D printing technology.

3.Hearing aids

Hearing aids can be manufactured by using 3D printing technology in three steps:

- scanning, modelling and printing.
- 65 hearing aid shells or 47 hearing aid moulds can be printed by printers within 60 to 90 minutes.
- The printing speed helps manufacturers to adjust demand to supply.

4.Anatomical Models

- Anatomical variations differ from individual to individuals. Therefore, appropriate knowledge about the patients' specific anatomy is very vital before an operation. 3D printed models have helped extensively in this respect, making them an important tool for surgical method. For example;
- Neuro-anatomical models generated by 3D-printing assist neurosurgeons by providing a representation of some of the most complicated structures in the human body.
- Japan's Kobe University Hospital utilized 3D printed models by using replica of patients' own organs to find a donor liver with least tissue loss.

5. Personalized medicine

- 3D printing of personalized medications offers the benefits of increasing the efficacy of drugs reducing the chances of adverse reaction. Drugs having narrow therapeutic index can fabricated using 3D printing, and by knowing the patient's pharmaco-genetic profile and other characteristics optimal dosage can be given to the patient. Personalized medicine is considered as tailoring medical treatments that suits the needs and preferences of each single patient. It involves purposely run diagnosis, therapy and follow-up. It can also include pre-emptive medicine aimed at reducing the risk of diseases a subject has shown susceptible to, by changing his lifestyle, diet and habits and by advising him on the use of supplements or drugs

6. 3D printed tablets

- Nitrofurantoin Antimicrobial Implant hydroxyapatite mixed polylactide feed with fused coating modelling of,5-fluorouracil implants with poly-lacto-co-glycol acid scaffolds Tablets are the most researched and developed 3D printed dosage form. They can be divided into single API tables and multiple API tables. For example, one API tablet contains poly vinyl alcohol loaded with prednisolone. Tablets, guaifenesin immediate-release bilayer tablets with HPMC2910 as a binder, sodium starch glycolate and micro crystalline cellulose was used as disintegrants in FDM (Fused Deposition Modelling) printed immediate release function, pseudoephedrine HCl-controlled tablets with hydroxy propyl methyl cellulose (HPMC) and Collido bases are designed by Powder bed Inkjet technique. Several API-containing tablets are developed using the fusion deposition modeling (FDM) such as lisinopril, indapamide, rosuvastatin, Amlodipine-loaded polypill with distilled water as a temporary emollient in the treatment of cardiovascular disease. 4-aminosalicylic acid, 5-aminosalicylic acid tablets with polyvinyl alcohol filaments for inflammatory bowel disease (IBD). Researchers have developed an osmotic pump-based tablet containing captopril, glipizide, nifedipine. APIs with 3D printing extrusion technology.

7. 3D printed capsules

- Researchers have developed Chrono Cap® an erodible pulsatile release capsule made up of hydroxypropyl cellulose (HPC) that can be used for various drug formulations developed utilizing FDM 3D printing technology was successfully adjusted with varying size and thickness. It can be filled with various liquid and solid dosage forms such as solutions, dispersions, powders, pellets, and other formulations. Another recent research developed gastro-resistant multi-compartmental PVA capsules named Super-H and Can-capsule loaded with ascorbic acid and dronedarone hydrochloride powder capable of intestinal delivery of a drug, these were formulated using Fused deposition modelling technology. These oral dosage forms can further contribute towards personalized drug delivery by personalizing the dosage and the loaded drugs.

CHALLENGES: -

- 3D printing technology has shown encouraging results in drug development and delivery, but the technology is still in the development phase. There are many obstacles in the optimization process, including improving the device performance for versatile use, choosing suitable excipients, post-processing method to improve the performance of 3D printed products and expanding the scope of applications in new drug delivery systems.
- To achieve normal 3D products, some important parameters must be optimized, such as print headline speed, printing speed, time interval between two printing layers, space between powder layer and nozzles, etc. Special attention must also be paid to post-processing, such as dry methods. necessary to achieve a better result.
- Many important parameters such as printing speed, printing speed, printing header speed, time between two printing layers, distance between nozzles and thus the powder layer must be properly optimized to achieve the quality of 3D products. To obtain high-quality 3D printed products, the chemistry and composition of the binder must be properly emphasized. In the 3D printing process, the selected binder must be compatible with the components of the printer. Uniaxial compression and suspension dispersion methods are used to increase drug loading capacity in a 3D printed tablet, but certain disadvantages include increased complexity and nozzle clogging.

