external environment. Constant osmotic pressure can be maintained by upholding a saturated solution of osmotic agent in the system. An osmotic agent can be added if the saturated solution of drug does not possess enough osmotic pressure. Osmogens are swellable hydrophilic polymers that interact with aqueous fluids and expand to a balanced state.

6.2.4. Membrane type

Any polymer that is porous to water but impermeable to solute can be chosen; namely, cellulose dilacerate, cellulose triacetate, cellulose propionate, ethyl cellulose, and Eudragit. Type and nature of polymers also play a significant role, and any polymer porous to water but impermeable to solute can be chosen. Membrane thickness has a perceptible result on the drug discharge from the system. Low molecular weight diluents are preferably added to change the physical properties and to obtain better film forms. Plasticizer converts the hard and fragile polymer into a flexible material and preferably makes it more resistant to automatic stress.

6.3. Advantages of Osmotic Drug Delivery Systems

ODDS were invested for controlled delivery of various drugs. These systems produce numerous advantages; such as the release mechanism of osmotic drug delivery system does not depend upon the drug concentration in the dosage form. It has an initial lag time after which it produces zero-order release profile. Drug delivery can be made delayed or pulsed if desired, the release of drug from the system does not depend upon the pH of GIT and hydrodynamic conditions, and the presence of food does not affect the drug release from the system. Additionally, osmotic systems have a better release rate of drug over the conventional diffusion-based drug delivery systems, and rate of drug release can be predicted and is programmable with modification of certain composition of delivery system. Furthermore, controlled delivery from osmotic delivery system reduces the dosing frequency and side effects when compared with immediate release of the same drug. The drug release from osmotic dosage form can be correlated with in vivo plasma drug concentration to obtain level A in vitro-in vivo correlation.

However, there are certain limitations associated with osmotic drug delivery system, including manufacturing of delivery system with specific orifice and membrane thickness [57, 58, 60].

7. 3D PRINTING-BASED CONTROLLED-RELEASE FORMULATIONS

Recently, 3D printing has been combined with drug delivery systems and has increased the horizons for pharmaceutical manufacturing. It is based on additive manufacturing, which means that single layers are produced at a time in 2D, which are then developed into a 3D structure using digital design. This technique has found wide application in personalized medications. Pharmaceutical product development using 3D printing involves few common steps; such as development of the final product design, conversion of this design into a format that can be read by a machine, raw material processing, printing, and post processing (if required). Among the various techniques that can be employed in 3D printing, only a few can be used in pharmaceutical manufacturing [6, 7].

The immediate and delayed release tablets can be designed using the powder-based 3D printing technique. Spritam® (levetiracetam) is the first 3D printing-based product developed for the treatment of epilepsy. However, powder-based technique produces tablets with surface imperfections and poor mechanical properties. It is not suitable for small-scale production due to the large amount of waste produced.

Semisolid extrusion technique uses semisolid raw materials extruded by a syringe-based tool to fabricate tablets. This technique is suitable for making poly pills or bilayer tablets. It yields highly friable tablets after the drying process post operation.

Fused deposition modeling (FDM) 3D printing offers printed structures that are mechanically stable. It has a high resolution of 30–200 μm. It requires no additional processing steps after the operation. This technique is used by many consumers due to patent expiration and low costs involved [61]. Acrylonitrile butadiene styrene and polylactic acid are widely used in FDM 3D printing. Eudragit E can be used as a matrix former for immediate release [62]. However, the polymers used in FDM 3D printing possess poor mechanical properties and lack flexibility and thermal stability. Another major drawback is the improper miscibility of the polymer and the drug due to the semicrystalline nature of the polymer. Nowadays, immiscible plasticizers and fillers like Eudragit® and PEG 400 are used to overcome these limitations [63].

Other techniques include inkjet technique, photopolymerization or stereolithography, pen-based technique, color crafting, and racetrack printing that have certain additional advantages. 3D printing of pharmaceuticals is associated with various advantages when