IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

3D Printing: A New Emerging Technology in Pharmaceutical and Biomedical Era

[1]Shubhangi H. Bhowate*, [2]Dr. Dinesh R. Chaple, [3]Shreya B. Pathare,

[4]Binayak K. Sarkar, [5]Rehmat A. Ansari

[1]Student, [2]Principal, [3]Student, [4]Student, [5]Student

[1]Department of Pharmaceutical Chemistry

[1]Priyadarshini J. L. College of Pharmacy, Electronic Zone, Hingna Road, Nagpur, Maharashtra, India- 440011

Abstract
Using computer-aided design tools and programming, three-dimensional printing is a cutting-edge method that forms three-dimensional things by depositing material onto a substrate. A three-dimensional structure is created by depositing or solidifying successive layers of material in a process known as additive layer manufacturing, or 3D printing. Medicinal materials are set up in three dimensions using a computer-aided design module and converted into a form that can be read by a machine. This form indicates how the exterior of the three-dimensional dosage form appears. It then slices this surface into multiple printable layers and sends these layers to the machine. Various 3D printing methods have been developed to create innovative solid dosage forms, which are some of the most well-known and distinct items available today. The pharmaceutical industry aspires for the 3D printing procedure to be adopted and capable of investigating the wonders achieved by the method. Using 3D printing opens up a world of new possibilities for improving medicine. Contract manufacturers and pharmaceutical businesses who experiment with these 3D printing technologies are likely to gain a competitive edge as 3D printing capabilities advance, safety, and regulatory concerns are addressed, and technology costs come down. This review composes the basics, types & techniques used, advantages and disadvantages of 3D printing.

Keyword
3D Printing, Photopolymers, Selective Laser Sintering (SLS), Aerospace, Printing material

1. INTRODUCTION
Three-dimensional printing is an innovative technique that creates three-dimensional items by layering materials onto a substrate using computer-aided drawing technologies and programming.[1] It is a method of creating digital files into three-dimensional physical objects. These days, 3D printing may be used at every stage of the drug development process, from preclinical research and clinical trials to providing direct patient care.[2] Three-dimensional (3D) printing technology is being used to develop various drug delivery methods, such as oral controlled release systems, fast-dissolving tablets, microchips, pills, and oral controlled release systems. It has many advantages over traditional pharmaceutical product manufacturing techniques, including high production rates due to its quick operating systems, the ability to achieve high drug loading with much-needed precision and accuracy only for potent drugs applied in small doses, the ability to reduce material waste, which can lower production costs, and the ability to work with a wider range of pharmaceutical active

ingredients, including those that are poorly soluble in water, proteins, and drugs with narrow therapeutic indices.[3]

1.1 HISTORY

Since the start of 1990, 3D printing has served as a platform for personalized treatment. The FDA's Center for Device and Radiological Health (CDRH) has reviewed and approved 3DP medical devices, indicating significant progress in the field of 3D-printed medical devices.[4] Inkjet printing, which involves printing a binder solution onto a powder bed so that the particles bond together, was the first 3D printing technique utilized in pharmaceutics. Until the ultimate desired structure was achieved, the procedure was repeated. This was created and patented by Sachs et al. and initially occurred at the Massachusetts Institute of Technology in the early 1990s.[5] To harden the surface where heated polymer filaments are extruded through a heated nozzle and deposited onto a build platform layer by layer, Scott Crump filed a patent application for fused deposition modelling, another 3D printing technique, in 1989.[6] Spritam oral pills (levetiracetam) were the first 3D-printed medication to be approved by the Food and Drug Administration (FDA) in 2016. Aprecia Pharmaceuticals produced the tablets using an inkjet printing technology. In industries like automotive, aerospace, healthcare, tissue engineering, and even pharmaceuticals, 3D printing is the most cutting-edge technology available (initial phase). The FDA uses risk-based strategies to encourage the development of sophisticated manufacturing technologies like 3D printing.

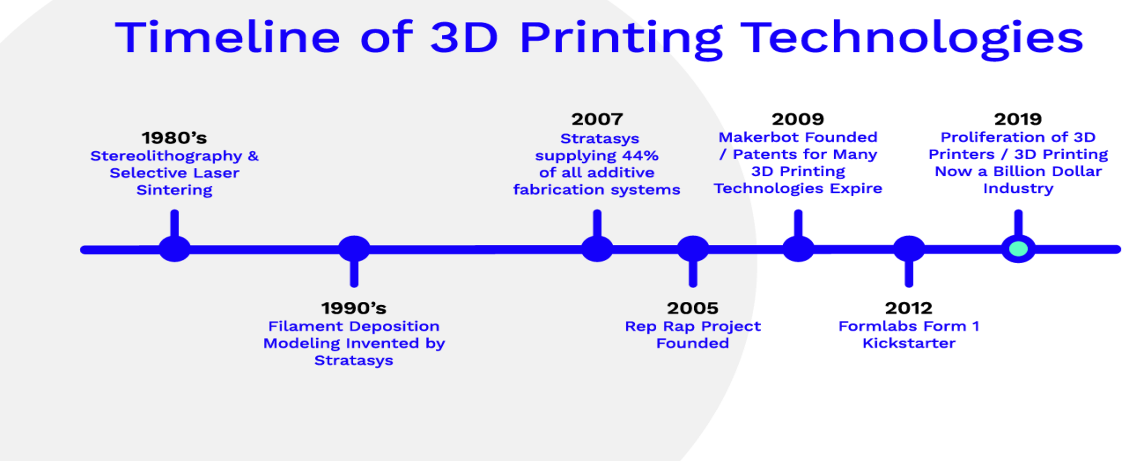

Figure 1: Timeline of 3D Printing Technologies

1.2 REGULATORY EXPECTATIONS

Technical Considerations for Additive Manufactured Medical Devices was a guidance document released by the US FDA in 2017. The requirements for Device Testing Considerations, Design and Manufacturing Process Considerations, and Labeling are described in this advice. Normal methods, also suggest validating the relevant processes to offer a high degree of certainty. Documentation must also attest to the Quality System Regulation's on-hand recommendations for device certification. Validating processes is necessary to guarantee and preserve quality. Every device and its component is constructed in a single build cycle, in between build cycles, and between machines in cases when further inspection and testing are unable to properly verify the process outcomes (i.e., output specifications). Additionally, the program needs to be verified for its intended usage following a well-known process.[7]