1) Nozzle mechanism: In 3DP, the dosage forms or layers of objects are created by a nozzle mechanism. A continuous flow of print material is imperative, even if the print head stops and restarts during the formation of successive layers. Clogged nozzles in the print head, binder migration, scratching, bleeding and incorrect powder feeding are common problems. For example, Drop-on-demand (DoD) print heads, most commonly used in 3DP technology, exhibit nozzle clogging.
2) Manufacturing with powder-based 3DP technology faces high disintegration of 3D dosage forms. The polymers used in such techniques must be in the form of small particles
3) The choices of raw material, paint and finishing materials are limited compared to the traditional production method. 3DP technologies, which involve printing at high temperatures, are not suitable for heat-sensitive drugs. 4. Expensive: The price of a 3D printer is very high. The need for different types of printers and materials for different processes makes it more expensive for small producers. With the development of such technologies, jobs in the manufacturing and manufacturing sector are drastically reduced. This has a big impact on the economy [35,36,37]

CONCLUSION: -

3D printing technology has proven to be an important and potential tool for the pharmaceutical industry, resulting in personalized medicine that focuses on patient needs. As highlighted, the versatility of 3D printing offers several advantages, such as increased cost efficiency and production speed. Although the development of 3DP in the pharmaceutical industry is still in its infancy, soon the 3DP approach will be used to produce and design a variety of new dosage forms, to achieve optimized release profiles of drugs, to develop personalized drugs to avoid multidrug interactions. incompatibilities, draw. multiple release dosage forms, limit the degradation of biological molecules and more. However, there is still a significant hurdle to overcome for 3D printed drugs to be as effective, safe and stable as drugs traditionally produced in the pharmaceutical industry.

References:-

1. Alhnan MA, Okwuosa TC, Sadia M, Wan KW, Ahmed W, Arafat B. Emergence of 3D Printed Dosage Forms: Opportunities and Challenges. Pharm Res [Internet]. 2016;33(8):1817–32.
2. Goole J, Amighi K. 3D printing in pharmaceutics: A new tool for designing customized drug delivery systems. Int J Pharm. 2016;499(1– 2):376–94.
3. Norman J, Madurawe RD, Moore CMV, Khan MA, Khairuzzaman A. A new chapter in pharmaceutical manufacturing: 3D-printed drug products. Adv Drug Deliv Rev [Internet]. 2017;108:39–50.
4. Awad A, Fina F, Goyanes A, Gaisford S, Basit AW. 3D printing: Principles and pharmaceutical applications of selective laser sintering.72Islam et al.Int J Pharm. 2020 Aug 30;586:119594.
5. US4575330A - Apparatus for production of three-dimensional objects by stereolithography - Google Patents. [cited 2020 Nov 16].
6. Tan DK, Maniruzzaman M, Nokhodchi A. Advanced pharmaceutical applications of hot-melt extrusion coupled with fused deposition modelling (FDM) 3D printing for personalised drug delivery. Pharmaceutics. 2018;10(4).
7. Ursan I, Chiu L, Pierce A. Three-dimensional drug printing: A structured review. J Am Pharm Assoc [Internet]. 2013 [cited 2020 Nov 16];53(2):136–44.
8. Koçak E, Yıldız A, Acartürk F. Three dimensional bioprinting technology: Applications in pharmaceutical and biomedical area. Colloids Surfaces B Biointerfaces. 2020;197.
9. Trombetta R, Inzana JA, Schwarz EM, Kates SL, Awad HA, Hall RBG. HHS Public Access. 2018;45(1):23–44.
10. Bansal M, Sharma V, Singh G, Harikumar SL. 3D printing for the future of pharmaceuticals dosages forms. Int J Appl Pharm. 2018;10(3):1–7.
11. Asad Ali, Usama Ahmad and Juber Akhtar. 3D Printing in Pharmaceutical Sector: An Overview, Pharmaceutical Formulation Design -Recent Practices, Usama Ahmad and Juber Akhtar, IntechOpen, DOI: 10.5772/intechopen.90738.
12. Ghadge S, Nagesh A, Suresh S. A Decisive Overview on Three-Dimensional Printing in Pharmaceuticals. Journal of Drug Delivery and Therapeutics. 2019; 9(3): 591-598.
13. Hue P. Le. Progress and Trends in Ink-jet Printing Technology. J Imaging Sci Technol. 1998;42(1):49–62.
14. Visser CW, Pohl R, Sun C, Römer GW, Huis In 'T Veld B, Lohse D. Toward 3D Printing of Pure Metals by Laser-Induced Forward Transfer. Adv Mater. 2015;27(27):4087–92.
15. Fathi S, Dickens P. Jettability of reactive nylon materials for additive manufacturing applications. J Manuf Process [Internet]. 2012 Aug;14(3):403–13.
16. Sachs E, Cima M, Williams P, Brancazio D, Cornie J. Three-dimensional printing: Rapid tooling and prototypes directly from a CAD model. J Manuf Sci Eng Trans ASME. 1992;114(4):481–8.
17. Ziaee M, Crane NB. Binder jetting: A review of process, materials, and methods. Addit Manuf [Internet]. 2019 Aug;28:781–801.
18. Miyanaji H, Yang L. Equilibrium saturation in binder jetting additive manufacturing processes: Theoretical model vs. Experimental observeations. Solid Free Fabr 2016 Proc 27th Annu Int Solid Free Fabr Symp - An Addit Manuf Conf SFF 2016. 2016; i:1945–59
19. Tofail SAM, Koumoulos EP, Bandyopadhyay A, Bose S, O'Donoghue L, Charitidis C. Additive manufacturing: scientific and technological challenges, market uptake and opportunities. Mater Today. 2018;21(1):22–37.
20. L. Srinivas et al. 3D Printing in Pharmaceutical Technology: A Review. Int. Res. J. Pharm. 2019; 10(2): 8-17
21. Meléndez PA, Kane KM, Ashvar CS, et al. Thermal Inkjet Application in the Preparation of Oral Dosage Forms, Dispensing of Prednisolone Solutions and Polymorphic Characterization by Solid State Spectroscopic Techniques; Journal of Pharmaceutical Sciences. 2008; 97(7): 2619-2636.
22. M. Singh, et al. Inkjet Printing—Process and its Applications; Advanced Materials. 2010: 673-685
23. Fina F, Madla CM, Goyanes A, et al. Fabricating 3D Printed Orally Disintegrating Printlets Using Selective Laser Sintering. International Journal of Pharmaceutics. 2018; 541(1–2): 101–107.
24. Hoy MB. 3D Printing, Making Things at the Library; Med Ref Serv Q. 2013; 32(1):94-99.
25. Gokhare Vinod G, Dr. Raut D.N, Dr. Shinde D.K. A Review paper on 3D-Printing Aspects and Various Processes Used in the 3D-Printing.International Journal of Engineering Research & Technology. 2017; 6(6): 953-958.