1.3 3D PRINTING: A TECHNOLOGICAL EVOLUTION OF REVOLUTION

Emanuel Sachs and associate researchers at the Massachusetts Institute of Technology in Boston, USA, created 3D printing technology in the late 1980s (US patent number 5204055). Binder jet technology, which consists of first applying a coating of powder and then squirting a liquid binder onto the parts that need to solidify, was initially used to facilitate 3D printing.[8] Later, a number of changes to produce items with great process efficiency for a wide range of applications dramatically altered the science behind 3D printing. More advancements were achieved to create items with more precision and to make better use of materials for flexibility. In order to create three-dimensional items by stacking materials onto a substrate, computer-aided drawing technology and programming were combined with the 3D printing method in 1986. Once more, the idea entails connecting material from the printer to a solid surface on an x-y plane to form the object's base.[9] The printer then advances along the z-axis to print the entire object onto the base of the required thickness using the chosen material. Using this layer printing technique, things with certain forms and sizes can be produced with fine control over the printer nozzle geometry and movement. Consequently, there are three primary steps in the additive manufacturing process: scale-up application, rapid prototyping, and 3D printing.[10]

2. TECHNIQUES IN 3D PRINTING

Based on the additive process involved, 3D printing technology can be classified into seven primary kinds, according to ASTM (American Society for Testing and Materials). These include sheet lamination, vat photopolymerization, material extrusion, binder jetting, directed energy deposition, and substance jetting. Every procedure has benefits and drawbacks unique to its particular use. The variety is a result of the many additives that are employed to meet customer needs. These technologies can print items made of nanoscale to industrial-scale materials, depending on the specifications.[11]

2.1 Material jetting

Material jetting is the process of selectively depositing building material or additive droplets as layers to construct an object. The inkjet printers employ a very similar procedure to this one. The primary distinction is that these processes employ building materials or additives in place of ink, and instead of using paper, the material is directly deposited and cemented on the surface of a building platform, which is then adjusted in height and angle until the desired result is obtained. Elastomeric photopolymers, photopolymers based on acrylic, and substances resembling wax are utilized as liquid substrates in this method. These polymers have lengthy molecular chains attached to them, which makes them very appealing The material jetting process is also referred to as Aerosol Jet by Optomec Company, Laser-Induced Forward Transfer (LIFT), Ballistic Particle Manufacturing (BPM), Drop On Demand (DOD), Nano Metal Jetting (NMJ), Nano Particle Jetting (NPJ), Liquid Metal Jetting (LMJ), Polyjet by Stratasys Inc., Print optical Technology by Lux Excel, Thermojet Printing, Multi-Jet Modelling (MJM), and Multi-Jet-Printing or MJP by 3D Systems Corporation.[12]

2.2 Binder Jetting

To create solid 3D-printed objects, a liquid binding agent is used in a prototype 3D printing process to agglomerate powder into layers. In 1993, Sachs et al. at MIT initially developed this technology (1993).[13] The most common materials used as binder materials were ceramics like MgO doped alumina, metals like copper and cobalt, metal oxides like iron, nickel, and cobalt oxide, polymers like polyglycolic acid (PGA), polylactic acid (PLA), polycaprolactone (PCL), and polyethylene oxide (PEO), biomaterials like poly L-lactic acid, calcium phosphates, and calcium silicate. Low-viscosity materials that quickly fall off the nozzle and instantaneously form droplets are appropriate for binder materials. After each printed layer, the binder is typically somewhat dried off. Removing surface moisture, can also lower the immersion level and improve the spreading of the subsequent layer.[14] Other names for the binder jetting method are Zip dosage, Theriform, M-printing, S-printing, and so forth.

2.3 Direct Energy Deposition

Direct energy deposition, or DED, is a laser-focused material melting process that uses a laser beam or focused thermal power to melt material that is directed toward a nozzle and a platform for 3D printing an object. This method, in contrast to others, makes use of a motion-controlled nozzle with several axes of rotation. For DED printing, metals, and metalloids such as titanium, copper, cobalt, nickel, aluminium, and stainless steel are favoured over polymers and ceramics. Some well-known DED technologies are laser deposition (LD), laser-engineered net shaping (LENS), electron beam plasma, and arc melting.[15]

2.4 Sheet Lamination

The idea behind sheet lamination technology is to create an object by bonding sheets of materials together. Another name for it is laminated object manufacturing (LOM), which was initially developed in 1991 by Helisys and subsequently assessed in 2012 by Mcor-Technologies. Using LOM, a building material sheet is advanced onto a building stage (either with a glue backing or covered with adhesive throughout the construction cycle). Then, while the platform moves, a laser is utilized to cut a previously planned and designed structure into a sheet; this cycle is repeated repeatedly until the design is completed. Ceramics and polymers can be utilized for this purpose in addition to metals. One use of this technology is ultrasound consolidation/ultrasound additive manufacturing, or UC/UAM.[16]

2.5 Vat Photopolymerization

A laser beam or UV light source is used to solidify and cure a vat holding liquid photoreactive polymers in a process known as vat photopolymerization, which encompasses several 3D printing processes. Both the technique and photopolymers were first introduced in the 1960s. Vat photopolymerization technology includes techniques such as stereolithography (SLA), digital light projection (DLP), two-photon polymerization (2PP), continuous light interface production (CLIP), and lithography-based ceramic manufacturing (LCM). The two most commonly used techniques are stereolithography (SLA) and digital light projection (DLP). Despite certain technological differences, DLP and SLA used different light sources. The first vat photopolymerization method, SLA, uses a UV light source, while DLP uses an arc lamp or other conventional light source. When exposed to a light source, the liquid polymer radiation-curable resins will harden precisely and could result in a high-end product. This method's advantage is its part precision and surface finish.[17]

2.6 Powder bed fusion

As the name implies, the process of additive manufacturing involves fusing granules with the aid of thermal energy. Among the several powder bed fusion processes are Selective Laser Sintering (SLS), which was discovered by Carl Deckard in 1987, Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM), and Selective Heat Sintering (SHS). For this 3D printing method, solid particles such as metals, polymers, and ceramics can be added. New enhancements with rapid lasers are proposed to accelerate the procedure.[18]

2.7 Material Extrusion

This type of 3D printing involves pushing material through a nozzle to form it into the required shape. For various raw materials, multiple methods are available. Combined Deposition Simulation (FDM) The known process that makes use of a material extrusion mechanism is called semisolid extrusion, also known as fused filament fabrication (FFF) or fused layer modelling (FLM). Because it is the least expensive of all, fused deposition modelling is used extensively. It was first created in 1990, and by late 1991, it was on sale. Thermoplastic polymers are the primary type of polymers used in FDM as additive materials. It uses thermoplastic filament that has been heated and extruded to assemble parts layer by layer from bottom to top. Additionally, a nozzle system is used in the semisolid extrusion process to extrude gels or pastes on the construction plate layer by layer. After the solvent has dissipated, the extruded material solidifies similarly to FDM. Polymers or gel materials can be fed into an FDM 3D printer after they have melted.[19]

3. 3D PRINTING PROCEDURE

3.1 Material jetting

The basic process involved in material jetting is as follows:[20]

i. The build platform is underneath the printer head.
ii. A nozzle that can be moved horizontally deposits build material all over the build platform.
iii. After creating the material forming layers, UV light is used to cure and solidify them (UV).
iv. The first layer is formed when droplets of the construction material solidify.
v. Build Platform descends.
vi. Products obtained with good accuracy and surface finish.

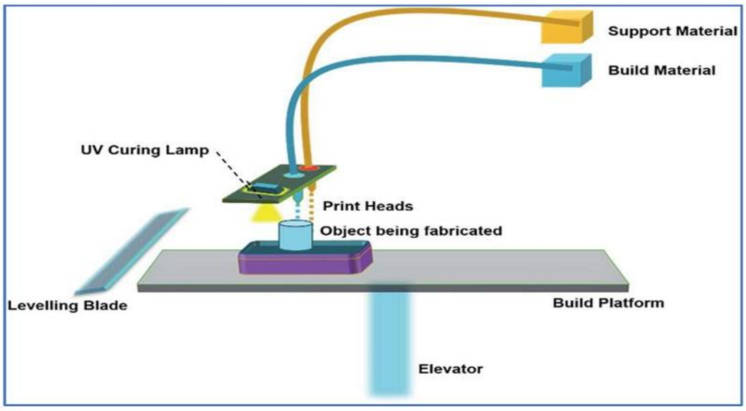

Figure 2: Basic diagram of Material jetting equipment

3.2 Binder Jetting

The basic process involved in the binder jetting method is as follows:[21]

i. Initially, an inkjet print head jets binder material.
ii. Next, a fresh layer of powder is applied using the roller on top of the previous layer.
iii. Subsequent layers are then printed and are tacked to the previous layer by the jetted binder.
iv. Finally, the residual powder in the bed ropes overhanging structures.

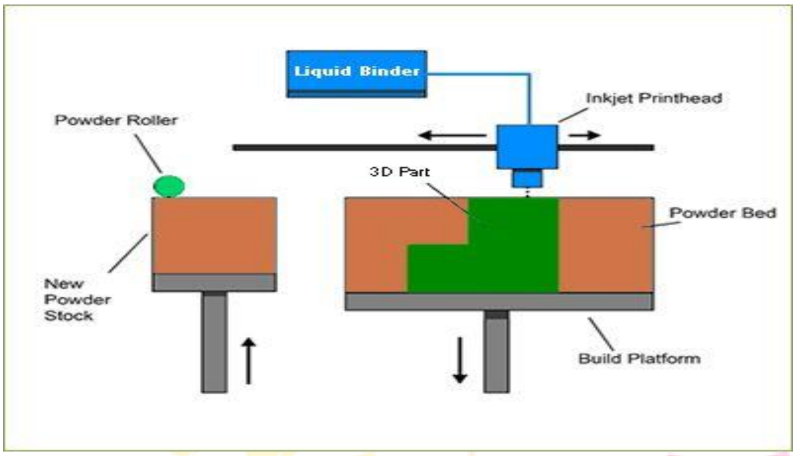

Figure 3: Basic diagram of Binder jetting equipment

3.3 Direct energy deposition

The basic processes involved in the direct energy deposition technique are as follows:[22]

i. A nozzle-equipped four- or five-axis arm rotates around a stationary item.
ii. The nozzle deposits building material all over the object's surface.
iii. Building materials are either supplied in wire or powder form, and during deposition, they are melted using a plasma arc, laser, or electron beam.
iv. Further material is added and solidifies layer by layer, and produces the final object.

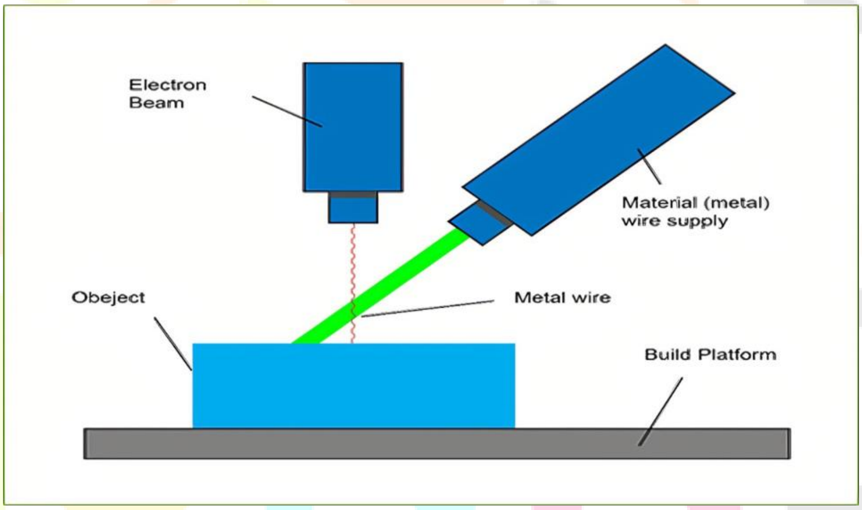

Figure 4: Basic diagram of Direct energy deposition equipment

3.4 **Sheet Lamination**

The basic process involved in the Sheet Lamination technique is as follows:[20]

i. The sheet or building material is set down on the cutting tray.
ii. Using the adhesives, the building material is joined to the preceding layer.
iii. Next, using a laser or scraper, the desired shape is carved out of the layer that was put.
iv. The next layer is added and the same process runs.