26. Klein GT, Lu Y, Wang MY. 3D Printing and Neurosurgery-Ready for Prime Time? Word Neurosurg. 2013; 80(3-4): 233-235.Schubert C, Van Langeveld MC, Donodo LA. Innovations in 3D Printing: A 3D Overview from Optics to Organs. The British Journal ofOphthalmology. 2014; 98(2): 159-161.
27. Ozbolat IT, Yu Y. Bioprinting towards Organ Fabrication: Challenges and Future Trends. IEEE Transactions on Biomedical Engineering. 2012; 60(3): 691-699.
28. Mertz L. Dream It, Design It, Print It In 3-D, What Can 3D Printing Do For You? IEEE Pulse. 2013; 4(6): 15-21.
29. Bartlett S. Printing Organs on Demand. Lancet Respiratory Medicine. 2013; 1(9): 684.
30. Ursan I, Chiu L, Pierce A. Three Dimensional Drug Printing, a Structured Review. J. Am Pharma Assoc. 2013; 53(2): 136-144.
31. Lipson H. New World of 3D Bioprinting Offers Completely New Ways of Thinking: Q & A with Author, Engineer, and 3-D Printing Expert Hod Lipson. IEEE Pulse. 2013; 4(6): 12-14.
32. Gu Y, Chen X, Lee JH et al. Inkjet Printed Antibiotic- and Calcium-Eluting Bioresorbable Nanocomposite Micropatterns for Orthopedic Implants. Acta Biomaterialia. 2018; 8(1): 424-431.
33. Agrawal A, Gupta AK. 3D Printing Technology in Pharmaceuticals and Biomedical: A Review. Journal of Drug Delivery and Therapeutics.2019; 9(2-A): 1-4.
34. Maulvi FA, Shah MJ, Solanki BS, et al. Application of 3D Printing Technology in the Development of Novel Drug Delivery Systems. Int J Drug Dev & Res. 2017; 9: 44-49.
35. Wu BM, Cima MJ. Effects of Solvent-Particle Interaction Kinetics on Microstructure Formation during Three-Dimensional Printing,Polymer Engineering & Science. 1999; 39: 249-260.
36. Kulkarni P, Marsan A, Dutta D. A Review of Process Planning Techniques in Layered Manufacturing, Rapid Prototyping Journal. 2000; 6:18-35.