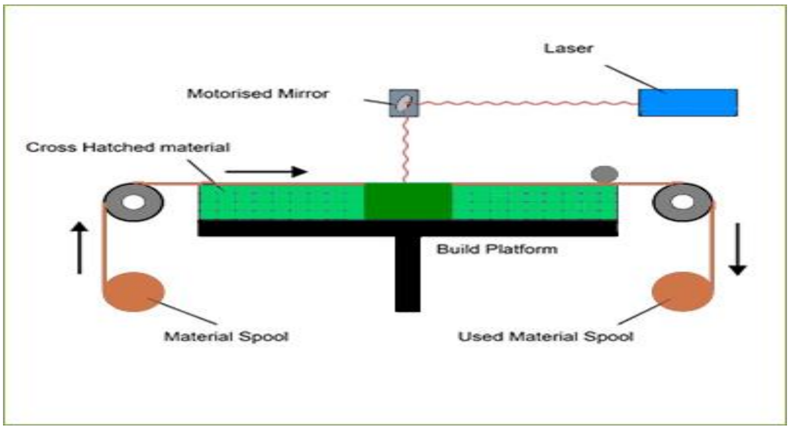

Figure 5: Basic diagram of Sheet Lamination equipment

3.5 Vat Photopolymerization

The basic processes involved in Vat photopolymerization are as follows:[20]

i. On the liquid resin's surface, a cross-sectional section is traced by a high-voltage laser beam.
ii. The elevator platform descends.
iii. The cross-sectional portion is scraped down with a blade dipped in resin, and new building material is applied on top.
iv. Then it is immersed in a chemical bath because this requires the use of supporting structures.

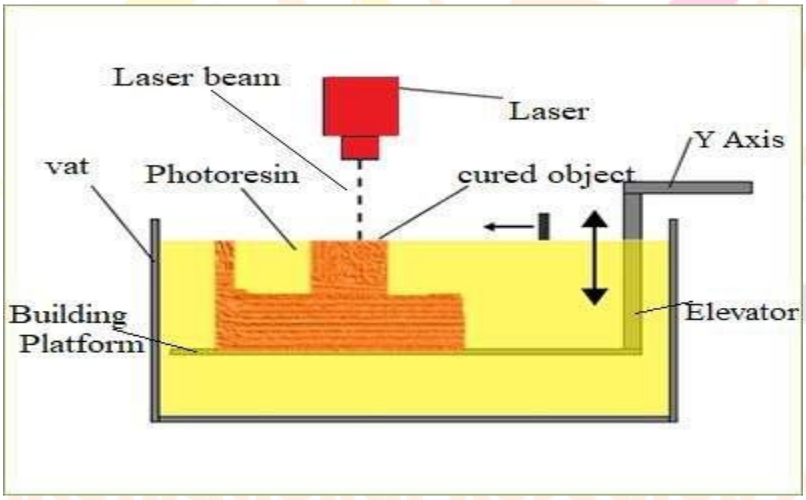

Figure 6: Basic diagram of Vat photopolymerization equipment

3.6 Powder bed fusion

The basic processes involved in Powder bed fusion are as follows:[20]

i. The build platform is first covered with a layer of building material (powder) that has a thickness of 0.1 mm.
ii. The powder material in the powder bed is warmed by the SLS (Selective Laser Sintering) system.
iii. Fusing the initial layer is done with a laser beam.
iv. Another new layer of powder is spread over the first layer.
v. Subsequent layers with cross-sections are fused and added.
vi. This flow of process repeats till the final object is created.

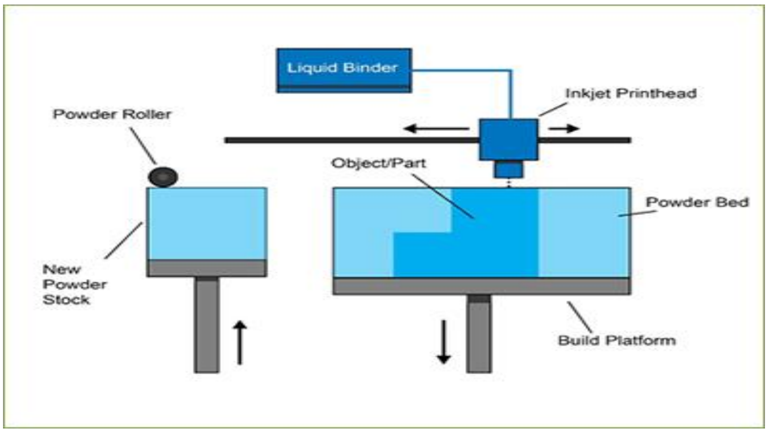

Figure 7: Basic diagram of Powder bed fusion equipment

3.7 Material Extrusion/ Fuse Deposition Modelling (FDM)

The basic processes involved in Material extrusion or Fuse deposition modelling (FDM) are as follows:[23]

i. A nozzle draws heated building material, which is then applied layer by layer.
ii. Layer by layer, the warmed building material is pulled in by a nozzle and deposited.
iii. Further layers are added onto the top point of the past layers.
iv. At a melted state, the layers are deposited to form an object.

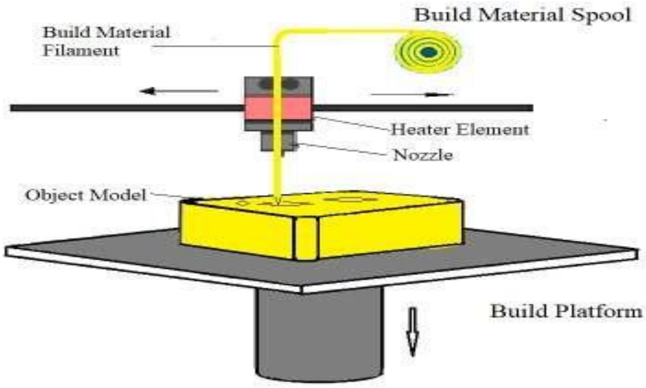

Figure 8: Basic diagram of Material Extrusion equipment

4. PRINTING MATERIALS USED IN PHARMACEUTICAL 3D PRINTING

Printing materials can represent stability, physical characteristics, printer settings, printing details, and release profiles. Moreover, printing materials with distinct qualities is necessary for various printing procedures. An illustration of 3D-printed components utilized in oral medication compositions is provided below.

4.1. Lactose

Lactose can be utilized in 3D powder bed printing, or SLA, for medicines as a diluent or filler. It can improve the powder mixture used in 3D-printed tablets' compactability, physical stability, and medication solubility. For 3D powder bed printing, a lactose monohydrate binder blend is typically recommended since it helps improve the tablet's mechanical qualities. Lactose's high solubility allowed for the successful formulation of a hydrophilic and hydrophobic API into a printed tablet.[24]

4.2. Polylactic Acid (PLA)

Biodegradable polymers like PLA are frequently utilized in 3D printing to create scaffolds, implants, and medication delivery systems. The Food and Drug Administration (FDA) of the United States has approved it and deemed it safe for use. PLA may be printed using the fused deposition modelling (FDM) process because it possesses enough thermoplastic characteristics. For the filaments, the appropriate PLA grade and molecular weight can be manufactured along with the appropriate plasticizer. To obtain the appropriate release kinetics, PLA can be compounded with a variety of medications and excipients. However, PLA degrades more slowly, which makes it appropriate for prolonged medication delivery.[25]

4.3. Polyvinyl Alcohol (PVA)

PVA is a water-soluble thermoplastic polymer that is frequently utilized in 3D-printed tablets as a binder or filler because of its dissolvability, biodegradability, and biocompatibility. It can enhance the printed dosage forms' mechanical strength and drug release characteristics. PVA can be printed via methods based on extrusion or inkjet technology. For instance, Goyanes and colleagues used fused deposition modelling to create customized oral caplets using PVA filaments that were either loaded with coffee or paracetamol. In addition, Kampanart and his associates employed PVA to create tablet housing that lifted the core tablet on stomach fluid for a minimum of eight hours, controlled the drug's release profile, and permitted zero-order release. 3D-printed PVA can be used for suppository dose forms as well as oral dosage forms. Tatsuaki and associates have created a controlled medication-release suppository shell made of water-soluble polymer (polyvinyl alcohol).[26]

4.4. Hydroxypropyl Methylcellulose (HPMC)

A cellulose-based polymer called HPMC is frequently utilized as a binder, diluent, supporting structure, and sustained-release agent in 3D-printed dosage forms. HMPC stands out from other 3D printing materials due to its low toxicity and dissolvability. In general, an extrusion process can be used to print HPMC in three dimensions. Prashant et al. used methyl cellulose and HPMC as biodegradable support structures. It was found that HPMC could be dissolved in water to readily remove it from the building material and that it could be printed while retaining the hollow structure of the original printed product. Yiliang and his colleagues manufactured semi-solid tablets with various drug-loading quantities at room temperature using an extrusion-based 3D printer. For a longer drug release profile, theophylline, the active pharmaceutical ingredient, was added to hydrogels made using HPMC K4M or E4M. [27]

4.5. Gelatin

Collagen, which is normally obtained from the skin and bones of cattle or pigs, is the source of gelatin, a naturally occurring protein-based biopolymer. It has been utilized for decades in many medicinal formulations because of its biocompatibility, biodegradability, and ease of processing. Gelatin can be printed using 3D printers as a printable material or as a bio-ink to create intricate structures and medication delivery systems. Gelatin has been used as a 3D-printed biodegradable excipient in gummy antiepileptic medication formulations for pediatric patients via the extrusion base approach because of its pliability, elasticity, and hydrophilicity.[28]

4.6. Polyethylene Glycol (PEG)

PEG is a flexible polymer that can be utilized for medicinal purposes in 3D printing. It is a biocompatible, biodegradable, and water-soluble polymer with several benefits for tissue engineering and medication delivery. Hsin-Yun Hsu created naproxen/PEG 3350 solid dispersions with PEG coatings of varying molecular weights using the drop printing process, which produced accurate doses and consistent compositional uniformity of API in three-dimensional structures.[29]

5. RISK ASSESSMENT DURING 3D PRINTING PROCESS

Determining the risk is a crucial stage in the technology of 3D printing. The primary goal of the procedure was to avoid quality assurance parameters like assay, content consistency, appearance, etc. from failing. To comply with the standards of the product that was produced in industries, risk factors are identified together with the process and process variables.[30]

Risk factors are checked in these conditions

- If a specific printer is unable to print a given pattern, software controls ought to be utilized.
- Real-time layer thickness monitoring is required to control layer thickness variations.
- Inadequate layering was mostly caused by changes in climatic circumstances, which could be controlled, including the production site's temperature and moisture content.
- By monitoring print head height and print head speed, one can prevent erroneous positioning in the printer and avoid improper placement during printing.
- Uneven layers can be avoided by keeping an eye on the powder's aqueous content and powder molecule size distribution.
- Print head obstruction can be lessened or completely avoided by ensuring the particle size distribution and keeping an eye on inkjet flow.
- Variations in binder viscosity or binder surface tension cause uneven aggregation.

6. ADVANTAGES OF 3D PRINTING

1. Increased productivity: 3D printing is more efficient than conventional techniques, especially when producing materials like implants and prostheses, which also benefit from its higher repeatability, precision, and dependability.
2. Personalized and Personalized Medicines: One of this technology's main benefits is its ability to make customized medical devices and supplies. Prosthetics, surgical equipment, and implants that are customized for each patient can be a huge help to doctors and patients alike. This technique can be used to produce high drug loading and accurate dosing of a strong medication.
3. Cost-effective: Because there is less material waste, 3D-printed products are less expensive.
4. Eco-friendly and sustainable: 3 DP technology is a creative and new method that uses less energy and better quality materials, resulting in less trash being produced.
5. Time-saving: The rapidity of three-dimensional printers allows for a reduction in the length of product development design cycles.
6. Toolless: 3DP can do away with the requirement to produce tools, which cuts down on the money, time, and labor involved. With 3DP, there is no need for tools during production, which saves money, time, and labor. [31-32]
7. Appropriate medication delivery for active components that are challenging to synthesize, such as medicines with limited therapeutic windows and low water solubility.
8. A patient's medication can be customized for them based on their environment, genetic variations, age, gender, and ethnicity.
9. When a patient is receiving multi-drug therapy with various dosage regimens, the treatment might be tailored to enhance patient adherence.
10. avoids batch-to-batch fluctuations that occur when producing conventional dosage forms in large quantities.
11. 3D printers are reasonably priced and take up very little room.

7. DISADVANTAGES OF 3D PRINTING

1. Nozzle issues present a significant challenge since halting the print head alters the structure of the finished product.
2. Another challenge is clogged powder printing.
3. Potential to adjust the final structure to account for effects of ink composition, mechanical stress, and storage conditions.
4. Printing quality and printer cost are impacted by printer-related characteristics.[30]

8. CHALLENGES IN 3D PRINTING TECHNOLOGY

1. Drug delivery is still in its infancy, despite evidence of encouraging outcomes.
2. Several obstacles need to be overcome to improve 3D printed products and broaden the range of applications for innovative drug delivery systems, including adaptable use, suitable excipient selections, and post-treatment techniques.
3. From a safety perspective, the most significant liability resource for redesigning using 3-dimensional printing may be the inherent flexibility.
4. The main parameters, including printing rate, pass, print heads line velocity, printing layers interval time, nozzles powder layer distance, etc., need to be changed to improve the quality of 3DP.[30]
5. Regulation and quality control: To guarantee the efficacy and safety of pharmaceutical goods manufactured using 3D technology, regulatory and quality control concerns need to be addressed.
6. Compatibility and material selection: There are limitations in the pharmaceutical industry's options for materials that can be used in 3D printing, and there are problems with some medications or formulas.
7. Increasing production: To meet market demand, 3D-printed objects must be produced at a faster rate, which presents technical hurdles.[33]

9. 3D PRINTING GLOBAL EFFECTS [34]

Global Effects on Manufacturing: The nature of 3D printing technology is enabling new methods of thinking about the social, economic, environmental, and security consequences of the manufacturing process, with generally positive results. This is already having an impact on how things are made. This statement is supported, among other things, by the possibility that 3D printing would reduce supply chain constraints by bringing production closer to the consumer or end-user. A.N.D. decreases or eliminates stocks and stockpiling a practice akin to how Amazon conducts business by utilizing the customization potential of 3D printing and the capacity to create small production batches on demand. Since replacement components may be 3D printed on-site, shipping goods and spare parts across the globe may eventually become obsolete. Future operations and interactions on a worldwide scale by consumers, the military, and corporations of all sizes may be significantly impacted by this. Many people's ultimate goal is for their 3D printer to be used at home or in their local community, where users may obtain digital blueprints of any kind of product (that can be customized) from the internet and send them to the printer once it is filled with the necessary materials (s). There is now some disagreement regarding when this will happen and even more acrimonious disagreement regarding whether it will ever happen. Increased use of 3D printing will probably lead to the re-invention of several previously developed products as well as the creation of an even greater number of brand-new ones. With a 3D printer, one can now build shapes and geometries that were previously unattainable, but the trip is far from over. Many people think that 3D printing has enormous potential to spur innovation and revive regional industries.

Potential Effects on the Global Economy: If 3D printing technology is widely used, it could have an impact on the international economy. The imbalance between export and import countries may be lessened by switching from the current model of production and distribution to a localized manufacturing model based on on-demand, on-site, customized production 3D printing could lead to the emergence of entirely new sectors and professions, such as those involved in the manufacture of 3D printers. Professional services related to 3D printing are available; these services can include intellectual property litigation and settlements as well as new types of product designers, printer operators, and material suppliers. For many IP holders, piracy is currently a worry about 3D printing. There are two sides to the impact of 3D printing on developing nations. Lower manufacturing prices due to the use of recycled and other local resources are one example of a positive consequence; nevertheless, the loss of manufacturing jobs could have a serious negative impact on many developing countries, which would take long to recover from. Possible Impacts on the World Economy The developed world, where concerns about workforce and production have arisen due to ageing populations and shifting age demographics, stands to gain the most from 3D printing. Furthermore, the advantages of using 3D printing for medicinal purposes would help an ageing Western culture.

Printing Benefits & Value: Regardless of the application industrial, personal, or local 3D printing offers many advantages over conventional production (or prototype) techniques. The ability to mass customize things to meet specific needs and specifications is made possible by 3D printing methods. The nature of 3D printing allows for the simultaneous manufacturing of many goods, tailored to the end user's specifications, at no additional process cost, even within the same build chamber. Customisation Products (developed in digital environments) with levels of intricacy that could not be created physically in any other way have proliferated with the introduction of 3D printing. Designers and artists have utilized this advantage to create striking visual effects, but it has also had a big impact on industrial applications. Complex components that are lighter and stronger than their predecessors are being materialized through applications. There are growing applications in the aerospace industry, where these are critical concerns.

10. APPLICATIONS OF 3D PRINTING

1. Possibility of application in pharmaceuticals, industrial design, aerospace, medical engineering, tissue engineering, and architecture for process optimization and performance modification.
2. It primarily focuses on the two possible locations to advance pharmaceutical product development into uncharted territory: the production of complex delivery systems and customized medicine.
3. In the medical field, to make dental implants.
4. On creating a multi-drug implant with a controlled release for treating bone TB.
5. aids in cell-laden materials, biomaterials, and organ printing.[35]
6. The creation of limbs and other body parts out of metal or other materials to replace lost or broken limbs is another use for 3D printing in the biomedical industry. In many regions of the world, people who have been injured in battle or by disease need prosthetic limbs. At the moment, prosthetic limbs are highly costly and typically not patient-specific. Custom prosthetic limbs are being designed and made using 3D printing to adhere to the patient's exact specifications. Designers and engineers are able to reconstruct the missing portion of the limb by scanning the patient's body and remaining bone structure.[34]
7. **Aerospace:** GE/Morris Technologies, Airbus/E.A.D.S., Rolls-Royce, B. A. E Systems, and Boeing are a few of the well-known users. While the majority of these businesses treat their current technological endeavours realistically, focusing mostly on research and development, some do become

highly optimistic about the future. The automotive industry was another early adopter of Rapid Prototyping technology, which was the precursor of 3D printing. Numerous automobile firms, especially those at the forefront of Formula One and motorsport, have traced a similar path to that of aeronautical industries.

8. **Automotive:** High degrees of skill and understanding in a variety of specialized professions, such as fabrication, mold-making, casting, electroplating, forging, silver/gold smithing, stone-cutting, engraving, and polishing, have historically been needed for the design and production of jewellery. When it comes to the production of jewellery, each of these professions has developed over many years and calls for technical understanding. One such instance is investment casting, which has roots dating back over 4,000 years. 3D printing has proven to be extremely disruptive for the jewellery industry. How 3D printing may and will advance this industry's growth is generating a great lot of curiosity and adoption. By enhancing conventional procedures, 3D printing, and C.A.D. provide additional design freedoms.
9. **Food:** Consumer 3D printing is the golden goal for 3D printing suppliers. The question of whether this is a possible future is hotly debated. Because entry-level smartphones have accessibility problems, customer acceptance is currently minimal (consumer machines). Larger 3D printing firms like 3D Systems and Makerbot, a Stratasys company, are making progress in this area as they work to improve the usability and accessibility of the 3D printing process and its auxiliary components (software, digital content, etc.). Right now, there are three primary methods that the average person can use 3D printing technology for consumer goods! • choose + print • design + print • Select + to fulfil 3D printing services Consumer.

11. DISCUSSION

With the use of a sophisticated layer-by-layer technique, 3D printing can produce complex, customized items as needed. 3D printing is a tempting way to create customized devices for drug delivery systems. Since a few years ago, the idea of 3D-printed medication formulation has quickly advanced, driven by the goal of improving therapy through patient-centric medicine. Following the FDA's initial approval of a medicine made using 3D printing technology, research on oral, oromucosal, and topical dosage forms was developed remarkably quickly. This potential technology gives formulation flexibility, which is challenging to obtain with standard technological processes. In contrast to conventional pharmaceutical manufacture, additional processing enables the preparation of various dose formulations with great accuracy of the ratio of API (Active Pharmaceutical Ingredient) to excipients. The potential to develop multifunctional drug delivery systems, multidrug devices, and drug formulations for customized therapy with rapid-release properties is another benefit of 3D printing. To provide the best possible therapeutic index, future research should focus on producing pediatric and geriatric dosage forms in individual dose and dimensionally-specific medication formulations. Growing numbers of drug development trials demonstrate the technique's clear benefits, but achieving maximal efficacy would need developing complex innovative dosage forms on an industrial scale. Pharma companies could benefit from 3D printing technology in terms of product research, production, and distribution.

12. CONCLUSION

Time and money can be saved by using 3D printing technology to create intricate shapes. It might enhance its uses in the biotechnological and pharmaceutical research domains. The pharmaceutical industry uses 3D printing for a wide range of technical applications, including the creation of new excipients, innovative medication delivery systems, enhanced drug compatibility, and customized dosage forms. In the future, the pharmaceutical industry and all other industries requiring a certain level of safety and security can regulate and adopt 3D printing.

13. REFERENCES

1. Ursan, I. D., Chiu, L., & Pierce, A. 2013. Three-dimensional drug printing: a structured review. Journal of the American Pharmacists Association, 53(2): 136-144.
2. Gross, B. C., Erkal, J. L., Lockwood, S. Y., Chen, C., & Spence, D. M. 2014. Evaluation of 3D printing and its potential impact on biotechnology and the chemical sciences. Analytical Chemistry, 86(7): 3240-3253.
3. Prasad, L. K., & Smyth, H. 2016. 3D Printing technologies for drug delivery: a review. Drug development and industrial pharmacy, 42(7): 1019-1031.

4. Dodziuk, H. 2016. Applications of 3D printing in healthcare. Kardiochirurgia i Torakochirurgia Polska/Polish Journal of Thoracic and Cardiovascular Surgery, 13(3): 283-293.
5. Konta, A. A., García-Piña, M., & Serrano, D. R. 2017. Personalised 3D printed medicines: which techniques and polymers are more successful?. Bioengineering, 4(4): 79.
6. Wang, J., Goyanes, A., Gaisford, S., & Basit, A. W. 2016. Stereolithographic (SLA) 3D printing of oral modified-release dosage forms. International journal of pharmaceutics, 503(1-2): 207-212.
7. U.S. Food and Drug Administration. Guidance for Industry and Food and Drug Administration Staff: Technical Considerations for Additive Manufactured Medical Devices. Center for Devices and Radiological Health Center for Biologics Evaluation and Research, U.S. Department of Health and Human Services. 2017.
8. Norman, J., Madurawe, R. D., Moore, C. M., Khan, M. A., & Khairuzzaman, A. 2017. A new chapter in pharmaceutical manufacturing: 3D-printed drug products. Advanced drug delivery reviews, 108: 39-50.
9. Gioumouxouzis, C. I., Karavasili, C., & Fatouros, D. G. 2019. Recent advances in pharmaceutical dosage forms and devices using additive manufacturing technologies. Drug Discovery Today, 24(2): 636-643.
10. Ozbolat, I. T., Peng, W., & Ozbolat, V. 2016. Application areas of 3D bioprinting. Drug Discovery Today, 21(8): 1257-1271.
11. Shahrubudin, N., Lee, T. C., & Ramlan, R. J. P. M. 2019. An overview on 3D printing technology: Technological, materials, and applications. Procedia Manufacturing, 35: 1286-1296.
12. Visser, C. W., Pohl, R., Sun, C., Römer, G. W., Huis in 't Veld, B., & Lohse, D. 2015. Toward 3D printing of pure metals by laser-induced forward transfer. Advanced materials, 27(27): 4087-4092.
13. Sachs, E., Cima, M., Williams, P., Brancazio, D., & Cornie, J. 1992. Three-dimensional printing: rapid tooling and prototypes directly from a CAD model. Journal of Manufacturing Science and Engineering, 114(4): 481-488.
14. Miyanaji, H., & Yang, L. 2016. Equilibrium saturation in binder jetting additive manufacturing processes: theoretical model vs experimental observations. In 2016 International Solid Freeform Fabrication Symposium. University of Texas at Austin. 1945-1959.
15. Tofail, S. A., Koumoulos, E. P., Bandyopadhyay, A., Bose, S., O'Donoghue, L., & Charitidis, C. 2018. Additive manufacturing: scientific and technological challenges, market uptake and opportunities. Materials today, 21(1): 22-37.
16. Molitch-Hou, M. 2018. Overview of additive manufacturing process. In Additive manufacturing, 1-38.
17. Ian Gibson, I. G. 2015. Additive manufacturing technologies 3D printing, rapid prototyping, and direct digital manufacturing, second edition. 1-498.
18. Zhang, Y., Jarosinski, W., Jung, Y. G., & Zhang, J. 2018. Additive manufacturing processes and equipment. In Additive manufacturing, 39-51.
19. Chaunier, L., Guessasma, S., Belhabib, S., Della Valle, G., Lourdin, D., & Leroy, E. 2018. Material extrusion of plant biopolymers: Opportunities & challenges for 3D printing. Additive Manufacturing, 21: 220-233.
20. Islam, R., & Sadhukhan, P. 2020. An insight of 3d printing technology in pharmaceutical development and application: an updated review. Current Trends in Pharmaceutical Research: 7, 56-80.
21. Ziaee, M., & Crane, N. B. 2019. Binder jetting: A review of process, materials, and methods. Additive Manufacturing, 28: 781-801.
22. Galante, R., Figueiredo-Pina, C. G., & Serro, A. P. 2019. Additive manufacturing of ceramics for dental applications: A review. Dental materials, 35(6): 825-846.
23. Mireles, J., Espalin, D., Roberson, D., Zinniel, B., Medina, F., & Wicker, R. 2012. Fused deposition modeling of metals. In 2012 International Solid Freeform Fabrication Symposium. University of Texas at Austin, 836-845.
24. van den Heuvel, K. A., de Wit, M. T., & Dickhoff, B. H. 2021. Evaluation of lactose-based 3D powder bed printed pharmaceutical drug product tablets. Powder Technology, 390: 97-102.
25. Farah, S., Anderson, D. G., & Langer, R. 2016. Physical and mechanical properties of PLA, and their functions in widespread applications—A comprehensive review. Advanced drug delivery reviews, 107: 367-392.
26. Salaoru, I., Zhou, Z., Morris, P., & Gibbons, G. J. 2016. Inkjet printing of polyvinyl alcohol multilayers for additive manufacturing applications. Journal of Applied Polymer Science, 133(25).

27. Polamaplly, P., Cheng, Y., Shi, X., Manikandan, K., Kremer, G. E., & Qin, H. 2019. 3D printing and characterization of hydroxypropyl methylcellulose and methylcellulose for biodegradable support structures. Procedia Manufacturing, 34: 552-559.
28. Tagami, T., Ito, E., Kida, R., Hirose, K., Noda, T., & Ozeki, T. 2021. 3D printing of gummy drug formulations composed of gelatin and an HPMC-based hydrogel for pediatric use. International Journal of Pharmaceutics, 594: 120118.
29. Hsu, H. Y., Harris, M. T., Toth, S., & Simpson, G. J. 2015. Drop printing of pharmaceuticals: Effect of molecular weight on PEG coated-naproxen/PEG 3350 solid dispersions. AIChE Journal, 61(12): 4502-4508.
30. Ponni, R. T., Swamivelmanickam, M., & Sivakrishnan, S. 2020. 3D Printing in Pharmaceutical Technology-A Review. International journal of pharmaceutical investigation, 10(1): 8-12.
31. Tan, D. K., Maniruzzaman, M., & Nokhodchi, A. 2018. Advanced pharmaceutical applications of hot-melt extrusion coupled with fused deposition modelling (FDM) 3D printing for personalised drug delivery. Pharmaceutics, 10(4): 203.
32. Bansal, M., Sharma, V., Singh, G., & Harikumar, S. L. 2018. 3D printing for the future of pharmaceuticals dosages forms. Int J Appl Pharm, 10(3): 1-7.
33. Bácskay, I., Ujhelyi, Z., Fehér, P., & Arany, P. 2022. The Evolution of the 3D-Printed Drug Delivery Systems: A Review. Pharmaceutics, 14(7): 1312.
34. Bhusnure, O. G., Gholve, S. V., Sugave, B. K., Dongre, R. C., Gore, S. A., & Giram, P. S. 2016. 3D printing & pharmaceutical manufacturing: opportunities and challenges. International Journal of Bioassays, 5: 4723-4738.
35. Katakam, P., Dey, B., Assaleh, F. H., Hwisa, N. T., Adiki, S. K., Chandu, B. R., & Mitra, A. 2015. Top-down and bottom-up approaches in 3D printing technologies for drug delivery challenges. Critical Reviews™ in Therapeutic Drug Carrier Systems, 32(1):61-87.